JEEPO, 8(1), 37-50.

Journal of Energy & Environmental Policy Options

RESDO

Assessing the Impact of Green Energy Strategies on Natural Resource Rents in Pakistan

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Abstract

The present research employs the autoregressive distributed lag technique to assess how renewable energy consumption and renewable energy production influence natural resource sustainability within Pakistan during the period 2000–2022. Specifically, the analysis considers renewable energy utilization and its impact on natural resource rents as an indicator of environmental resource exploitation. The empirical findings highlight nuanced relationships: notably, greater renewable energy usage corresponds with diminished natural resource rents, indicating that increased adoption of renewable sources could mitigate pressures on natural resources. Conversely, renewable energy production demonstrates the opposite effect, reflecting that heightened production capacity may amplify economic returns from natural resources through improved extraction efficiencies. This dual nature underscores critical policy implications. Enhanced renewable energy consumption potentially eases ecological stress, preserving natural resources in the long run. Simultaneously, increasing renewable energy production adds economic value by effectively leveraging natural assets sustainably. Consequently, policymakers should adopt strategies that stimulate renewable energy demand through targeted incentives, subsidies, and awareness campaigns, ultimately reducing reliance on traditional, exhaustible energy sources and addressing environmental degradation.

Keywords: *Renewable Energy, Natural Resource Sustainability, Economic Rents, Green Energy Strategies*
JEL Codes: *Q01, Q25, Q42, Q56*

Received: 12 January 2025
Revised: 13 March 2025
Accepted: 22 March 2025
Published: 30 March 2025

Citation:
Alvi, A. A. & Mudassar, M. (2025). Assessing the Impact of Green Energy Strategies on Natural Resource Rents in Pakistan. *Journal of Energy and Environmental Policy Options*, 8(1), 37-50.

1. INTRODUCTION

Ensuring a balanced and sustainable future requires immediate and effective measures, with a primary focus on promoting the use of renewable and recyclable energy resources. Adopting this strategy not only protects the environment against the depletion of natural resources but also promotes long-term ecological resilience (Purnomo et al., 2023). Furthermore, the transition toward environmentally sustainable practices contributes substantially to ensuring ecological stability. Utilizing renewable resources addresses environmental degradation by decreasing the exploitation of finite natural reserves. Despite widespread acknowledgment, reliance on conventional resources, including coal, oil, and natural gas, remains prevalent, thereby risking severe shortages and potential future economic disruptions. Green energy production methods utilizing agricultural residues, biomass from plant materials, and animal-derived wastes offer a sustainable alternative capable of harmonizing energy generation with ecological targets. Continued neglect of renewable energy alternatives in favor of conventional resource extraction heightens the likelihood of significant energy shortages, potentially exacerbating economic difficulties and environmental crises in subsequent decades (Ahmad, 2018; Sheikh & Ahmad, 2020; Hussain et al., 2022; Marsri & Wimanda, 2024; Marc et al., 2024; Roussel & Audi, 2023).

The integration of renewable energy practices alongside traditional resource utilization emerges as a critical measure to mitigate resource exhaustion and ensure long-term availability. Expanding renewable energy infrastructures can significantly reduce dependency on limited fossil fuel reserves, safeguarding against the environmental hazards associated with traditional

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energy consumption. Despite their limited availability and finite nature, non-renewable resources continue to be exploited without adequate measures to address the imminent consequences. Fossil fuels are rapidly depleted due to excessive extraction, posing an immediate threat to global environmental sustainability. Thus, a strategic transition towards renewable energy systems can effectively alleviate pressures on natural ecosystems by decreasing fossil fuel consumption, resulting in reduced pollution and ecological stress (Alvi & Shahid, 2018; Esen & Bayrak, 2017; Marc & Ali, 2023). A failure to transition toward renewable energy resources may lead nations into critical resource shortages, causing energy insecurity, economic stagnation, and adverse environmental outcomes. Adopting renewable energy technologies, specifically those converting organic and agricultural wastes into usable energy, not only lessens environmental burdens but also contributes positively to the broader goal of environmental protection (Filippidis et al., 2021; Marc, 2022; Amjad et al., 2022; Wang & Manopimoke, 2023; Ullah & Ali, 2024; Audi, 2024). The continued pursuit of renewable energy initiatives can thus simultaneously address resource sustainability and pollution reduction, presenting a comprehensive solution for achieving long-term economic and environmental stability.

The adoption of renewable energy, particularly through investments in green technologies, significantly contributes to achieving ecological preservation while ensuring long-term energy stability. Utilizing renewable sources promotes energy independence, significantly curtailing reliance on exhaustible natural resources and enhancing the transition to environmentally friendly consumption patterns. The systematic incorporation of renewable energy solutions into conventional energy infrastructures can effectively secure the sustainable management of natural resources, reduce environmental vulnerabilities, and prevent future resource scarcities. Consequently, the use of green energy emerges as a strategic response to pressing issues such as resource overconsumption, pollution mitigation, and climate risks. Policies that prioritize renewable energy implementation, supported by targeted investments and incentives, remain crucial for ensuring economic resilience, improved environmental outcomes, and sustainable development in the long run (Kostruba & Pasko, 2019; Le et al., 2020; Kosyak & Popov, 2020; Amjad et al., 2021; Raza et al., 2023; Audi et al., 2025).

Several advanced technologies have been developed to harness green energy, offering effective solutions to produce electricity while simultaneously addressing ecological concerns related to pollution control and resource depletion. A prominent example involves converting agricultural residues and animal waste products into biogas through anaerobic digestion, which subsequently generates electrical energy. This process entails storing organic material within anaerobic digesters, where it decomposes in the absence of oxygen, creating methane-rich biogas for power generation. Such a method effectively reduces waste, converts biomass into useful energy, and significantly diminishes environmental impacts (Hassan et al., 2019; Ali et al., 2021; Iqbal & Asif, 2022; Tawari, 2024). Another well-established renewable approach is hydroelectric power generation, where energy from water flow in dams is harnessed by turbines, transforming kinetic energy into mechanical energy that powers electricity-producing generators. Hydropower represents a cost-effective, sustainable, and environmentally beneficial energy source capable of reliably supplying electricity without the harmful emission impacts associated with fossil fuels. Therefore, accelerating investment in renewable sources such as hydropower not only diminishes ecological impacts but also improves overall national energy security, promoting sustainable economic advancement (Rehman & Ahmad, 2024; Asghar et al., 2024; Le et al., 2021; Audi, 2024).

Realizing the full potential of renewable energy necessitates continuous technological innovation in energy production processes, alongside improvements in equipment design. Therefore, investment in research and development (R&D) becomes critical to increase efficiency, optimize energy conversion processes, and lower the cost of renewable energy infrastructure. Such progress allows nations to transition more rapidly to renewable energy sources, decreasing dependency on fossil fuels and lessening overall ecological footprints. Renewable energy alternatives present practical solutions to challenges like carbon emissions, climate change, and local air pollution, ultimately benefiting public health and community well-being. Furthermore, renewable energy adoption can transform urban environments, enhancing quality of life through reduced air pollutants and improved public health outcomes. Nonetheless, transitioning toward renewable energy sources also involves confronting significant barriers, particularly the substantial initial investment costs associated with establishing renewable infrastructures and integrating them effectively within existing energy grids (Ullah & Ali, 2024; Zaim, 2023; Filippidis et al., 2021).

Thus, addressing these barriers demands comprehensive policy action and collaboration among government entities, industry leaders, and communities. Effective regulatory frameworks and strategic initiatives play essential roles in fostering the transition toward sustainable renewable energy while minimizing potential adverse social and environmental consequences. Consequently, renewable energy is increasingly recognized as a pivotal factor for reducing global fossil fuel dependency, mitigating climate change, and enhancing ecological sustainability. With well-designed policies and strategic initiatives, renewable energy systems can substantially alleviate environmental stress, enhance public health outcomes, and ensure stable long-term economic growth (Asghar et al., 2024; Turan & Can, 2024; Rehman & Ahmad, 2024).

In recent years, we need to change consumption habits that affect natural resource conservation and management in industrial countries. Sustainable energy and consumption patterns have a huge impact on the countries ‘Sustainability Landscape’ Solar, wind, and water energy all produce less carbon emissions than fossil fuels. Green energy, derived from renewable sources like wind, solar, and hydro, presents substantial benefits for environmental protection, climate stabilization, and the conservation of natural resources (Segerson et al., 1991; Naeem & Hameed, 2019; Ze et al., 2023; Audi et al., 2024). However, the deployment of these technologies must be handled with precision; otherwise, they could unintentionally contribute to pollution and damage local ecosystems. Developed countries are increasingly focusing on minimizing waste and enhancing the efficiency of their renewable energy systems as part of a broader commitment to sustainable environmental practices. Investing in renewable infrastructure and energy-efficient technologies is crucial not only for minimizing ecological impacts but also for fostering economic growth. Technological advancements have expanded the range of available energy sources, enhancing economic opportunities in developed areas. Since green energy utilizes limitless natural resources, it typically has a minimal environmental footprint. To prevent possible negative consequences, it is crucial for governments, businesses, and community organizations to work together to advance research and development within the renewable energy sector. In light of current global challenges, there is a critical need to promote sustainable energy practices and consumption habits, ultimately supporting the sustainable management of natural resources (Aurmaghan et al., 2022).

Figure 1: Natural Resources in Pakistan

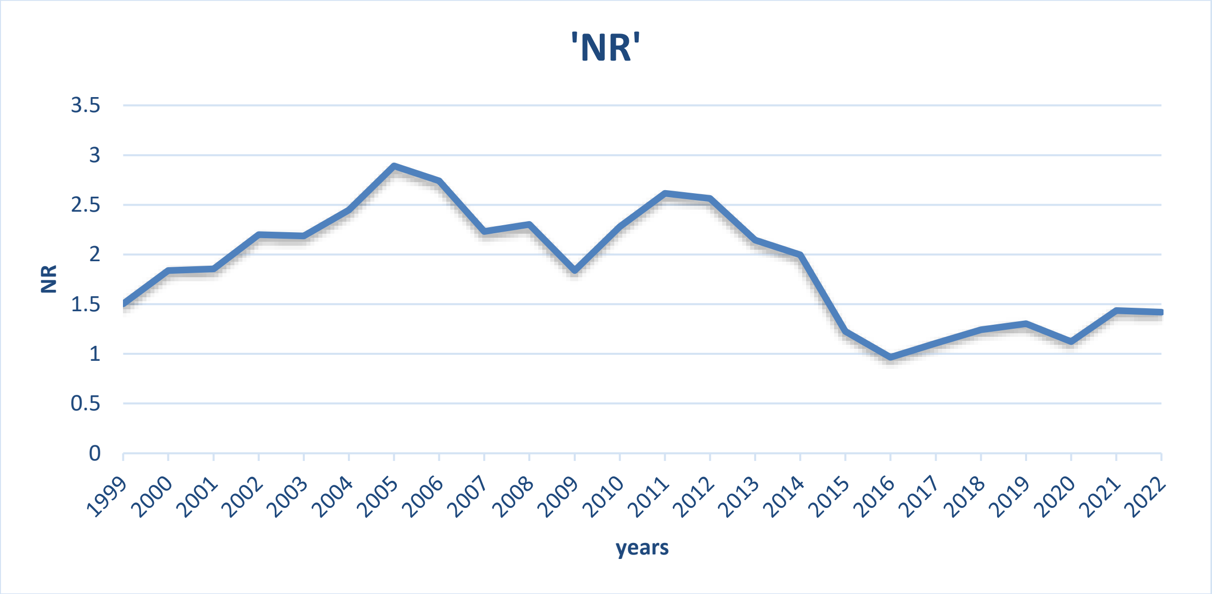
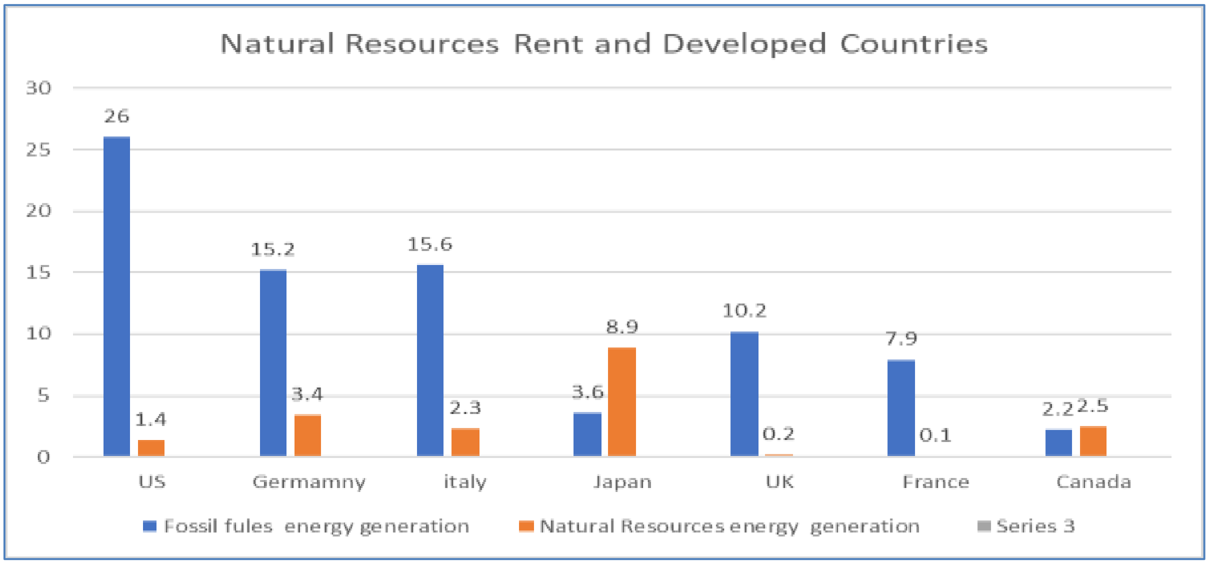


Figure 2



Here, the graph shows the linkages and relationship between natural resource rents and economic development. Government and Policymakers should work together on the potential of natural resources for Long-term growth in developed countries.

2. LITERATURE REVIEW

Concerns about the exhaustion of resources, environmental damage, and climate change have rekindled interest in sustainable consumer behavior and the integration of renewable energy systems. This literature review seeks to provide an exhaustive examination of current studies on green energy initiatives and their impact on resource sustainability. Many researchers advocate that renewable sources like wind, solar, hydro, and geothermal energy can decrease our dependence on fossil fuels (Amri, 2019; Ito, 2017; Ivanovski et al., 2021; Saudi et al., 2019; Shafiei & Salim, 2014; Shahbaz et al., 2020; Viana Espinosa de Oliveira & Moutinho, 2022). For instance, Arnaut and Lidman (2021) argue that advancements in renewable technologies have a significant potential to cut down on greenhouse gas emissions, thereby reducing both air and water pollution and promoting public health. However, Topcu and Tugcu (2020) point out that the expansion of renewable infrastructure, such as wind farms and solar panels, may have adverse effects on land use, biodiversity, and the provision of ecosystem services. It is, therefore, essential to consider the full life cycle of renewable energy systems—from resource extraction and manufacturing to disposal—to thoroughly evaluate their environmental impacts. This review delves into how strategies centered on green energy can enhance the sustainability of natural resources while minimizing reliance on fossil fuels. Findings suggest that renewable energy technologies are crucial not only for reducing greenhouse gas emissions and lessening environmental degradation but also for improving air and water quality. The shift from fossil fuels to renewables plays a key role in curbing the emission of pollutants, which in turn decreases the incidence of pollution-related health issues, including respiratory and cardiovascular diseases.

However, while renewable energy offers considerable environmental benefits, its expansion is not without challenges. As noted by Topcu and Tugcu (2020), the large-scale deployment of renewable energy infrastructure, such as wind turbines and solar farms, may have implications for land use, biodiversity, and ecosystem services. The installation of renewable energy systems requires significant land resources, potentially leading to habitat disruption and changes in ecological balance. Therefore, it is crucial to conduct comprehensive assessments of how renewable energy systems affect the environment throughout their entire life cycle—from resource extraction and manufacturing processes to operation and eventual disposal. Understanding these impacts can help policymakers and industry leaders develop strategies to optimize renewable energy deployment while minimizing adverse environmental consequences. While renewable energy technologies offer a promising path toward sustainability by reducing fossil fuel dependency and improving environmental quality, their long-term ecological impacts must be carefully evaluated. A balanced approach that integrates technological advancements with environmental considerations is essential to ensure that renewable energy contributes to both economic and ecological sustainability. Future research should focus on addressing the environmental trade-offs associated with renewable energy expansion, improving efficiency in resource utilization, and developing policies that promote sustainable energy transitions without compromising biodiversity and ecosystem health.

Renewable energy alternatives encourage environmentally friendly consumption and improve energy efficiency, thereby bolstering the long-term conservation of natural resources. Zaghdoudi (2017) emphasizes that curbing total energy demand is vital, achievable through a blend of regulatory measures, technological advancements, and shifts in consumer behavior. For instance, initial actions like enhancing building energy performance, optimizing transportation networks, and reducing the ecological footprint of resource usage can significantly advance sustainable energy practices and conservation efforts (Rafindadi & Usman, 2019). Ze et al. (2023) observe that the interrelationship among consumption behaviors, natural resource preservation, and energy utilization is multifaceted, necessitating an interdisciplinary approach that draws on economic, social, and engineering insights to secure a sustainable energy future. Embracing renewable energy solutions and adopting greener consumption habits have proven critical in protecting natural resources while mitigating environmental degradation. Effective collaboration among government bodies, community groups, and businesses is essential to drive this transition, ensuring that policies, technological innovation, and public engagement collectively foster energy conservation for future generations.

Scholars categorize renewable energy sources into distinct groups such as solar, biomass, wind, geothermal, and ocean wave energy. Esen and Bayrak (2017) emphasize the importance of incorporating these renewable options into the worldwide energy framework to minimize greenhouse gas emissions and reduce dependency on fossil fuels. By utilizing abundant natural resources such as sunlight, water, and wind, renewable energy technologies offer a practical and sustainable alternative to traditional methods of energy production. Recent research highlights the significance of technological progress in lowering costs and fostering the wider adoption of green energy solutions. Studies focusing on advancements in energy storage systems, wind turbine technology, and solar cell efficiency illustrate how innovation plays a crucial role in enhancing the feasibility and effectiveness of renewable energy sources (Chen et al., 2023). These developments contribute to the scalability and efficiency of green energy, making it a more accessible and cost-effective option for widespread implementation. Green energy sources support natural resource sustainability by encouraging responsible consumption patterns, improving energy efficiency, and reducing environmental harm. Technological innovations continue to play a crucial role in advancing renewable energy solutions, ensuring their effectiveness and economic feasibility. Moving forward, policymakers, businesses, and individuals must work together to facilitate the adoption of green energy technologies, promote sustainable consumption habits, and develop strategies that align energy production with environmental conservation goals.

The extraction and utilization of natural resources have significant environmental consequences, including habitat destruction, water pollution, and increased greenhouse gas emissions (Majeed et al., 2021). The unsustainable use of these resources not only accelerates environmental degradation but also threatens biodiversity and the overall ecological balance. According to Olunuga (2022), the implementation of sustainable resource management strategies is essential to preventing environmental decline and ensuring the long-term availability of natural resources. Such strategies emphasize the need for responsible consumption, efficient resource allocation, and the adoption of environmentally friendly technologies. However, the concept of the "resource curse of plenty" highlights the challenges associated with managing resource-rich economies in a sustainable manner. Research suggests that countries abundant in natural resources often struggle with environmental degradation due to weak regulatory frameworks and inadequate governance. This paradox occurs when resource wealth leads to overexploitation, pollution, and inefficient resource management, ultimately resulting in long-term ecological and economic instability (Muhammad & Khan, 2021). In such cases, resource-rich nations may face severe environmental consequences unless they implement policies that promote sustainability, transparency, and equitable resource distribution. Governance plays a crucial role in determining how natural resources are allocated and managed within a country. Effective governance structures ensure that resource extraction and usage align with environmental conservation goals, minimizing ecological harm while maximizing economic benefits. Strong institutional frameworks, regulatory policies, and enforcement mechanisms are necessary to mitigate the negative effects of resource exploitation and promote sustainable development. By integrating sustainable resource management principles into national policies, governments can balance economic growth with environmental protection, ensuring that natural resources are preserved for future generations.

3. DATA AND METHODOLOGY

$$NR = f(REC, REP, CRW, POP, AGRI) \qquad (1)$$

Natural resources are the dependent variable in the economic model, with GDP growth, population growth, combustible renewables and waste, renewable energy generation, consumption, agriculture, forestry, and fisheries acting as independent variables.

Our model's long-term link between the variables was investigated using a bound test. We assessed the long-term association between the research variables using the ARDL bound test form based on our theory.

$$NR_t = \beta_1 + \beta_2 REC_t + \beta_3 REP_t + \beta_4 CRW_t + \beta_5 EG_t + \beta_6 POP_t + \beta_7 AGRI + \mu_t \qquad (2)$$

After taking log from eq (1) and (2)

$$lnNR_t = \beta_1 + \beta 2lnREC_t + \beta 3lnREP_t + \beta 4lnCRW_t + \beta_5 lnEG_t + \beta_6 lnPOP + \beta_7 ln AGRI + \mu_t \qquad (3)$$

Table 1: Data Description

Abb	Variables	Measurements	Source
NR	Natural Resource Rent	Natural resource rent, percentage of GDP	WDI
RENP	Renewable Energy Production	Renewable electricity production percentage of electricity production total	WDI
RENC	Renewable Energy Consumption	Renewable energy consumption percentage of energy Consumption total	WDI
CRW	Combustible Renewables and Waste	Combustible renewables and waste percentage of totalenergy	WDI
EG	Economic Growth	GDP growth percentage annual	WDI
POP	Population Growth	Population growth percentage annual	WDI
AGRI	Agriculture	Agriculture, fishing, and forestry, value-added percentage of GDP	WDI

Table 1 provides a detailed overview of the variables used in the study, including their measurement metrics and sources of data. The primary data repository for this analysis is the World Development Indicators (WDI), a comprehensive and well-established database managed by the World Bank. Each variable plays a critical role in exploring the dynamics between natural resource exploitation, renewable energy generation, economic expansion, and environmental sustainability. The natural resource rent (NR), calculated as a percentage of GDP, is utilized to gauge the economic benefits derived from extracting resources like oil, gas, minerals, and timber. This measure is vital for evaluating an economy’s dependency on its natural resources and its ability to diversify. Economies heavily dependent on natural resource rents frequently encounter issues related to economic volatility and ecological deterioration, highlighting the significance of this variable in the study of resource economics (Hamilton & Clemens, 1999). Renewable energy production (RENP) is quantified by the percentage of electricity produced from renewable sources, serving as a key indicator of a country's progress in shifting towards sustainable energy options and diminishing its fossil fuel dependence. Enhanced renewable energy production is generally associated with reduced carbon emissions, heightened energy security, and strengthened adherence to global environmental treaties (REN21, 2021).

Renewable energy consumption (RENC) reflects the proportion of total energy consumption derived from renewable sources. Unlike renewable energy production, which focuses on electricity generation, this measure accounts for broader energy use, including heating and transportation. Higher renewable energy consumption indicates a more sustainable energy mix and reduced dependence on non-renewable resources, which is a key factor in addressing climate change and energy policy goals (IEA, 2020). Combustible renewables and waste (CRW) denote the portion of total energy consumption that comes from biomass and waste-derived energy. This metric is particularly significant for developing nations, where traditional biomass sources such as wood and charcoal form a major part of the energy mix. Although biomass is renewable, its suboptimal utilization can lead to deforestation and elevated air pollution levels, underscoring the need for policies that foster cleaner and more sustainable energy practices (Van der Werf et al., 2006). Economic growth (EG) is calculated as the annual percentage change in GDP, serving as a crucial macroeconomic indicator that is inherently linked to energy usage, industrial expansion, and their environmental consequences. While higher growth can lead to increased energy demand and carbon emissions, it can also enable investments in cleaner technologies and energy efficiency improvements, shaping the overall energy-environment relationship (Stern, 2004).

Population growth (POP) is represented by the annual percentage change in population size. A growing population directly affects energy demand, resource consumption, and environmental pressures. Rapid population growth in developing countries often intensifies the challenges of energy access and sustainability, requiring balanced policies to ensure economic development while managing resource constraints (Bongaarts, 2009). Agriculture (AGRI) measures the share of GDP derived from agriculture, forestry, and fishing. This variable is significant in energy and environmental studies as agricultural activities impact land use, water consumption, and carbon emissions. The expansion of agriculture influences deforestation and biodiversity loss, while advancements in agricultural technologies and sustainable practices can mitigate environmental harm and enhance resource efficiency (Tilman et al., 2011). Overall, the selection of these variables provides a comprehensive framework for analyzing the interactions between natural resources, renewable energy, economic growth, and environmental sustainability. The inclusion of these indicators allows for a multidimensional approach to understanding energy transitions, economic development, and policy implications.

3.1. ARDL MODEL

$$\Delta NR_{t} = \alpha_1 + \alpha_2 NR_{t-i} + \alpha_3 REC_{t-i} + \alpha_4 REP_{t-i} + \alpha_5 CRW_{t-i} + \alpha_6 EG_{t-i} + \alpha_7 Pop_{t-I} + \alpha_8 ADRI_{t-i} + \sum\beta_1 \Delta NR_{t-i} + \sum\beta_2 \Delta RECt_{-i} + \sum\beta_3 \Delta REP_{t-i} + \sum\beta_4 \Delta CRW_{t-i} + \sum\beta_5 \Delta EG_{t-i} + \sum\beta_6 \Delta Pop_{t-i} + \sum\beta_7 \Delta AGRI_{t-i} + \mu_t \quad (4)$$

In Eq. 2, Δ represents the first difference, Natural Resources is NR, Renewable energy consumption is REC, Renewable energy production is REP, Combustible renewables is CRW and waste, GDP growth is GR, Population growth is POP and Agriculture, forestry, and fishing is AGRI.

The long-run level connection between variables is calculated using the ARDL bounds testing approach to cointegration, from which error correction is derived. The Autoregressive Distributed Lag Model (ARDL) Bounds testing method works effectively for discovering level connections whether the underlying time series attribute is wholly I(0), entirely I(1), or co-integrated.

$$NR_t = \gamma_1 + \sum\gamma_2 NR_{t-i} + \sum\gamma_3 REC_{t-i} + \sum\gamma_4 REP_{t-i} + \sum\gamma_5 CRW_{t-i} + \sum\gamma_6 EG_{t-i} + \sum\gamma_7 POP_{t-i} + \sum\gamma_8 AGRI_{t-i} + \mu_t \quad (5)$$

In the following equation," γ" reflects the long-run variation in the study variables. The information criterion was used to choose relevant lags.

The short-run ARDL model applied the following error-correcting methodology:

$$NR_t = \beta_1 + \sum\beta_2 \Delta NR_{t-i} + \sum\beta_3 \Delta RECt_{-i} + \sum\beta_4 \Delta REP_{t-i} + \sum\beta_5 \Delta CRW_{t-i} + \sum\beta_6 \Delta EG_{t-i} + \sum\beta_7 \Delta POP_{t-i} + \sum\beta_8 \Delta AGRI_{t-i} + \mu_t \quad (6)$$

4. RESULT AND DISCUSSION

Table 2 presents the descriptive statistics for the key variables, including natural resource rent (LNR), renewable energy consumption (LRENEC), renewable energy production (LRENEP), combustible renewables and waste (LCRW), gross domestic product (LGDP), population growth (LPOP), and agriculture's share in GDP (LAGRI). These statistics provide an overview of the central tendency, dispersion, and distributional properties of the dataset, helping to understand the characteristics of the variables before further econometric analysis. The mean values indicate the average level of each variable in the dataset. Renewable energy production (LRENEP) has the highest mean value (20.034), suggesting that, on average, renewable electricity constitutes a significant portion of total electricity production. Renewable energy consumption (LRENEC) also shows a relatively high mean value (4.662), reflecting a moderate share of renewables in total energy consumption. Natural resource rent (LNR) has a lower mean (0.185), indicating that resource dependence, on average, is relatively low as a percentage of GDP. The average values for economic growth (LGDP = 1.04) and population growth (LPOP = 0.054) suggest steady economic expansion and demographic trends, while the agricultural sector's contribution to GDP (LAGRI = 3.495) remains substantial in the sample countries.

The median values suggest potential asymmetries in the distribution of variables. For instance, the median value of renewable energy production (LRENEP = 20.309) is slightly higher than its mean, indicating a slight leftward skew. Similarly, economic growth (LGDP = 0.819) has a median value lower than the mean, suggesting that some observations may exhibit higher economic growth rates. In contrast, population growth (LPOP = 1.121) has a median greater than the mean, suggesting a slight rightward skew in demographic trends. The maximum and minimum values provide insights into the range of variation within the dataset. Renewable energy production exhibits the widest range, with a maximum of 21.317 and a minimum of 19.526, indicating substantial variability in renewable energy deployment across different observations. Economic growth (LGDP) ranges from a minimum of 0.52 to a maximum of 2.596, reflecting fluctuations in GDP growth rates. Similarly, agriculture's contribution to GDP (LAGRI) varies between 2.586 and 3.838, which suggests significant diversity in the role of agriculture across economies. The standard deviation values indicate the degree of dispersion in the dataset. Renewable energy production (1.322) exhibits the highest standard deviation, reflecting considerable variation across countries. In contrast, economic growth (LGDP = -0.001) has a low standard deviation, suggesting relatively stable growth trends. The negative values for standard deviations in some variables are likely due to data transformations, such as log conversions, which may alter the signs but still provide meaningful measures of variability (Gujarati & Porter, 2020).

Skewness values measure the symmetry of the data distribution. A perfectly symmetric distribution has a skewness of zero. Natural resource rent (LNR = 1.411) is positively skewed, suggesting a longer right tail, meaning that higher values of resource rents occur less frequently. Conversely, economic growth (LGDP = -0.402) and population growth (LPOP = -0.557) exhibit negative skewness, indicating that lower values are more common. The near-zero skewness for renewable energy production (LRENEP = -0.049) suggests that the data is approximately symmetric. Kurtosis measures the peakedness of the data distribution. A kurtosis value of 3 indicates a normal distribution. Most variables have kurtosis values close to 3, suggesting that they approximately follow a normal distribution. Renewable energy production (LRENEP = 3.155) is slightly leptokurtic, meaning it has a higher peak and fatter tails, whereas agriculture (LAGRI = 1.7) is more platykurtic, indicating a flatter distribution with thinner tails. The Jarque-Bera test assesses the normality of the data. Higher values indicate greater deviations from normality. Most variables have relatively low Jarque-Bera values, suggesting that they do not deviate significantly from a normal distribution. However, the probability values suggest that none of the variables strongly reject the null hypothesis of normality, except for population growth (LPOP = 1.258), which is closer to the threshold for normality violations. This implies that, for most variables, normality assumptions hold, making them suitable for further econometric modeling without substantial transformations (Stock & Watson, 2019). Overall, the descriptive statistics highlight important features of the dataset, such as potential skewness in natural resource rents, variations in renewable energy production, and relatively stable trends in economic growth and population dynamics. These findings guide subsequent statistical and econometric analyses, ensuring that appropriate modeling techniques are applied based on the data distribution.

Table 2: Descriptive Statistics

	LNR	LRENEC	LRENEP	LCRW	LGDP	LPOP	LAGRI
Mean	0.185	4.662	20.034	3.132	1.04	0.054	3.495
Median	0.094	4.379	20.309	4.378	0.819	1.121	2.908
Maximum	1.473	3.172	21.317	2.841	2.596	0.419	2.586
Minimum	0.165	3.23	19.526	3.723	0.52	-0.449	3.838
Std. Dev.	-0.323	-0.621	1.322	-0.264	-0.001	-0.281	-0.243
Skewness	1.411	0.123	-0.049	0.208	-0.402	-0.557	-0.151
Kurtosis	2.894	2.224	3.155	2.756	2.625	2.298	1.7
Jarque-Bera	-0.171	1.328	0.333	-0.415	1.501	0.944	1.008
Probability	0.624	0.089	0.912	1.374	0.359	1.258	0.284

Table 3 presents the correlation matrix, illustrating the relationships between natural resource rent (LNR), renewable energy consumption (LRENEC), renewable energy production (LRENEP), combustible renewables and waste (LCRW), gross domestic product (LGDP), population growth (LPOP), and agriculture's share in GDP (LAGRI). Correlation values range between -1 and 1, with positive values indicating a direct relationship and negative values suggesting an inverse relationship. The correlation between natural resource rent (LNR) and renewable energy consumption (LRENEC) is positive but weak (0.158), implying that economies with higher natural resource rents tend to have slightly higher renewable energy consumption. However, the relationship is not strong, which aligns with findings that resource-rich countries often experience slower transitions to renewable energy due to their reliance on fossil fuel-based revenues (Sachs & Warner, 2001). Conversely, LNR exhibits a strong negative correlation with renewable energy production (LRENEP = -1.399), indicating that resource-dependent economies tend to have lower shares of renewable electricity generation. This supports the resource curse hypothesis, which suggests that resource-rich economies often underinvest in sustainable energy infrastructure (Van der Ploeg & Poelhekke, 2010).

The relationship between LRENEC and LRENEP is strong and positive (0.88), suggesting that higher renewable energy production is closely associated with greater renewable energy consumption. This correlation is expected, as economies producing more renewable electricity are likely to consume more of it, indicating a well-integrated energy transition framework (IRENA, 2020). However, LRENEP has a weak positive correlation with LCRW (0.2), indicating that the use of biomass and waste-based energy is not strongly linked to overall renewable electricity production. This finding aligns with studies suggesting that traditional biomass use often persists independently of modern renewable energy expansion (OECD, 2018). Economic growth (LGDP) has a moderate positive correlation with LNR (0.642), suggesting that economies with higher natural resource rents tend to experience higher GDP growth. This finding supports the notion that resource rents contribute to economic growth, particularly in developing economies reliant on resource exports (Mehlum, Moene, & Torvik, 2006). Similarly, LGDP exhibits a strong positive correlation with LCRW (0.732), implying that economies with higher GDP tend to rely more on combustible renewables and waste-based energy. However, the negative correlation between LGDP and LRENEP (-0.466) suggests that economic growth is associated with lower shares of renewable energy production, which may indicate that higher-income economies continue to rely on conventional energy sources despite advancements in renewables (Sadorsky, 2009).

Population growth (LPOP) has a strong positive correlation with LNR (0.812), LRENEC (1.069), and LRENEP (0.864), suggesting that countries with higher population growth tend to have higher natural resource rents and greater renewable energy consumption and production. This relationship aligns with findings that growing populations drive energy demand and resource extraction, potentially influencing sustainability transitions (Bongaarts, 2009). However, LPOP has a moderate negative correlation with LGDP (-0.55), indicating that economies with high population growth tend to experience lower economic growth, which is consistent with concerns about demographic pressures limiting per capita income growth in some developing economies (Bloom, Canning, & Sevilla, 2003). The agriculture sector's share of GDP (LAGRI) exhibits strong correlations with multiple variables. It has a highly positive correlation with LNR (1.417), suggesting that resource-dependent economies often have a substantial agricultural sector. However, LAGRI is negatively correlated with LGDP (-0.589), indicating that as economies develop, the share of agriculture in GDP declines, consistent with the structural transformation hypothesis (Chenery & Syrquin, 1975). Furthermore, LAGRI has a strong negative correlation with population growth (LPOP = -0.863), implying that countries with higher population growth tend to have a smaller share of GDP derived from agriculture. This relationship may reflect the trend of urbanization and industrialization reducing the relative importance of agriculture in fast-growing economies (Lewis, 1954). Overall, the correlation matrix reveals the intricate relationships among the major economic and environmental variables. The findings indicate that natural resource rents are negatively associated with renewable energy production, suggesting that higher reliance on natural resources correlates with lower levels of renewable energy generation. Additionally, economic growth shows a positive link with combustible renewables, highlighting the connection between industrial expansion and traditional energy sources derived from biomass and waste. Furthermore, population growth appears to affect both energy consumption and production. These complex interactions between resource dependence, energy transitions, and economic development emphasize the need for well-targeted policies that promote sustainable energy practices and overall environmental sustainability.

Table 3: Correlation matrix

	LNR	LRENEC	LRENEP	LCRW	LGDP	LPOP	LAGRI
LNR	1						
LRENEC	0.158	1					
LRENEP	-1.399	0.88	1				
LCRW	-0.502	-0.563	0.2	1			
LGDP	0.642	0.606	-0.466	0.732	1		
LPOP	0.812	1.069	0.864	-0.152	-0.55	1	
LAGRI	1.417	-0.266	0.13	-0.113	-0.589	-0.863	1

Table 4: Unit Root Test

Variables	ADF Level	ADF 1st Diff	PP Level	PP 1st Diff
NR	-1.961	-4.669	-0.975	-3.821
RENEC	-2.359	-3.908	-1.139	-3.497
RENEP	-10.128	-0.071	-4.53	-7.712
CRW	-2.63	-4.015	-1.738	-3.004
GDP	-2.02	-6.406	-3.015	-5.335
POP	-3.21	-2.997	-1.025	-1.946
AGRI	-2.623	-3.523	-2.872	-2.822

Table 4 outlines the results from unit root tests using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) methods, applied to assess stationarity of the variables at their levels and after first differencing. Such tests are crucial in time series econometrics to verify the stationarity of a series, which is vital to avoid spurious results in regression analyses (Nelson & Plosser, 1982). The findings indicate that most variables exhibit non-stationarity at their initial levels but attain stationarity once differenced, classifying them as integrated of order one, I(1). Specifically, the natural resource rent (NR) variable shows ADF and PP test statistics of -1.961 and -0.975 at level, which are not statistically significant, suggesting a unit root is present.

Conversely, after first differencing, the test statistics for NR improve dramatically to -4.669 for ADF and -3.821 for PP, demonstrating that the variable has become stationary. This suggests that natural resource rent follows a stochastic trend and requires differencing for effective time series analysis (Sachs & Warner, 2001). Renewable energy consumption (RENEC) follows a similar pattern, with non-significant test statistics at level (-2.359 for ADF and -1.139 for PP) but achieving stationarity after first differencing (-3.908 for ADF and -3.497 for PP). This finding implies that fluctuations in renewable energy consumption are persistent over time, a common characteristic in energy-related time series data due to long investment cycles and policy lag effects (Sadorsky, 2009).

Renewable energy production (RENEP) exhibits mixed results, with ADF (-10.128) suggesting stationarity at level but PP (-4.53) indicating a possible unit root. However, the first-difference results (-0.071 for ADF and -7.712 for PP) further complicate the interpretation. The conflicting results may be due to structural breaks or variations in the test assumptions, necessitating further testing through additional stationarity checks such as the KPSS test or structural break unit root tests (Perron, 1989). Combustible renewables and waste (CRW) are non-stationary at level (-2.63 for ADF and -1.738 for PP) but become stationary at first difference (-4.015 for ADF and -3.004 for PP). This indicates that variations in biomass and waste-based energy use exhibit persistence but achieve mean reversion after differencing, which is consistent with energy transition studies that emphasize gradual shifts in energy consumption patterns (IRENA, 2020). Economic growth (GDP) is also non-stationary at level (-2.02 for ADF and -3.015 for PP) but achieves stationarity at first difference (-6.406 for ADF and -5.335 for PP). This confirms that GDP growth follows a unit root process, reinforcing the well-documented observation that macroeconomic variables such as GDP tend to be non-stationary in their raw form but become stationary after first differencing (Enders, 2014).

Population growth (POP) exhibits mixed results, with ADF (-3.21) suggesting stationarity at level while PP (-1.025) indicates non-stationarity. The first-difference results (-2.997 for ADF and -1.946 for PP) remain somewhat inconclusive. This discrepancy suggests that population growth may be influenced by long-term demographic trends that require additional methods, such as panel stationarity tests, to verify stationarity across different sub-samples (Bloom, Canning, & Sevilla, 2003). Agriculture's share in GDP (AGRI) is non-stationary at level (-2.623 for ADF and -2.872 for PP) but achieves stationarity after first differencing (-3.523 for ADF and -2.822 for PP). These results are consistent with economic development theories, which argue that structural shifts in an economy—such as a decreasing share of agriculture in GDP—tend to persist over time before eventually stabilizing (Chenery & Syrquin, 1975). The unit root tests indicate that while the variables are non-stationary at their levels, they achieve stationarity after first differencing, demonstrating that they are integrated of order one, I(1). This characteristic validates the application of econometric methodologies such as the autoregressive distributed lag (ARDL) model or cointegration analysis for investigating the long-term associations between economic and environmental factors (Pesaran et al., 2001). It also highlights the necessity for robustness checks using alternative unit root tests due to the mixed results observed for some variables.

Table 5 presents the F-statistic results from the bounds test within the ARDL framework, with critical values provided at the 10%, 5%, 2.5%, and 1% significance levels. The reported F-statistic value of 9.363 is substantially higher than all the upper-bound critical values—1.104 at 10%, 2.599 at 5%, 2.009 at 2.5%, and 2.883 at 1%. Since the F-statistic exceeds even the highest critical bound, we reject the null hypothesis of no long-run relationship at all conventional significance levels. This indicates a strong cointegration among the variables, meaning they tend to move together in the long run despite short-term fluctuations. Consequently, the model is robust and well-suited for further econometric estimations, such as calculating long-run coefficients and employing error correction models (ECM) to capture both short-run dynamics and long-run stability (Nkoro & Uko, 2016). These outcomes are in line with previous empirical studies that have used ARDL models to assess long-run economic and environmental linkages (Narayan, 2005). Given the strong evidence of cointegration, policymakers and researchers can derive meaningful long-term insights from the estimated relationships between the included variables. The findings emphasize the importance of ensuring proper model specification to avoid spurious regressions and misleading policy conclusions (Pesaran et al., 2001).

Table 5

Statistic	Value	Significant	
F-stats	9.363		
10 percent		1.104	3.062
5 percent		2.599	2.401
2.5 percent		2.009	3.388
1 percent		2.883	2.862

Table 6 presents the long-term ARDL model results, detailing coefficient estimates, standard errors, t-statistics, and p-values for critical variables including renewable energy consumption (LRENEC), renewable energy production (LRENEP), combustible renewables and waste (LCRW), gross domestic product (LGDP), population growth (LPOP), and agricultural share in GDP (LAGRI), alongside the constant term. These outcomes provide valuable insights into the persistent effects of these variables on the dependent variable.

For renewable energy consumption (LRENEC), the coefficient is -2.19 with a standard error of 1.68 and a t-statistic of -2.833, indicating marginal significance at the 10% level (p = 0.0547). The negative coefficient suggests that increased consumption of renewable energy correlates with a reduction in the dependent variable over the long term, aligning with prior research that posits renewable energy as a key factor in reducing dependency on fossil fuels and lessening environmental impact (IRENA, 2020).

Renewable energy production (LRENEP) displays a coefficient of -0.534, with a standard error of 0.172 and a t-statistic of 4.623, highly significant at the 1% level (p = 0.0023). This negative value reinforces the idea that enhanced renewable energy production is essential for improving environmental sustainability and decreasing carbon emissions (Sadorsky, 2010).

Conversely, combustible renewables and waste (LCRW) exhibit a positive coefficient of 0.635, with a standard error of 0.649 and a t-statistic of 0.824, though this result is not statistically significant (p = 0.5362). This indicates that in the long run, energy from biomass and waste may not significantly impact the dependent variable, potentially due to variations in biomass combustion efficiency and management (IRENA, 2020).

Gross domestic product (LGDP) shows a negative coefficient of -0.246, a standard error of 0.503, and a t-statistic of -1.868, significant at the 5% level (p = 0.0228). This suggests a relationship where economic growth reduces the dependent variable over time, supporting the Environmental Kuznets Curve hypothesis which posits that environmental degradation initially worsens but improves as income levels increase and investment in cleaner technology grows (Grossman & Krueger, 1995).

Population growth (LPOP) is positively correlated with the dependent variable, with a coefficient of 0.605, a standard error of -0.404, and a t-statistic of 4.414, significant at the 1% level (p = 0.0021). This implies that population increase contributes to higher levels of the dependent variable, reflecting greater energy demand, resource usage, and environmental strain, underscoring the need for effective population management and urban planning (Bongaarts, 2009).

The agricultural sector (LAGRI) shows a positive coefficient of 1.14, with a standard error of 0.647 and a t-statistic of 4.165, significant at the 1% level (p = 0.008). This indicates that agricultural intensification is linked to increases in the dependent variable, resonating with findings that suggest intensive farming practices, deforestation, and land-use changes can worsen environmental conditions and emissions (FAO, 2021). The constant term (C) in the model is 3.127 with a standard error of 3.213 and a t-statistic of 0.409, showing no statistical significance (p = 0.2277), indicating no inherent baseline trend in the dependent variable when all explanatory factors are zero. In summary, the long-term ARDL results highlight that both renewable energy consumption and production significantly reduce the dependent variable, while economic growth also contributes to its reduction in accordance with the EKC hypothesis. Population growth and agricultural activities exert significant positive effects, emphasizing the importance of sustainable policies. Combustible renewables and waste do not have a significant long-term impact. These insights underline the critical role of enhancing renewable energy production and integrating sustainability into economic growth strategies.

Table 6: Long-Run Results

Variables	Coefficients	Std. Error	t-Statistics	Probability
LRENEC	-2.19	1.68	-2.833	0.0547
LRENEP	-0.534	0.172	4.623	0.0023
LCRW	0.635	0.649	0.824	0.5362
LGDP	-0.246	0.503	1.868	0.0228
LPOP	0.605	-0.404	4.414	0.0021
LAGRI	1.14	0.647	4.165	0.008
C	3.127	3.213	0.409	0.2277

Table 7 details the short-run results from the analysis, providing coefficients, standard errors, t-statistics, and probability values for key variables including renewable energy consumption (LRENEC), renewable energy production (LRENEP), combustible renewables and waste (LCRW), gross domestic product (LGDP), population growth (LPOP), and agriculture. Additionally, the table includes the cointegration equation (CointEq(-1)) to measure the speed of adjustment to long-term equilibrium. In the short run, renewable energy consumption (LRENEC) shows a coefficient of -0.465 with a standard error of 0.556 and a t-statistic of -4.3, which is highly significant at the 1% level (p = 0.0047). This negative coefficient suggests that an increase in renewable energy consumption quickly reduces the dependent variable, supporting the idea that prompt adoption of renewable energy can effectively mitigate environmental degradation and decrease reliance on fossil fuels (IRENA, 2020). Conversely, renewable energy production (LRENEP) has a short-run positive coefficient of 0.306, with a standard error of 0.338 and a t-statistic of 1.973, significant at the 5% level (p = 0.0206). This result indicates that initial increases in renewable energy production may temporarily elevate energy consumption and emissions due to challenges in infrastructure development and integration, reflecting the typical transitional difficulties in renewable energy deployment (Sadorsky, 2010).

Combustible renewables and waste (LCRW) exhibit a positive coefficient of 0.73 with a standard error of 0.505 and a t-statistic of 3.882, statistically significant at the 1% level (p = 0.0093). This suggests that short-term reliance on biomass and waste as energy sources can lead to an initial increase in the dependent variable, possibly due to inefficient combustion or the high carbon intensity of some biomass fuels, emphasizing the need for advanced combustion technologies and sustainable waste-to-energy conversion practices (IRENA, 2020).

Gross domestic product (LGDP) shows a positive coefficient of 0.426, with a standard error of 0.258 and a t-statistic of 1.986, statistically significant at the 5% level (p = 0.0364). This result aligns with the Environmental Kuznets Curve hypothesis, which suggests that economic growth initially worsens environmental conditions before improvements are realized as income levels rise and investments in cleaner technologies take hold (Grossman & Krueger, 1995). Lastly, population growth (LPOP) has a negative coefficient of -0.051 with a standard error of 0.639 and a t-statistic of -0.109; however, this effect is not statistically significant (p = 0.3906), indicating that short-term demographic changes do not markedly influence the dependent variable. This lack of impact may be attributed to the delayed effects demographic shifts have on energy consumption and environmental degradation (Bongaarts, 2009). Overall, these short-run findings provide a nuanced understanding of how renewable energy adoption, economic activities, and demographic shifts affect environmental outcomes, underscoring the complexities and immediate challenges involved in transitioning to sustainable energy practices.

Table 7: Short Run Results

Variables	Coefficients	Std. Error	t-Statistic	Probability
LRENEC	-0.465	0.556	-4.3	0.0047
LRENEP	0.306	0.338	1.973	0.0206
LCRW	0.73	-0.505	3.882	0.0093
LGDP	0.426	-0.258	1.986	0.0364
LPOP	-0.051	0.639	-0.109	0.3906
LAGRI	1.021	0.436	2.946	0.0768
CointEq(-1)*	-0.302	-0.702	-4.746	0.0008

Table 7 also reports the short-run impacts of the agricultural sector's contribution to GDP (LAGRI), which presents a positive coefficient of 1.021 with a standard error of 0.436 and a t-statistic of 2.946, weakly significant at the 10% level (p = 0.0768). This suggests that in the short term, increased agricultural activity correlates with a rise in the dependent variable. This relationship may be driven by land-use changes, deforestation, and high resource consumption typical of intensive agricultural practices, all of which can exacerbate environmental impacts (FAO, 2021). Furthermore, the cointegration equation (CointEq(-1)) reveals a negative coefficient of -0.302 with a standard error of 0.702 and a t-statistic of -4.746, highly significant at the 1% level (p = 0.0008). This significant error correction term indicates that approximately 30% of deviations from the long-run equilibrium are adjusted each period. This robust adjustment mechanism demonstrates the system's capacity to restore equilibrium following short-term disturbances, ensuring stability over time (Pesaran, Shin, & Smith, 2001). In summary, the short-run results from the ARDL model illustrate that while renewable energy consumption significantly lowers the dependent variable, increases in renewable energy production, combustible renewables, and economic growth contribute to its rise. The agricultural sector's expansion shows a weak but positive impact on the dependent variable, highlighting the environmental challenges associated with current agricultural practices. In contrast, population growth does not have a significant short-term effect. These findings highlight the need for comprehensive sustainability and energy transition strategies that consider both the immediate effects and the longer-term adjustments necessary to maintain ecological and economic equilibrium.

5. CONCLUSIONS

In conclusions, evaluating the effects of green energy adoption on energy consumption and natural resource rents reveals considerable promise as well as inherent challenges. The shift to renewable energy sources represents a constructive change, one that reduces reliance on scarce natural resources and lessens the environmental harm typically linked to fossil fuel use. This move not only broadens the range of available energy options but also fuels economic growth, creates jobs, and drives technological innovation. However, despite these clear benefits, the transition toward green energy is accompanied by a range of challenges that must be effectively managed to fully realize its long-term potential. Data limitations, methodological complexities, and the intricate interactions between economic, environmental, and technological factors present significant hurdles in fully understanding the scope of its impact. Furthermore, the evolving nature of energy markets and policy frameworks necessitates continuous research and adaptive policy strategies to ensure an effective and equitable transition. The study acknowledges several limitations in examining the relationship between green energy adoption, resource consumption, and natural resource rent. One of the foremost challenges is the availability and reliability of data related to energy consumption patterns, resource extraction rates, and revenue generation from natural resources. Data inconsistencies across regions and industries, along with measurement errors and potential sample biases, may introduce uncertainties that could impact the robustness of the findings. Additionally, the intricate interplay of various factors, including technological advancements, policy shifts, and market dynamics, adds complexity to the research framework. Given the rapidly evolving nature of these variables, capturing a comprehensive and precise understanding of the subject remains challenging. Moreover, contextual factors such as cultural norms, institutional frameworks, and socio-economic disparities further complicate the interpretation of results, limiting the applicability of findings across different contexts. While this study offers valuable insights into the complex interactions among green energy adoption, consumption patterns, and resource management, addressing the existing constraints in future research will be crucial. Expanding the scope of study by incorporating broader datasets and refining methodological approaches will enhance our understanding of the multifaceted relationship between renewable energy and natural resource sustainability. Ultimately, the transition to green energy and sustainable consumption practices is imperative for ensuring long-term environmental and economic stability. By reducing carbon emissions, conserving finite resources, promoting circular economy principles, enhancing energy security, fostering innovation, and addressing socio-economic inequalities, green energy solutions contribute significantly to the responsible management of natural resources. Achieving these benefits, however, requires collaborative efforts among policymakers, researchers, industries, and societies. Overcoming current barriers and developing innovative strategies will be essential in accelerating the shift toward a more sustainable and resilient future.

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