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Renewable Energy Consumption, Climate Change, and Economic Growth: A Case of Selected Countries

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Abstract

This research examines the nexus between renewable energy consumption, climate change, and economic growth across 88 countries, categorized by income levels (high, upper-middle, lower-middle, low, and Arab countries) from 1990-2020. Using the Panel Autoregressive Distributed Lag (PARDL) model, the study captures both short- and long-term relationships among the variables. Key findings reveal that economic growth is linked to rising temperatures, while the impact on precipitation varies across income groups. Non-renewable energy consumption has mixed effects: it mitigates climate change in developed countries but exacerbates pollution in developing nations. Conversely, renewable energy lowers average temperatures in lower-income countries, but in high-income countries, it shows positive correlations with climate change indicators. The significant error correction terms across all panels indicate a quick adjustment toward long-run equilibrium. The study underscores the need for tailored climate and energy strategies, advocating for increased renewable energy infrastructure in developing countries and improved energy efficiency in developed nations. For Arab countries, which face specific climate risks, enhanced regional cooperation on mitigation measures is recommended. This research emphasizes that addressing climate change requires strategies that consider the distinct economic and environmental contexts of different country groups.

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Keywords: *Economic Growth, Nonrenewable Energy Consumption, Renewable Energy Consumption, Climate Change, Panel ARDL.*

JEL Codes: O40, O44, O47, Q54, C33

Introduction

The intricate relationship between renewable energy consumption, climate change, and economic growth has gained immense importance in the contemporary discourse on sustainable economic development. Energy is the initial requirement for socio-economic development.

As global temperatures continue to rise and environmental concerns accelerate, within the context of economic development this has been a crucial challenge facing economists and researchers who suggest the causality relationship between economic growth and energy utilization, and how its interactions can affect the potential balance of environmental and economic objectives.

Climate change can be defined as an increase in average surface temperatures and precipitation anomaly caused by increasing greenhouse gas (GHG) and carbon dioxide (CO2), (Nordhaus, 1993; Pala, 2020). The conception reflects a substantial long-term alteration in the associated aspects of the global climate system (Brini, 2021) it reflects the shifts that happened in weather patterns and average temperature. the International Renewable Energy Agency (IRENA) report on Global Energy Transformation: A Roadmap to 2050 (IRENA, 2019a), mentioned the importance of increasing the share of renewable energy in the power sector from 25% in 2017 to 86% by 2050 to mitigate the climate change impacts (IRENA, 2019b).

This research delves into these dynamics within the context of selected countries which have been categorized into five classes; high-income, upper-middle-income, lower-middle income, lower-income, and Arab countries as World Bank classifications, aiming to provide insights into how nonrenewable, renewable energy, and economic growth policies can affect the climate change variables in terms of these classifications.

Renewable energy sources, such as solar, wind, hydro, and biomass, substantially reduce greenhouse gas emissions. In contrast to fossil fuels, renewables do not produce carbon dioxide when generating energy. The relationship between energy consumption and economic growth has been extensively studied,

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generating mixed results based on the kind of energy consumed and the economic context of the countries examined. In high-income countries, renewable energy supports economic growth by creating jobs, fostering technological innovation, and reducing dependency on imported fuels. However, in low-income countries, the impact of renewable energy on the growth process can be complex, influenced by factors such as infrastructure availability, investment in technology, and regulatory environments (UNDP, 2016; IRENA, 2018; Ferroukhi et al.,2016).

This study investigates the relationship between climate change, economic growth, and nonrenewable and renewable energy consumption in a selection of countries representing diverse economic contexts. A panel data model was employed, covering the period from 1990 to 2020 for 88 countries worldwide. These countries were divided into four + one income groups. The World Bank classifies countries into four main income groups: high-income, upper-middle-income, lower-middle-income, and low-income, based on their Gross National Income (GNI) per capita. High-income countries often have strong economies, advanced infrastructure, and greater technological capabilities. This permits them to invest more easily in renewable energy projects, which can support sustainable growth and reduce dependency on fossil fuels. Upper-middle-income countries also have the capacity to grow and invest, but they might face challenges like inequality or uneven access to technology, which can limit their progress in adopting renewable energy. In contrast, lower-middle-income and low-income countries typically struggle with limited infrastructure, fewer financial resources, and weaker regulatory frameworks. These factors can make it harder for these countries to shift towards renewable energy sources and sustain economic growth. Understanding these differences is crucial for constructing policies that support sustainable development and address climate change effectively, considering the unique circumstances of each income group (World Bank, 2023; IRENA, 2018; IPCC, 2014)

Arab countries were added to these groups to be included as a separate group, distinct from the traditional income-based classifications. It can be justified by the unique economic, social, and environmental characteristics shared by these countries. While income classification provides valuable insights, the Arab region displays specific features such as reliance on fossil fuels, distinct climate conditions, and shared cultural and geopolitical dynamics that may not be fully captured by income level alone. Additionally, the Arab region faces common environmental challenges, including water scarcity
and high temperatures, which are closely linked to their energy consumption patterns. By analyzing Arab countries as a distinct group, this study aims to provide more regionally relevant insights and policy recommendations tailored to the specific needs and conditions of these nations.

The main paper's objectives are to analyze the impact of energy consumption and economic growth on climate change indicators. The topics related to economic growth, energy consumption, and environmental economics have an increasing attention in the recent literature. The nexus between those variables is the main core of this study. One of the most challenging matters in the present discourse of sustainability is exploring the impact of economic growth renewable energy and climate change on climate change. The quest for alternative nonrenewable energy sources is a necessity because it is supposed to work as a way to alleviate the environmental impact of (CO_2) at the same time fulfilling the energy needs for economic growth. Many countries try to find ways to motivate social and economic growth by developing the renewable energy sector. It is likely that investment in renewable energy can create a new basis of growth and extend the industrial sector and on the other hand it is a way to expand and diversify the sources of energy in the light of non-renewable energy sources depletion. This study inspected how economic growth, and renewable, nonrenewable energy consumption, affect climate change, for 88 selected countries categorized into five groups for the period 1990-2020.

Literature Review

An extensive body of research has depicted different aspects of the relationship between renewable energy, nonrenewable energy consumption, and economic growth, highlighting various impacts and trends observed across different countries. In the late 20th century studies that examined the relationship between climate change and economic growth emerged and have significantly attracted environmental economists and policymakers to evaluate the economic impacts of climate change. Many studies on energy consumption, environmental issues, and economic growth interconnection have yielded diverse results using various empirical methods and different groups of countries. Some of these studies used a group of countries from the same region or the same characteristics such as (Pala, 2020; Brini, 2021; Chen et al., 2016; Gorus & Ayden, 2019; Aroura et al., 2012), and allowed for heterogeneous effects within countries,

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while others used a single country to explore the relationship among the variables of the study (Hoang & Huynh, 2020; Acaroglu & Gullu, 2022).

The study by Chen et al., (2016) in 188 countries for the periods 1993-2010 revealed a long-run relationship between economic growth, energy consumption, and carbon dioxide emissions for all countries. Their results indicate that energy consumption negatively affects GDP in the world and in developing countries, but not in developed countries and there is an existence of unidirectional causality from energy consumption to carbon dioxide emissions both in developing and developed countries. In the case of 28 European Union countries, (Pala, 2020) estimated random coefficient panel regression for the period 1996-2014 to find out that increasing carbon emission positively affects economic growth in relatively cold side countries especially through agricultural and tourism sector productions, while the impact of CO2 is insignificant for South-west countries. Onofrei et.al., (2022) explored 27 EU countries' data during 2000-2017. The results showed a long run co-integration between economic growth and CO2 emissions, also using the Dynamic Ordinary Least Squares (DOLS) model revealed a statistically significant positive impact of economic growth on CO2 emissions. They evoked in their study that higher income scales may lead to a rise in the demand for environmental protection.

The links between CO2 emissions, economic growth, and energy consumption have also been explored by Maria et al., (2023) for 31 countries, most of which are developed countries with 4 emerging countries during the period 1974-2018. They approved that the relationship among their variables is unstable, allowing for structural breaks to take place in their analysis for each country in the sample. The outcome revealed that most countries succeeded in decoupling the level of CO2 emissions from their economic growth suggesting that more than 80% of the reviewed countries adopted suitable procedures to diminish CO2 emissions without hurting economic growth.

Aslan et al., (2020) studied the nexus among climate change, economic growth, and other variables in N-11 countries for 1980-2018. Using the Panel Vector Autoregression model (PVARM) resulted in energy consumption reduces CO2 emissions while foreign direct investment increases pollution. In addition, there is evidence of unidirectional causality from carbon dioxide emissions and energy consumption to economic growth. Focusing on 10 newly industrialized countries over the period 1990-2015, Azam et al., (2021) investigated the impact and the causality relationship between renewable and non-renewable electricity consumption and economic growth by applying a Panel fully modified Ordinary Least Square model (FMOLS) and Granger causality test. The empirical results confirmed a positive long-run effect of renewable and nonrenewable electricity consumption on economic growth and the presence of bidirectional causation between renewable electricity consumption and economic growth in the short and long term.

Zaidi & Saidi (2018) examined the causality relationship between environmental pollution and economic growth and other variables in the Sub-Saharan African countries for the period of 1990-2015. The result of the Vector Error Correction Model (VECM) Granger causality showed a bidirectional causality relationship between CO2 emissions and GDP per capita. For other developing countries group from Africa, Brini (2021) applied the Panel Pooled Mean Group-Autoregressive distributed lag model (ARDL-PMG) and found a long-run harmful effect of non-renewable energy consumption and economic growth on climate change, while renewable energy consumption helps climate change moderation in African countries. Moreover, the results showed a bidirectional causality relationship between non-renewable energy consumption and climate change in the short run. At the same time, it revealed a unidirectional causality relationship running from climate change to renewable energy consumption. In a different context, (Fotourehchi, 2017) examined the long-run causal relationship between renewable energy consumption and economic growth for 42 developing countries for the period 1990-2012. Using Canning & Pedroni (2008) long-run causality test, it was concluded that a long-run causality running from renewable energy consumption to economic growth.

Soytas & Sari (2007) explored the nexus between energy use and income with CO2 emissions in the United States for the period 1960-2004. They found no long-run Granger causality running from income to CO2 emissions, while energy use Granger causes the CO2 emissions.

Acaroglu & Gullu (2022) studied the relationship between energy consumption, economic growth, and temperature and precipitation as climate change variables in Turkey over the period 1980 to 2019. Using the Toda-Yamamoto causality test they found no support for any causality relationship between temperature and non-renewable and renewable energy consumption, while it is found a bidirectional

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causality relationship between non-renewable energy consumption and precipitation. Moreover, a time series ARDL estimate showed that nonrenewable energy consumption hurts temperature, while nonrenewable energy consumption positively affects precipitation.

Hoang & Huynh (2020) investigated an inverse approach, by treating climate change variables as exogenous variables rather than dependent ones for the nine provinces in Vietnam's Coastal South-Central region for the period 2006-2015. Using the Cobb-Douglas production function and applying the Feasible Generalized Least Squares econometrics method, they found a negative significant impact of climate change on regional economic growth, remarking the usage of four proxied indicators for climate change; storms and floods, total number of damaged houses, total number of dead and injured, total estimated damage which all caused by storms and floods. The impact of climate change on economic growth has also been detected by Doganlar et al., (2023), atmospheric pressure (AP) and temperature (TEM) are used as climate change indicators. Analyzing the static and dynamic panel data of the impact of climate change on economic growth in the most polluting 20 countries for the period 1990-2019, using a linear model they found no impact of temperature and precipitation on economic growth in these countries while the results of using nonlinear model showed a positive primary impact and negative secondary impact of temperature on economic growth, whereas precipitation found to have no impact on economic growth.

Osobajo et al., (2020) employed data from 70 countries over the period 1994 -2013. Using pooled OLS and fixed effects methods they found that economic growth and nonrenewable energy consumption positively affected CO_2 emissions. In addition, the results showed a long-run relationship among the variables, and a bidirectional Granger causality relationship between economic growth and CO_2 emissions, whereas there was a unidirectional causality running from nonrenewable energy consumption to CO_2 emissions.

Osuntuyi & Lean (2022) investigated the growth-energy-environmental nexuses and studied how education may affect this relationship. They used heterogeneous income countries of 92, categorized into four income groups from 1985 to 2018. They found that economic growth has a long-run impact on reducing environmental deterioration represented by a reduction of CO_2 in high-income and upper-income countries. In contrast, the growth process in lower-middle-income and low-income countries worsens environmental deterioration. Furthermore, their findings assert the role of energy consumption in contributing to environmental degeneration in all income groups. Similarly, Dissanayake et al., (2023) inspected the causality relationships between renewable (REC) and non-renewable energy consumption (NRE), CO_2 emissions, and economic growth (GDP) in four sub-groups; developed, developing, and less developed countries (LDCs) and Economies in transition over the period 1990- 2019 for 152 countries. The Granger-causality test results indicated that outside transitional economies, there is no causal link between GDP and either renewable (REC) or non-renewable energy consumption (NRE). However, in transitional economies, GDP drives both REC and NRE. Additionally, a unidirectional causality running from GDP to CO_2 emissions exists in all countries, whereas a bidirectional causal relationship between GDP and CO_2 was found in transitional countries. implying the need for serious CO_2 reduction efforts across these economies.

One of few studies that investigated the nexus between energy consumption, economic growth, and CO_2 emissions in eight oil-rich MENA countries (Arab region) is Gorus & Aydin (2018), they used single- and multi-country Granger causality models in the frequency domain for the period 1975-2014. The study found no adverse effect of energy conservation policies on economic growth in the short-run and intermediate-run, whereas their effects were negative in the long run, furthermore, they didn't find any causal relationship between economic growth and CO_2 emission in this set of countries. Soliman et al. (2024) found that climate change hurts economic growth in a panel of twelve selected Arab countries for the period 2010-2019. Utilizing the GMM method the results showed that CO_2 and climate-altering land cover index (LC) measurements harmed economic growth, while the impact of temperature change and annual precipitation was insignificant.

In the context of examining the relationship between economic growth, energy, and environmental deterioration linkages, many studies focused on the growth-environmental nexus. It suggested a long-run inverted U-shape relationship between economic development and Carbon emissions, this relationship is known as the Environmental Kuznets Curve (EKC). The (EKC) model assumes that the increase in economic growth leads to an increase in pollution until reaching a turning point, after this threshold the pollution starts to decrease as economic growth increases. Acel et al., (2017) studied the relationship between carbon dioxide (CO_2) emissions per capita and economic growth for 20 Latin American and

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Caribbean countries, during the period 1971-2011. Their empirical outcomes led to contradictory results, and because of the existence of cross-dependence in the model, a long-run equilibrium relationship couldn't be recognized and thus EKC does not exist. Similar mixed results were obtained by Ozcan et al., (2019), who studied the time-varying causality connections between energy consumption, economic growth, and environmental degradation in 33 Organization for Economic Cooperation and Development (OECD) countries for the period of 2000-2013. Nearly 25 countries experience the EKC in the case of using the ecological footprint and in 23 countries in the case of the Environmental Performance Index which is used as an environmental degradation indicator. In addition, some countries have been showing different types of curves. Regarding the Arab region, Arouri et al., 2012 examined the cointegration relationship between CO2 emissions, energy consumption, and real GDP for 12 Middle East and North African Countries (MENA) from the period 1981 to 2005. They found that economic growth has a quadratic nexus with CO2 emissions which supported the EKC hypothesis for the MENA region. However, the study also explored the EKC at the country level, the results revealed poor evidence in support of the EKC hypothesis in most countries. Similarly, Sirag and Talha (2023) found evidence of the EKC hypothesis in panel data of selected 16 Arab countries for the period 1980-2020.

This study aims to contribute to the existing literature by comprehensively analyzing how renewable energy consumption influences climate change and economic growth in different contexts. By identifying best practices and potential challenges, the findings can inform policymakers in crafting strategies that promote sustainable development.

Methodology

Data and Sources

The main aim of this study is to explore the nexus between climate change, energy consumption, and economic growth across different income group countries. The research employed a panel data model, covering the period 1990-2020 for 88 countries worldwide, divided into five income groups based on the purpose of the study using the World Bank classifications; high-income, Upper-middle-income, lower-middle-income, Low-income, and Arab countries, which are referred by Panel A, Panel B, and Panel C, Panel D, Panel E respectively. The annual data is chosen according to data availability and collected from different sources. The dependent variables include climate change indicators; the annual average temperatures (TEM), and the annual precipitation (AP) anomaly which are obtained from the Climate Change Knowledge Portal (CCKP), World Bank (2022), whereas the independent variables enclose Real Gross Domestic Product per capita (GDPER) in constant 2015$ and renewable energy consumption (REC) as a percentage of total final energy consumption which are obtained from World Bank national accounts data, World Bank Sustainable Energy (2022), and non-renewable electricity net generation (billion kWh) (NRE), from US Energy Information Administration database (2022), and for the constancy of data, all the variables are taken in natural logarithms. Table 1 provides the descriptive statistics at the country sub-category level. The total observation in the full dataset is 2726 of which 620, 589, 773, 403, and 341 for high-income, upper-middle-income, lower-middle-income, lower-income, and Arab countries, respectively. The list of countries is provided in Appx.1. Descriptive statistics showed that the highest mean annual average temperature and renewable energy consumption of 3.18 % and 4.45 %, respectively were in lower-income countries. Furthermore, high-income countries show the highest mean annual nonrenewable energy consumption of 4.29%, with the highest average GDP per capita growth of 10.23%.

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	LTEM	LAP	LREC	LNR	LG
High-Income Countries					
Mean	2.395522	6.737438	1.886832	4.290238	10.22874
Maximum	3.394173	8.001456	4.067316	8.242404	11.38978
Minimum	0.215111	5.385870	-1.845947	-1.145704	8.304174
Std. Dev.	0.481510	0.445215	1.354099	1.928373	0.641380
Observations	620	620	620	620	620
Upper- Income Countries					
Mean	2.883237	7.077902	2.594551	2.469693	8.475276
Maximum	3.314913	8.315811	4.155388	8.592691	9.395876
Minimum	1.735189	5.764627	-0.325643	-4.342806	6.701751
Std. Dev.	0.458787	0.655371	1.005427	2.831440	0.486041
Observations	589	589	589	589	589
Lower-Middle Income Countries					
Mean	2.997649	7.035043	3.581934	0.778619	7.420098
Maximum	3.386422	8.379645	4.563514	7.145116	8.640820
Minimum	-3.912023	5.001258	-0.820981	-11.51293	6.238513
Std. Dev.	0.708143	0.731434	1.179650	3.353006	0.528654
Observations	773	773	773	773	773
Lower- Income Countries					
Mean	3.181106	6.947618	4.453595	-2.579847	6.203475
Maximum	3.392829	7.619744	4.582315	1.302940	7.221545
Minimum	2.935982	5.579654	4.149148	-6.969631	5.318239
Std. Dev.	0.122536	0.407848	0.085236	1.960531	0.395164
Observations	403	403	403	403	403
Arabs Countries					
Mean	3.075099	5.331905	1.893451	1.828738	7.830877
Maximum	3.383373	7.923460	4.450014	5.108597	9.117683
Minimum	2.598235	2.386926	-2.813411	-4.342806	6.626161
Std. Dev.	0.180766	1.180885	1.760323	2.266137	0.556041
Observations	341	341	341	341	341

Econometric Model

To investigate the nexus between renewable and non-renewable energy consumption, economic growth, and climate change elements the statistical technique of the Panel Autoregressive Distributed Lag (ARDL)

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model has been used to analyze the short-term and long-term relationships between these variables (Olayungbo, 2021). Following Refs. (Brini, 2021; Acaroglu & Gullu 2022), two models for causality and cointegration relations between the variables are represented by the following Equations (1) and (2):

LAPit = *f* (LGDPERit, LRECit, LNREit) (1)

LTEMit = *f* (LGDPERit, LRECit, LNREit) (2)

where the first equation considers the annual precipitation (LAP) as the dependent variable, and the second model uses the annual average temperature (LTEM) as another dependent variable, both of them are proxies for climate change, (LGDPER) is the real gross domestic product per capita (constant 2015 US$, (LNRE) is the non-renewable electricity (billion kWh), and (LREC) is the renewable energy consumption (% of total final energy consumption), and all of them is in the natural logarithm form.

Using a selection of countries representing diverse economic contexts and according to the availability of data, first, we test for the existence of panel unit roots utilizing a variety types of panel unit root tests such as Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1981), PP (Phillips & Perron, 1988), LLC (Levin et al., 2002), IPS (Im et al., 2003). All tests assume the existence of a unit root for its null hypothesis. If all or some of the variables are not stationary, we have to go to the next phase of statistical analysis and the existence of cointegration among variables for each country category must be checked. Two groups of panels cointegration tests suggested by Pedroni (1999, 2004), the within and the between dimension tests can be utilized. The null hypothesis for all Pedroni tests assumed no cointegration among variables. If the statistical results fail to accept the null hypothesis for most panel cointegration tests, we can go to the third phase which is the estimate of the short-run and long-run relationship between the dependent and independent variables of the study. The Auto Regressive Distributed Lag Model (ARDL) approach introduced by Pesaran et al., (1999) inspects the dynamic relationship structure among variables. It includes a cointegration test that is valid even if the variables become stationary at different levels.

The ARDL model allows us to estimate the long-run nexus between TEM, AP and GDPER, REC, and NRE which can be represented through the following equations of climate change:

Model 1

$$\Delta LAP_{it} = \beta_{0i} + \beta_{1i} LAP_{i,t-1} + \beta_{2i} LGDPER_{i,t-1} + \beta_{3i} LREC_{i,t-1} + \beta_{4i} LNRE_{i,t-1} + \sum_{J=1}^{p} \rho_{ij} \Delta LAP_{i,t-j} + \sum_{J=0}^{q} \alpha_{1ij} \Delta LGDPER_{i,t-j} + \sum_{J=1}^{r} \alpha_{2ij} \Delta LREC_{i,t-j} + \sum_{J=1}^{n} \alpha_{3ij} \Delta LNRE_{i,t-j} + \mu_i + \varepsilon_{it} \quad (3)$$

Model 2:

$$\Delta LTEM_{it} = \beta_{0i} + \beta_{1i} LTEM_{i,t-1} + \beta_{2i} LGDPER_{i,t-1} + \beta_{3i} LREC_{i,t-1} + \beta_{4i} LNRE_{i,t-1} + \sum_{J=1}^{p} \alpha_{ij} \Delta LTEM_{i,t-j} + \sum_{J=0}^{q} \alpha_{1ij} \Delta LGDPER_{i,t-j} + \sum_{J=1}^{r} \alpha_{2ij} \Delta LREC_{i,t-j} + \sum_{J=1}^{n} \alpha_{3ij} \Delta LNRE_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4)$$

$i=1, 2, \ldots, N \quad t=1,2, \ldots, T$

represents the country-specific effects which are unique to each country, (εit) is the white noise term, (β1, β2, β3, β4) represent coefficients in the long run, and (α1, α2, α3, α4) are the coefficients in the short run. The terms p, q, r, and n represent the optimal lag of the variables. The ARDL test-based error correction model (ECM) is constructed to foresee the short-run relationship between variables in Eqs. 5-12 as follows:

$$\Delta LAP_{it} = \lambda_1 ECT_{t-1} + \sum_{J=1}^{p} \rho_{ij} \Delta LAP_{i,t-j} + \sum_{J=0}^{q} \alpha_{1ij} \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \alpha_{2ij} \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \alpha_{3ij} \Delta LNRE_{i,t-j} + \mu_1 + \varepsilon_{1t} \quad (5)$$

$$\Delta LGDPER_{it} = \lambda_2 ECT_{t-1} + \sum_{J=1}^{p} \omega_{ij} \Delta LGDPER_{i,t-j} + \sum_{J=0}^{q} \varphi_{1ij} \Delta LAP_{i,t-j} + \sum_{J=0}^{r} \varphi_{2ij} \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \varphi_{3ij} \Delta LNRE_{i,t-j} + \mu_2 + \varepsilon_{2t} \quad (6)$$

$\Delta LREC_{it} = \lambda_3\ ECT_{t-1} + \sum_{J=1}^{p} \tau_{ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{q} \beta_{1ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \beta_{2ij}\ \Delta LAP_{i,t-j} + \sum_{J=0}^{n} \beta_{3ij}\ \Delta LNRE_{i,t-j} + \mu_3 + \varepsilon_{3t}$ (7)

$\Delta LNRE_{it} = \lambda_4\ ECT_{t-1} + \sum_{J=1}^{p} \sigma_{ij}\ \Delta LNRE_{i,t-j} + \sum_{J=0}^{q} \gamma_{1ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \gamma_{2ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \gamma_{3ij}\ \Delta LAP_{i,t-j} + \mu_4 + \varepsilon_{4t}$ (8)

$\Delta LTEM_{it} = \lambda_5\ ECT_{t-1} + \sum_{J=1}^{p} \rho_{ij}\ \Delta LTEM_{i,t-j} + \sum_{J=0}^{q} \alpha_{1ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \alpha_{2ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \alpha_{3ij}\ \Delta LNRE_{i,t-j} + \mu_5 + \varepsilon_{5t}$ (9)

$\Delta LGDPER_{it} = \lambda_6\ ECT_{t-1} + \sum_{J=1}^{p} \omega_{ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{q} \varphi_{1ij}\ \Delta LTEM_{i,t-j} + \sum_{J=0}^{r} \varphi_{2ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \varphi_{3ij}\ \Delta LNRE_{i,t-j} + \mu_6 + \varepsilon_{6t}$ (10)

$\Delta LREC_{it} = \lambda_7\ ECT_{t-1} + \sum_{J=1}^{p} \tau_{ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{q} \beta_{1ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \beta_{2ij}\ \Delta LTEM_{i,t-j} + \sum_{J=0}^{n} \beta_{3ij}\ \Delta LNRE_{i,t-j} + \mu_7 + \varepsilon_{7t}$ (11)

$\Delta LNRE_{it} = \lambda_8\ ECT_{t-1} + \sum_{J=1}^{p} \sigma_{ij}\ \Delta LNRE_{i,t-j} + \sum_{J=0}^{q} \gamma_{1ij}\ \Delta LGDPER_{i,t-j} + \sum_{J=0}^{r} \gamma_{2ij}\ \Delta LREC_{i,t-j} + \sum_{J=0}^{n} \gamma_{3ij}\ \Delta LTEM_{i,t-j} + \mu_8 + \varepsilon_{8t}$ (12)

whereas the error correction term ECT_{t-1} represents the resultant from the long-run equilibrium relationship and the λ_i is the parameter of the speed of adjustment.

Empirical Results

Panel Unit Root Test

The unit root tests were conducted to assess the stationarity of key variables across different income groups, namely high-income, upper-middle-income, lower-middle-income, low-income, and Arab countries. The results of panel unit root tests for all series with intercept and with intercept and trend have been introduced in Table 2. The tests employed include the Levin, Lin & Chu (LLC) test, Im, Pesaran & Shin (IPS) test, Augmented Dickey-Fuller (ADF) test, and Phillips-Perron (PP) test. The findings are summarized as follows; for high-income countries, the variables Log of Annual Precipitation (LAP) and Log of Average Temperature (LTEM) are stationary at levels across all tests with a significance level of 1%. Conversely, the Log of Real GDP per Capita (LGDPER) is stationary with a trend according to the ADF and PP tests but not under LLC and IPS tests. LGDPER becomes stationary at the 1% level after the first differencing. Similarly, the Log of Non-Renewable Energy (LNRE) is non-stationary in levels but stationary after first differencing. The Log of Renewable Energy Consumption (LREC) shows mixed results at levels but is stationary after first differencing at the 1% level.

In upper-middle-income countries, LAP and LTEM are stationary at levels across all tests with a 1% significance level. LGDPER is non-stationary in levels but becomes stationary after first differencing, consistent with the high-income group. LNRE is stationary under LLC and ADF tests but shows mixed results under other tests in levels. It becomes stationary after first differencing. LREC is non-stationary in levels but becomes stationary at the 1% level after first differencing.

For lower-middle-income countries, LAP and LTEM are stationary at levels across all tests. LGDPER exhibits mixed results, being non-stationary in levels but stationary after first differencing. LNRE is non-stationary in levels but becomes stationary at the 1% level after first differencing. LREC is non-stationary in levels across all tests but becomes stationary after first differencing.

Low-income countries show that LAP and LTEM are stationary at levels across all tests. LGDPER is non-stationary at levels but becomes stationary after first differencing. LNRE is non-stationary in levels under most tests but becomes stationary after first differencing. LREC is non-stationary in levels but becomes stationary after first differencing, consistent with the other income groups. For Arab countries, LAP and

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LTEM are generally stationary at levels across all tests. LGDPER, LNRE, and LREC exhibit non-stationarity in levels but become stationary after first differencing. This pattern is similar to other income groups.

Overall, the unit root tests reveal that most variables are non-stationary at levels but become stationary after first differencing, suggesting that they are integrated for order one, I (1). The consistent stationarity of LAP and LTEM which are integrated for order zero, I (0) across various income groups indicates their relative stability compared to economic variables like GDP per capita and energy consumption metrics.

Table 2. Panel unit root tests

Panel A- high income countries								
	Levin,Lin		Im		ADF		PP	
	Intercept	Trend	Intercept	Trend	Intercept	Trend	Intercept	Trend
LAP	-9.92624 (0.0000)*	-8.86116 (0.0000) *	-11.3650 (0.0000)*	-10.1470 (0.0000)*	202.473 (0.0000)*	170.415 (0.0000)*	368.672 (0.0000)*	806.188 (0.0000)*
LTEM	-3.42600 (0.0003)*	-6.56561 (0.0000)*	-4.85488 (0.0000)*	-9.73095 (0.0000)*	86.6489 (0.0000)*	162.520 (0.0000)*	195.969 (0.0000)*	361.104 (0.0000)*
LGDPER	-6.56458 (0.0000)*	2.81318 (0.9975)	-1.94362 (0.0260)**	3.20353 (0.9993)	52.2532 (0.0928)***	28.6771 (0.9088)	78.5834 (0.0003)*	23.4908 (0.9825)
ΔLGDPER	0.90565 (0.8174)	1.48481 (0.9312)	-6.66167 (0.0000)*	-6.12065 (0.0000)*	122.537 (0.0000)*	110.005 (0.0000)*	167.228 (0.0000)*	379.657 (0.0000)*
LNRE	-3.88661 (0.0001)*	2.54956 (0.9946)	0.47433 (0.6824)	6.33059 (1.0000)	64.6133 (0.0082)*	16.0006 (0.9997)	117.925 (0.0000)**	22.2159 (0.9898)
ΔLNRE	-5.22620 (0.0000)*	-8.44766 (0.0000)*	-8.16966 (0.0000)*	-12.3807 (0.0000)*	159.416 (0.0000)*	216.515 (0.0000)*	305.993 (0.0000)*	640.942 (0.0000)*
LREC	2.26721 (0.9883)	-1.18438 (0.1181)	6.09270 (1.0000)	-0.27321 (0.3923)	18.0841 (0.9989)	46.0112 (0.2374)	44.1446 (0.3007)	65.1674 (0.0072)*
Δ LREC	-7.05311 (0.0000)*	-5.50037 (0.0000)*	-10.8081 (0.0000)*	-9.64115 (0.0000)*	193.160 (0.0000)*	165.002 (0.0000)*	373.653 (0.0000)*	1135.29 (0.0000)*

Panel B - Upper middle income

LAP	-9.19101 (0.0000)*	-7.76259 (0.0000)*	-9.98222 (0.0000)*	-7.70545 (0.0000)*	172.873 (0.0000)*	128.884 (0.0000)*	287.834 (0.0000)*	254.726 (0.0000)*

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LTEM	-5.68436 (0.0000)*	-9.58056 (0.0000)*	-4.30986 (0.0000)*	-8.72043 (0.0000)*	80.2768 (0.0001)*	142.302 (0.0000)*	125.925 (0.0000)*	261.784 (0.0000)*
LGDPER	-3.56818 (0.0002)*	1.46364 (0.9284)	1.08520 (0.8611)	1.06834 (0.8573)	26.2433 (0.9252)	43.3558 (0.2536)	21.4486 (0.9860)	32.6671 (0.7141)
ΔLGDPER	-2.88834 (0.0019)**	-1.78692 (0.0370)**	-6.00826 (0.0000)*	-2.67372 (0.0038)**	113.867 (0.0000)*	75.1801 (0.0003)*	136.238 (0.0000)*	95.6930 (0.0000)*
LNRE	-5.86127 (0.0000)*	-0.40565 (0.3425)	-3.06027 (0.0011)**	0.98907 (0.8387)	70.9940 (0.0009)*	48.9170 (0.1105)	75.6764 (0.0003)*	49.5338 (0.0996)
ΔLNRE	-7.43783 (0.0000)*	-7.64102 (0.0000)*	-10.3360 (0.0000)*	-10.6071 (0.0000)*	183.063 (0.0000)*	178.595 (0.0000) *	309.327 (0.0000)*	412.416 (0.0000)*
LREC	-3.18913 (0.0007)*	0.32652 (0.6280)	-1.86209 (0.0313)**	1.79595 (0.9637)	72.9691 (0.0006)*	42.1519 (0.2960)	66.9901 (0.0025)**	33.8344 (0.6625)
Δ LREC	-6.51646 (0.0000)*	-5.63270 (0.0000)*	-9.86910 (0.0000)*	-8.95702 (0.0000)*	177.672 (0.0000)*	157.673 (0.0000)*	284.536 (0.0000)*	413.454 (0.0000)*
Panel C - Lower middle income								
LAP	-10.4219 (0.0000)*	-9.24865 (0.0000)*	-12.0622 (0.0000)*	-10.4831 (0.0000)*	242.888 (0.0000)*	199.901 (0.0000)*	460.153 (0.0000)*	435.731 (0.0000)*
LTEM	-6.41100 (0.0000)*	-11.1422 (0.0000)*	-4.95759 (0.0000)*	-10.1336 (0.0000)*	105.487 (0.0000)*	192.409 (0.0000)*	161.793 (0.0000)*	297.632 (0.0000)*
LGDPER	-2.64868 (0.0040)*	-0.57224 (0.2836)	2.90601 (0.9982)	-0.27502 (0.3916)	26.4866 (0.9975)	55.4328 (0.2773)	18.2497 (1.0000)	72.2652 (0.0214)
ΔLGDPER	-0.57479 (0.2827)	3.39058 (0.9997)	-6.54943 (0.0000)*	-2.25659 (0.0120)**	135.268 (0.0000)*	82.0819 (0.0028)**	201.053 (0.0000)*	141.054 (0.0000)*
LNRE	-4.03961 (0.0000)*	-0.85973 (0.1950)	0.46601 (0.6794)	-0.37113 (0.3553)	50.6760 (0.4467)	66.2754 (0.0614)***	88.3794 (0.0007)*	158.155 (0.0000)*
ΔLNRE	-10.5727 (0.0000)*	-9.17769 (0.0000)*	-13.1899 (0.0000)*	-11.9874 (0.0000)*	271.137 (0.0000)*	236.519 (0.0000)*	442.454 (0.0000)*	1178.32 (0.0000)*
LREC	-1.33797 (0.0905)***	0.78958 (0.7851)	1.59109 (0.9442)	1.18773 (0.8825)	41.7907 (0.7890)	35.2866 (0.9428)	30.1917 (0.9880)	37.9675 (0.8940)
Δ LREC	-6.04088 (0.0000)*	-3.21939 (0.0006)*	-10.9947 (0.0000)*	-7.86385 (0.0000)*	234.872 (0.0000)*	176.983 (0.0000)*	389.373 (0.0000)*	411.780 (0.0000)*

Table. Unit root test – Cont

Panel D – Lowe income countries								
	Levin,Lin		Im		ADF		PP	
	Intercept	Trend	Intercept	Trend	Intercept	Trend	Intercept	Trend

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LAP	-7.67456 (0.0000)*	-8.75424 (0.0000)*	-7.58858 (0.0000)*	-8.24761 (0.0000)*	109.668 (0.0000)*	113.260 (0.0000)*	216.742 (0.0000)*	569.285 (0.0000)*
LTEM	-3.56866 (0.0002)*	-3.76555 (0.0001)*	-3.73088 (0.0001)*	-5.19629 (0.0000)*	57.7130 (0.0003)*	73.5806 (0.0000)*	94.8941 (0.0000 *	130.733 (0.0000)*
LGDPER	-0.43310 0.3325	-0.01027 0.4959	2.20574 0.9863	0.15346 0.5610	22.6759 0.6512	29.0910 0.3070	27.6795 0.3744	36.3442 0.0855
ΔLGDPER	-5.62759 (0.0000)*	-4.41876 (0.0000)*	-8.27798 (0.0000)*	-6.61911 (0.0000)*	118.477 (0.0000)*	92.5018 (0.0000)*	232.784 (0.0000)*	299.568 (0.0000)*
LNRE	0.72285 (0.7651)	-1.31032 (0.0950)	1.88675 (0.9704)	-0.59566 (0.2757)	25.3961 (0.4967)	32.1618 (0.1878)	45.8284 (0.0095)**	42.0604 (0.0242)**
ΔLNRE	-7.23381 (0.0000)*	-5.43330 (0.0000)*	-8.01222 (0.0000)*	-6.31884 (0.0000)*	112.630 (0.0000)*	85.4707 (0.0000)*	244.133 (0.0000)*	282.378 (0.0000)*
LREC	3.15811 (0.9992)	1.19472 (0.8839)	3.62477 (0.9999)	1.45503 (0.9272)	16.5968 (0.9208)	18.6700 (0.8501)	14.3925 (0.9675)	13.4954 (0.9791)
Δ LREC	-3.53441 (0.0002)*	-2.54868 (0.0054)*	-7.40167 (0.0000)*	-6.13862 (0.0000)*	104.373 (0.0000)*	84.3217 (0.0000)*	184.522 (0.0000)*	179.925 (0.0000)*

Table. Unit root test – Cont

Panel D – Lowe income countries

	Levin,Lin		Im		ADF		PP	
	Intercept	Trend	Intercept	Trend	Intercept	Trend	Intercept	Trend
LAP	-7.67456 (0.0000)*	-8.75424 (0.0000)*	-7.58858 (0.0000)*	-8.24761 (0.0000)*	109.668 (0.0000)*	113.260 (0.0000)*	216.742 (0.0000)*	569.285 (0.0000)*
LTEM	-3.56866 (0.0002)*	-3.76555 (0.0001)*	-3.73088 (0.0001)*	-5.19629 (0.0000)*	57.7130 (0.0003)*	73.5806 (0.0000)*	94.8941 (0.0000 *	130.733 (0.0000)*
LGDPER	-0.43310 0.3325	-0.01027 0.4959	2.20574 0.9863	0.15346 0.5610	22.6759 0.6512	29.0910 0.3070	27.6795 0.3744	36.3442 0.0855
ΔLGDPER	-5.62759 (0.0000)*	-4.41876 (0.0000)*	-8.27798 (0.0000)*	-6.61911 (0.0000)*	118.477 (0.0000)*	92.5018 (0.0000)*	232.784 (0.0000)*	299.568 (0.0000)*
LNRE	0.72285 (0.7651)	-1.31032 (0.0950)	1.88675 (0.9704)	-0.59566 (0.2757)	25.3961 (0.4967)	32.1618 (0.1878)	45.8284 (0.0095)**	42.0604 (0.0242)**
ΔLNRE	-7.23381 (0.0000)*	-5.43330 (0.0000)*	-8.01222 (0.0000)*	-6.31884 (0.0000)*	112.630 (0.0000)*	85.4707 (0.0000)*	244.133 (0.0000)*	282.378 (0.0000)*
LREC	3.15811 (0.9992)	1.19472 (0.8839)	3.62477 (0.9999)	1.45503 (0.9272)	16.5968 (0.9208)	18.6700 (0.8501)	14.3925 (0.9675)	13.4954 (0.9791)
Δ LREC	-3.53441 (0.0002)*	-2.54868 (0.0054)*	-7.40167 (0.0000)*	-6.13862 (0.0000)*	104.373 (0.0000)*	84.3217 (0.0000)*	184.522 (0.0000)*	179.925 (0.0000)*

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Panel E - Arab countries

LAP	-5.80106 (0.0000)*	-3.93000 (0.0000)*	-7.82285 (0.0000)*	-5.62001 (0.0000)*	101.896 (0.0000)*	69.8499 (0.0000)*	207.111 (0.0000)*	439.832 (0.0000)*
LTEM	-5.02411 (0.0000)*	-6.04304 (0.0000)*	-2.84334 (0.0022)*	-5.81949 (0.0000)*	40.5104 (0.0094)**	72.7716 (0.0000)*	76.9746 (0.0000)*	157.288 (0.0000)*
LGDPER	-2.08034 (0.0187)**	4.89498 (1.0000)	0.25064 (0.5990)	4.89074 (1.0000)	18.8786 (0.6528)	9.77068 (0.9883)	25.9366 (0.2544)	25.3311 (0.2815)
ΔLGDPER	2.68065 (0.9963)	3.13567 (0.9991)	-3.80360 (0.0001)*	-2.97288 (0.0015)*	62.7925 (0.0000 *	54.1416 (0.0002)*	159.582 (0.0000) *	380.512 (0.0000)*
LNRE	-5.07654 (0.0000)*	0.78893 (0.7849)	-0.15906 (0.4368)	2.15024 (0.9842)	34.7868 (0.0408)**	18.9260 (0.6499)	34.2915 (0.0459)**	14.7943 (0.8709)
ΔLNRE	-4.08563 (0.0000)*	-5.98054 (0.0000)*	-5.46456 (0.0000)*	-5.59013 (0.0000)*	78.5496 (0.0000)*	75.7220 (0.0000)*	160.306 (0.0000)*	382.758 (0.0000)*
LREC	2.21183 (0.9865)	1.96310 (0.9752)	1.96472 (0.9753)	1.37702 (0.9157)	18.1887 (0.6947)	16.8866 (0.7696)	23.2119 (0.3899)	27.8597 (0.1804)
Δ LREC	-4.94343 (0.0000)*	-4.98642 (0.0000)*	-7.95718 (0.0000)*	-7.06713 (0.0000)*	108.207 (0.0000)*	92.3675 (0.0000)*	222.548 (0.0000)*	344.440 (0.0000)*

Note: *Significance at 1% level; ** Significance at 5% level; * **Significance at 10% level.

Panel Cointegration Results

The cointegration relationship between variables was examined based on panel unit root results for all five subgroups. Before continuing the optimal lag was obtained from (Vector autoregressive) VAR lag order selection criteria, a Schwarz Information Criterion (SIC), and an Akaike Information Criterion (AIC), The Pedroni cointegration test results indicate significant long-run relationships among the studied variables. Two models were used, first by assuming LAP as the dependent variable with other independent variables, GDPER, LNRE, and LREC. Secondly, by including TEM as the dependent variable with the other independent variables, LGDPER, LNRE, and LREC. Both AP and TEM as mentioned earlier represent the climate change indicators, the results for all subgroups as shown in Table 3. a, b, c, d, and e.

The test consistently shows strong evidence of cointegration among the variable combinations for the data set with annual aggregated accumulated precipitation LAP and the average temperature TEM. Seven-panel statistics and weighted statistics (rho, PP, ADF statistics) of the within dimension, and three group statistics (rho, PP, ADF statistics) of the between dimension asserted the presence of cointegration at 1% significant level for high-income countries, suggesting that these countries have established long-term equilibrium relationships between climate change indicators and energy consumption metrics. The results are robust across various test statistics.

In upper-middle-income, lower-middle income, lower-income, and Arab countries six-panel statistics and weighted statistics (rho, PP, ADF statistics) of the within dimension, and three group statistics (rho, PP, ADF statistics) of the between dimension revealed the presence of cointegration at 1% significant level in both models when AP is the dependent variable and one when TEM is the dependent variable, except for the lower-middle income the Pedroni cointegrations test satisfied 7 tests out of 8 of between dimension and three within dimension when using TEM as dependent variable. Despite income or regional variations, the Pedroni cointegration tests confirm significant long-run relationships linking economic performance with climate and energy variables across different income levels.

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Table 3.a. Pedroni Cointegration Test, Panel A: High-income Countries

(LAP as dependent variable, LGDPER, LNRE, LREC)							
Within dimension	Statistic	Prob.	Weighted Statistic	Prob.	Between dimension	Statistic	Prob
Panel v-Statistic	3.030576	0.0012	1.016125	0.1548			
Panel-rho-Statistic	-5.972899	0.0000	-4.422107	0.0000	Group rho-Statistic	-4.722126	0.0000
Panel-PP-Statistic	-17.56954	0.0000	-16.43996	0.0000	Group PP-Statistic	-26.24970	0.0000
Panel-ADF-Statistic	-9.074599	0.0000	-9.090606	0.0000	Group ADF-Statistic	-10.21460	0.0000
(LTEM as dependent variable, LGDPER, LNRE, LREC)							
Panel v-Statistic	5.151969	0.0000	-0.288314	0.6134			
Panel rho-Statistic	-8.102066	0.0000	-4.776870	0.0000	Group rho-Statistic	-6.173240	0.0000
Panel PP-Statistic	-14.83827	0.0000	-18.37129	0.0000	Group PP-Statistic	-24.65920	0.0000
Panel ADF-Statistic	-6.071590	0.0000	-11.61466	0.0000	Group ADF-Statistic	-11.38077	0.0000

Table 3.b. Pedroni Cointegration Test, Panel B: Upper-Income Countries

(LAP as dependent variable, LGDPER, LNRE, LREC)							
Within dimension	Statistic	Prob.	Weighted Statistic	Prob.	Between dimension	Statistic	Prob
Panel v-Statistic	0.059051	0.4765	-1.960920	0.9751			
Panel rho-Statistic	-4.356594	0.0000	-5.414067	0.0000	Group rho-Statistic	-4.158656	0.0000
Panel PP-Statistic	-13.97444	0.0000	-15.98035	0.0000	Group PP-Statistic	-23.97233	0.0000
Panel ADF-Statistic	-9.111608	0.0000	-7.723566	0.0000	Group ADF-Statistic	-9.661197	0.0000
(LTEM as dependent variable, LGDPER, LNRE, LREC)							
Panel v-Statistic	-2.156170	0.9845	-2.029625	0.9788			
Panel rho-Statistic	-4.242334	0.0000	-3.504999	0.0002	Group rho-Statistic	-2.676902	0.0037
Panel PP-Statistic	-9.215315	0.0000	-10.50036	0.0000	Group PP-Statistic	-16.56955	0.0000
Panel ADF-Statistic	-5.669939	0.0000	-8.416267	0.0000	Group ADF-Statistic	-10.27961	0.0000

Table 3.c. Pedroni Cointegration Test, Panel C: Lower Middle-income Countries

(LAP as dependent variable, LGDPER, LNRE, LREC)							
Within dimension	Statistic	Prob.	Weighted Statistic	Prob.	Between dimension	Statistic	Prob
Panel v-Statistic	-0.095300	0.5380	-1.728179	0.9580			

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Panel rho-Statistic	-9.159830	0.0000	-8.739498	0.0000	Group rho-Statistic	-7.734911	0.0000
Panel PP-Statistic	-20.19699	0.0000	-21.45048	0.0000	Group PP-Statistic	-27.90210	0.0000
Panel ADF-Statistic	-10.74345	0.0000	-11.52060	0.0000	Group ADF-Statistic	-12.42831	0.0000
(LTEM as dependent variable, LGDPER, LNRE, LREC)							
Panel v-Statistic	6.700940	0.0000	-1.207483	0.8864			
Panel rho-Statistic	-10.12738	0.0000	-6.497460	0.0000	Group rho-Statistic	-5.043615	0.0000
Panel PP-Statistic	-21.28082	0.0000	-14.00170	0.0000	Group PP-Statistic	-17.99608	0.0000
Panel ADF-Statistic	-11.43225	0.0000	-11.08799	0.0000	Group ADF-Statistic	-12.66723	0.0000

Table 3.d. Pedroni Cointegration Test, Panel D: Lower-Income Countries

(LAP as dependent variable LGDPER, LNRE, LREC)							
Within dimension	Statistic	Prob.	Weighted Statistic	Prob.	Between dimension	Statistic	Prob
Panel v-Statistic	1.967320	0.0246	-1.413993	0.9213			
Panel rho-Statistic	-5.516828	0.0000	-4.115059	0.0000	Group rho-Statistic	-4.032557	0.0000
Panel PP-Statistic	-14.08877	0.0000	-14.10717	0.0000	Group PP-Statistic	-20.96459	0.0000
Panel ADF-Statistic	-7.932341	0.0000	-7.868735	0.0000	Group ADF-Statistic	-8.981175	0.0000
(LTEM as dependent variable, LGDPER, LNRE, LREC)							
Panel v-Statistic	0.361996	0.3587	-1.744277	0.9594			
Panel rho-Statistic	-3.433591	0.0003	-3.874009	0.0001	Group rho-Statistic	-2.632523	0.0042
Panel PP-Statistic	-7.651415	0.0000	-7.844301	0.0000	Group PP-Statistic	-11.22093	0.0000
Panel ADF-Statistic	-3.467735	0.0003	-3.620406	0.0001	Group ADF-Statistic	-4.260459	0.0000

Table 3.e. Pedroni Cointegration Test, Panel E: Arab Countries

(LAP, LGDPER, LNRE, LREC)							
Within dimension	Statistic	Prob.	Weighted Statistic	Prob.	Between dimension	Statistic	Prob
Panel v-Statistic	0.591390	0.2771	-0.667058	0.7476			
Panel rho-Statistic	-5.073722	0.0000	-4.262370	0.0000	Group rho-Statistic	-3.553179	0.0002
Panel PP-Statistic	-11.50937	0.0000	-11.62145	0.0000	Group PP-Statistic	-16.66323	0.0000
Panel ADF-Statistic	-5.054097	0.0000	-5.487169	0.0000	Group ADF-Statistic	-6.210735	0.0000
(LTEM, LGDPER, LNRE, LREC)							
Panel v-Statistic	0.942508	0.1730	-1.160015	0.8770			
Panel rho-Statistic	-6.349467	0.0000	-5.764682	0.0000	Group rho-Statistic	-4.993501	0.0000
Panel PP-Statistic	-18.44370	0.0000	-15.70540	0.0000	Group PP-Statistic	-21.61470	0.0000
Panel ADF-Statistic	-8.561423	0.0000	-7.880725	0.0000	Group ADF-Statistic	-9.344533	0.0000

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Results and Discussions

This section presents the empirical findings from the panel data analysis of the impact of GDP per capita (GDPER), non-renewable energy consumption (NRE), and renewable energy consumption (REC) on the climate change indicators accumulated precipitation (AP) and average temperature (TEM) across different income groups. The long and short-run results are reported in Tables 4 and 5. The study covers five panels: high-income, upper-middle-income, lower-middle-income, low-income, and Arab countries, with separate estimates for long-run and short-run dynamics.

In high-income countries, the long-run estimates reveal that non-renewable energy consumption (NRE) is found to have a significant negative effect on the annual precipitation (AP) and average temperature TEM, with the coefficients of -0.051, and -0.047, respectively. indicating that increased non-renewable energy consumption will lower the AP and TEM in the long run. The GDP per capita and renewable energy consumption show a statistically insignificant impact on AP, whereas the results show that GDP per capita and REC have a statistically significant effect on TEM with coefficients of 0.170 and -0.047 respectively. In the short run, all the variables show significant effects on average temperature; however, the coefficient of the error correction term (ECT (-1)) is negative and highly significant indicating a strong adjustment mechanism toward long-run equilibrium in both models.

In the upper-middle-income group, GDP per capita shows a significant positive long-run impact on climate change (AP) and (TEM) with coefficients of 0.073 and 0.029 respectively. Whereas nonrenewable energy consumption and renewable energy consumption have a statistically significant negative long-run impact on AP with coefficients of -0.102 and -0.087 respectively, while both two variables have a significant positive impact on (TEM) with coefficients of 0.005 and 0.007 respectively. In the short run, coefficients are not statistically significant in the two models for all independent variables still, the error correction term (ECT (-1)) is significant and negative indicating an adjustment towards the long-run equilibrium.

The results for lower-middle-income countries indicate a significant long-run effect of GDP per capita, nonrenewable energy consumption, and renewable energy consumption on average temperature (TEM) with coefficients of 0.006, 0.0.003, and -0.006, respectively. Interestingly, renewable energy consumption (LREC) has a negative and significant long-run effect, suggesting that in these countries, higher renewable energy consumption reduces the average temperature in the long run. None of the dependent variables have any significant effect on accumulated precipitation (AP) in the long run. In the short run, none of the variables exhibit significant effects on average temperature nor the accumulated precipitation (AP), except for nonrenewable and renewable energy consumption which revealed a significant effect on the accumulated precipitation (AP) with coefficients of -0.0129 and 0.256 respectively. The coefficients of the error correction term ECT (-1) remain negative and statistically significant at the 1% level.

For low-income countries experience, GDP per capita (GDPER) is positively and significantly related to climate change (AP) and (TEM) in the long run with coefficients of 0.090 and 0.010 respectively. Non-renewable energy consumption (NRE) is found to be insignificant in the long run in both models. Noticeably renewable energy consumption (REC) was found to have a significant negative impact on climate change indicators (AP) and (TEM) in the long run with coefficients of -0.131 at the 10% level of significance and -0.047 at the 1% level of significance respectively. In the short run, only GDP per capita has a positively significant effect on (AP) with a coefficient of 0.032 at the 5% level of significance, whereas nonrenewable and renewable energy consumption have a significant short-run impact on (TEM) at a level of significance of 5% and 10% respectively. The error correction term ECT (-1) is negative and highly significant in both climate change models (AP) and (TEM) with coefficients of -0.975 ($p < 0.001$) and -0.651 ($p < 0.001$) respectively, suggesting a moderate speed of adjustment toward long-run equilibrium.

The group of Arab countries of countries has been chosen to see how the climate change of the Arab region has been affected by economic growth and energy consumption compared with other sub-group countries. The long-run results indicate that the climate change represented by accumulated precipitation (AP) has been influenced negatively by GDP per capita with a coefficient of -0.154, with no significant

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relationship with energy consumption. Moreover, the GDP per capita and nonrenewable energy consumption (NRE) have a significant positive long-run impact on average temperature (TEM) with coefficients of 0.052 and 0.008 respectively. However, renewable energy consumption (REC) is found to be insignificant when related to climate change in selected Arab countries, in the long run. In the short run, none of the variables exhibit significant relationships with climate change except that GDP per capita shows that it has a significant short-run impact on TEM with a low level of significance at nearly 10% level. Still, the coefficient of error correction term ECT (-1) is negative and highly significant with coefficient = -0.938, ($p < 0.001$), indicating a strong adjustment mechanism.

Table 4: Panel ARDL results: (LAP) is the dependent Variables)

Long run equation				Short run equation			
Panel A: high - Income Countries- Selected Model: ARDL (1, 1, 1, 1)							
Variables	Coefficient	T- test	Prob	Variable	Coefficient	T- test	Prob
LGDPER	0.0115	0.2581	0.7964	ΔLGDPER	0.4208***	3.0618	0.0023
LNRE	-0.0509**	-1.9904	0.0471	ΔLNRE	-0.51134***	-4.0693	0.0001
LREC	-0.0211	-1.4243	0.1550	ΔLREC	0.2359***	3.1585	0.0017
				C	6.2981***	24.485	0.0000
				Ect (-1)	-0.9194***	-23.397	0.0000
Panel B: Upper - Income Countries- Selected Model: ARDL (5, 5, 5, 5)							
LGDPER	0.0730***	8.900940	0.0000	ΔLAP (-1)	0.4917*	1.9045	0.0584
LNRE	-0.1017***	-21.98875	0.0000	ΔLAP (-2)	0.2550	1.6022	0.1108
LREC	-0.0870***	-12.80974	0.0000	ΔLAP (-3)	0.2282	1.4696	0.1433
				ΔLAP (-4)	0.0306	0.3237	0.7465
				ΔLGDPER	0.3122	1.0044	0.3165
				ΔLGDPER (-1)	-0.3446	-0.7213	0.4716
				ΔLGDPER (-2)	0.1028	0.1657	0.8686
				ΔLGDPER (-3)	0.1631	0.3774	0.7063
				ΔLGDPER (-4)	0.3297	0.8833	0.3782
				ΔLNRE	-0.4126	-2.2616	0.0249
				Δ LNRE (-1)	-0.1461	-0.5143	0.6077
				ΔLNRE (-2)	-0.3888	-1.1829	0.2384
				ΔLNRE (-3)	-0.1346	-0.5024	0.6160
				ΔLNRE (-4)	0.2430	0.7970	0.4264
				ΔLREC	0.0899	0.4817	0.6306
				ΔLREC (-1)	0.2409	1.0894	0.2774
				ΔLREC (-2)	-0.0204	-0.1034	0.9177
				ΔLREC (-3)	0.1131	0.6739	0.5012
				ΔLREC (-4)	-0.0407	-0.2715	0.7863
				C	11.3915***	5.2020	0.0000
				Ect (-1)	-1.6235***	-5.2270	0.0000
Panel C: Lower Middle-Income Countries - Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	-0.0009	-0.0554	0.9558	ΔLGDPER	0.1250	0.5419	0.5881
LNRE	0.0005	0.1655	0.8686	ΔLNRE	-0.1289**	-2.2243	0.0265
LREC	-0.0133	-0.9099	0.3632	ΔLREC	0.2558*	1.8116	0.0705
				C	6.9189***	19.864	0.0000
				ECT (-1)	-0.9753***	-22.971	0.0000
Panel D: Low-Income Countries - Selected Model: ARDL (1, 1, 1, 1)							

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LGDPER	0.0898***	4.5038	0.0000	ΔLGDPER	0.2715	1.4899	0.1372
LNRE	0.0030	0.9687	0.3334	ΔLNRE	-0.0504**	-2.0687	0.0393
LREC	-0.1308*	-1.6916	0.0917	ΔLREC	-0.3312	-1.0035	0.3163
				C	6.9768***	19.249	0.0000
				ECT (-1)	-1.0050***	-17.439	0.0000
Panel E: Arab Countries-Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	-0.1537**	-2.5258	0.0121	ΔLGDPER	-0.1336	-0.3478	0.7282
LNRE	0.0064	0.3378	0.7357	ΔLNRE	-0.1586	-0.6673	0.5051
LREC	-0.0240	-0.8361	0.4038	ΔLREC	0.2246	0.8591	0.3910
				C	6.3994***	13.079	0.0000
				ECT (-1)	- 0.9645***	-26.0780	0.0000

***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively. Δ is the first difference operator,

Table 5. Panel ARDL Results (LTEM is the dependent Variables)

Long run equation				Short run equation			
Panel A: high-Income Countries - Selected Model: ARDL (1, 1, 1, 1)							
Variables	Coefficient	T-test	Prob	Variable	Coefficient	T-test	Prob
LGDPER	0.1702***	9.7142	0.0000	ΔLGDPER	-0.0857	-1.2059	0.2284
LNRE	-0.0472***	-5.7498	0.0000	ΔLNRE	-0.1332	-1.3279	0.1848
LREC	0.0070**	2.5375	0.0115	ΔLREC	0.0120	0.2083	0.8351
				C	0.6430***	6.5716	0.0000
				ECT (-1)	- 0.8333***	-14.4306	0.0000
Panel B: Upper - Income Countries - Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	0.0292***	5.5376	0.0000	ΔLGDPER	-0.0526	-1.201553	0.2301
LNRE	0.0052***	3.0728	0.0022	ΔLNRE	0.0254	0.8062	0.4205
LREC	0.0067**	2.3624	0.0185	ΔLREC	0.0059	0.4175	0.6765
				C	1.8740***	12.2578	0.0000
				ECT (-1)	-0.7114***	-16.6060	0.0000
Panel C: Lower Middle-Income Countries-Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	0.0063	2.2558	0.0244	ΔLGDPER	-0.0932	-0.9981	0.3186
LNRE	0.0027	6.0338	0.0000	ΔLNRE	0.6810	1.0110	0.3124
LREC	-0.0058	-2.0479	0.0410	ΔLREC	-0.0255	-0.3711	0.7107
				C	2.0576***	11.131	0.0000
				ECT (-1)	-0.7030***	-15.183	0.0000
Panel D: Low-Income Countries-Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	0.0102**	2.4183	0.0161	ΔLGDPER	0.0319**	2.2498	0.0251
LNRE	-0.0002	-0.3668	0.7140	ΔLNRE	0.0005	0.1576	0.8749
LREC	- 0.0470***	-3.3358	0.0009	ΔLREC	0.0449	1.5798	0.1151
				C	2.1790***	7.0984	0.0000

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				ECT (-1)	-0.6513***	-7.300307	0.0000
Panel E: Arab Countries-Selected Model: ARDL (1, 1, 1, 1)							
LGDPER	0.0516***	8.7270	0.0000	ΔLGDPER	-0.0527*	-1.6778	0.0945
LNRE	0.0083***	4.8357	0.0000	ΔLNRE	-0.0190	-0.6195	0.5361
LREC	-0.0027	-0.8443	0.3992	ΔLREC	0.0133	1.6040	0.1098
				C	2.4855***	11.5764	0.0000
				ECT (-1)	-0.9383***	-11.4393	0.0000

***, **, and * indicate the level of significance at 1%, 5%, and 10% respectively. Δ is the first difference operator,

Noticeably, it can be recognized that mixed outcomes were obtained for the different five classification groups. Utilizing two models to investigate how climate change indicators were influenced by economic growth and energy consumption shed light on how significant income classification is in altering expected outcomes.

The results for the long-run coefficients of the panel ARDL model show that economic growth participates in climate change deterioration, as can be noticed that the growth process contributes to raising the average temperature (TEM) across all income groups. These outcomes are consistent with the results in Brini, (2021), and with Osuntuyi & Lean (2022) just for lower-middle-income and low-income countries. Economic growth leads to an increase in annual precipitation (AP) in upper-income and low-income countries, in contrast with Arab countries as the results suggested.

Interestingly non-renewable energy consumption has a mixed impact, with a generally negative or insignificant long-run effect on climate change in most panels, except in the lower-middle-income and Arab countries where it showed a positive relationship. The nonrenewable energy consumption mitigates climate change in high-income countries, whereas it worsens the situation in upper-middle-income, lower-middle-income, and Arab countries.

Renewable energy consumption's impact varies across income groups, with a positive long-run effect on high-income and upper-middle-income countries, revealing unforeseen outcomes since REC is expected to reduce climate change-TEM. In contrast with lower-middle-income and low-income countries, the REC positively affected climate by reducing the average temperatures.

The significance and direction of the short-run coefficients vary, but the error correction term is consistently significant across all panels, highlighting the importance of long-run equilibrium adjustments in all country groups.

Conclusions

This research aimed at analyzing the effects of economic growth, and energy consumption of nonrenewable, and renewable on climate change by dividing the sample countries into sub-groups based on their level of income. The direction of the causal relationship between climate change and the economic variables showed different results in terms of income level classifications. Our empirical results revealed that economic growth, as defined by GDP per capita, has a positive correlation with temperature rise in all income groups and Arab countries. This finding means, on one hand, economic activities are a key factor in determining the growth. On the other hand, the growth process is causing detrimental to the environment by raising temperature levels, However, this relationship varies by income level. For instance, economic growth significantly increases the annual precipitation in upper-middle-income and low-income countries, while in Arab countries, it negatively impacts precipitation levels. The nonrenewable Energy Consumption has a mixed impact on climate change indicators. In developed countries, non-renewable energy consumption appears to mitigate some effects of climate change, showing a negative relationship

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with accumulated precipitation and temperature which means the risk of flooding and high temperatures decreased. However, in lower-middle-income and Arab countries, non-renewable energy consumption worsens climate change, indicating a positive relationship with rising temperatures. This finding highlights the fact of different impacts of energy use depending on the technological and legal structure widespread in different income groups. Finally, the study also found that renewable energy consumption has different impacts across various income groups. While renewable energy consumption helps reduce average temperatures in lower-middle-income and low-income countries, its impact is positive and significant in high-income and upper-middle-income countries. This suggests that reliance on renewable energy sources as a way of fighting climate change may not be sufficient unless strong policies and structures that support renewable energy are put in place. climate change unless complemented by robust policies and infrastructure that enhance its effectiveness. The significant and negative error correction terms across all panels indicate a strong adjustment toward long-run equilibrium for the long-run and short-run dynamics. This means that though there might be short-term fluctuations in the system due to economic activities and energy consumption, there is a tendency for the equilibrium to return to normal, this shows that for effective management of climate change impacts, there is a need to have consistent and long-run policies.

Author contributions

Dr. khawlah A. A. Spetan: conceptualization, data curation, analysis, writing, review & editing. Mohammad M AL-Rawabdeh: resources, data analysis, investigation, writing & editing. Ghazi Al-Assaf: analyzing, writing, reviewing & editing. Raad Al-Tal: data analysis, writing, & editing. "All authors read and approved the final manuscript".

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Availability of data and materials

All data analyzed during this study are included in the websites in reference.

Declarations

Competing interests

The authors declare no competing interests.

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Appendix

List of countries considered for the study.

High-income countries
Aruba, Austria, Belgium, British (United Kingdom), Chile, Cyprus, Denmark, Greece, Italy, Japan, France, Spain, Romania, Poland, Singapore, Switzerland, United States (USA), Sweden, Germany, South Korea.
Upper-Middle- income countries
Armenia, Azerbaijan, Belarus, Brazil, Bulgaria, Colombia, China, Cuba, Dominica, Ecuador, Fiji, Guyana, Malaysia, Mexico, Thailand, Tonga, Türkiye, South Africa, Peru.

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Lower-Middle-income countries
Angola, Bangladesh, Benin, Bhutan, Bolivia, Cameroon, Comoros, Republic of Congo, El- Salvador, Ghana, Honduras, India, Indonesia, Iran, Kenya, Mongolia, Pakistan, Philippines, Samoa, Senegal, Sri Lanka, Tanzania, Ukraine, Vietnam, Zimbabwe.
Lowe-income countries
Burkina Faso, Mali, Togo, Uganda, Rwanda, Burundi, Central African Rep, Malawi, Madagascar, Mozambique, Ethiopia, Zambia, Guinea.
Arab countries
Sudan, Syria, Algeria, Egypt, Lebanon, Mauritania, Morocco, Tunisia, Jordan, Iraq, Comoros.