Finans Politik & Ekonomik Yorumlar (672) Haziran 2025: 105-138
Araştırma Makalesi

RENEWABLE ELECTRICITY CONSUMPTION AND ECONOMIC GROWTH: A CROSS-INCOME PANEL ARDL ANALYSIS WITH IMPLICATIONS FOR ENERGY TRANSITION

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Gönderim tarihi: 28.01.2025 *Kabul tarihi: 02.06.2025*

ABSTRACT

The transition to renewable energy and the corresponding use of electricity generated from renewable sources is an inevitable solution that must be adopted to mitigate the effects of the climate crisis. The extant literature on the energy-economic growth nexus present mixed findings – some studies suggest the existence of a relationship while others find no significant relationship. Nevertheless, a growing number of recent studies provide evidence of an existing relationship. This study employs the panel ARDL techniques PMG, MG and DFE to investigate the short-run and long-run dynamics between renewable electricty consumption (RELC) and economic growth over the period 2000-2022 across 48 countries classified by income level. The results clearly indicate that the use of green electricity has a positive effect on economic growth across all income levels, albeit with varying magnitudes. Findings of the study provide particularly encouraging empirical evidence for a green transition in developing countries, underscoring the need for more attention to the unique challenges and opportunities faced by these economies.

Keywords: Energy Transition, Sustainable Economy, Renewable Electricity, Developing Economies, Economic Growth, Panel ARDL.

JEL Classification: O44, Q42, Q43

ÖZ

Yenilenebilir enerjiye geçiş ve buna bağlı olarak yenilenebilir enerji kaynaklı elektrik kullanımı, iklim krizinin etkilerini hafifletmek amacıyla kaçınılmaz olarak benimsenmesi gereken bir çözümdür. Enerji ile ekonomik büyüme bağlantısına ilişkin mevcut literatür farklı bulgulara ulaşmış; kimi çalışmalar bir ilişkinin varlığını öne sürerken, kimileri de önemli bir bağlantı tespit etmemiştir. Bununla birlikte, giderek artan sayıda yeni çalışma mevcut ilişkiye dair kanıt sunmaktadır. Bu çalışma, 2000-2022 döneminde gelir düzeyine göre sınıflandırılmış 48 ülkede yenilenebilir elektrik tüketimi (YET) ile ekonomik büyüme arasındaki kısa ve uzun vadeli dinamikleri araştırmak için panel ARDL teknikleri PMG, MG ve DFE'yi kullanmaktadır.. Sonuçlar, yeşil elektrik kullanımının, değişen büyüklüklerde de olsa, tüm gelir düzeylerinde ekonomik büyüme üzerinde olumlu etkiye sahip olduğunu açıkça göstermektedir. Çalışmanın bulguları, özellikle gelişmekte olan ülkelerde yeşil dönüşüme ilişkin cesaretlendirici ampirik kanıtlar sunmakta olup, söz konusu ekonomilere özgü zorluk ve fırsatlara daha fazla dikkat edilmesi gerektiğinin altını çizmektedir.

Anahtar Kelimeler: Enerji Geçişi, Sürdürülebilir Ekonomi, Yenilenebilir Elektrik, Gelişmekte Olan Ekonomiler, Ekonomik Büyüme, Panel ARDL.

JEL Sınıflandırması : O44, Q42, Q43

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1. Introduction

Amidst ominous environmental concerns, the connection between the consumption of renewable energy and economic growth has gained traction. In the wake of this reality, it has become necessary to reduce our reliance on fossil dependent systems in favour of ones that can be powered by cleaner energy. The International Energy Agency (IEA) (2024) reports that electricity generation accounted for approximately 37.4% of CO_2 emissions globally in 2023. This realisation among other factors, is driving a change in the power generation landscape towards green electrification. Wilkinson et al. (2007) note that adopting renewable energy alternatives does not only offer significant potential for reducing greenhouse gas emissions but also enhances energy security and sustainable economic growth.

Primarily, this study aims to probe the cross-country income level interlinkage between renewable electricity consumption (RELC) and economic growth. Consequently, this query will extend to two critical timeframes: the short-run and the long-run. The short-run analysis will focus on how investments in renewable power generation will impact a nation's economic wellbeing immediately. In the long run the analysis will provide insights, on the sustained influence of renewable energy investments on a nation's economic advancement.

Four potential linkages between RELC and economic growth can be drawn from the existing literature on this subject. These are the neutrality hypothesis (RELC has no significant impact on economic growth), the energy conservation hypothesis (economic growth propels RELC), the growth hypothesis (RELC propels economic growth), and the feedback hypothesis (both RELC and economic growth propel each other).

The study considers countries as they have been categorized based on the World Bank's income classifications. This approach considers the different socio-economic characteristics and energy needs of countries at different development stages. The panel autoregressive distributed lag (ARDL) methodology was adopted to analyse the data. Specifically, the mean group (MG), pooled mean group (PMG) and dynamic fixed effects (DFE) estimations provide error correction terms (ECT) to infer cointegration and estimate the short-run and long-run coefficients.

The subsequent sections of the work are structured as follows: Section two conducts a review on the current empirical literature focusing on the four main hypotheses. Section three introduces the data, outlines the model and discusses the methodology. Section four presents the results of the analysis. Section five is the conclusion.

2. Literature Review

The available library of empirical literature, investigating the interaction between energy consumption and economic growth have not reached a consensus. These discrepancies can be attributed to the variations in timeframes, analytical methods, and diverse countries and country-groups studied. Nonetheless, a more detailed examination of the body of work on the energy-growth nexus reveals growing evidence in favour of either a unidirectional or bidirectional linkage, with fewer finding suggesting neutrality. This suggests that energy plays an increasingly important role in development.

A large number of studies have been carried out on the connection between economic development and energy consumption. The body of work validating the conservation hypothesis argues that economic growth propels energy consumption. Kraft & Kraft (1978) pioneered the study of the causal relationship between gross energy inputs and Gross National Product (GNP) in the post-World War II. The study found a strong one-way causal link from GNP to energy consumption in the USA. Cheng & Lai (1997) found no cointegration between energy consumption (EC) and Gross Domestic Product (GDP) based on data from Taiwan for the period 1955–1993 Nevertheless, they observed unidirectional causality from economic growth to EC, and from EC to employment. This suggests a nexus where economic growth stimulates employment through energy consumption. Narayan & Smyth (2005) employed a multivariate model from Australian economic data spanning 1966 to 1999 to investigate the electricity-income linkage. The study revealed a weak unidirectional Granger causality from real income to electricity usage. It was further observed in this study that in the long run, real income and employment Granger caused electricity consumption. From the study conducted by Yoo & Kim (2006) in Indonesia from 1971 to 2002, a one-way causality from GDP to electricity usage was established. The study further noted two things, that rising incomes led to increased electricity consumption by households, and expanding manufacturing sectors also demanded more electricity. In another study, Yoo & Kim (2006) investigated the link between electricity consumption and real GDP across four Asian countries, from 1971 to 2002. It was concluded that causation ran from economic growth to electricity consumption in Indonesia and Thailand, but not in the other two economies.

For Cyprus, Zachariadis & Pashourtidou (2007) collected data on household and commercial electricity consumption, income, prices, and the weather data from 1960 to 2004. It was found that, electricity usage was Granger caused by income. However, feedback causality was discovered between household electricity utilization and private income. Sari et al. (2008) employed monthly data from January 2001 to June 2005 to analyse the impact of disaggregated energy sources on industrial output and employment in the USA. Cointegration between the energy sources, industrial output, and employment, especially for wind, solar, and hydro energy was found. The study found causality from GDP per capita to electricity usage per capita. In another study spanning 1994 to 2003, the impact of income on renewable energy use was investigated by Sadorsky (2009) in 18 emerging economies. The study found a positive relationship between real income and clean energy consumption. In Sekantsi & Okot (2016), the relationship between electricity consumption and real GDP in Uganda from 1981 to 2013 was analysed. The results indicated a short-run causation from GDP growth to electricity consumption. Balcilar et al. (2019) investigated the nexus in Pakistan by collecting data on electricity consumption, real GDP, and carbon dioxide emissions from 1971 to 2014. A causality link from real GDP to electricity consumption was observed over the period.

Similarly, Bekun & Agboola (2019) studied the relationship between electricity consumption, real GDP, and carbon dioxide emissions in Nigeria from 1971 to 2014. The findings of the study supported cointegration among the variables, with evidence for the conservation hypothesis. With data from 1971 to 2014, Samu et al. (2019) replicated the study for Zimbabwe. The outcome of this study confirmed causality from real GDP to electricity consumption. Additionally, the researchers found that, electricity consumption was unresponsive to carbon dioxide emissions in Zimbabwe. Mighri & Ragoubi (2020) investigated the linkage between electricity consumption and real GDP in Tunisia from 1971 to 2013. They found long-run cointegration between the two variables, with causality running from GDP to electricity consumption in the long run.

Studies supporting the growth hypothesis posit that increased energy consumption fuels economic growth. With data spanning 1947 to 1990 for the USA, Stern (1993) tested for a causal relationship between GDP, EC, and capital stock. Initially, EC did not Granger cause GDP. Nonetheless, after adjusting for different fuel mixes, the new measure of energy showed causality from energy to GDP. Masih & Masih (1996) examined six Asian nations from 1955 to 1990 and found cointegration present in Indonesia, Pakistan, and India. The study also found a unidirectional causation from energy consumption to GDP India. Nevertheless, the study also found the prevalence of the conservation hypothesis for Indonesia while Pakistan produced mixed results. Masih & Masih (1998) studied Sri Lanka and Thailand from 1955 to 1991 with the outcome of their probe indicating the existence of cointegration between energy consumption, real income, and price. In addition, one-way causation from energy consumption to real income and price was uncovered, particularly pronounced in Thailand. In another study, Stern (2000) extended his analysis and found unidirectional causality from energy to GDP in the USA, consistent with his earlier findings using a modified energy measure.

Soytas et al. (2001) investigated the energy-GDP relationship for Turkey from 1960 to 1995. The researchers concluded that energy consumption Granger caused income, supporting the growth hypothesis. Ghosh (2002) analysed Indian data from 1950 to 1997. Even though the analysis found no cointegration, it unveiled a unidirectional causation from income growth to electricity use. Shiu & Lam (2004) studied GDP and electricity consumption in China from 1971 to 2000. According to their results, cointegration existed between the two variables over the period studied. Furthermore, the authors observed a unidirectional relationship from electricity consumption to GDP, driven by industrial demand for electricity. In Lee (2005) a sample of 18 developing countries spanning the years 1975 to 2001 were examined. The study found cointegration present between energy usage and economic growth. Furthermore, a unidirectional causation to GDP from energy usage was observed. Subsequently, the study suggested, that this observation could be due to the industrialisation phase that developing countries tend to be in. For Fiji, Kumar Narayan & Singh (2007) analysed the relationship between electric power consumption, labour force, and economic growth from 1971 to 2002. The researchers found unidirectional causation from electricity to economic growth, suggesting that limiting electricity usage could adversely affect economic growth. They also observed a two-way relationship between income and the labour force in the short run. Considering the period from 1966 to 2002, Ho & Siu (2007) investigated electricity consumption and real GDP data for Hong Kong. The study reported a long run cointegration relationship between the variables. In addition, it was concluded that electricity Granger caused real GDP without feedback. Soytas & Sari (2007) probed the nexus in Turkey from 1968 to 2002. Their work discovered a long-run relationship between electricity consumption and manufacturing output. The study further observed a unidirectional causation linkage from electricity usage to manufacturing output in the long run, with no significant impact in the short run. Additionally, they found that electricity utilization additionally Granger caused labour and fixed investment in the long run. Yuan et al. (2007) examined the causality between real income and electricity utilization for China from 1978 to 2004. A unidirectional causation running from electricity consumption to real income was discovered, suggesting that disruptions in electricity supply could impede economic growth in China.

Narayan & Smyth (2008) identified a causal linkage from electricity utilisation to GDP, with a long-run relationship between electricity consumption, GDP, and capital formation. Their study was on G7 countries from 1972 to 2002. Even though the short-run causality found was weak, a strong significance for long-run causality was discovered. Odhiambo (2009) examined Tanzania's EC, electricity consumption and economic growth nexus from 1971 to 2006. This probe revealed a unidirectional causation from both EC and electricity consumption to economic growth in both the short and long run. In another study covering the years 1980 to 2005, Nondo & Kahsai (2009) provided evidence on the relationship between energy consumption and economic growth in 19 COMESA countries. They found the existence of unidirectional causality from EC to economic growth, suggesting support for the growth hypothesis. The study recommended the promotion of clean energy development in the region to augment energy supply. Warr & Ayres (2010) examined the relationship between energy (split into exergy and useful work) and GDP for the USA from 1946 to 2000. They found distinct influences of both energy measures on income: useful work Granger caused GDP in the long run and exergy Granger caused GDP in both the short and long run. Yoo & Kwak (2010) explored the relationship between electricity consumption and economic prosperity in 6 South American nations. The probe found causation from electricity consumption to economic prosperity in Ecuador, Chile, Brazil, and Argentina. With data on the Chinese economy from 1972 to 2006, Wang et al. (2011) looked into the energy-growth nexus. The findings of their study suggested a one-way causation link from EC to economic growth in the long run. Nevertheless, a weak two-way causation was observed in the short run. In a study on Tunisia, Chouaibi & Abdessalem (2011) investigated the nexus between electricity utilization and GDP from 1971 to 2007. Their findings pointed out a causal relationship from electricity utilization to GDP over the observed period. Eggoh et al. (2011) studied the impact of electricity consumption on economic expansion in net energy-importing and net energy-exporting countries. Their study verified the presence of cointegration between real GDP and electricity consumption in both groups, with net energy-importing countries showing higher responsiveness to electricity usage. Pata & Yurtkuran (2017) examined the association between electricity consumption and GDP in five European countries and the USA from 1964 to 2014. The ARDL bounds tests was applied to the data which then confirmed cointegration was present in all the countries under consideration, with electricity consumption influencing income growth. The short-run impacts were also found to be statistically significant. Hossen & Hasan (2018) investigated the link among electricity-induced carbon dioxide emissions, electricity consumption, real GDP, and heat production in Bangladesh from 1972 to 2011. The study found a sustained equilibrium relationship among the variables in the long term, supporting the growth hypothesis. Considering the period 1990 to 2016, Bekun & Agboola (2019) studied the influence of electricity consumption on real GDP in India. The results from the research presented evidence of causation, indicating that electricity consumption affects real GDP.

For Zimbabwe, Samu et al. (2019) scrutinised the relationship between electricity usage and real income between the years 1971 to 2014. The results of the research confirmed the growth hypothesis, with electricity usage fostering growth in GDP. In a study on the Chinese economy, Zhong et al. (2019) investigated the electricity consumption-income linkage in a multivariate model with total employment as the third variable. Data covering the years 1971 to 2009 was used in the study. The authors of the study found that a significant long-term equilibrium connection exists between the variables. Moreover, causation that ran from GDP to electricity utilization in the short term was confirmed. Considering the top five oil-producing African nations from 1980 to 2015, Awodumi & Adewuyi (2020) analysed the effects of non-renewable energy consumption (NREC) on economic growth and CO_2 emissions. Their findings indicated that the impact of NREC on economic growth and environmental conditions across the nations varied. Nigeria in particular experienced slowed economic growth but improved environmental quality due to NREC. For the Vietnamese economy, Ha & Ngoc (2021) distinguished their work by exploring a possible non-linear influence of electrical power use on income growth between 1971 to 2017. The study confirmed cointegration among the variables. In addition, a causality probe indicated GDP caused electricity utilization in both the short and long run, giving support to the growth hypothesis

From an alternative perspective suggesting that renewable energy sources can fuel economic growth, Ewing et al. (2007) studied the impact of various energy sources, including biomass, on industrial output. It was uncovered that, biomass energy accounted for about 16% of variations in industrial output over the observed period. Payne (2011) analysed data from 1949 to 2007 to investigate the relationship between real GDP, biomass energy, capital, and labour in the USA. The Toda-Yamamoto causality technique was then applied to the data. This revealed that, biomass energy unidirectionally caused income growth. In another study for the USA that spanned 2001 to 2005, Yildirim et al. (2012) examined the relationship between renewable energy sources, including biomass, and GDP in the USA from 1949 to 2010. A one-way causation from biomass to GDP was uncovered. Ocal & Aslan (2013) analysed the causality link between GDP and green energy usage in Turkey from 1990 to 2010. According to this study, renewable energy usage adversely impacted economic growth from ARDL analysis. However, the Toda-Yamamoto causality tests revealed causality ran from economic growth to green energy consumption. Twerefou et al. (2018) investigated the effect of aggregate energy consumption, including biomass, on economic growth in West African nations spanning 36 years from 1980. The investigation found no causality between total EC and economic progress but observed a unidirectional causation from economic growth to electricity utilization. In another study from 1980 to 2012 on sub-Saharan African countries, Adams et al. (2018) considered the effects of renewable and non-renewable energy on economic growth. The study included a measure of governance type. The investigation found cointegration among the variables. Additionally, the study discovered that, the impact energy sources were enhanced with democracy as the prevailing regime. Thus, highlighting the importance of governance factors in shaping this relationship. Maji et al. (2019) also found that renewable energy sources, including biomass, were limiting factors for income growth in West African countries from 1995 to 2014. This observation was attributed to heavy reliance on biomass in the region

Banday & Aneja (2020) explored the causal nexus between economic growth, carbon dioxide emissions, and renewable energy usage in the BRICS from 1990 to 2017. It was uncovered that a feedback causation was valid for Brazil and China. In contrast, the growth hypothesis prevailed in Russia whiles neutrality dominated in India over the years studied. Shahbaz et al. (2020), with data spanning 1990 to 2018 assessed the economic spurring impact of renewable and non-renewable energy consumption in 38 nations. The researchers found heterogeneity in the impact of both energy sources on real GDP across the countries examined, with non-renewable energy showing a more substantial influence in many cases. The study undertaken by Chen et al. (2020) employed threshold modelling techniques to demonstrate that the influence renewable energy usage exerts on economic expansion can vary, based on consumption volume. The study observed adverse effects at initial low consumption volumes. However, this impact transitioned to a positive one after exceeding some thresholds of consumption, particularly in developing countries. Abbasi et al. (2020) investigated the effects of renewable and non-renewable energy on GDP growth in Pakistan from 1970 to 2018, finding favourable outcomes associated with renewable energy consumption and adverse effects linked to non-renewable energy. Kouton (2021) evaluated the impact of renewable energy consumption on inclusive growth in sub-Saharan African nations from 1981 to 2015 and found a beneficial and statistically significant influence on inclusive growth.

Among studies that have explored the feedback hypothesis, in other words, the bilateral relationship between economic growth, and both conventional and renewable energy sources, Nachane et al. (1988) investigated the long-run equilibrium relationship between energy consumption and GDP across 25 countries. In this study, cointegration in 16 nations and bidirectional causality between GDP and energy consumption prevailed in most cases. Ebohon (1996) examined the growth-energy linkage in Nigeria and Tanzania and found bidirectional causation between economic growth and energy consumption in both nations. Masih & Masih (1997) expanded the analysis by including the Consumer Price Index (CPI) in addition to GDP and EC in their probe for the Taiwanese and South Korean economies. The findings revealed a three-way causal linkage between GDP, prices, and EC in Taiwan and South Korea. Glasure & Lee (1998) provided mixed results with their probe on Singapore and South Korea. While cointegration tests showed a connection between GDP and energy consumption in both countries, their VAR model results indicated no connection for South Korea, and a one-way relationship for Singapore. However, VECM results showed a bidirectional causation linkage in both countries.

Yang (2000) applied Hsiao's Granger causality to explore the relationship between EC and income in Taiwan from 1954 to 1997. The study discovered bidirectional causation between aggregate EC and GDP, as well as for electricity and coal consumption. Jumbe (2004) differentiated his study by examining the nexus between electricity usage and GDP in different sectors in Malawi. The study verified cointegration between electricity consumption and GDP, particularly in the non-agricultural sector. Furthermore, the study found that non-agricultural GDP, Granger caused electricity consumption. Ghali & El-Sakka (2004) applied a neoclassical production function to analyse the relationship between income and energy use in Canada. The investigation revealed a bidirectional causation nexus between the variables of interest, a contradiction to the neoclassical assumption of energy neutrality to growth. Mahadevan & Asafu-Adjaye (2007) investigated the energy-growth nexus in net energy importing and exporting countries from 1971 to 2002. The probe found unidirectional causation from GDP to EC in the short run, and bidirectional causality in the long run for net-exporting nations and developing net importers. Mutual causation prevailed for developed net energy importers.

Foon Tang (2009) found bidirectional causality, between electricity consumption and income in Malaysia between the years 1970 to 2005. In another study on Malaysia spanning the years 1971 to 2008, Nanthakumar & Subramaniam (2010) applied an error correction model of the ARDL bounds testing procedure to confirm a two-way causal relationship between GDP and electricity consumption. Ozturk (2010) scrutinised data from 57 countries across unique income groups and verified cointegration between EC and economic growth. The study further confirmed bidirectional causation in the lower-middle and upper-middle-income countries, and unidirectional causality from income to EC in low-income countries. In Sebri & Ben-Salha (2014), an exploration into the nexus in the BRICS was performed. The inquest found a direct relationship between GDP and renewable energy consumption. A two-way causation link, between GDP and renewable energy consumption, particularly pronounced in Brazil was confirmed.

Nazlioglu et al. (2014) in their probe using data from 1967 to 2007 on Turkey identified bidirectional causality between income and electricity consumption. Bildirici (2016) found bidirectional causality between real GDP and electricity consumption in five South American countries from 1970 to 2010. Hwang & Yoo (2016) noted mutual causation between income and real GDP in Nicaragua from 1971 to 2010. Khobai & le Roux (2017) discovered bidirectional causality between electricity consumption and income growth in South Africa from 1971 to 2013. Similarly for India with data from 1971 to 2014, Sultan & Alkhateeb (2019) found bidirectional causality between electricity consumption and economic expansion. Azam et al. (2021) observed bidirectional causality between renewable electricity consumption and economic growth in ten newly industrialized countries from 1990 to 2015.

Apergis & Payne (2010a) probed data spanning 1985 to 2005 to examine the relationship between income and renewable energy consumption (REC) in the OECD. The study discovered a two-way causal link between the two variables of interest. In another study conducted by Apergis & Payne (2010b), a panel vector error correction model (VECM) was applied to 13 Eurasian countries from 1992 to 2007. The results revealed both variables shared mutual causation in the countries examined. A year later, Apergis & Payne (2011) investigated the nexus in 6 Central American countries from 1980 to 2006. The study tested Granger causality between RELC and GDP using a panel VECM. This confirmed the presence of bidirectional causality. A fully modified ordinary least squares (FMOLS) estimation model also revealed that RELC has a positive impact on GDP. In another broader panel model covering 80 countries, spanning the years 1990 to 2007, Apergis & Payne (2012) again explored the relationship between conventional energy usage, real GDP, and green energy usage. The investigation, using the FMOLS method unveiled a positive impact of renewable energy usage on GDP, with mutual causation found between the two variables. For Turkey, Tugcu (2013) studied the impact of different energy forms, on total factor productivity growth from the year 1970 to 2011. The results of the study showed a positive effect of REC on total factor productivity growth, with both variables mutually causing each other.

In contrast to the previously discussed hypotheses, some studies propose a neutrality hypothesis, suggesting a weak or non-existent relationship between economic growth and energy consumption. Akarca & Long (1980) revisited the relationship between gross energy consumption and GNP in the United States from 1947 to 1972, challenging the findings of Kraft & Kraft (1978). The study concluded that, no causal association existed between GNP and EC. Extending the work of Akarca & Long (1980) to 1979, Yu & Hwang (1984) examined the connection between GNP, EC, and employment. Their work found no causal link between GNP and EC. However, a weak unidirectional causation to EC from employment was identified. In a separate study Erol & Yu (1987) conducted on newly industrialised countries, a neutral connection between GNP and EC for Canada, France, and the UK was established. The period examined spanned 1950 to 2000. Nevertheless, the growth hypothesis was confirmed for Japan and Italy. Hwang & Gum (1991) analysed monthly data on EC, income, and employment for the USA from the year 1974 to 1990. The study concluded that a neutral, long-run relationship between income, employment, and EC prevailed. In another investigation from 1947 to 1997, Cheng (1995) studied annual USA data on GNP and EC. This probe concluded with support for the neutrality hypothesis. Altinay & Karagol (2004) discovered a neutral causal association between GDP and energy consumption in Turkey between the years 1950 to 2000, indicating no significant causal link between the two factors of interest. Ciarreta & Zarraga (2010) investigated the electricity-GDP linkage for Spain from 1971 to 2005, and confirm the prevalence of the neutrality hypothesis over the years investigated. Gross (2012) analysed the energy-growth nexus in the USA from 1970 to 2007, and discovered a bi-directional relationship between growth and income, as well as in the industrial sector only in the short run. Conversely, neutrality was observed in the commercial sector. Tamba et al. (2017) also examined the electricity-GDP linkage in Cameroon from 1971 to 2013. This study concluded that there was no significant effect of GDP on electricity consumption, and vice versa. Nyoni & Phiri (2020) presented contrasting findings for South Africa from 1991 to 2016, where they found no cointegration between renewable energy and economic growth.

For the United States, Bowden & Payne (2010) investigated the relationship between real GDP, and both non-renewable energy consumption (NREC) and renewable energy consumption (REC) from 1949 to 2006. The study concluded in favour of the neutrality hypothesis, suggesting that, the consumption of renewable energy in the industrial and commercial sectors had no significant long-run effect on real GDP. However, the study observed a unidirectional positive causality from residential use of renewable energy to real GDP. Subsequently, Payne (2011) again scrutinised the linkage between aggregate non-renewable and renewable energy consumption and income growth in the United States from 1949 to 2006 and discovered no Granger causality relationship between renewable energy consumption and real GDP, supporting the neutrality hypothesis.

3. Data and Methodology

The data employed in this study are renewable electricity consumption (RELC) measured in terawatt hours (TWh) and real GDP (constant 2005 US$). Data for real GDP is taken from the World Bank's World Development Indicators database. Data for RELC is obtained from the database of Our World in Data. The data for these variables are compiled for 48 countries from 2000 to 2022. The sample was chosen with priority given to data availability for the variables of interest over the period observed. The list of countries used for the study are provided in table 1.

Table 1: List of countries

HIGH-INCOME COUNTRIES	UPPER MIDDLE-INCOME COUNTRIES	LOWER MIDDLE & LOW-INCOME COUNTRIES
Australia	Argentina	India
Austria	Bulgaria	Indonesia
Belgium	Costa Rica	Nicaragua
Denmark	Dominican Republic	Tajikistan
Finland	Kazakhstan	Ukraine
Germany	Malaysia	Vietnam
Iceland	Mauritius	Ethiopia
Ireland	Mexico	Madagascar
Luxembourg	Russia	Mali
Netherlands	Serbia	Mozambique
Norway	Thailand	Tanzania
Sweden	Turkey	Togo
Switzerland	China	Burkina Faso
United States	Armenia	Burundi
Japan	Brazil	Central African Republic
United Kingdom	Colombia	Democratic Republic of Congo

The countries in the study were classified into income groups (low, lower-middle, upper-middle, and high income) based on the World Bank's annual GNI per capita thresholds (Hamadeh et al., 2022). Following this classification the sample consisted of 16 high income countries, 16 upper middle-income countries, and 16 low-income and lower middle-income countries. Due to limited availability of data, low-income and lower-middle income have been lumped together to facilitate the analysis.

Following Ozturk et al. (2010) the model employed to test for the effect of RELC on economic growth is as follows:

$$LnGDP_{it} = \beta_0 + \beta_1 LnRELC_{it} + \varepsilon_{it} \qquad (1)$$

$LnGDP_{it}$ is the natural logarithm of real GDP and $LnRELC_{it}$ is the logarithm of renewable electricity consumption. ε_{it} expresses the error term. *i* refers to the individual countries in the cross-section component while *t* represents the time series for each unit.

4. Empirical Analysis

Given the objectives of this study, cross sectional dependence is first tested for in the data. If cross sectional dependence is present, second-generation unit root tests are used to test the stationarity of the data. If not, first generation unit roots are used to check for stationarity. Then, the panel ARDL estimations of MG, PMG and DFE are estimated for the data. A Hausman test is then performed to indicate which model is best for the data and the results of that is further interpreted for each income group.

4.1 Cross-Sectional Dependence Tests

To test for cross sectional dependence in the data, the Pesaran cross-sectional dependence (CD) test and the Breusch Pagan LM test are used. The test is applied to the whole dataset initially and then to the sub samples classified by income brackets as shown in table 2 below.

Table 2: Cross sectional dependence tests

	ALL	HIGH INCOME	UPPER MIDDLE INCOME	LOWER-MIDDLE & LOW INCOME
LnGDP				
Breusch Pagan LM test	10998.440***	1326.076***	874.254***	844.206***
Pesaran CD test	142.172***	49.028***	49.168***	41.921***
LnRELC				
Breusch Pagan LM test	7553.160***	988.126***	671.493***	715.540***
Pesaran CD test	110.183***	41.792***	33.495***	33.685***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

Source: Authors' own calculations

From the table indicating the test for cross sectional dependence, it is observed that that there is cross-sectional dependence for the variables of interest in the panel even at the 1% significance level. Consequently, the unit root testing methods that can be used in the study have to be relevant in dealing with this situation. That is, we can only adopt second generation unit testing techniques to confront the problems from cross sectional dependency.

4.2 Unit Root Test

The cross-sectionally augmented IPS test by Pesaran (2007) and the demeaned Breitung unit root tests are employed to test for cross sectional dependence in the data. The tests are performed on the level and first differences of each variable with the constant and constant with trend options considered for each level. Furthermore, the tests are applied to the whole data set and are also applied to the various subgroups differentiated by their income levels.

Table 3: Unit root tests

		Variables	Level		First Difference	
			C	C+T	C	C+T
CADF test	All	LnGDP	-1.709	-1.711	-3.230***	-3.326***
		LnRELC	-2.477***	-2.399	-4.632***	-4.781***
	High income	LnGDP	-1.349	-1.546	-3.613***	-3.946 ***
		LnRELC	-1.779	-2.394	-4.570***	-5.019***
	Upper middle income	LnGDP	-1.913	-1.700	-2.945***	-2.794**
		LnRELC	-2.881***	-3.149***	-4.990***	-5.118***
	Low & Lower-middle income	LnGDP	-2.071	-2.067	-3.590***	-3.553***
		LnRELC	-2.144*	-2.075	-4.386***	-4.466***
Breitung Demeaned unit root test	All countries	LnGDP	13.4865	5.9893	-9.106***	-5.373***
		LnRELC	4.5843	-1.3249*	-12.85***	-12.81***
	High Income countries	LnGDP	4.948	0.9803	-9.18***	-6.133***
		LnRELC	4.3296	1.9225	-8.089***	-6.745***
	Upper middle-income countries	LnGDP	4.7306	3.0500	-4.380***	-2.3998***
		LnRELC	1.0995	-3.432***	-7.041***	-7.292***
	Low & Lower-middle income	LnGDP	6.4488	1.7550	-4.512***	-3.343***
		LnRELC	0.6339	-1.5629*	-7.491***	-8.453***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

Source: Authors' own calculations

Per the CADF test results in Table 3 above, in the whole sample, economic growth is not stationary at level but integrated of the order I (1) which is significant at the 1% significance level. RELC is not stationary at level with trend but stationary without trend at level. However, stationarity is observed with both constant and constant and trend options at first difference. For the high-income subgroup, both GDP and RELC do not exhibit stationarity at level, but the presence of unit root is eliminated at first difference which is also significant even at the 1% level. In the upper middle-income subgroup, LnGDP is not stationary at level for both trend and trend and constant specifications. It becomes stationary after its first difference is taken and it is significant at the 1% level as well. RELC on the other hand is stationary even at level also at the 1% significance level. The low income and lower middle-income group also exhibit non-stationarity at level for both LnGDP and LnRELC. Nonetheless, LnRELC is stationary at first difference for the constant only specification although only weakly significant. The two variables are integrated of order I (1) at the 1% significance level for both variables.

Considering the Breitung demeaned unit root test, the sample with all the countries proved to have unit root for both variables at level in both constant and constant with trend specifications except for LnRELC which was stationary but only weakly significant at the 10% level. However, at first difference both variables became stationary. For the high-income countries sample, both LnRELC and LnGDP only became stationary after their first differences were taken. For the upper middle-income countries, LnRELC was stationary at level with the constant and trend specification. The rest of the variables under both specifications had unit root present. However, both variables became stationary under both constant and constant and trend specifications at first difference. In the lower-middle income and low-income subgroup, LnGDP was not stationary at level. LnRELC was not stationary at level with the constant specification but was stationary at level with the constant and trend specification but only weakly significant. The two variables however exhibited an absence of unit root when the tests were applied to their first differences.

The two tests present relatively similar results pointing to a mixed outcome with regards to the presence of unit root in the data for both LnRELC and LnGDP. While the results are quite mixed, they still present resolute evidence to support the fact that none of the variables are integrated of order I (2) or beyond.

4.3 Panel ARDL

The long-run relationship between economic growth and electricity utilisation is examined using the ARDL approach. As Pesaran et al. (2001), indicated, this method is appropriate when either the variables are integrated of different levels or when the level is integration of the variables is not clear. However, the variables should not be stationary at second difference or beyond. Table 4 presents the results for three estimations: the pooled mean group (PMG), the mean group (MG), and the dynamic fixed effect (DFE) estimations for the whole sample as well as the various income groups.

Table 4: PMG, MG and DFE estimations

ALL	**LONG RUN**	**SHORT RUN**	**ERROR CORRECTION TERM**
PMG	0.119***	0.0196**	-0.0952***
MG	0.3581*	0.0054	-0.1394***
DFE	0.2622***	0.0112	-0.0462***
HIGH INCOME			
PMG	0.0847***	0.0152	-0.1657***
MG	0.0194839	0.0079482	-0.2302245***
DFE	0.1382857	0.0104414	-0.0354889*
UPPER MIDDLE INCOME			
PMG	0.62322***	-0.02132	-0.0850577***
MG	0.4362024	-0.020096	-0.025099***
DFE	0.4162381***	-0.0133854	-0.0867708***
LOW AND LOWER MIDDLE INCOME			
PMG	0.2236706***	0.0379336	-0.0654337***
MG	0.6185553	0.028348***	-0.085641***
DFE	0.4677116***	0.01648	-0.0386382***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively
Source: Authors' own calculations

An overview of the outcome of the estimations indicate they present largely similar but slightly varied results. For the entire sample, all three estimations produced a negative and statistically significant error correction coefficient which implies that for all the countries considered, there is a long run cointegration relationship between RELC and economic growth. The long-run coefficients are also positive in all estimations, indicating that RELC has a positive impact on economic growth. However, the long-run coefficient in the MG estimation is weakly significant at the 10% level. The short-run coefficients are also positive for all estimations employed but only that of the PMG estimation was statistically significant. The other coefficients in the other estimation methods were not statistically significant.

For high income countries in this study, the error correction coefficient was also negative and statistically significant in the PMG and MG estimations but not the DFE estimation. The long-run coefficient was also positive in all estimations but only that of the PMG estimation was statistically significant. For the short-run coefficients, all three estimations produced positive values but none of them was statistically significant.

In the upper middle income sample estimations, just like the previous samples the error correction coefficient was also negative and statistically significant, implying that cointegration exists between GDP and renewable electricity usage. The long-run coefficients were also positive for all the estimation methods. The PMG and DFE long-run coefficients were statistically significant but that of the MG estimation was not statistically significant. The short-run coefficient in the PMG estimation was positive and weakly significant as well. In sharp contrast, the coefficients of the MG and DFE estimations were both negative and insignificant.

The low and lower middle-income subgroup also like the others had negative and statistically significant error correction terms. The long-run coefficients of all estimations were also positive but whiles the PMG and DFE produced statistically significant error correction terms, the coefficient in the MG estimation was not. The short-run coefficient was also positive for all estimations but only that of the MG estimation was statistically significant.

In general, it seems that cointegration is veritable between RELC and economic progression in the sampled groups in this study based on the three estimation methods examined. To a large extent as well, there is a seemingly positive impact on income growth from RELC in the long run but in varying magnitudes depending on the level of income and estimation method. The short-run influence of RELC on economic expansion appears to less pronounced, evidenced by the lesser number of statistically significant coefficients produced by all three estimation methods, with all three estimations churning negative coefficients for the upper middle-income sample in the short run.

It is evident that the three estimation methods present quite diversified outputs with different implications on understanding the dynamic interaction between electricity usage from green sources and economic growth at different income levels. As such, it is imperative to choose a model out of the three estimations that best fits the data. To choose an appropriate model for interpretation, the Hausman test is applied to select an apt model that best fits the data. To achieve this objective, the Hausman test is applied on the MG model against the PMG model, then the DFE model is tested against the PMG model. The findings of the Hausman test are given in table 5.

Table 5: Hausman test

Sample Group	Models	Chi^2	Prob>chi^2	Selected Model
All	MG vs PMG DFE vs PMG	1.35 5.66	0.2446 0.0174	DFE
High income countries	MG vs PMG DFE vs PMG	0.03 0.40	0.8723 0.5263	PMG
Upper middle-income countries	MG vs PMG DFE vs PMG	0.48 17.58	0.4903 0.0000	DFE
Low and lower middle-income countries	MG vs PMG DFE vs PMG	1.14 3.37	0.2866 0.0665	PMG

Source: Authors' own calculations

For the whole sample, when the MG estimation is tested against the PMG estimation, we fail to reject the null hypothesis indicating the PMG estimation is better. However, when the DFE is tested against the PMG model, we reject the null hypothesis, implying that the DFE model is the best fit when considering the whole sample. In the high-income subgroup, the p-value when the MG model is tested against the PMG model implies the PMG model is better. Again, when the PMG model is tested against the DFE, the PMG model still comes out as the better option. Hence, for the high-income countries in this study the PMG model provides a better fit. For the upper middle-income countries, the PMG model is again a better fit when compared to both the MG estimation. The DFE estimation is then compared to the PMG model and the p-value indicated the rejection of the null hypothesis. Thus, the DFE estimator is the best fit for the model with only upper middle-income countries. Furthermore, for the low and lower middle-income countries, the p-value from the Hausman test indicates a weak significance for the DFE model at the 10% significance level. However, the PMG model is preferred as the best model since it is significant at the 5% level. The Hausman test gives us exactly the models to interpret as they are the best fit for the data. The Hausman test espouses that the DFE model is best when considering the whole sample as a unit as well as for upper middle-income countries. The PMG model is the best when considering the high-income sub sample and the lower middle income and low-income samples.

Table 6: Appropriate models

	Long-Run Coefficient	**Short-Run Coefficient**	**Error Correction Coefficient**
All Countries	0.2622***	0.0112	-0.0462***
High Income Countries	0.0847***	0.0152	-0.1657***
Upper Middle-income Countries	0.41624***	-0.0134	-0.08677***
Low And Lower Middle-income Countries	0.2237***	0.0379	-0.0654***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively
Source: Authors' own calculations

From table 6, per the DFE model, when considering all the countries in study together, RELC is cointegrated with economic growth, and this is evidenced by the negative and significant error correction term in the model. As such, in the subsequent period, corrections are made for 4.62% of the departures from the long-term equilibrium observed in the previous period. Also, the positive and significant coefficient of the long-run variable implies that a percentage increase in RELC will result in a 0.26% rise in economic expansion. Meanwhile, in the short-run RELC does not have a significant impact on growth in the economy.

The PMG model for the high-income countries in this study reveals a long run cointegration relationship between RELC and economic growth. The coefficient of the error correction term in this model shows that 16.57% of deviations from the long-run equilibrium are corrected in the next period. Additionally, in the long run a 1% rise in RELC leads to in a 0.0847% growth in income. In the short run however, there is no impact.

Upper middle-income countries just like high income countries in this study also have a long run cointegration relationship between RELC and economic growth as shown by the DFE model. Also, 8.68% of deviations from the equilibrium in the current period are corrected in the next period. The long-run influence of RELC on economic growth is a 0.416%

rise in income per percentage increase in RELC. Meanwhile in the short run, there is no effect of a change in RELC on real GDP.

Considering the low and lower middle-income sample, the existence of cointegration is confirmed by the negative and statistically significant coefficient of the error correction term. In addition, 6.5% of deviations from the equilibrium in one period are corrected in the subsequent period. Also, a unit percentage rise in RELC results in a 0.22% growth in income in the long run. The short-run influence of RELC on economic progression is not statistically significant, in congruence with that of the other samples in the model.

The selected models from the Hausman test demonstrate that upper middle-income countries gain the most from RELC, as income growth is propelled by 0.42% from every unit percentage rise in RELC. Meanwhile, high income countries benefit the least from RELC with a recorded 0.085% increase in income growth, an increase that falls below that recorded for the lower-middle and low-income countries which recorded a 0.22% increase in income growth from a percentage increase in RELC. Meanwhile, even though the short run impact coefficients were not statistically significant in any the selected models, it is worth noting that upper middle-income subgroup while having the highest of RELC in the long run, it also recorded the only negative impact in the short run from RELC. Additionally, the short-run impact observed was largest for the low and lower-middle income subgroup with high income countries recording the second highest effect of RELC in the short run.

Even though the PMG model imposes an assumption of long run homogeneity in its estimation, it allows the short run coefficients and the error correction coefficients to differ among the individual countries. The high-income and the lower- middle- and low-income samples had their PMG models selected as the best fit based on the Hausman test. As such, it benefits the analysis to delve into the estimation of these two coefficients. It also provides additional insight into the short run and error correction effect of RELC on income growth in the individual countries for which the PMG model was deemed appropriate. Table 7 and Table 8 provide the short-run and error correction estimates for the high-income countries and the lower-middle and low-income countries in the study.

Table 7: High income countries

COUNTRY	SHORT-RUN COEFFICIENT	ERROR CORRECTION COEFFICIENT
Australia	-0.0261189	-0.0275057**
Austria	-0.016243	-0.0946149
Belgium	-0.0158237	-0.6009016**
Denmark	0.0276639	-0.0553981
Finland	0.0962752**	-0.2125289***
Germany	0.0317947	-0.2403146
Iceland	0.1130846	-0.0722779
Ireland	0.0169285	0.0747874
Luxembourg	0.0242	-0.0727964
Netherlands	-0.0232282	-0.2540703*
Norway	0.035008	-0.0419672
Sweden	0.0095529	-0.035007
Switzerland	0.0043141	-0.0149077
United States	-0.0251799	-0.0174293
Japan	0.021286	-0.325157**
United Kingdom	-0.0297243	-0.6607329***

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively
Source: Authors' own calculations

The error correction coefficient for the high-income countries reveals that there is a strong statistically significant cointegration relationship between RELC and income growth for Australia, Belgium, Finland, Japan, and the United Kingdom as evidenced by their negative and significant error correction coefficients as illustrated in table 6.6. 2.75% of deviations from the equilibrium in one period are corrected in the next period in the case of Australia. For Belgium, 60% of deviations from the equilibrium are corrected in the next period whereas 21.25% of deviations are corrected for Finland. 32.52% and 66.1% departments from the equilibrium are corrected for Japan and the United Kingdom respectively. The error correction mechanism is thus strongest in the United Kingdom and weakest in Australia. For the

Netherlands, 25.41% of equilibrium deviations are corrected in the next period. However, the cointegration relationship is only weakly significant. The rest of the high-income countries (10 countries) demonstrate no statistically significant cointegration relationship between RELC and income growth. In the short run, all the high-income countries are not impacted by RELC with the exception of Finland. A unit percentage increase in RELC in Finland causes income growth to rise by 0.096% in the short run. Furthermore, even though cointegration was confirmed between RELC and income growth for Australia, Belgium and the United Kingdom, the corresponding short run impacts recorded were negative although not significant.

Table 8: Lower middle- and low-income countries

COUNTRY	SHORT-RUN COEFFICIENT	ERROR CORRECTION COEFFICIENT
India	0.049721	-0.0265795
Indonesia	-0.0034904	-0.0198043
Nicaragua	0.0014942	-0.0763435
Tajikistan	0.1648502**	-0.0169517**
Ukraine	0.0227462	-0.2859683***
Vietnam	-0.0379653**	-0.0202342**
Ethiopia	0.1305765	0.0074263
Madagascar	0.1348009	-0.047008
Mali	-0.0231472	-0.1119462**
Mozambique	0.0141735	-0.0587072***
Tanzania	-0.014958	-0.0172008***
Togo	0.0199264*	0.0542363*
Burkina Faso	0.0020233	-0.0140707
Burundi	0.019897	-0.0550644
Central African Republic	0.0883098	-0.3671199**
Democratic Republic of Congo	0.037979	0.0083963

Note: *, ** and *** indicate statistical significance at the 10%, 5% and 1% levels respectively

Source: Authors' own calculations

In the case of the lower-middle- and low-income countries analysed, Tajikistan, Ukraine, Vietnam, Mali, Mozambique, Tanzania, Togo, and the Central African Republic experience a cointegration relationship between RELC and income growth. Nevertheless, the existing cointegration between income growth and RELC for Togo is weakly significant. India, Indonesia, Nicaragua, Ethiopia, Madagascar, Burkina Faso, Burundi and the Democratic Republic of Congo demonstrate no cointegration between income growth and RELC.

Approximately 1.7% of discrepancies from the equilibrium are corrected in the next period in Tajikistan and Tanzania, which makes them the two countries with the weakest error-correction mechanism among the lower-middle income- and the low-income sample. 28.6% of departures from the equilibrium in one period in Ukraine are amended in the subsequent period. Additionally, for Vietnam and Mali, 2.02% and 11.19% respectively of divergencies from equilibrium are resolved in the following period. Inconsistencies from balance in Mozambique are rectified at a 5.87% adjustment rate in the next period. The Central African Republic experiences a 36.71% amendment in shifts away from the equilibrium in the next period, making it the country with the strongest error correction mechanism in this particular sample. A weakly significant error correction in the subsequent period of 5.42% is experienced in the case of Togo.

Tajikistan and Vietnam showed statistically significant impacts of RELC on income growth in the short run. A one percentage rise in RELC in the short run in Tajikistan stimulated economic growth by 0.164%. In contrast, the short run effect of a rise in RELC in Vietnam rather caused a shrinkage in economic growth by 0.038%. For Togo, although RELC causes income growth to rise by approximately 0.02% in the short run, it is only weakly significant.

The results of this study provide backing for the growth hypothesis, suggesting that economic growth is driven by RELC. It also makes a big case for the use and promotion of renewable energy especially electricity as it does not only drive growth, but it also draws economies closer to sustainable development. The outcome of the model for upper middle, low and lower middle income countries is in concurrence with the work of Azam, Rafiq, Shafique, & Yuan (2021) who found that renewable electricity drives economic growth in developing countries. This exact finding however contrasts that of Chen et al. (2020) who found that REC rather caused negative growth in the economies of developing countries. Furthermore Bhuiyan et al. (2022) also found that renewable energy is not a limiting factor on economic progression in developing, emerging and developed countries.

5. Conclusion

With ever growing concerns on the impact of climate change and the imperative need to reverse the damage done by cutting greenhouse gas emissions, green electrification has emerged as a front runner to accelerate sustainable development and reduce the cost of current development on future generations. Considering this situation, this study has looked at the bearing of renewable electricity utilization on income growth in 48 countries. The 48 countries were further divided into three subgroups according to their levels of income as defined by the World Bank: namely low-income, lower middle income, upper middle income, and high-income countries. These clearly defined groups are analysed to ascertain the influence of RELC in the short-run as well as in the long-run on the growth of their economies with a focus on how RELC distinctly affects economic prosperity in the groups.

This research contributes to the existing literature by providing a comparative insight into the green electricity use and economic growth linkage across different stages of development. That is, the nexus as it pertains to high-, middle- and low-income country statuses. Also, unlike other studies that have studied the impact on single or single-grouped countries, this study looks at the insights generated, i.e., the impacts when all countries are considered as whole and when they are analysed per income level. Panel ARDL methods were employed in analysing the data. In particular, the PMG, MG and DFE panel ARDL methods were employed to estimate three models for each distinct income group. The Hausman test was then employed to select the best fit model for the data for each income group. This then revealed that for the entire sample as one unit the DFE model was the best fit. However, for the high income, upper middle income and the lower-middle- and low-income countries the best fit estimations were the PMG, DFE and PMG respectively. The study also further provided individual country estimates of the error correction effect and short-term coefficients as the PMG permitted for the high income and lower-middle- and low-income categories.

The findings from the study show that RELC and economic growth are cointegrated in the long-run regardless of whether it is being looked at from the whole world's perspective or from an income-level based perspective. Also, RELC has a positive impact on economic growth across the whole sample and all the sub-samples examined. However, the impact of RELC on income growth is greatest in upper middle-income countries with lower-middle- and low-income countries ranking second in benefitting from the impact. High-income countries recorded the lowest addition to income growth from RELC. As such, RELC has a larger stimulation effect on economic expansion in developing countries (middle income and low income) than in developed countries. In other words, developing countries benefit more significantly from the consumption of renewable energy than developed countries. Furthermore, RELC mostly has a weak effect or no effect on economic expansion in the immediate term. Moreover, it appears the error correction effect in stronger in developed countries than it is in developing countries. The observed corrections from deviations from equilibrium is higher when income levels are higher, and it falls as the defined income level group falls.

The insight from this study gives strong support for the adoption of green electricity production sources across all economies in the world regardless of income levels as RELC propels economic growth regardless of income levels. This finding is also important for the formulation and pursing of international policies that tackle reduction in greenhouse gas emissions. This also provides extra incentive for developing countries as policy makers in developing countries do not have to worry about negative impacts of transitioning to renewable electricity sources that could result from job losses from cutting down fossil fuel reliant electricity sources due to the adoption of green electricity production technologies.

While this research provides valuable insight on the effect of RELC on economic growth across the various income categories representing levels of development, much like every research work it also has some limitations. First, to facilitate the analysis, the lower middle income and the low-income categories had to be lumped together as one due to limited availability of data. As such, the study could not provide the impact of RELC on income growth in these income groups distinctively. Furthermore, the countries and number of countries used in the study were prioritised based on data availability. Hence the countries used may not be the most accurate representation of the world at large.

To further expand our understanding of the interaction between RELC and income growth, future research could delve into examining the impact of RELC on the output of different sectors of the economy. It would be valuable to know the dynamics of the impact of RELC on an economic sectoral basis. Also, some future research could also focus on the impact of different sources of green electricity on economic growth. Some sources of renewable electricity might be more beneficial to income growth than others potentially due to the varying resource and infrastructure availability. Thirdly, it will be valuable for future research to explore the impact of RELC on inequality. Due to the capital-intensive requirement of renewable electricity production technologies, it is plausible that investments in its production and use is mainly done by the wealthy who can afford thereby making returns and savings mostly accruing to those high up the wealth chain and further widening the gap between the rich and the poor. Results from such research could led policy on how to formulate and implement subsidies on the adoption of renewable electricity and energy sources.

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