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Renewable and Non-Renewable Energy Consumption and Its Impact on Economic Growth

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Abstract: Energy is an important factor in boosting and sustaining the economic growth level of a country. The aim of this study was to investigate the relationship between energy consumption and the economic growth of selected developed and developing countries from 1993–2019. For this purpose, we used the Pedroni co-integration method to determine the long-term relationship between economic growth and energy consumption. To estimate the long-term parameters, the panel fully modified OLS method and the Dumitrescu and Hurlin heterogeneous panel causality estimation technique were used, and the causality direction between variables was considered. The results showed that energy consumption had a positive and significant effect on the economic growth of both groups of countries. The causality analysis revealed the existence of a protection effect between renewable energy consumption and economic growth in developed countries. Hence, policies that lead to an increase in independent growth in these countries can effectively impact their growth. On the other hand, the existence of the feedback effect in developing countries shows that storage policies and reduced energy consumption may pose a threat to economic growth in these countries.

Keywords: renewable energy consumption; non-renewable energy consumption; sustainability; economic growth

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1. Introduction

The sustainability of economic growth, amongst other preconditions, depends on the effective use of production input factors [1]. Energy is an important factor of growth for all countries [2]. Traditional energy sources such as oil, natural gas, and coal are the most effective drivers of economic growth, providing more than 80% of the energy consumption [3,4]. The demand for traditional energy sources in recent decades has increased for various reasons, including social and economic developments [5]. On the other hand, environmental concerns, the depletion of fossil fuel reserves, energy price shocks, non-renewable features of oil, natural gas and coal as energy sources, and global warming have caused renewable energies to be considered as an alternative to traditional energy sources [6,7]. For example, while world energy consumption was 355.486 quad Btu in 1993, this consumption had risen to 601.117 quad Btu by 2019. The share of oil, coal, and natural gas was, respectively, 32.82%, 27.26%, and 24.37% successful in meeting this demand by 2019. In other words, 84% of the world's energy needs in 2019 were met with traditional energy sources [8]. Many international environmental and energy organizations, such as the International Energy Agency (EIA) and the International Renewable Energy Agency (IRENA), have claimed that renewable energy resources can offer a significant opportunity for economic development and environmental quality improvement for many countries around the world [9]. Therefore, it's important to understand the dynamics between renewable energy consumption and economic growth [10]. In this frame, the relationship between energy consumption and economic growth is based on four hypotheses of growth, conservation, feedback, and neutrality. The growth hypothesis claims that there is a one-way causal relationship between energy consumption and economic growth. According to this hypothesis, energy-saving policies have a negative effect on economic growth [11]. The conservation hypothesis implies that economic growth causes energy consumption. This position implies that an increase in economic growth leads to an increase in energy consumption [12]. As a result of this hypothesis, energy-saving policies and demand management policies will have no negative effect on economic growth [9]. The feedback hypothesis indicates that energy consumption and economic growth are interdependent and complementary [13]. This hypothesis is supported when there is a two-way/mutual causality relationship between energy consumption and economic growth. In this case, the increase/decrease in energy use leads to an increase/decrease in economic growth, and similarly, the increase/decrease in economic growth leads to an increase/decrease in energy use [9,14]. Lastly, the neutrality hypothesis postulates that there is no causality relationship between energy consumption and economic growth [13]. In this case, reducing energy use through energy conservation policies will have no impact on economic growth [15]. These four hypotheses have provided the foundation for empirical tests investigating the energy consumption–growth relationship [16].

Figure 1 shows the non-renewable energy consumption in quadrillion Btu and the GDP (constant 2015 US $) for developed countries from 1993–2019 (World Bank data). The overall growth of non-renewable energy consumption and economic growth suggests that the growth hypothesis and the feedback hypothesis are more applicable in developed countries than the conservation hypothesis or the neutral hypothesis.

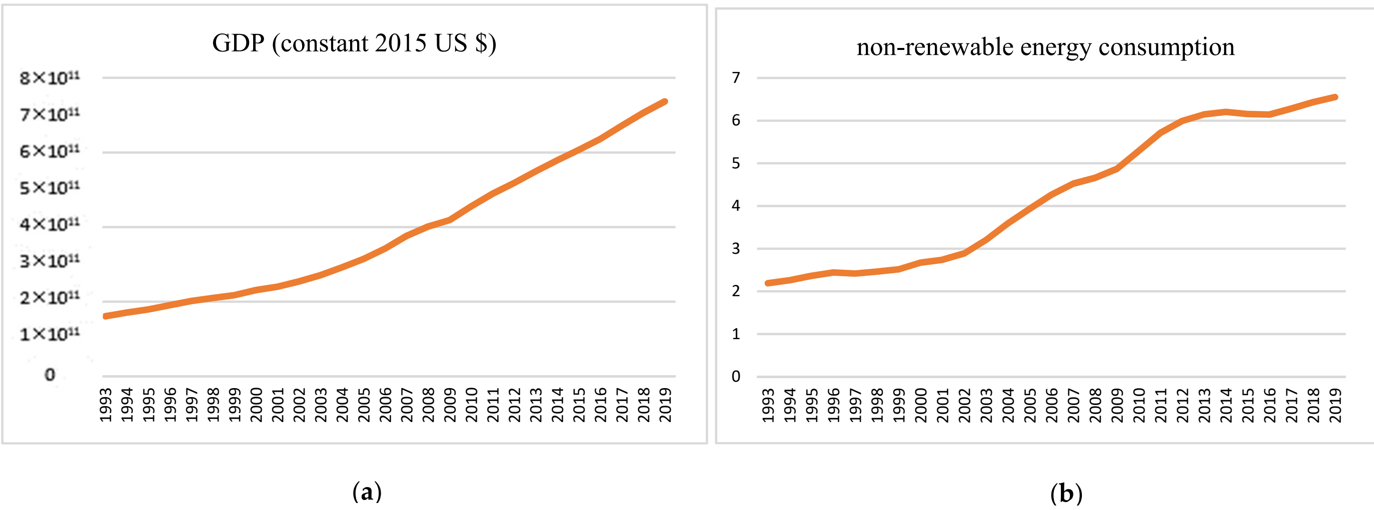

Figure 1. (**a**) GDP (constant 2015 US $) for developed countries from 1993–2019; (**b**) non-renewable energy consumption in quadrillion Btu for developed countries from 1993–2019.

Figure 2 shows the non-renewable energy consumption in quadrillion Btu and the GDP (constant 2015 US $) for developing countries from 1993–2019 (World Bank data). The overall growth of non-renewable energy consumption and economic growth suggests that the growth hypothesis and the feedback hypothesis are more applicable in developed countries than the conservation hypothesis or the neutral hypothesis.

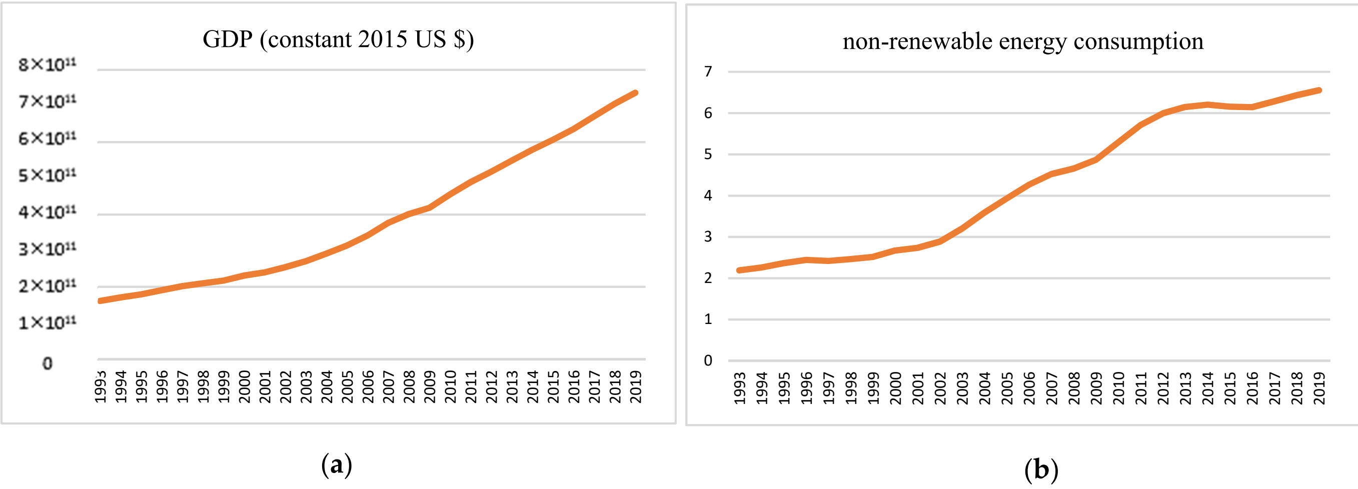

Figure 2. (**a**) GDP (constant 2015 US $) for developing countries from 1993–2019; (**b**) non-renewable energy consumption in quadrillion Btu for developing countries from 1993–2019.

2. Literature Review

Considering the four hypotheses of growth, feedback, conservation, and neutrality, many studies have examined the relationship between energy consumption and economic growth in different countries and different periods of time, which indicates different results [17]. Empirical evidence on the direction of causality, the presence, and the nature of the long-run relationship among the variables varies according to countries and regions, study periods, econometric approaches, and the sources and nature of energy consumed [16]. In this context, [18] examined the relationship between renewable energy and industrial production from 1981–2013 in the USA with monthly data using the wavelet coherence method, and the results support the growth hypothesis. The results of [13] showed a two-way causality between energy consumption and GDP from 1970–2012 for Canada, Japan, and the United States. Authors of [19] examined the relationship between energy consumption and economic growth and how democracy moderates this relationship from 1971 to 2013 in 16 sub-Saharan African (SSA) countries, and their results confirm the feedback hypothesis for energy consumption and growth. In [20] the impacts of renewable energy consumption on German economic growth were considered and the results showed that renewable energy consumption in Germany consolidates the country's economic growth prospects. The causality analysis, on the other hand, revealed the existence of a feedback effect between renewable energy consumption and economic growth. In [11], the relationship between renewable energy consumption and economic growth from 1990–2012 in nine Black Sea and Balkan countries was considered. The results showed a long-term balance relationship between renewable energy consumption and economic growth, and renewable energy consumption had a positive impact on economic growth. Analysis results support the growth hypothesis in Bulgaria, Greece, Macedonia, Russia, and Ukraine; the feedback hypothesis in Albania, Georgia, and Romania; and the neutrality hypothesis in Turkey. According to the panel dataset including all nine countries, the results support the feedback hypothesis. With the findings, it was concluded that renewable energy consumption has a significant impact on economic growth in Balkan and Black Sea Countries. In [21], the authors examined the effect of renewable and non-renewable electricity generation on economic growth from 1980–2012 in 174 countries. The result showed a strong positive and statistically significant relationship between renewable and non-renewable electricity generation and growth. Authors of [22] examined the dynamics between energy consumption and economic growth in Ecuador from 1970–2015. The result showed a one-way causality from energy consumption to economic growth. In [23], the authors analyzed the existing literature on the relationship between energy consumption and economic growth in the six Gulf Cooperation Council (GCC) countries (Saudi Arabia, United Arab Emirates, Bahrain, Qatar, Oman, and Kuwait) from 2006–2019. The result of this study revealed that 18% of the observations supported the growth hypothesis, 26% supported the conservation hypothesis, 43% supported the feedback hypothesis, and 13% supported the neutral hypothesis. In [24], authors examined the impact of the COVID-19 pandemic on electricity consumption and the economic growth nexus using 30 European countries' quarterly data between 2015Q1 and 2021Q3. The result showed that there is bi-directional causality between electricity consumption and economic growth. In [25], the authors compared the impact of renewable and non-renewable electricity consumption on economic growth for 10 newly industrialized countries from 1990 to 2015. The result showed that both renewable and non-renewable energies have a positive and significant long-run effect on economic growth. Furthermore, Granger causality tests suggested short-run and long-run bidirectional causality relationships between renewable electricity consumption and economic growth.

Moreover, some studies have examined the relationship between energy consumption and economic growth in the agricultural sector. In [26] the authors examined the relationship between energy consumption, agricultural growth, and export using time series econometric techniques, including causality and co-integration tests, from 1967–2015. The results showed that there is unidirectional causality from energy consumption to agricultural growth and a one percent increase in energy-use results, including a 1.29 percent rise in agricultural growth in the long-run. In [27], the authors examined the relationship between carbon emissions, energy consumption, and economic growth in the agricultural sector using data from China's main grain-producing areas between 1996 and 2015. The results showed that there is a unidirectional causality from agricultural energy consumption to agricultural carbon emissions and agricultural economic growth.

Due to the importance of energy consumption on economic growth, especially in developing countries, the main objective of this study was to examine and compare the impact of renewable energy consumption (REC) and non-renewable energy consumption (NREC) on economic growth in developed and developing countries. While there are many studies on the relationship between energy consumption and economic growth, most studies did not separate the two types of energy. Other studies looked at the impact of renewable energy or non-renewable energy, while some have compared the impact of the two. This study tries to fill this gap. Accordingly, unlike other studies, beyond estimating the impact of REC and NREC on economic growth, the analysis involved to two groups of developing and developed countries. This allows us to investigate and compare the effect of two types of energy consumption on economic growth. We used a panel data approach to gain a sample from developed and developing countries from 1993–2019. The hypothesis of the research is:

Hypothesis 1 (H1). *The effect of energy consumption on economic growth is different in developed and developing countries.*

3. Materials and Methods

3.1. Methods

In this study, the production function that labor, capital, and renewable and non-renewable energy are considered as its inputs is defined as follows:

$$Y_{it} = f(K_{it},\ L_{it},\ REC_{it},\ NREC_{it}) \tag{1}$$

In Equation (1), Y_{it} is economic growth or GDP growth, K_{it} is capital stock, L_{it} is labor force, REC_{it} is total renewable energy use, and $NREC_{it}$ is total non-renewable energy consumption. Equation (1) was transformed into a log-linear specification by taking all the variable's logarithms. The logarithmic equation will have advantages, such as avoiding problems caused by dynamic dataset conditions [17] and more consistent and efficient results [28]. For these reasons, Equation (1) is modeled as with log-linear function as follows:

$$lnY_{it} = \beta_0 + \beta_{1i}K_{it} + \beta_{2i}L_{it} + \beta_{3i}REC_{it} + \beta_{4i}NREC_{it} + \varepsilon_{it} \quad (2)$$

In Equation (2), *i* and *t* indexes show the number of countries and the time-period. β_1, β_2, β_3, and β_4 are the elasticity of capital, labor, and renewable and non-renewable energy consumption, and ε_{it} is the stochastic error term. Equation (2) was estimated with the panel data approach and to estimate the long-term parameters, the panel fully modified ordinary least squares (panel FMOLS) method was used. Finally, the causality test among all variables was undertaken using the Dumitrescu and Hurlin [29] method. The significant advantage of this test is that it takes into consideration the dependence among the countries and heterogeneity. Moreover, it can be performed when the time dimension (T) is higher or lower than the cross-section dimension (N). In this method, analysis is performed with 2 stable series, and if the series used in the analysis are not stable, they should be stabilized by taking their discrepancy [11].

3.2. Data Description and Model Variables

In this study, the theoretical model was estimated using a panel data analysis approach from 1993–2019 for 59 countries, including 30 developed and 29 developing countries. The list of countries is in Appendix A. The variables have been calculated and reported in the form of natural logarithms for better scaling. A description of research variables and their sources and units are explained in Table 1.

Table 1. Description of variables and their source.

Variable	Description	Unit	Source
GDP	Gross Domestic Product	Constant 2015 US Dollars	World Bank
K	Gross fixed capital formation	Constant 2015 US Dollars	World Bank
L	Total population aged 15 and older who supply labor for the production of goods and services	-	World Bank
RE	Renewable energy consumption	quadrillion Btu	EIA
NRE	Non-renewable energy consumption	quadrillion Btu	EIA

4. Results and Discussions

The descriptive statistics of variables are presented in Table 2. According to Table 2, in developing and developed countries lnGDP is positively correlated with lnK, lnL, LnRE, and LnNRE. To further investigate the relationship between variables, reliable statistical methods, such as co-integration and causality analysis, were tested for the exact examination of the relationship between the studied variables.

Before estimating the effects of renewable and non-renewable energy consumption on economic growth, some tests are necessary. First, to avoid any spurious regression problems, a unit root test is used for the stationary status of the variables. Since the results shown in Table 3 confirmed the existence of cross-sectional dependence (CD) between variables, traditional panel unit root tests developed under the independence assumption of the errors are invalid. A panel unit root test CD should be appropriate. Therefore, we used the cross-sectionally augmented IPS (CIPS) panel unit root test developed by [30]. In Table 4, the results of stationary tests for all variables are reported.

Table 2. Descriptive statistics and correlation matrix for variables.

Developed Countries					
Descriptive Statistics	**LnL**	**LnK**	**LnGDP**	**LnNRE**	**LnRE**
Mean	15.836	30.002	26.905	0.823	−1.368
Median	15.527	29.812	26.711	0.497	−1.306
Maximum	18.929	33.668	30.623	4.547	2.439
Minimum	11.904	25.681	22.775	−3.477	−5.357
Std. Dev.	1.500	1.416	1.403	1.596	1.537
Observations	810	810	810	810	810
LnGDP			1		
LnK		1	0.991		
LnL	1	0.899	0.911		
LnRE	0.661	0.642	0.667		1
LnNRE	0.955	0.926	0.932	1	0.594
Developing Countries					
Mean	15.627	28.064	24.943	−3.195	−0.438
Median	15.383	27.720	24.683	−2.987	−0.733
Maximum	20.500	34.048	30.291	2.873	4.898
Minimum	13.055	23.241	21.730	−10.176	−3.875
Std. Dev.	1.603	1.755	1.673	2.240	1.733
Observations	783	783	783	783	783
LnGDP			1		
LnK		1	0.981		
LnL	1	0.916	0.925		
LnRE	0.890	0.881	0.882		1
LnNRE	0.769	0.718	0.732	1	0.539

Table 3. Pesaran’s test and Frees’ test of cross-sectional independence.

Developed Countries		
Test	**Statistic**	**Probability**
Pesaran (CD)	103.427 ***	0.0000
Friedman	730.086 ***	0.0000
Frees	26.720 ***	Critical values from Frees’ Q distribution alpha = 0.10: 0.1035 alpha = 0.05: 0.1350 alpha = 0.01: 0.1947
Developing Countries		
Test	**Statistic**	**Probability**
Pesaran (CD)	45.893 ***	0.0000
Friedman	320.158 ***	0.0000
Frees	10.479	Critical values from Frees’ Q distribution alpha = 0.10: 0.1124 alpha = 0.05: 0.1470 alpha = 0.01: 0.2129

Notes: CD-test has N (0, 1) distribution, under H0: cross-sectional independence. *** represents significance levels of 1%.

Table 4. Panel unit root test results for developed and developing countries, 1993–2019.

Developed Countries				
Variable	**Statistic**	**CIPS**		
		Critical Values		
		10%	5%	1%
LGDP	−1.829	−2.07	−2.15	−2.3
LRE	−2.809 ***			
LNRE	−1.454			
LK	−1.515			
LL	−1.768			
ΔLGDP	−3.382 ***			
ΔLRE	−5.381 ***			
ΔLNRE	−5.295 ***			
ΔLK	−3.514 ***			
ΔLL	−3.808 ***			
Developing Countries				
Variable	**Statistic**	**CIPS**		
		Critical Values		
		10%	**5%**	**1%**
LGDP	−2.437 ***	−2.07	−2.15	−2.3
LRE	−1.513			
LNRE	−2.144 ***			
LK	−2.359 ***			
LL	−1.110			
ΔLGDP	−3.713 ***			
ΔLRE	−4.547 ***			
ΔLNRE	−4.653 ***			
ΔLK	−4.257 ***			
ΔLL	−3.487 ***			

All variables are in natural logarithms. *** represents significance levels of 1%, respectively. CIPS test assumes cross-sectional dependence in the form of a single, unobserved common factor, and the null hypothesis in the series is I (1).

The results of panel unit root tests are presented in Table 4. The results indicate that all variables, except LRE in developed countries, are not stationary at their levels, but become stationary at their first differences at 1%, 5%, and 10% level of significance. Furthermore, in developing countries, only LRE and LL variables are not stationary at their level. This suggests that there is at least one co-integrating relationship between growth and all the explanatory variables. Hence, a long-run equilibrium relationship between the variables is possible. According to the results, we must check the co-integration relationship between the variables.

In this paper, the co-integration relationship between all variables is tested using Kao's residual co-integration tests and the panel co-integration tests of Pedroni. The empirical results in developed and developing countries support the hypothesis of co-integration among all variables. Therefore, the empirical results confirm to the existence of a long-term equilibrium between real GDP, renewable energy use, non-renewable energy use, capital, and labor force (Tables 5 and 6).

Table 5. Pedroni co-integration tests for developed and developing countries, 1993–2019.

Developed Countries					
	Within-Dimension				**Between-Dimension**
	Statistic	**Prob**	**Statistic**	**Prob.**	
Panel v-Statistic	6.290 ***	0.0000			
Panel rho-Statistic	2.011	0.9779	3.597	0.999	Group rho-Statistic
Panel PP-Statistic	−2.888 ***	0.0019	−2.581 ***	0.0049	Group PP-Statistic
Panel ADF-Statistic	−1.017	0.1545	−0.740	0.229	Group ADF-Statistic
Developing Countries					
Panel v-Statistic	5.196 ***	0.0000			
Panel rho-Statistic	−0.809	0.209	3.784	0.999	Group rho-Statistic
Panel PP-Statistic	−8.267 ***	0.0000	−1.694 ***	0.045	Group PP-Statistic
Panel ADF-Statistic	−3.971 ***	0.0000	1.950 ***	0.974	Group ADF-Statistic

Notes: null hypothesis: no co-integration. Trend assumption: deterministic intercept and trend. Lag selection: automatic SIC with a max lag of three. Newey–West bandwidth selection with Bartlett kernel is used. *** designates the significance at the 1% significance level.

Table 6. Kao co-integration test for developed and developing countries, 1993–2019.

Developed Countries		
	t-Statistic	**Prob.**
ADF	−4.6844 ***	0.0000
Residual variance	0.000627	
HAC variance	0.000716	
Developing Countries		
	t-Statistic	**Prob.**
ADF	−5.219 ***	0.0000
Residual variance	0.002	
HAC variance	0.002	

Notes: null hypothesis: no co-integration. Trend assumption: no deterministic trend. Automatic lag selection based on SIC with max lag of five. *** designates the significance at the 1% significance level.

According to the Pedroni test results, three of the seven test statistics in developed countries support the co-integration relationship between lGDP, lK, lL, lRE, and lNRE, and the results of the Pedroni test in developing countries shows five of the seven test statistics are significant.

The Kao test results in both developed and developing countries support the hypothesis of co-integration among all variables.

After confirming the long-run relationship between the variables, the next step is to estimate this relationship. The FMOLS method was used, and the empirical findings are reported in Table 7. The results of panel FMOLS show that in developed countries, coefficients for lnRE, lnNRE, K, and lnL are positive and statistically significant at 1% level of significance. In addition, since all series are in logarithms, all estimated coefficients of the long-term relationship can be interpreted as long-run elasticity. The results show that a one percent increase in renewable energy consumption, non-renewable energy consumption, capital, and the labor force would increase GDP by 0.121, 0.201, 0.477, and 0.540 percent, respectively. Our empirical findings are like those of [11], which showed evidence for the significant and positive impact of renewable consumption on economic growth in the long term. Furthermore, studies showed the impact of both renewables and non-renewable energies on long-term economic growth [9]. The effect of the labor force variable on economic growth is high and significant, which indicates the high productivity of labor in developed countries.

Table 7. Parameter estimation using FMOLS for developed and developing countries, 1993–2019.

Variable	Coefficient	t-Statistic	Prob
Developed Countries			
LnRE	0.121 ***	8.789	0.0000
LnNRE	0.201 ***	4.726	0.0000
LnK	0.477 ***	22.660	0.0000
LnL	0.540 ***	7.550	0.0000
Developing Countries			
LnRE	0.042 ***	10.592	0.0001
LnNRE	0.235 ***	56.293	0.0000
LnK	0.195 ***	8.814	0.0000
LnL	0.283 **	−23.521	0.0230

Notes: *** designates the significance at the 1% significance level. Designates the significance at the 5% significance level.

According to Table 7, coefficients for lnRE, lnNRE, and lnK are positive and statistically significant at the 1% and lnL is positive and statistically significant at 5% in developing countries. Based on these results, a one percent increase in renewable energy consumption, non-renewable energy consumption, capital, and labor would increase lGDP by 0.042, 0.235, 0.195, and 0.283 percent, respectively. Therefore, there will be an increase in economic growth in these countries. In addition, compared to developed countries, the labor force has less impact on the economic growth of developing countries because despite the high level of inputs in these countries, their productivity is relatively lower.

Results of the short- and long-run ARDL estimation for developed countries are shown in Table 8. The results indicate that in the short-run and long-run, NRE will have a positive impact on economic growth in developed countries. It means that an increase in the NRE by 1% leads to an increase in economic growth by 0.456% in the long-run and by 0.078% in the short-run. The lag of error correction term (ECT_{t-1}) represents the speed of adjustment of GDP to its long-run equilibrium following a shock. The coefficient of −0.105 is negative and significant at the 1% level. These results indicate the existence of a stable long-run relationship between LREC, LNRE, LK, LL, and LGDP. The same results suggest that a deviation from the long-run equilibrium level of real GDP in one year is corrected by 10.5% in the next year.

Table 8. Long- and short-run estimates for developed countries. Selected model: ARDL (1, 2, 2, 2).

Variable	Coefficient.	Standard Error	T-Statistic	*p*-Values
Long-Run Analysis				
LnRE	0.187 ***	0.009	20.588	0.0000
LnNRE	0.456 ***	0.041	10.927	0.0000
LnK	0.254 ***	0.014	17.602	0.0000
LnL	0.166 **	0.087	1.909	0.0567
Short-Run Analysis				
Constant	1.771 ***	0.532	3.323	0.0010
Δ LnRE	0.010	0.008	1.175	0.240
Δ LnRE(−1)	−0.015	0.013	−1.214	0.224
Δ LnNRE	0.078 **	0.031	2.528	0.011
Δ LnNRE(−1)	0.047 **	0.023	2.065	0.039
Δ LnK	0.230 ***	0.025	9.200	0.0000
Δ LnK(−1)	−0.014	0.011	−1.267	0.205
Δ LnL	0.088	0.104	0.850	0.395
Δ LnL(−1)	−0.019	0.097	−0.199	0.842
ECT(−1)	−0.105 ***	0.031	−3.305	0.0010

Notes: *** designates the significance at the 1% significance level. ** designates the significance at the 5% significance level.

Results of the short- and long-run ARDL estimations for developing countries are shown in Table 9. The results indicate that coefficients for NRE in the short-run and long-run will have a positive and significant impact on economic growth in developing countries. It means that an increase in the NRE by 1% leads to an increase in economic growth by 0.042% in the short-run and 0.169% in the long-run. Furthermore, an increase in the RE by 1% leads to an increase in economic growth by 0.012% in the short run. The lag of error correction term (ECT_{t-1}) is −0.240 and is significant at the 1% level. These results indicate the existence of a stable long-run relationship between LREC, LNRE, LK, LL, and LGDP. The results suggest that a deviation from the long-run equilibrium level of real GDP in one year is corrected by 24% in the next year.

Table 9. Long- and short-run estimates for developing countries. Selected model: ARDL (1, 1, 1, 1).

Long-Run Analysis				
Variable	**Coefficient.**	**Standard Error**	**T-Statistic**	***p*-Values**
LnRE	0.015	0.010	1.527	0.1273
LnNRE	0.169 ***	0.021	8.022	0.0000
LnK	0.267 ***	0.009	27.871	0.0000
LnL	0.296 ***	0.041	7.228	0.0000
Short-Run Analysis				
Constant	3.063 ***	0.602	5.085	0.0000
Δ LnRE	0.012 **	0.006	1.901	0.057
Δ LnNRE	0.042 **	0.020	2.050	0.040
Δ LnK	0.101 ***	0.019	5.347	0.0000
Δ LnL	−0.222	0.281	−0.790	0.429
trend	0.005 ***	0.001	3.521	0.0005
ECT(−1)	−0.240 ***	0.047	−5.010	0.0000

Notes: *** designates the significance at the 1% significance level. ** designates the significance at the 5% significance level.

The results of the heterogeneous panel causality test for the developed and developing countries are presented in Table 10. According to the results, there is a two-way causality relationship between lnK and lnGDP, between lnNRE and LnGDP, and a one-way relationship between LnGDP and LnRE, and LnGDP and LnL. These results support the conservation hypothesis between economic growth and renewable energy consumption, and the feedback hypothesis between non-renewable energy consumption and economic growth in developed countries.

Table 10. Heterogeneous panel causality test results for developed and developing countries.

Developed Countries			Developing Countries		
	Wald-Stat	**Prob.**		**Wald-Stat**	**Prob.**
LnK→LnGDP	3.995 ***	0.0000	LnK→LnGDP	3.713 ***	0.0000
LnGDP→LnK	8.123 ***	0.0000	LnGDP→LnK	2.837 ***	0.0000
LnL→LnGDP	2.716	0.275	LnL→LnGDP	4.249 ***	0.0000
LnGDP→LnL	7.578 ***	0.0000	LnGDP→LnL	2.679 ***	0.0000
LnRE→LnGDP	2.572	0.439	LnRE→LnGDP	2.061 ***	0.0000
LnGDP→LnRE	4.523 ***	0.0000	LnGDP→LnRE	4.931 ***	0.0000
LnNRE→LnGDP	3.188 **	0.033	LnNRE→LnGDP	3.558 ***	0.0018
LnGDP→LnNRE	6.517 ***	0.0000	LnGDP→LnNRE	4.102 ***	0.0000

Notes: "→" means the direction of the causality relationship. *** illustrates 1% statistical significance. ** illustrates 5% statistical significance.

The results of causality tests in developing countries show that all variables have a two-way causality with economic growth. These results support the feedback hypothesis between energy consumption (non-renewable and renewable) and economic growth.

5. Conclusions, Implications, and Limitations

5.1. Main Findings

One of the most important economic goals of all countries, especially developing countries, is to achieve high rates of economic growth. Energy, as one of the key factors of production, plays an important role in production and economic growth. The main objective of this study was to investigate the relationship between renewable and non-renewable energy consumption and economic growth using a panel data framework between developed and developing countries from 1993–2019. Experimental results of the Pedroni co-integration test provide proof for the existence of a long-term equilibrium between economic growth, energy consumption from renewable and non-renewable sources, labor, and capital. The parameters for this relationship are estimated by the panel FMOLS method developed by Pedroni. According to the estimation of long-term results, we conclude that renewable and non-renewable energy consumption have a positive and significant impact on economic growth in developed and developing countries.

The empirical result for the direction of the relationship between energy consumption (renewable and non-renewable) and economic growth is estimated by the panel causality analysis developed by [29], which showed that the conservation hypothesis supported economic growth and renewable energy consumption in developed countries. Our empirical findings are like those reported by [31] in Italy, which showed the causal flow from economic growth to energy consumption becomes dominant at lower scales (up to four years).

Furthermore, the feedback hypothesis supported energy consumption (renewable and non-renewable) and economic growth in developing countries. Our empirical findings are like those reported by [32] which showed evidence for the feedback link between non-renewable energy consumption and gross domestic product in Algeria.

5.2. Theoretical and Practical Implications

Based on our findings, the policy implications are addressed as follows. Considering that NREC plays an important role in causing pollution by emitting CO_2, it is recommended to create a context for private sector investment in existing and planned renewable energy projects along with the management of economic activities. In addition to significantly reducing pollution, this approach can also improve the path of economic growth.

The empirical result showed that economic growth is a factor that supports energy consumption and, in this case, energy saving, and energy supply shocks do not affect economic growth in a negative way. Therefore, energy conservation is not a good way to influence economic growth in developed countries, but policies that lead to an increase in independent growth in these countries can have a more effective impact on the growth of these countries.

Energy consumption and economic growth are interdependent and complement each other in developing countries. On the one hand, growth feeds on energy consumption. On the other, a higher energy consumption is sponsored by increased economic growth. Consequently, energy-saving policies and energy supply shocks affect economic growth in a negative way, and accordingly, this negativity is reflected in energy consumption. Given the existence of a two-way relationship between energy consumption and economic growth in developing countries, the use of this input is one of the key factors affecting economic growth in these countries. Therefore, an increase economic growth will increase energy consumption, and increasing energy consumption will increase economic growth. As a result, energy policies, especially storage policies and reduced energy consumption, may pose a threat to economic growth in these countries. On the other hand, policies that lead to increased energy efficiency can eliminate the harmful effects of the inefficient increase in traditional energy sources. Therefore, it is necessary to take precautionary measures to curtail energy policies.

The limitations of the present study included missing observations and the non-availability of data due to the non-development of the renewable sector, especially in developing countries. Moreover, this study considered an aggregate of the total energy consumption. To gain a better understanding, future studies may study and compare energy consumption sources such as wind, solar, and hydropower in two groups of countries. It may help decision makers better understand the causality relationship between energy consumption and economic growth in specific sectors.

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Appendix A

Table A1. Countries in the sample.

Developed Countries			
Australia	Germany	Norway	United Kingdom
Austria	Hong Kong SAR	New Zealand	Chile
Argentina	Ireland	Portugal	Denmark
Belgium	Iceland	Spain	Italy
Canada	Japan	Switzerland	Russian
France	Korea, Rep	Sweden	Romania
Finland	Luxembourg	Singapore	
Greece	Netherlands	United States	
Developing Countries			
Albania	Cuba	Panama	
Algeria	Dominican Republic	Peru	
Armenia	Ecuador	Sri Lanka	
Azerbaijan	Georgia	Thailand	
Belarus	Iran (Islamic Republic of)	Trinidad and Tobago	
Brazil	Lebanon	Tunisia	
Bulgaria	Malaysia	Turkey	
China	Mauritius	Ukraine	
Colombia	Mexico	Uruguay	
Costa Rica	Mongolia		

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