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Assessing the Impact of Renewable Energy in Mitigating Climate Change: A Comprehensive Study on Effectiveness and Adaptation Support

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ABSTRACT

The objective of this study is to evaluate the effectiveness of renewable energy in combating climate change and supporting adaptation efforts. By applying the ARDL model to data from 58 countries spanning the period from 1990 to 2022, this study sheds light on the opportunities and challenges associated with this involved relationship. The results indicate that renewable energy plays a significant role in reducing greenhouse gas emissions and mitigating temperature anomalies. Specifically, wind energy, biomass, geothermal energy, solar energy, and waste utilization demonstrate a positive correlation with greenhouse gas emission reduction. Moreover, wind energy, solar energy, waste utilization, and the proportion of renewable energy in primary energy consumption are also linked to a decrease in temperature anomalies. These findings emphasize the importance of implementing concrete measures such as promoting sustainable transportation, ensuring sustainable management of natural resources, raising awareness and enhancing education, increasing subsidies and incentives for renewable energy and strengthening regulations on greenhouse gas emissions.

Keywords: Effectiveness, Renewable Energy, Greenhouse Gas Emissions, Climate Change, and Adaptation
JEL Classifications: C52, Q42, Q54, Q56, Q58.

1. INTRODUCTION

In recent decades, the global community has witnessed a growing concern for the health of our planet and the urgent need for sustainable and environmentally friendly solutions. Climate change, primarily caused by human activities, has become one of the most critical challenges of our time. Its extensive and profound impacts have compelled nations worldwide to take action and explore innovative approaches that address both climate change mitigation and adaptation simultaneously.

In this context, renewable energies (REs) are at the forefront of the transition to a sustainable future, and their technology has transformed the energy landscape by offering a cleaner and more sustainable alternative to traditional fuel sources. Additionally, their potential to reduce greenhouse gas (GHG) emissions and decrease our reliance on fossil fuels has garnered significant attention as a crucial strategy for mitigating climate change (Seung and Soonae, 2023).

While the primary objective of renewable energy (RE) development is to mitigate climate change, its potential for climate change adaptation is gaining recognition. This boils down to the fact that renewable energies (REs) offer a multitude of opportunities for adaptation, ranging from enhancing energy security and reducing vulnerability to supporting sustainable land use practices and fortifying economic resilience (Grigorios and Ioannis, 2023). However, the relationship between renewable energies, climate change mitigation, and adaptation is intricate and interdependent, necessitating a comprehensive understanding of its various facets and interactions. To address this, this paper aims to explore the effectiveness of renewable energies (REs) in reducing greenhouse gas (GHG) emissions and mitigating climate change. In doing so, it delves into the intricate interplay between renewable energies, climate change mitigation, and adaptation, highlighting the opportunities and challenges they present.

Numerous studies have explored various aspects of renewable energies and climate change mitigation, such as the works of Seung and Soonae (2023), Grigorios and Ioannis (2023), Stephen et al. (2023), Camilo et al. (2023), and Suman (2021). Suman (2021) examined the various renewable energy technologies available in Nepal, their current adoption, growth potential, impact on climate change, and their contribution to mitigation and adaptation. The findings of this study demonstrate that the progressive growth in renewable energy utilization has led to a reduction in greenhouse gas (GHG) emissions. Grigorios and Ioannis (2023) assert that collaboration between the public and private sectors optimizes resource utilization and expertise, resulting in more effective mitigation and adaptation measures to address climate change. In their study, Grigorios and Ioannis (2023) investigated the interaction between climate change mitigation and adaptation measures in Greece and the European Union (EU). On the other hand, Seung and Soonae (2023) focused on regional heterogeneity and its relationship with the transition to renewable energies and climate change adaptation. This study highlighted the importance of considering spatial inequalities in climate adaptation when developing and implementing renewable energy (RE) policies. Nevertheless, previous studies on renewable energies exhibit certain significant limitations and gaps. Firstly, these studies typically focus on specific types of renewable energies, notably solar and wind energy, while regrettably overlooking other forms that might bear a different environmental impact. Overlooking energy derived from wood, waste, or biomass energy, these studies have inadvertently excluded potential contributors to the broader spectrum of renewable resources. Such omission presents a significant limitation, as these alternative forms of renewable energy also play a pivotal role in the energy landscape and warrant closer examination. Wood energy, derived from sustainable forestry practices, and energy from waste or biomass sources possess both promising potential and environmental implications that necessitate inclusion in comprehensive assessments of renewable energy's impact on the environment and sustainability efforts. Furthermore, the majority of this research has centered on specific country cases, neglecting a cross-country or transnational perspective. This hampers our ability to generalize findings and comprehend the actual effectiveness of renewable energies in mitigating global warming and adapting to climate change. Some research has also overlooked the importance of carbon capture and storage, as well as the development of environmental technologies associated with renewable energies. Lastly, the share of renewable energies in our primary energy consumption has been underexplored in prior works, raising questions about how we can accelerate the transition to a greener and sustainable economy.

Therefore, this paper aims to address this knowledge gap by analyzing and synthesizing existing research to examine the effectiveness of renewable energies in climate change mitigation and adaptation. By exploring the numerous links and potential trade-offs, we seek to provide a comprehensive understanding of how the deployment of renewable energies can contribute to both mitigation efforts and adaptation strategies.

To achieve this, the paper will begin with a review of the current state of knowledge regarding renewable energy technologies and their effectiveness in climate change mitigation. Subsequently, we will explore the various ways in which renewable energies can contribute to climate change adaptation, examining the numerous adaptation co-benefits associated with the deployment of renewable energies. Furthermore, the paper will explore potential trade-offs and challenges that may arise in balancing climate change mitigation and adaptation goals within the renewable energy (RE) sector. By critically examining existing case studies and empirical evidence, we will identify key success factors that can facilitate the simultaneous pursuit of these closely linked goals.

Overall, this paper aims to provide valuable information to policy makers, researchers and practitioners involved in renewable energy planning, climate change mitigation and adaptation strategies. It aims to contribute to a more complete understanding of the relationship between renewable energy, climate change mitigation and adaptation, thereby promoting the development of sustainable and resilient pathways towards a decarbonized world.

2. LITERATURE REVUE

2.1. The Effect of Renewable Energy (RE) Deployment on Greenhouse Gas (GHG) Emissions and Attempts to Mitigate Climate Change

The impact of deploying renewable energies on GHG emissions and climate change mitigation efforts has consistently attracted researchers' attention. Numerous studies, including the works of Oriza et al. (2023), Na et al. (2023), and Kais and Anis (2020), have demonstrated that the widespread adoption of RE sources, such as solar and wind energy, can significantly reduce GHG emissions and contribute to climate change mitigation. One of the primary advantages of REs is their ability to generate electricity without producing carbon dioxide emissions (Kais and Anis (2020)). By harnessing the power of the sun, wind, or water, RE systems can produce electricity with minimal or zero emissions during their operation. This shift to cleaner energy sources helps decrease the amount of GHGs released into the atmosphere, thereby mitigating climate change.

In addition to emissions reduction, the deployment of REs also offers potential for improving energy efficiency. Many renewable energy technologies, such as solar panels and wind turbines, have become more efficient over time, resulting in increased energy production for a given input. This enhanced efficiency can further reduce GHG emissions by eliminating the need for additional fossil fuel-based electricity generation.

Furthermore, the deployment of renewable energies has the potential to create significant co-benefits for climate change mitigation efforts. For example, the transition to renewable energies can reduce air pollution, thereby improving air quality and human health. Additionally, the development and implementation of renewable energy technologies can stimulate economic growth, create employment opportunities, and enhance energy security. In this regard, Oriza et al. (2023) emphasized that the adoption of renewable energy sources is not only essential to address environmental concerns but also plays a crucial role in global economic growth. To study the relationship between renewable energy usage, economic growth, and GHG emissions, this study employs a Structural Vector Autoregression (SVAR) methodology. By comparing the effects and outcomes of increased renewable energy utilization in middle-income (MIC) and high-income countries (HIC), the study reveals that transitioning to renewable energy sources for power generation generates positive economic effects in both the short and long term. In a similar vein, Kais and Anis (2020) suggested that to achieve Sustainable Development Goals (SDGs), bridging the carbon emissions and economic development gap is essential. This study examines the potential of renewable energy in promoting economic growth and reducing carbon emissions in 15 major renewable energy-consuming countries. Two estimation techniques are used, namely Fully Modified Ordinary Least Squares (FMOLS) and Vector Error Correction Model (VECM). The results reveal that renewable energies contribute to increased economic growth and reduced carbon emissions. The analysis also identifies a bi-directional causality between economic growth and renewable energies in both the short and long term, confirming the feedback hypothesis. Furthermore, a two-way relationship is observed between CO_2 emissions and renewable energies in the short term, while no cause-and-effect relationship is evident in the long term. Similarly, Phebe and Samuel (2016) underscored the role of renewable energies in climate change mitigation. Phebe and Samuel (2016) examined the opportunities associated with the use and production of renewable energies, with a primary focus on energy security, access to energy, social and economic development, climate change mitigation, and the reduction of environmental and health impacts. The results of this study show that international cooperation can reduce the costs of REs and eliminate barriers to accessing green energy. In addition, Na et al. (2023) advocated for an accelerated transition to REs due to global population growth and increasing energy demand. They emphasized the need to further promote and support the development and use of REs to ensure a sustainable future. This research investigated the interplay among urbanization, carbon dioxide emissions, economic growth, and the production of RE. The findings of the study revealed a significant and enduring correlation between urbanization, carbon dioxide emissions, economic growth, and RE production. Furthermore, the results highlighted the essential role of REs in climate change mitigation in developing countries.

Furthermore, Suman (2021) conducted research on REs in Nepal. The results of this study demonstrate that REs can generate alternative income sources, thus contributing to sustainable economic development. Similarly, the results revealed a gradual increase in the adoption of REs, leading to a reduction in GHG emissions and improved carbon sequestration. In a similar vein, Ibrahim (2008) studied the energy pricing reform plan to promote energy efficiency and consequently reduce GHG emissions in Turkey. The results of this study stated that GHG reduction in Turkey can only be achieved when policies are favorable and well-targeted. The results also emphasized the role of public awareness regarding environmental degradation. Additionally, Elum and Momodu (2017) highlighted the role of policy initiatives in integrating REs into the energy mix. This study focuses on Nigeria and shows that sociopolitical barriers are the most significant hindrances to the rapid implementation of a green economy.

2.2. The Role of Renewable Energy (RE) in Building Adaptive Capacity to Climate Change

Climate change poses significant challenges to societies worldwide. While many countries strive to promote REs to mitigate climate change, little is known about the impacts of energy policies on vulnerability to climate change. In this regard, Seung and Soonae (2023) attempted to explain how the transition to REs can have disproportionate impacts on climate change adaptation due to regional differences. To address this question, they used variations in the use of REs to test the effectiveness of climate adaptation policies in terms of climate sensitivity and vulnerability. Through the fuzzy analytic hierarchy process and panel data regression, the study analyzes the spatio-temporal correlation between the transition to REs and climate vulnerability worldwide. The findings demonstrated that, while the usage of RE grows proportionately with climate exposure and sensitivity, certain nations display inequalities between RE transition and climate vulnerability. The promotion of renewable energies is concentrated in countries with greater adaptive capacity while bypassing the most vulnerable countries. These results indicate that current RE policies might worsen climate inequalities and undermine the advantages of transitioning to REs by neglecting the spatial variations in climate vulnerability.

Conversely, Rohan et al. (2023) demonstrated that energy security policies can achieve long-term environmental goals for countries transitioning to renewable sources without harming economic growth. This study examined the impact of Austria’s climate strategy on RE consumption using OECD national data from 1990 to 2015 and the synthetic control method amid the European energy crisis. The study revealed that Austria’s RE consumption increased between 2.64% and 4.43% annually, with no significant decrease in per capita production.

Furthermore, the study conducted by Suman (2021) recommends that governments respond to local energy demand and climate change-related issues by revising energy policy and utilizing local RE resources. This study focuses on Nepal and discusses its potential for RE development, its energy status, its potential for adopting new renewable energy technologies, its relationship with climate change, and its roles in mitigation and adaptation. Although the majority of Nepal’s energy consumption is generated from traditional sources, REs are gradually increasing, resulting in reduced GHG emissions and improved carbon sequestration. In a similar vein, Alka et al. (2014) focused on the analysis of renewable energy technologies (RET) such as biogas, improved cook stoves (ICS), micro-hydropower (MH), and solar power (SP) in Nepalese rural areas. The analysis takes into account the energy efficiency, socio-economic, and environmental impacts of various RET, with biomass in new technologies such as biogas and ICS contributing to increased energy security and reducing the negative effects of traditional biomass use. MH and SP proved to be the most promising for replacing candles and kerosene lamps in electricity production. This study also utilizes the Long-range Energy Alternatives Planning system (LEAP) model to develop a plan for RET utilization in Nepal, with a focus on domestic energy consumption in rural areas, and evaluates the role of biogas, ICS, MH, and SP technologies in reducing CO_2 emissions.

2.3. The Challenges and Opportunities of Financing and Scaling Renewable Energy Technologies (RET)

Financing and scaling up RET present both challenges and opportunities in the global transition to a sustainable energy future. One of the primary challenges is the high initial investment costs associated with implementing RE projects. The initial expenditure necessary for the development and implementation of technologies such as solar panels, wind turbines, or energy storage systems can be significant, which may discourage potential investors. Additionally, because RE sources are intermittent, grid integration challenges arise, as infrastructure modifications and energy storage solutions are required to maintain a steady and constant power supply.

Furthermore, the growth of REs presents opportunities for job creation, economic development, and energy security. As the industry expands, it generates employment opportunities across various sectors, ranging from manufacturing and installation to research and development. Local communities can benefit from the implementation of RE projects, attracting investments, stimulating economic growth, and reducing reliance on imported fossil fuels. Moreover, diversifying energy sources through renewable technologies enhances energy security by reducing dependence on limited and geopolitically sensitive fossil resources.

However, Yuyu and Li (2023) examined the impact of green finance on sustainable development in China between 1990 and 2020. The panel data model used in this study shows that green finance has a negative effect on pollution and a positive impact on sustainable development. Renewable energies and technological innovation enhance sustainable development and private sector investments. Investment, trade, and human capital have significant effects on sustainable development. Green finance has the potential to promote the advancement of eco-friendly technology and contribute to mitigating environmental pollution. Non-public enterprises play a mediating role, but not state-owned enterprises due to enterprise ownership heterogeneity. In a similar context, Juntao et al. (2023) explored the role of green financing and government policies in facilitating the transition to REs in China. The empirical illustration, based on a panel threshold regression model and a sample of 30 Chinese provinces from 2001 to 2019, shows that green financing initiatives contribute to accelerating the transformation of the Chinese energy industry by promoting an increase in the share of REs, especially in regions with well-performing markets. Additionally, the results show that improvements in energy efficiency governance and environmental regulation positively moderate the impact of green financing on the transition to clean energy.

Similarly, Zeyun et al. (2022) analyzed data at both the micro and macro levels in China from 2015 to 2020 to study the impact of green financing, volatility, and geopolitical risk on investments in RE sources. The results showed positive effects of green financing and environmental regulations in promoting investments and negative effects of oil price volatility and geopolitical risk on clean energy investments. The study recommends encouraging green businesses in China to consider investing in RE sources as a long-term strategy. In the same context, Chunlong et al. (2023) examined the relationship between economic growth, green finance, investments in RE, geopolitical risk, and environmental sustainability in BRICS countries between 2000 and 2020. The results of this study, obtained via the Cross-Sectionally ARDL model, suggest that increasing green financing, investments in RE and energy innovation reduce environmental pollution. Additionally, GPR shocks have long-term beneficial effects on the development of green finance, and the adoption of REs is positively influenced by GPR.

On the other hand, Gang (2023) examined the impact of green finance and REs on carbon intensity in 10 Asian economies. The findings from the Quantile Autoregressive Distributed Lag (QARDL) panel model suggest that both green finance and RE consumption negatively affect carbon intensity in both the short and long term. This confirms their significant role in reducing carbon intensity. In a similar vein, Hongsheng et al. (2022) explored the impact of economic development, RE use, green finance, and agricultural development on carbon dioxide (CO_2) emissions in China. To investigate the correlations, the ARDL limit test strategy and the DOLS method were applied to time series data from 1990 to 2020. The results demonstrate that industrial and agricultural development increases carbon intensity, with a 1% increase in business development associated with a 1.64% increase in CO_2 emissions. However, increased reliance on REs and green finance can reduce carbon emissions and enhance environmental protection.

Summing up, previous research has significant limitations and shortcomings, including:

- Studies often focus on specific types of REs, limiting the overall understanding of their potential and impacts.
- The majority of work has concentrated on specific country cases, without considering a transnational or "cross-country" perspective, limiting the ability to generalize results.
- Research has mainly addressed the relationship between REs and climate change without delving into their actual effectiveness in reducing global warming or in climate change adaptation.
- Some studies have overlooked the significant role of carbon capture and storage, as well as the development of environmental technologies related to REs.
- The share of REs in our primary energy consumption has also been understudied in previous research.

3. DATA AND METHODOLOGY

3.1. Data

The objective of this study is to assess the effectiveness of REs in reducing GHG emissions and mitigating climate change. It examines data from 58 countries, including 38 OECD economies and 20 non-OECD economies, over the period from 1990 to 2022. This period was characterized by various energy, health, and economic shocks, highlighting the growing importance of REs. The data used in this study were extracted from the oecd.org, irena.org, and statista.com databases. The data were transformed using logarithms to verify their normal distribution.

3.2. Empirical models

To analyze the short-term and long-term relationship between the variables RGHGE, RLOTA, RE, CCS, EFRN, IRE, and IT described below, we employ the ARDL model. The model can be defined as follows:

$$RGHGE=f\,(RE, CCS, EFRN, IRE, IT) \tag{1}$$

$$RLOTA=f\,(RE, CCS, EFRN, IRE, IT) \tag{2}$$

The two independent variables, RLOTA and RGHGE, respectively represent the reduction in global land and ocean temperature anomalies and the decrease in GHG emissions. The variables reflecting renewable energy (RE) encompass HPC, GEC, SEC, WEC, WOEC, WAEC, BC, and BEC, signifying consumption levels of Hydroelectric Power, Geothermal Energy, Solar Energy, Wind Energy, Wood Energy, Waste Energy, Biofuels Energy, and Biomass Energy. The "carbon capture and storage" (CCS) variable pertains to measures designed to capture carbon dioxide (CO_2) emissions originating from industrial sources or power plants and securely store them, thereby mitigating GHG emissions. It serves to assess the effectiveness of carbon capture and storage technologies in reducing CO_2 emissions and their impact on climate change. Moreover, it is employed to examine the policies and measures implemented to endorse carbon capture and storage as a strategy for combating global warming.

The variable "The share of renewable energies in our primary energy consumption" (EFRN) reflects the percentage of energy consumption derived from renewable sources. This variable provides for an assessment of renewable energy's contribution to the entire energy mix, as well as its impact on environmental sustainability, GHG emissions reduction, and the phenomena of global warming. The "Investment in renewable energies" (IRE) variable mirrors the financial resources allocated to the development and promotion of renewable energy sources. It enables the assessment of the financial dedication to REs. Furthermore, it is employed to scrutinize the policies and measures designed to incentivize investments in REs as a sustainable solution to address global energy needs. The "Development of environmental technologies" (IT) variable reflects the efforts and advancements made in researching, designing, and implementing technologies aimed at resolving environmental issues. This variable facilitates the evaluation of innovation and the adoption of environmentally friendly technologies, as well as their impact on sustainability and environmental protection. It is also employed to examine the policies and measures in place to encourage the development and dissemination of environmental technologies.

However, it is possible to express equations (1) and (2) as follows:

$$Yt = \alpha_0 + \alpha_{1t} + \sum\nolimits_{i=1}^{p} \theta_i\, y_{t-1} + \sum\nolimits_{j=1}^{k} \sum\nolimits_{lj=0}^{qj} \beta j, lj, xj, \mathrm{t} - l_{\mathrm{j}} + \varepsilon_t \tag{3}$$

where ε_t is the error term, ε_0 is a constant term, and α_1, θ_i, β_j, l_j are respectively the coefficients associated with a linear trend, lags of Y_t, and lags of the k regressors $x_{j,t}$ for j=1,….k. The choice of the ARDL model is justified by four main advantages, namely:

- Flexibility: The ARDL model can be used to analyze short-term and long-term relationships between variables, enabling the examination of both short-term effects and long-term adjustments.
- Efficient Estimation: The ARDL model is estimated using robust econometric techniques, such as Ordinary Least Squares (OLS) or Generalized Method of Moments (GMM). These methods enable the robust and efficient estimation of model parameters.
- Economic Interpretation: The ARDL model allows for the interpretation of estimated coefficients in economic terms. This means it is possible to understand how variables influence each other and analyze both short-term and long-term effects.
- Error Diagnosis: The ARDL model enables the diagnosis of specification errors and testing for autocorrelation, heteroscedasticity, and non-normality of residuals. This ensures the validity of the obtained results.

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Descriptive Statistics

The descriptive statistics, presented in Table 1, suggest that the series L_RLOTA, L_RGHGE, L_BC, L_GEC, L_WAEC, and L_WOEC exhibit negative skewness, indicating a negative asymmetry in their distributions. This implies that the tails of the distributions of these series are extended to the left, with the majority of values located on the right side of the distributions. The distributions are, therefore, slightly skewed to the right. In contrast, the series L_BEC, L_CCS, L_EFRN, L_HPC, L_IRE, L_IT, L_SEC, and L_WEC exhibit positive skewness, indicating a positive asymmetry in their distributions. This means that the tails of the distributions of these mentioned series are extended to the right, with the majority of values located on the left side of the distributions. The distributions are, therefore, slightly skewed to the left. Additionally, the descriptive statistics show that the series exhibit positive kurtosis, indicating slightly leptokurtic distributions. However, the Jarque-Bera test findings show that the series has a normal distribution. Furthermore, the correlation analysis results reveal a lack of strong correlation between the variables.

4.2. Unit Root Analysis

In the context of studying the stationarity of the series, we employ the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. The results of these tests are presented in Table 2. The P-value I(0) of the ADF test is below the threshold of 0.05 only for the variables L_RLOTA, L_RGHGE, L_BC, and L_WEC, allowing us to reject the null hypothesis and conclude that these series are stationary at the level. However, the P-value I(0) is above

Table 1: Descriptive statistics and correlation matrix

	L_RLOTA	L_RGHGE	L_BC	L_BEC	L_CCS	L_EFRN	L_GEC	L_HPC	L_IRE	L_IT	L_SEC	L_WAEC	L_WEC	L_WOEC
Mean	−0.309	3.426	2.819	3.564	1.164	0.947	2.273	3.436	5.713	0.998	2.152	2.665	2.447	3.341
Median	0.000	4.904	2.884	3.514	1.077	0.896	2.269	3.429	5.712	1.009	1.834	2.669	2.421	3.345
Maximum	0.000	7.124	3.384	3.708	1.629	1.129	2.331	3.561	5.726	1.118	3.272	2.761	3.585	3.387
Minimum	−1.155	0.000	2.045	3.419	0.792	0.856	2.182	3.347	5.703	0.896	1.761	2.561	1.463	3.287
Std. Dev.	0.419	3.069	0.501	0.107	0.269	0.088	0.045	0.054	0.009	0.058	0.510	0.051	0.793	0.025
Skewness	−0.766	−0.162	−0.164	0.196	0.430	0.927	−0.117	0.574	0.249	0.063	1.054	−0.064	0.029	−0.180
Kurtosis	1.859	1.178	1.322	1.317	1.726	2.464	1.667	2.833	1.416	2.389	2.481	2.024	1.362	2.308
Jarque−Bera	5.016	4.710	4.021	4.106	3.249	5.122	2.521	1.852	3.792	0.534	6.477	1.332	3.692	0.836
Probability	0.081	0.095	0.134	0.128	0.197	0.077	0.284	0.396	0.150	0.766	0.039	0.514	0.158	0.658
L_RLOTA	1													
L_RGHGE	0.1194	1												
L_BC	0.1208	0.1919	1											
L_BEC	0.1108	0.0966	0.1349	1										
L_CCS	0.0137	−0.1205	0.1215	−0.4063	1									
L_EFRN	0.0888	0.1502	−0.3274	−0.2994	−0.3610	1								
L_GEC	0.0673	0.1935	0.3662	0.8010	−0.2055	−0.4397	1							
L_HPC	−0.2162	−0.0459	−0.4174	−0.4843	0.0776	0.5428	−0.5971	1						
L_IRE	−0.1426	0.0812	0.1389	0.4658	−0.2983	−0.0992	0.5455	−0.2844	1					
L_IT	−0.0262	0.2282	0.1841	0.2295	0.0795	−0.0152	0.3521	−0.3110	0.5601	1				
L_SEC	0.0610	0.2484	−0.2668	−0.1888	−0.3341	0.6837	−0.4275	0.3780	−0.1186	0.0280	1			
L_WAEC	−0.1585	0.0126	−0.0824	−0.0594	−0.4535	0.4822	−0.0384	0.4935	0.3266	0.0071	0.2751	1		
L_WEC	−0.2308	0.2362	−0.1789	0.4124	−0.3333	−0.0085	0.2983	0.1639	0.2794	0.1779	−0.0386	0.3391	1	
L_WOEC	−0.1036	−0.0626	−0.0599	−0.0485	−0.5268	0.5136	−0.1613	0.4046	0.3540	0.0074	0.3095	0.7683	0.1947	1

Table 2: Results of unit root tests

Variables	PP test		ADF test	
	I (0)	I (1)	I (0)	I (1)
L_RLOTA	−7.5608 (0.0000)*	−18.7322 (0.0001)*	−5.3122 (0.0002)*	−5.2898 (0.0002)*
L_RGHGE	−8.5062 (0.0000)*	−19.8091 (0.0001)*	−9.1769 (0.0000)*	−7.8123 (0.0000)*
L_BC	−5.2186 (0.0002)*	−15.7202 (0.0000)*	−5.2137 (0.0002)*	−7.7079 (0.0000)*
L_BEC	−1.6534 (−0.4445)	−17.9559 (0.0001)*	−1.4191 (0.5606)	−4.2501 (0.0024)*
L_CCS	−1.6801 (−0.4314)	−5.5337 (0.0001)*	−1.6421 (0.4501)	−5.5337 (0.0001)*
L_EFRN	−1.6665 (−0.4381)	−5.2876 (0.0001) *	−1.6665 (0.4381)	−5.2928 (0.0001)*
L_GEC	−1.8946 (−0.3305)	−6.9224 (0.0000)*	−1.8996 (0.3283)	−6.944 (0.0000)*
L_HPC	−2.4417 (−0.1389)	−6.9455 (0.0000) *	−2.4493 (0.137)	−5.1589 (0.0003) *
L_IRE	−2.2984 (−0.1786)	−5.9576 (0.0000)*	−2.2598 (0.1905)	−5.6631 (0.0001)*
L_IT	−2.4912 (−0.1269)	−5.3281 (0.0001)*	−2.3688 (0.1581)	−5.3089 (0.0001)*
L_SEC	−3.7667 (0.0076)*	−12.6883 (0.0000)*	−1.4676 (0.5364)	−11.594 (0.0000)*
L_WAEC	−2.2126 (−0.2059)	−5.3344 (0.0001)*	−1.9094 (0.324)	−5.3223 (0.0001)*
L_WEC	−5.1312 (0.0002)*	−9.6592 (0.0000)*	−4.9691 (0.0003)*	−7.6783 (0.0000)*
L_WOEC	−2.3816 (−0.1546)	−6.2338 (0.0000)*	−2.4244 (0.1433)	−6.0913 (0.0000)*

***, ** and * denote significance at 10%, 5% and 1%, respectively

the threshold for the remaining variables, so we cannot reject the null hypothesis, and the series is considered non-stationary. In this regard, we proceed to the ADF test's initial difference, I(1). The results of this test suggest that we can reject the null hypothesis and conclude that all series are stationary. The results of the Phillips-Perron (PP) test are similar to those of the Augmented Dickey-Fuller (ADF) test and have shown that the variables used are stationary at most at the first difference I(1). In this regard, we can use the Autoregressive Distributed Lag (ARDL) model.

4.3. Cointegration Analysis

The Johansen cointegration test is employed to determine the number of cointegration relationships among the variables in the time series. The trace statistics indicate the number of cointegration relationships present in the series. The results of this test, presented in Table 3, reveal a number of cointegration relationships higher than the critical value, thus indicating the existence of at least 5 cointegration relationships among the variables for the two models used. This result is supported by the probability associated with the test statistic, which is below the critical value of 0.05.

4.4. Results of ARDL Model

To assess the short and long-term relationships between the variables, we proceed with the estimation of the ARDL model.

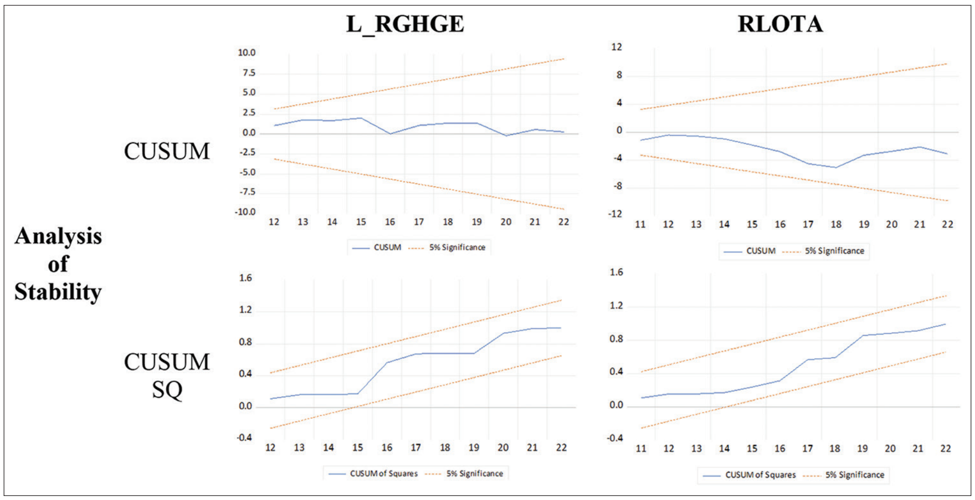
4.4.1. The effectiveness of renewable energy (RE) in reducing greenhouse gas (GHG) emissions

The results of the short-term ARDL estimation are presented in Table 4, Panel A. Consistent with the works of Na et al.

Table 3: Results of the Johansen cointegration test

Series: L_RGHGE L_BC L_BEC L_CCS L_EFRN L_GEC L_HPC L_IRE L_IT L_SEC L_WAEC L_WEC L_WOEC					Series: L_RLOTA L_BC L_BEC L_CCS L_EFRN L_GEC L_HPC L_IRE L_IT L_SEC L_WAEC L_WEC L_WOEC				
Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 CV	Prob.**	Hypothesized No. of CE (s)	Eigenvalue	Trace Statistic	0.05 CV	Prob.**
At most 1*	0.977126	508.8593	348.9784	0.0000	At most 1*	0.970809	531.5929	374.9076	0.0000
At most 2*	0.924116	387.9715	298.1594	0.0000	At most 2*	0.942258	418.5083	322.0692	0.0000
At most 3*	0.877091	305.4577	251.2650	0.0000	At most 3*	0.912440	327.2515	273.1889	0.0000
At most 4*	0.823195	238.3757	208.4374	0.0008	At most 4*	0.837683	249.3179	228.2979	0.0035
At most 5*	0.805491	182.9291	169.5991	0.0081	At most 5*	0.800663	191.1353	187.4701	0.0321
At most 6	0.714071	130.5362	134.6780	0.0854	At most 6	0.704677	139.5270	150.5585	0.1766
At most 7	0.589914	90.47180	103.8473	0.2737	At most 7	0.656033	100.4971	117.7082	0.3633
At most 8	0.527016	61.94739	76.97277	0.3974	At most 8	0.548005	66.34639	88.80380	0.6493
At most 9	0.388854	37.98920	54.07904	0.5732	At most 9	0.419082	40.93572	63.87610	0.8168
At most 10	0.310905	22.23180	35.19275	0.5798	At most 10	0.313491	23.55505	42.91525	0.8559
At most 11	0.170158	10.31575	20.26184	0.6088	At most 11	0.214763	11.51870	25.87211	0.8440
At most 12	0.127024	4.347126	9.164546	0.3629	At most 12	0.111473	3.782080	12.51798	0.7734

Figure 1: CUSUM and CUSUM SQ test



(2023), Gang (2023), and Alka et al. (2014), the findings of this study underscore the crucial role of renewable energies in reducing GHG emissions. The ARDL estimation results show a significant and positive relationship between the reduction of GHG emissions and the consumption of geothermal energy, as well as the share of renewable energies in our primary energy consumption. This suggests that an increase in geothermal energy consumption effectively contributes to reducing GHG emissions. Similarly, a positive relationship between the reduction of GHG emissions and the share of renewable energies in our primary energy consumption indicates that transitioning to increased use of REs is economically beneficial. Renewable energies, such as geothermal energy, are often more sustainable and less polluting than traditional energy sources. By increasing the share of REs in our energy mix, we reduce our dependence on fossil fuels, which can have economic benefits, such as lowering costs associated with GHG emissions. In the long term, the ARDL estimation results, presented in Table 4, Panel B, demonstrate a significant and positive relationship between the reduction of GHG emissions and the consumption of wind energy and biomass energy. This relationship may lead to a decrease in costs associated with environmental regulations, such as carbon emission taxes or compliance costs with stricter environmental standards. Additionally, it can stimulate the local and regional economy by generating additional income and fostering technological innovation. These results align with those of Oriza et al. (2023), Kais and Anis (2020).

Furthermore, the long-term ARDL estimation suggests that Wood Energy consumption may slow down the pace of GHG emission reduction. This can be justified by the fact that burning wood to produce energy generates GHG emissions, primarily carbon dioxide (CO_2). However, when wood energy is used unsustainably, meaning when wood consumption exceeds the forests' regeneration capacity, it can lead to a decrease in the number of trees and degradation of forest ecosystems. In addition, the ARDL estimation results show a positive relationship, both in the short term and the long term, between the reduction of GHG emissions and the consumption of wind energy and biomass energy. This indicates that these two RE sources are effective, sustainable, and can contribute significantly to reducing GHG emissions over an extended period. This could be attributed to several factors, such as the continuous development of wind and biomass technology, investment in the necessary infrastructure, and long-term supportive policies to promote the use of these energy sources.

Table 4: ARDL model results: Renewable energy and greenhouse gas emissions

Panel A. ARDL short run				
Variable	**Coefficient**	**SE**	**t-statistic**	**Prob.***
L_RGHGE(-1)	-0.506377	0.110192	-4.595398	0.0008*
L_BC	1.160760	1.191310	0.974356	0.3508
L_BEC	85.31968	28.08591	3.037811	0.0113**
L_BEC(-1)	-38.59237	11.93908	-3.232442	0.0080*
L_CCS	0.624315	2.260134	0.276229	0.7875
L_EFRN	14.04116	5.687859	2.468620	0.0312**
L_EFRN(-1)	18.32362	8.665929	2.114443	0.0581***
L_GEC	173.4711	92.97731	1.865735	0.0890***
L_GEC(-1)	-273.1871	80.40737	-3.397537	0.0060*
L_HPC	-2.903658	15.01672	-0.193362	0.8502
L_HPC(-1)	-36.08938	13.21565	-2.730808	0.0196**
L_IRE	-21.99355	57.85359	-0.380159	0.7111
L_IRE(-1)	-240.8186	79.33965	-3.035287	0.0113**
L_IT	-0.316183	8.512321	-0.037144	0.9710
L_SEC	-0.637093	1.605692	-0.396772	0.6991
L_WAEC	-22.51020	13.74767	-1.637383	0.1298
L_WEC	2.100263	0.546883	3.840422	0.0027*
L_WEC(-1)	1.684092	0.922852	1.824878	0.0953***
L_WOEC	8.552942	22.67489	0.377199	0.7132
L_WOEC(-1)	34.34129	24.85473	1.381680	0.1945
C	1574.648	444.3133	3.544002	0.0046*
R-squared	0.915618	S.D. dependent var		3.054715
F-statistic	5.967977	Prob (F-statistic)		0.002056
Panel B. ARDL long run				
C	59.34545	289.6285	0.204902	0.8404
L_RGHGE(-1)*	−1.546231	0.129329	−11.95583	0.0000*
L_BC(−1)	4.633398	1.343883	3.447770	0.0036*
L_BEC**	65.25734	25.30470	2.578863	0.0210**
L_CCS(−1)	−1.577251	3.078527	−0.512339	0.6159
L_EFRN**	8.505210	5.822258	1.460810	0.1647
L_GEC(−1)	−161.5030	62.84729	−2.569768	0.0213**
L_HPC**	6.134279	15.12108	0.405677	0.6907
L_IRE**	47.54464	59.24710	0.802480	0.4348
L_IT**	2.770803	8.426084	0.328836	0.7468
L_SEC**	2.913441	0.943112	3.089177	0.0075*
L_WAEC**	−11.91967	14.58083	−0.817489	0.4264
L_WEC**	1.748876	0.559615	3.125143	0.0070*
L_WOEC**	−63.62455	26.35897	−2.413772	0.0290**
D (L_BC)	3.175280	0.980300	3.239090	0.0055*
D (L_CCS)	3.956281	2.739903	1.443950	0.1693
D (L_GEC)	−84.27789	70.33733	−1.198196	0.2494
Levels Equation				
L_BC	2.996576	0.959408	3.123358	0.0070*
L_BEC	42.20414	17.59887	2.398117	0.0299**
L_CCS	−1.020062	1.998530	−0.510406	0.6172
L_EFRN	5.500608	3.780829	1.454868	0.1663
L_GEC	−104.4495	43.55850	−2.397912	0.0299**
L_HPC	3.967247	9.930009	0.399521	0.6951
L_IRE	30.74873	38.97899	0.788854	0.4425
L_IT	1.791973	5.436279	0.329632	0.7462
L_SEC	1.884222	0.596283	3.159943	0.0065*
L_WAEC	−7.708858	9.761862	−0.789691	0.4420
L_WEC	1.131058	0.373111	3.031426	0.0084*
L_WOEC	−41.14816	17.03085	−2.416095	0.0289**
C	38.38072	186.4703	0.205827	0.8397
F-Bounds Test			Null Hypothesis: No levels relationship	
Test Statistic	Value	Signif.	I (0)	I (1)
			Asymptotic: n=1000	
F-statistic	19.29642	10%	1.76	2.77
k	12	5%	1.98	3.04
		2.5%	2.18	3.28
		1%	2.41	3.61

***, ** and * denote significance at 10%, 5% and 1%, respectively

4.4.2. Renewable energy (RE) and climate change mitigation

The short-term and long-term ARDL estimation results are presented in Table 5, Panel A and Panel B, respectively. Consistent with the findings of Gang (2023), Hongsheng et al. (2022), and Phebe and Samuel (2016), the results of this study highlight the central role of REs in mitigating climate change.

In the short term, the ARDL estimation results reveal a significant and positive relationship between solar energy consumption and the reduction of temperature anomalies. This suggests that the increasing use of solar energy is associated with a decrease in abnormal temperature variations. Economically speaking, solar energy is a clean and RE source that does not produce GHGs during its production. By increasing solar energy consumption, dependence on fossil fuels is reduced, contributing to a decrease in GHG emissions responsible for climate change. Global economies can benefit from this advantage as the growth in solar energy consumption can foster the development of the solar industry. This opens the door to new economic opportunities, including job creation in the manufacturing, installation, and maintenance of solar systems. Furthermore, the results suggest that the use of energy from waste can contribute to the reduction of GHG emissions in the short term. By utilizing waste as an energy source, the release of GHGs that would occur during their decomposition or incineration is avoided. This can help mitigate climate change and meet international goals for emission reduction. Similarly, the use of energy from waste plays a crucial role in reducing energy costs. By using waste as an energy source, the need for more expensive energy sources is avoided. This can have a positive impact on household, business, and government economies, freeing up resources for other investments or expenses. In addition, Waste Energy consumption can stimulate the development of the RE industry, creating new employment opportunities in waste collection, processing, and conversion into energy. This can contribute to economic growth and unemployment reduction.

Additionally, this study provides empirical evidence regarding the positive and significant relationship between the share of renewable energies in our primary energy consumption and the reduction of temperature anomalies. The results show that an increase in the share of renewable energies helps reduce GHG emissions, contributing to the fight against climate change and the reduction of costs associated with mitigation measures. However, in contrast to the findings of Yuyu and Li (2023) and Chunlong et al. (2023), the results of this study reveal a significant and negative relationship between the reduction of temperature anomalies and the consumption of Hydroelectric Power and investment in REs. This could be justified by the fact that the environmental impact of hydroelectric energy can vary depending on several factors, such as the size of installations, water management, and dam construction practices. It is also worth mentioning that the construction of large hydroelectric dams can have significant environmental consequences, such as the disruption of aquatic ecosystems and alterations to hydrological regimes. These impacts can indirectly influence local temperatures by modifying water flows and natural habitats.

The results of the long-run ARDL model estimation indicate a positive and significant relationship between the reduction of global land and ocean temperature anomalies and the consumption of Waste Energy, carbon capture and storage, and the share of renewable energies in our primary energy consumption. However, it is important to note that the consumption of waste energy must be carried out responsibly and in an environmentally friendly manner. Measures should be taken to minimize air pollutant emissions and ensure that waste is managed safely and appropriately. One effective measure in reducing air pollutant and GHG emissions is carbon capture and storage (CCS). Indeed, one of the key advantages of CCS is that it allows for the permanent storage of CO_2, preventing its release into the atmosphere. By storing carbon for extended periods, CCS contributes to maintaining climate balance by reducing the accumulation of GHGs in the atmosphere, which can help stabilize global temperatures.

4.4.3. Renewable energy, climate change mitigation and adaptation

The results of our study indicate that REs play a significant role in reducing GHG emissions and temperature anomalies. Specifically, wind energy, biomass energy, geothermal energy, solar energy, and the utilization of energy from waste are all associated with a reduction in GHG emissions. Wind energy, solar energy, the use of energy from waste, and the share of renewable energies in primary energy consumption are also linked to a decrease in temperature anomalies.

These results suggest that policies and investments aimed at promoting REs are essential in combating climate change and its effects. In particular, policies and investments focused on increasing the production of wind energy, biomass energy, geothermal energy, solar energy, and the utilization of energy from waste should be a priority. Based on these findings, the following measures can be adopted:

- Transition to Renewable Energies: A key measure is to increase the consumption of renewable energies such as wind energy, biomass energy, geothermal energy, and solar energy. These energy sources produce fewer GHGs compared to fossil fuels, thereby helping to reduce emissions and mitigate the effects of climate change.
- Improvement of Energy Efficiency: Reducing energy consumption by enhancing energy efficiency in residential, commercial, and industrial sectors is another crucial measure. This can be achieved through the adoption of energy-efficient technologies, building insulation, use of efficient heating and cooling systems, and awareness of energy conservation.
- Promotion of Sustainable Mobility: Encouraging the use of public transportation, carpooling, cycling, and walking can contribute to reducing GHG emissions from the transportation sector. Additionally, transitioning to electric or low-emission vehicles can play a significant role in reducing GHG emissions.
- Sustainable Management of Natural Resources: Adopting practices of sustainable natural resource management, such as responsible forest management, can contribute to reducing GHG emissions. For instance, responsible use of wood as an energy source and proper reforestation can help maintain a balance between carbon emissions and absorption.
- Awareness and Education: Informing and raising awareness among the public about climate change issues and individual

Table 5: ARDL model results: Renewable energy and climate change mitigation

Panel A. ARDL short run				
Variable	**Coefficient**	**SE**	**t-statistic**	**Prob.***
L_RLOTA(-1)	−0.219415	0.147613	−1.486420	0.1593
L_BC	−0.131411	0.156857	−0.837772	0.4162
L_BC(−1)	0.279990	0.119026	2.352352	0.0338**
L_BEC	−5.337950	3.929213	−1.358529	0.1958
L_BEC(−1)	5.049025	1.158676	4.357581	0.0007*
L_CCS	0.862744	0.437455	1.972189	0.0687***
L_EFRN	3.594997	1.068943	3.363133	0.0046*
L_GEC	0.779763	10.51465	0.074160	0.9419
L_HPC	−6.291974	2.240501	−2.808289	0.0140**
L_HPC(−1)	−2.836142	1.764157	−1.607647	0.1302
L_IRE	−28.09917	10.64052	−2.640771	0.0194**
L_IT	−1.086679	1.458489	−0.745072	0.4686
L_SEC	0.134750	0.152780	0.881984	0.3927
L_SEC(−1)	−0.863449	0.168745	−5.116898	0.0002*
L_WAEC	7.807876	2.286600	3.414622	0.0042*
L_WEC	−0.006797	0.089229	−0.076176	0.9404
L_WOEC	1.420309	3.611792	0.393242	0.7001
C	163.0398	58.09685	2.806344	0.0140**
R-squared	0.845907	S.D. dependent var		0.422368
F-statistic	4.520834	Prob (F-statistic)		0.003328
Panel B. ARDL long run				
C	163.0398	58.09685	2.806344	0.0140**
L_RLOTA(-1)*	−1.219415	0.147613	−8.260884	0.0000*
L_BC(−1)	0.148579	0.217984	0.681608	0.5066
L_BEC(−1)	−0.288925	3.907597	−0.073939	0.9421
L_CCS**	0.862744	0.437455	1.972189	0.0687***
L_EFRN**	3.594997	1.068943	3.363133	0.0046*
L_GEC**	0.779763	10.51465	0.074160	0.9419
L_HPC(−1)	−9.128115	2.536926	−3.598101	0.0029*
L_IRE**	−28.09917	10.64052	−2.640771	0.0194**
L_IT**	−1.086679	1.458489	−0.745072	0.4686
L_SEC(−1)	−0.728700	0.232089	−3.139745	0.0072*
L_WAEC**	7.807876	2.286600	3.414622	0.0042*
L_WEC**	−0.006797	0.089229	−0.076176	0.9404
L_WOEC**	1.420309	3.611792	0.393242	0.7001
D (L_BC)	−0.131411	0.156857	−0.837772	0.4162
D (L_BEC)	−5.337950	3.929213	-1.358529	0.1958
D (L_HPC)	−6.291974	2.240501	−2.808289	0.0140**
D (L_SEC)	0.134750	0.152780	0.881984	0.3927
Levels equation				
L_BC	0.121845	0.180185	0.676220	0.5099
L_BEC	−0.236938	3.204404	−0.073941	0.9421
L_CCS	0.707507	0.375058	1.886390	0.0802***
L_EFRN	2.948132	0.996524	2.958416	0.0104**
L_GEC	0.639456	8.621597	0.074169	0.9419
L_HPC	−7.485650	2.220469	−3.371202	0.0046*
L_IRE	−23.04315	7.687919	−2.997319	0.0096*
L_IT	−0.891148	1.249492	−0.713208	0.4874
L_SEC	−0.597581	0.202182	−2.955659	0.0104**
L_WAEC	6.402968	1.862538	3.437765	0.0040*
L_WEC	−0.005574	0.073202	−0.076146	0.9404
L_WOEC	1.164746	2.975593	0.391433	0.7014
C	133.7032	41.59622	3.214312	0.0062*
F-bounds test			Null Hypothesis: No levels relationship	
Test statistic	Value	Signif.	I (0)	I (1)
			Asymptotic: n=1000	
F-statistic	10.31017	10%	1.76	2.77
k	12	5%	1.98	3.04
		2.5%	2.18	3.28
		1%	2.41	3.61

***, ** and * denote significance at 10%, 5% and 1%, respectively

Table 6: Diagnostic test results

Diagnostic test	L_RLOTA		L_RGHGE	
	F-statistics	P-value	F-statistics	P-value
Breusch-godfrey serial correlation LM	1.206117	0.3332	0.861628	0.3751
Heteroskedasticity test: Breusch-Pagan-Godfrey	0.724397	0.7389	0.314903	0.9880
Heteroskedasticity Test: ARCH	0.671966	0.4191	0.187537	0.6682
Ramsey RESET Test	3.541731	0.0866	1.022207	0.3358
Analysis of Stability				
CUSUM	Stable		Stable	
CUSUM SQ	Stable		Stable	

actions that can be taken is essential. Education on sustainable practices, energy conservation, and emission reduction can encourage active participation in the fight against climate change.
- Increase Subsidies and Incentives for Renewable Energies: This will make renewable energies more affordable and competitive.
- Enforce Stricter Regulations on GHG Emissions: This will incentivize businesses to invest in cleaner technologies.
- Invest in Research and Development of Renewable Energies: This will lead to the development of new, more efficient and affordable technologies.

However, the following specific adaptation measures can be implemented in:
- Increasing the share of renewable energy in our energy mix. This can be done by investing in new renewable infrastructure, such as wind and solar farms.
- Reducing our dependence on fossil fuels. This can be achieved by improving energy efficiency and investing in public and active transportation.
- Adapting our infrastructure to the effects of climate change. This may include building levees and flood protection walls or adapting irrigation systems to drought conditions.

Similarly, to implement these specifics, the following measures should be considered:
- Policies and regulations: Governments can implement policies and regulations to promote RE and encourage energy efficiency. This may involve tax incentives for businesses and individuals adopting sustainable practices, as well as strict emission standards for industries.
- Investments in sustainable infrastructure: Investments in sustainable infrastructure, such as smart grids, eco-friendly public transportation, and low-energy buildings, can facilitate the transition to more sustainable lifestyles and energy systems.
- Collaboration between the public and private sectors: Collaboration among governments, businesses, non-governmental organizations, and civil society is crucial to implementing sustainable solutions. This may involve public-private partnerships for renewable energy project development, joint research and development initiatives, and awareness programs.
- Technological innovation: Technological innovation plays a crucial role in combating climate change. The development of clean technologies, such as energy storage, electric vehicles, and energy management systems, can help reduce GHG emissions and promote the use of renewable energy.

4.5. Diagnostic Test Results

The diagnostic test results, presented in Table 4 Panel A, suggest that 91.56% of the observed variability in the target variable RGHGE is explained by the regression model. Furthermore, the results show a Prob (F-statistic) below the 0.05 threshold, allowing us to reject the null hypothesis and conclude that the independent variables have a significant effect on the dependent variable. Thus, we can assert that the model is globally significant. Similarly, the diagnostic test results presented in Table 5 Panel A indicate that the regression model explains 84.6% of the observed variation in the target variable RLOTA. Additionally, the results reveal a Prob(F-statistic) below 0.05, allowing us to reject the null hypothesis and conclude that the independent variables have a significant effect on the dependent variable. Therefore, we can assert that the model is globally significant. Furthermore, the F-Bounds test presented in Table 4 Panel B and Table 5 Panel B, based on the Error Correction (EC) representation of the ARDL model, shows that the F-statistic value is higher than the critical value. This suggests that the null hypothesis of no significant long-term relationship is rejected, indicating the presence of a substantial long-term relationship between the variables in the ARDL model.

On the other hand, Table 6 presents the results of various diagnostic tests conducted to validate the statistical models used in this study. Initially, the Breusch-Godfrey Serial Correlation LM was employed. The results of this test indicate an F-statistic of 0.862 and 1.206 for the first and second models, respectively. Similarly, it shows a probability higher than the critical value of 0.05. Therefore, we retain the null hypothesis indicating the absence of serial correlation. The Breusch-Pagan-Godfrey heteroscedasticity test and the ARCH test were also used in this study, and their results suggest the absence of heteroscedasticity issues. Additionally, the research employed the Ramsey Reset test to detect possible specification errors in the models. It specifically examines two types of specification errors, namely omitted variables and errors in the functional form specification. The results of this test suggest that the model is free from specification errors and correctly specified.

Finally, the stability of the model was confirmed by the CUSUM and CUSUMsq tests presented in Table 6 and Figure 1.

5. CONCLUSION

The objective of this study is to explore the effectiveness of renewable energies in mitigating climate change and facilitating adaptation. This study investigates this complex relationship and highlights the opportunities and challenges associated with it. To achieve this, we employed the ARDL model.

The results of this study indicate that wind energy and biomass energy are effective, sustainable, and can significantly contribute to the reduction of GHG emissions over an extended period.

The results of the short-term ARDL estimation confirm the crucial role of renewable energies in reducing GHG emissions, consistent with the research findings of Na et al. (2023), Gang (2023), and Alka et al. (2014). Furthermore, these results show a significant and positive relationship between the reduction of GHG emissions, geothermal energy consumption, and the share of REs in our primary energy consumption. In the long term, the ARDL estimation results also demonstrate a positive and significant relationship between the reduction of GHG emissions and the consumption of wind energy and biomass energy, aligning with the research of Oriza et al. (2023), Kais and Anis (2020).

However, it should be noted that the consumption of wood energy may slow down the pace of GHG emissions reduction, due to the GHG emissions generated by the combustion of wood, primarily carbon dioxide (CO_2).

Furthermore, in line with the studies of Gang (2023), Hongsheng et al. (2022), and Phebe and Samuel (2016), this study highlights the central role of renewable energies in mitigating climate change. Short-term ARDL estimation results show a significant and positive relationship between solar energy consumption and the reduction of temperature anomalies. Additionally, the use of energy from waste is also associated with a significant reduction in GHG emissions in the short term. This study also provides empirical evidence of a positive and significant relationship between the share of renewable energies in our primary energy consumption and the reduction of temperature anomalies. However, contrary to the findings of Yuyu and Li (2023) and Chunlong et al. (2023), this study reveals a significant and negative relationship between the reduction of temperature anomalies and hydroelectric energy consumption, as well as investment in REs. This observation can be explained by the fact that the environmental impact of hydroelectric energy can vary depending on several factors, such as the size of installations, water management, and dam construction practices. It is also worth noting that the construction of large hydroelectric dams can have significant environmental consequences, such as disrupting aquatic ecosystems and altering hydrological patterns, which can indirectly influence local temperatures by modifying water flows and natural habitats.

In the long term, the results indicate a positive and significant relationship between the reduction of global land and ocean temperature anomalies and the consumption of energy from waste, carbon capture and storage, as well as the share of renewable energies in our primary energy consumption. These findings underscore the importance of these factors in the fight against climate change and the long-term reduction of temperature anomalies.

In conclusion, the results of this study demonstrate that renewable energies play a crucial role in reducing GHG emissions and temperature anomalies. These findings suggest that policies and investments aimed at promoting renewable energies are essential in combating climate change and its effects. It is recommended to prioritize policies and investments to increase the production of wind, biomass, geothermal, solar energy, and the use of energy from waste. Based on these results, the following measures can be considered:

- Transition to Renewable Energies: It is essential to increase the consumption of renewable energies such as wind, biomass, geothermal, and solar energy. These energy sources produce fewer GHG emissions compared to fossil fuels, contributing to reducing emissions and mitigating the effects of climate change.
- Improvement of Energy Efficiency: Reducing energy consumption by enhancing energy efficiency in residential, commercial, and industrial sectors is another crucial measure. This can be achieved through the adoption of energy-efficient technologies, building insulation, the use of efficient heating and cooling systems, and awareness of energy conservation.
- Promotion of Sustainable Mobility: Encouraging the use of public transportation, carpooling, cycling, and walking can contribute to reducing GHG emissions from the transportation sector. Additionally, the transition to electric vehicles or low-emission vehicles can play a significant role in reducing GHG emissions.
- Sustainable Management of Natural Resources: Adopting sustainable practices for managing natural resources, such as responsible forest management, can contribute to reducing GHG emissions. For example, responsible use of wood as an energy source and adequate reforestation can help maintain a balance between emissions and carbon absorption.
- Awareness and Education: Informing and educating the public about the challenges of climate change and individual actions that can be taken is crucial. Education on sustainable practices, energy conservation, and emission reduction can encourage active participation in the fight against climate change.
- Increased Subsidies and Incentives for Renewable Energies: This will help make renewable energies more affordable and competitive.
- Strengthening GHG Emission Regulations: This will encourage companies to invest in cleaner technologies.
- Investment in Research and Development of Renewable Energies: This will facilitate the development of new, more efficient, and affordable technologies.

However, specific adaptations can be implemented, such as increasing the share of renewable energies in our energy mix by investing in new renewable infrastructures.

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