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The impact of total and renewable energy consumption on economic growth in lower and middle- and upper-middle-income groups: Evidence from CS-DL and CCEMG analysis

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ABSTRACT

Among the literature that examined the total and renewable energy-growth nexus, few of them were conducted in low and middle-income countries, however, the total-renewable energy-growth nexus in the lower and middle-income countries at the regional and global levels has not discussed. In this respect, this study examines the impact of total and renewable energy consumption on growth at the global and regional levels across the low-, lower and middle-, and upper-middle-income groups for a sample of 75 countries from 1980 to 2016. The cross-sectional augmented Autoregressive distributed lagged (CS-DL) and common correlated effect means group (CCEMG) have been employed. The findings reveal that total energy is significantly and positively affects economic growth in three income groups; especially this effect is increasing concerning the level of income group, and renewable energy consumption positively affects economic growth at the global level. At the regional levels, the effect of total and renewable energy consumption on growth is mixed across the income groups. Furthermore, negative and neutral effects of renewable energy on growth are highly prevalent than those from total energy at the regional levels. Therefore, policymakers need to reflect on cause-led negative effects and set relative policies, which could attract investors in renewable energy projects so that renewable energy will positively affect economic growth in all regions across income groups.

1. Introduction

The Energy-growth nexus is well documented in high-income countries, and leading to considerable socio-economic development, see [1–3]. This impact dissimilar to the countries classified in low-, lower and middle-, and upper-middle-income groups, whereas they mostly suffer from insufficient energy resources, energy poverty, and energy security, lead to insignificant economic growth [4,5]. Distinct from the slight increase in the economy; achieving Sustainable Development Goals (SDGs) related to energy access and emission reduction [6] is a long process due to deficient energy generation. This decelerates satisfaction of the global energy demand and linked services[1] [7,8] and to mitigates CO2 emission [9,10].

According to The World Bank, the global economic growth in terms of gross domestic product (GDP) raised from $27.871 trillion US dollars in 1980 to $80.445 trillion US in 2016 (constant 2010 US $) with an average yearly growth rate of 2.7 % [11]. The increase in the economy moved parallel to the increase in global energy consumption and demand, whereas, the renewable energy consumption raised from 20.736 in 1980 to 58.013 Quadrillion Btu in 2016 (measured in British unit), with an aggregate of 2.8 times; and total energy consumption raised from 292.246 in 1980 to 575.578 quadrillion Btu in 2016 with an aggregate of 1.96 times [11,12]. The

List of most used abbreviations: LI, Low-income; LMI, lower and middle-income; UMI, upper-middle-income; CS-DL, cross-sectional augmented distributed lags; CCEMG, common correlated effect means group; EC, total energy consumption; REC, renewable energy consumption; GDP, gross domestic product used as economic growth; L, labor; K, capital; ln, natural logarithm; ECA, Europe and Central Asia; ASM, East South, and Middle-East Asia.

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[1] With the renewable energy generation, about 12.4 % of global energy demand is projected to be reach on by 2023 [8].

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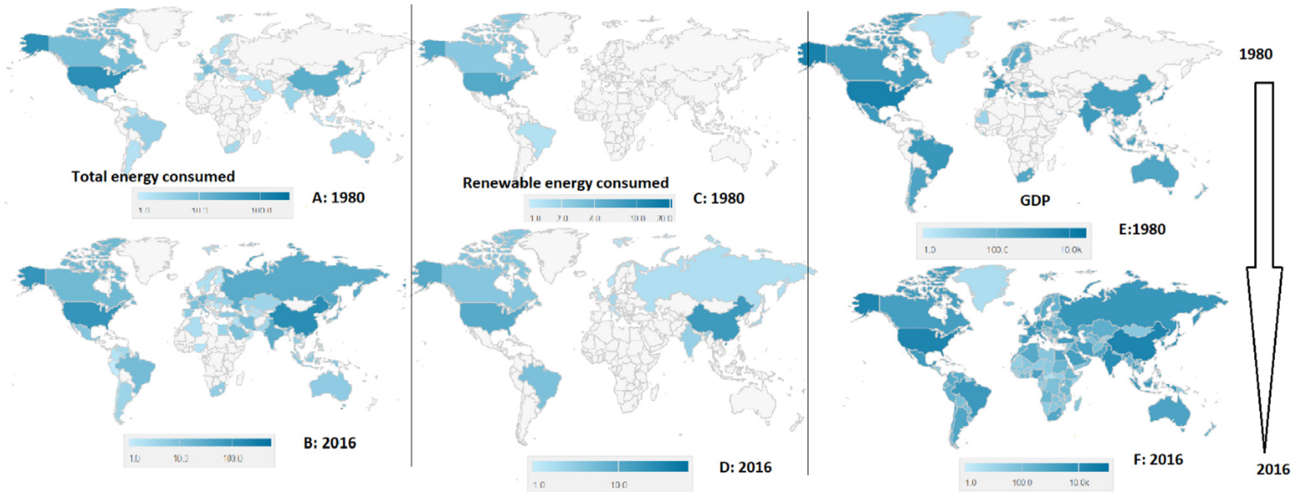

Fig. 1. The increase in total and renewable energy consumption, and GDP at regional levels; A and B are the total energy, C and D are the renewable energy, and E and F are GDP from 1980 to 2016 (data source: EIA [12]).

global increment in GDP and energy consumption is linked to the elevating number of countries moved from low-income to high-income countries, see Fig. 1. By this, it is interesting to investigate whether the increment of energy consumption led to the increase in economic growth with respect to the income groups (low-, lower and middle-, and upper-middle-income countries) at the global and regional levels.

Recently, some studies argued that renewable energy consumption positively affects economic growth at the global and regional levels [13]; in seven Asian countries [14]; in 38 high-income countries [15]; and 17 developed and developing countries [16]. Other studies showed that total energy consumption positively affects economic growth in developed/developing countries, OECD countries [15,17,18]. Furthermore, other studies revealed that total energy and renewable energy consumption negatively affect economic growth, others indicated weak effects and neutral effects in country-specific and multi-country studies that used sampled countries from low and middle-income groups [1,19–21]. In the case of low and middle-income countries, some conclusions confirm that energy consumption disturbs economic plans and targets [22]. As a result, a high number of populations in low and middle-income countries predominantly use wood biomass and fuel fossil, which appeared to positively affect economic growth, although environmental relief degraded due to deforestation and higher CO_2 emissions [23,24]. These consequences raised while several low- and middle-income countries are rich in energy generation, such as non-renewable energy and developing renewable energy systems, thus, this study motivated to examine the effect of the energy sector on the economic sector in these countries.

In fact, some studies confirm that total energy and renewable energy consumption differently affect growth. Ozturk et al. [19] and Huang et al. [25] suggested that total energy and renewable energy uses differently impact economic growth across the globe based on income categories, especially, in low and middle-income countries. Tugcu et al. [26] also argued that the estimated coefficients on energy consumption could differ intensely within two different types of energy uses. In this respect, this study provides evidence of the total energy consumption and the effect of renewable energy consumption on economic growth to offer new policy implications to the energy sector and income generation. Most cross-national studies conducted on this research topic, however, ignored differences across regional variations in the income levels of low and middle-income countries involved in the study. Furthermore, the patterns and changes among total energy, renewable energy use, and economic growth are different across regionals. Responding to these deficiencies, we found that conducting this study across income and regional levels can grasp potential impact for scientific support towards Sustainable Development Goals (SDGs). Grouping countries based on regionals and income levels allow this study to deeply examine the impact of total energy, and renewable energy uses on economic growth across the globe.

Effective policy implications are available for research that focused on the impact of total energy and renewable energy uses on economic growth in high-income countries. This is different from low and middle-income countries, due to the lack of sufficient related studies. Therefore, examining whether the increment of total energy and renewable energy uses led to the significant increase in the economy at the global and regional levels across the income levels, could bring new insight that may lead to new development plans in the low- and middle-income countries. In this regard, the aim is that if the total energy causes dynamic changes in economic growth, new policies will be directed to the main inputs of the energy sector, such as linking gained energy and energy markets. On the other hand, if renewable energy use negatively affects economic growth, policymakers ought to set policies that may reflect on the cause-led negative influences and motivate existing and new investors in renewable energy projects according to new policies. This will support green growth policy, which relied on renewable energy uses as a new way of sustainable development [27], OECP countries (OECP, 2011), and UNEP (UNEP, 2011) as well as increasing income generated from the energy sector across regionals and income levels. These measures will be attentionally taken regarding that some energy types, such as non-renewable energy may negatively affect environmental sustainability through emissions [28].

Most of the studies on this topic were merely on the four hypotheses (feedback, growth, conservative and neutral hypotheses) to present the brief relationship between total energy and renewable energy consumption and economic growth. Again, various estimators, such as panel co-integration, panel causality, Panel vector autoregressive, Granger causality, Autoregressive distributed lags (ARDL), and others have been used to examine the energy-growth nexus, see [19,20,24,29]. Some estimators hardly deal with cross-sectional dependence among the cross-countries studies, such as dynamic ordinary least square (POLS), and fully modified ordinary least square (FMOLS). These estimators are located in the first-generation estimators for panels, which are both relatively simple and clear and able to examine how energy affects economic growth, see [17,30]. However, Hajko [31] and Breitung [32] argued that using these estimators may lead to a misleading conclusion and insufficient information due to the methodological omission and ignore the cross-section dependence effect among the variables. The second-generation estimators, such as the augmented mean group (AMG) developed by Eberhardt and Bond [33]; and the pooled mean group (PMG) estimator of Pesaran et al. [34], allow cross-sectional dependence across countries studies were proposed, however, some of them do not estimate the effect of cross-sectional dependence and lags. These estimators have been used in some studies, such as Salim et al. [35] and Azam [35] used PMG to examine the effect of renewable energy on economic growth in OECD countries.

However, to the best of our knowledge, few cross-national studies on the total-renewable energy-growth nexus do not conduct this research at the global level and regional level coupled with income groups. Moreover, the cross-sectional dependence may exist within cross-national studies on the nexus of total-renewable energy-growth were mostly ignored, which can lead to inconsistent results and misleading information [17,19,36] Responding to these gaps and contribute to the literature, this study aims to examine the impact of total energy and renewable energy on economic growth for a sample of 75 countries at the global level and regional levels across the low-, lower and middle-, and upper-middle-income groups from 1980 to 2016. Given the cross-sectional dependence at the regional levels (subpanels) and global level (panel) concerning income groups; the causality framework containing panel unit root, cointegration, estimation, and causality tests are used in this study. This study used the most recent estimators of panel cross-sectional augmented distributed lags (CS-DL) and common correlated effect means group (CCEMG) proposed by Chudik et al. [37,38], which allows the cross-sectional dependence, lags values, and heterogeneity to affect the variable of interest, and deal with multicollinearities.

Three main points differentiate our study from the existing studies on a similar research topic and add input to filling the gap in the literature. First, considering the differences in different regions, 75 countries are divided into four regions and combined to form a global panel across three income groups (low-, lower and middle-, and upper-middle-income), and thus, the impact of total and renewable energy uses to economic growth are identified across regions and income groups. Second, different from existing studies that used the first-generation estimators, which ignore cross-sectional dependence, this study used the most recent second-generation estimators, which estimate the effect of cross-sectional dependence on the variables of interest and tackle the multicollinearity issues. These estimators can provide a more robust analysis of the causal links between the selected variables. Third, unlike the widely considered short-spanning observations, this study employed large and update observations from the total, renewable energy and economic growth for 1980–2016. This will facilitate policymakers to allocate the long-term impact of total and renewable energy uses on economic growth, and reflect on them accordingly across regions and income levels.

The rest of the study is presented as follows: Section 2 is the literature review. Section 3 is the methodology and data, Section 4 provides the empirical results, discussion, and policy implications, and last Section 5 is the conclusion.

2. Literature review

2.1. Existing studies of total-renewable energy-growth nexus

Concerning the rapidly growing energy consumption (total and renewable), the swelling stream of literature has been conducted to energy consumption effect on economic growth at the country, regional, and global levels, see (Chen et al. [1] for renewable energy use and economic growth, and Mahadevan et al. [36] for energy use and economic growth). Table 1 shows very few studies examined the effect of the total, and renewable energy consumption on economic growth by considering income groups (low-, lower and middle-, and upper-middle-income). These studies mostly test four famous hypotheses, which are: First, the feedback hypothesis (bi-directional causal relationship between total/renewable energy and economic growth); Second, the growth hypothesis (one directed causal relationship from total/renewable energy consumption to economic growth); Third, the conservative hypothesis (one-way directed causal relationship from economic growth to total/renewable energy consumption); and last is the neutrality hypothesis.

Various studies showed that total energy and renewable energy positively affect economic growth and vice-versa when the panel dataset is large and the extremely higher consumed energy, and this occurred in the multi-developed/developing countries [16,30,39,42–44]. Except one study supported feedback hypothesis in middle-income countries [19], others conducted in country-specific, and regional level but considering single and sampled countries from low and middle-income countries showed the neutral effect of the total, renewable energy on economic growth [19,25,45]. Further studies supported conservative and growth hypotheses between total, renewable energy, and economic growth [24,25,40,46,47]. However, very few studies investigated the effect of total and renewable energy on economic growth by considering income groups (low-, lower and middle-, and upper-middle-income countries), with most using a very short period. For instance, Ozturk et al. [19] and Huang et al. [25] showed that energy consumption has a positive effect on economic growth in low- and middle-income countries. Dogan et al. [40] recently showed that renewable energy negatively affects economic growth in middle and upper-income quantiles, and positively affects economic growth in lower and low-income quantiles. Therefore, this study plays a vital role to add input to the literature by examining how the effect of total and renewable energy consumption on economic growth differs across regions and global in low-, lower and middle-, and upper-middle-income groups.

2.2. Existing studies on panel estimation methods

The estimation approaches employed for panel analysis can be divided into two classes: first- and second-generation estimators. The most intensively used methods include fully modified ordinary least squares (FMOLS), dynamic OLS (DOLS), and generalized methods of the moment (GMM). For example; several studies used the first-generation estimators to examine the effect of total and renewable energy on economic growth, see (Bhattacharya et al. [17] in 85 countries, Narayan and Doytch [30] in 89 countries, Ozturk and Bilgili [24] in 51 African countries).c et al. [19] and Huang et al. [25] used FMOLS and DOLS to this research topic by considering income groups. Although the first-generation approaches are both simple and able to show how energy (total and renewable) consumption affects economic growth, they are not potential to the cross-sectional dependence that may occur within cross-countries, and using them can provide inconsistent results or misleading information [32].

Table 1
The summary of recent empirical studies on the impact of total energy consumption (EC) and renewable energy consumption (REC) on economic growth (Y) in low and middle-income countries.

Study	Study type	Country	Period	Methodology	Findings (effect of EC and REC on Y)		
					hypothesis	Effect of EC	Effect of REC
Ozturk et al. (2010) [19]	EC and Y	Low, middle, and upper-middle countries (51)	1971 −2005	panel co-integration and causality	$Y\leftrightarrow EC$ (middle), $Y\rightarrow EC$ (low)	positive	–
Huang et al. (2008) [25]	EC and Y	Low, middle- and high-income countries (82)	1972 −2002	Panel VAR, GMM model	$Y\rightarrow EC$	positive	–
Wolde-Rufael (2005) [20]	EC and Y	9 African countries	1971 −2001	Toda Yamamoto's Granger causality	Mixed results	positive	-
Akinlo (2008) [29]	EC and Y	11 countries in sub-Saharan Africa	1980 −2003	ARDL bounds test	Mixed results	Positive and negative	-
Ozturk and Bilgili (2015) [24]	REC and Y	51 Sub-Sahara African countries	1980 −2009	Panel co-integration, DOLS	$Y\rightarrow REC$	–	positive
Bhattacharya et al. (2017) [17]	REC and Y	85 countries	1991 −2012	System GMM FMOLS	$Y\rightarrow REC$	–	positive
Narayan and Doytch (2017) [30]	REC and Y	89 countries	1971 −2011	GMM methods Fixed effects (FE)	$Y\leftrightarrow EC$	–	positive
Tugcu and Topcu (2018) [39]	EC, REC, and Y	G7 countries	1980 −2014	NARDL and asymmetric causality	Asymmetric & symmetric causation	positive	positive
Salim et al. (2014) [35]	REC and Y	29 OECD countries	1980 −2011	Pooled Mean Group	$Y\leftrightarrow REC$	–	Positive and negative
Dogan et al. [40]	REC and Y	OECD countries	1990 −2010	FE-OLS	-	–	Positive and negative
Pala [41]	EC and Y	G20 countries	1990 −2016	FMOLS and DOLS	$Y\leftrightarrow EC$	positive	–

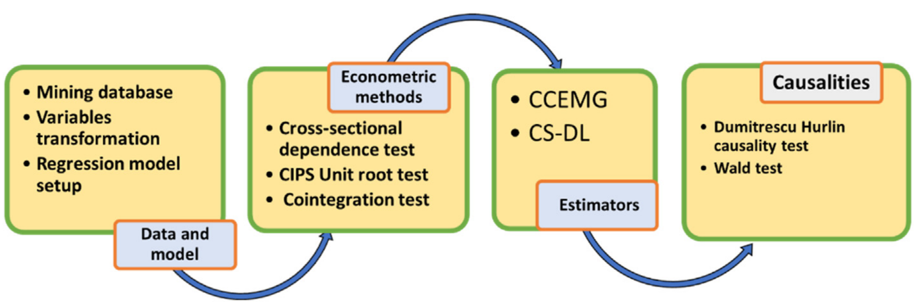

Fig. 2. Methodological flowchart.

The second-generation estimators have been developed to overcome the limitations of the first-generation estimators. Some of them are common correlated effects mean group (CCEMG) proposed by Pesaran [48], advanced by Kapetania et al. [49]; the augmented mean group (AMG) developed by Eberhardt and Bond [33]; and the pooled mean group (PMG) estimator of Pesaran et al. [34], which allow cross-sectional dependence across country studies. These estimators have been used in some studies, such as Salim et al. [35] and Azam [35] used CCEMG and PMG to examine the effect of renewable energy on economic growth in OECD countries. However, this study used the most recent estimators of panel cross-sectional augmented distributed lags (CS-DL) and CCEMG proposed by Chudik et al. [37,38]. These estimators allow the presence of lagged values of the endogenous and exogenous regressors in the panel data model to estimate the long-run relationship and potential to detect cross-sectional dependence and heterogeneity among the selected variables.

3. Methodology and data

This section shows the brief introduction of the data, mathematical model, cross-sectional dependence tests, CIPS panel unit root test, Westurland cointegration test, CS-DL and CCEMG estimators, and causality test, see Fig. 2 for the methodological flowchart.

3.1. Data

To examine the impact of total energy and renewable energy consumption on economic growth at the regional levels and global level in the low-, lower and middle, and upper-middle-income countries (see the list in the appendix Table A); the panel data mined from The World Bank database and U.S Energy Information Administration database (EIA) [12] have employed. The total energy consumption and renewable energy consumption measured in Quadrillion Btu[2] and transferred into kg of oil equivalent per capita, GDP (in constant 2010 U S. dollars) used as economic growth from 1980 to 2016 period. Labor and capital (in constant 2010 U S. dollars) have been used as control variables. The selected variables have been transferred to per capita units by dividing the yearly total population, and then apply the natural logarithm to achieve a

[2] British thermal Units.

Table 2
Descriptive statistics.

Regions		LI			LMI			UMI		
		lnGDP	lnEC	lnREC	lnGDP	lnEC	lnREC	lnGDP	lnEC	lnREC
Africa	Mean	2.672	1.604	0.948	3.233	2.478	1.262	3.752	2.927	1.052
	Median	2.666	1.599	0.934	3.207	2.446	1.229	3.827	2.985	1.270
	Maximum	3.278	2.371	1.752	3.683	3.174	2.219	4.312	3.453	2.322
	Minimum	2.215	0.959	−0.071	2.84	1.474	−0.356	2.695	1.846	−36.70
	Observations	380	380	380	380	380	380	152	152	152
Europe and Central Asia	Mean	–	–	–	2.789	2.913	2.762	3.671	3.167	2.200
	Median	–	–	–	2.813	2.924	2.779	3.671	3.141	2.207
	Maximum	–	–	–	3.010	3.112	2.886	4.172	3.612	2.793
	Minimum	–	–	–	2.564	2.800	2.633	3.094	2.722	0.280
	Observations	–	–	–	26	26	26	114	114	114
East, South and Middle-east Asia	Mean	–	–	–	3.175	3.212	2.000	3.483	2.960	1.437
	Median	–	–	–	3.208	3.171	1.823	3.510	2.992	1.448
	Maximum	–	–	–	3.521	3.647	2.821	4.069	3.461	2.433
	Minimum	–	–	–	2.728	2.969	1.097	2.540	2.296	−0.185
	Observations	–	–	–	104	104	104	228	228	228
North- Central-South America	Mean	–	–	–	3.251	2.535	1.826	3.709	3.002	2.125
	Median	–	–	–	3.217	2.520	1.806	3.672	2.997	2.168
	Maximum	–	–	–	3.536	2.888	2.192	4.078	3.361	3.257
	Minimum	–	–	–	3.021	2.273	1.321	3.305	2.293	1.058
	Observations	–		–	152	152	152	380	380	380
Global panels	Mean	2.810	1.923	1.154	3.131	2.409	1.407	3.653	2.999	1.769
	Median	2.742	1.733	1.100	3.165	2.424	1.542	3.647	3.004	1.983
	Maximum	3.601	3.422	3.283	3.683	3.422	3.283	4.312	3.612	3.257
	Minimum	2.215	0.922	−0.099	2.272	0.922	−0.356	2.540	1.846	−36.70
	Observations	722	722	722	874	874	874	874	874	874

LI: low income, LMI: lower and middle-income, UMI: upper-middle-income.

robust analysis. Descriptive statistics of all selected variables are presented in Table .2.

3.2. Mathematical model

In this study, we are interested to examine the impact of total energy, and renewable energy consumption on economic growth. To effectively examine the impact of total and renewable energy, existing input variables of the production function, such as labor and capital are used as control variables, and then for the country i in income group j at the time t , y_{ijt} is given by the following mathematical equation:

$$y_{ijt} = f\left(L_{ijt}, K_{ijt}, EC_{ijt}, REC_{ijt}\right) \tag{1}$$

For $i = 1, 2, \ldots N$ represent the country, $j = 1, 2, 3$ income group, $t = 1, 2, \ldots T$ time, y_{ijt} is the economic growth, EC_{ijt} is total energy consumption, REC_{ijt} is renewable energy consumption, L_{ijt} is labor, and K_{ijt} is the capital. Therefore, the multivariate mathematical equation can be written as follow:

$$y_{ijt} = \alpha_{0ij} + \alpha_{1ij}EC_{ijt} + \alpha_{2ij}REC_{ijt} + \alpha_{3ij}L_{ijt} + \alpha_{4ij}K_{ijt} + u_{it} \tag{2}$$

For α_{0ij} is the unobserved country fixed effect, $\alpha_1 -\ \alpha_4$ are the long-run equilibrium coefficients, and u_{it} error term.

3.3. Econometric methods

3.3.1. Cross-sectional dependence tests

Goldin [50] suggested that cross-sectional dependence is a critical issue to be concerned within panel data, and would lead to inconsistent estimates and misleading information when it is ignored. In this case, Pesaran [51] proposed Pesaran CD and standardized Lagrange Multiplier (LM) tests, and Breusch and Pagan [52] proposed also Breusch-Pagan LM test for initially detecting cross-sectional dependence in panel data. The standardized test proposed by Pasaran is potential for large panel data size N and time T, and can be estimated as follows:

$$LM = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T_{ij}\mu_{ij}^2 - 1\right) \rightarrow N(0,1) \tag{3}$$

$$CD = \sqrt{2/N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\mu_{ij}^2 \rightarrow N(0,1) \tag{4}$$

Where equation (3) used for large size and changeable time T, and equation (4) used for large N and fixed T, however, the Breusch-pagan LM test is efficient for small size and T, can be estimated as follows:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij}\mu_{ij}^2 \rightarrow \chi^2\left(N(N-1)/2\right) \tag{5}$$

For μ_{ij}^2 is the correlation coefficients obtained from the residuals of the equation (3), can be estimated as follows:

$$\mu_{ij} = \mu_{ji} = \frac{\sum_{t-1}^{T} \varepsilon_{ij}\varepsilon_{ji}}{\left(\sum_{t-1}^{T} \varepsilon_{ij}^2\right)^{\frac{1}{2}} \left(\sum_{t-1}^{T} \varepsilon_{jt}^2\right)^{1/2}} \tag{6}$$

Where ε_{ij} *and* ε_{ji} are standard errors.

3.3.2. Pesaran CIPS unit root test

In the case of panel data, the Pesaran CIPS panel unit root test proposed by Pesaran [53] allows the cross-sectional dependence by considering the averages of lagged levels and differences for each unit. This approach is denoted as cross-sectionally augmented Dickey-Fuller, and can be expressed as follows:

$$\Delta y_{it} = \psi_i + \alpha_i y_{i,\,t-1} + \beta_i \overline{y}_{t-1} + \sum_{j=0}^{p} d_{ij}\Delta\overline{y}_{t-j} + \sum_{j=1}^{p}\xi_{ij}\Delta y_{i,t-j} + u_{it} \tag{7}$$

For $\overline{y}_{t-1}$ and $\Delta\overline{y}_{t-j}$ are the cross-sectional averages of lagged levels, and the first difference, respectively. The cross-sectionally augmented Dickey-Fuller (CADF) statistics used to estimate the CIPS statistic in the following expression:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF_i \tag{8}$$

3.3.3. Panel cointegration test

In this study, we used the error correction panel cointegration test proposed by Westerlund [54]. This approach is effective for cross-sectional dependence by applying an error correction term (ECT), and it is expressed as follows:

$$\Delta z_{it} = \alpha_i' d_i + \vartheta_i\left(z_{i(t-1)} + \pi_i' y_{i(t-1)}\right) + \sum_{j=1}^{m}\varphi_{ij}\Delta z_{i(t-1)} + \sum_{j=0}^{m}\phi_{ij}\Delta y_{i(t-1)} + \omega_{it} \tag{9}$$

For ϑ_i is the adjustment term, d_i is a vector of deterministic components, while other parameters introduce the nuisance in the variable of interest. Therefore, referred to the estimates of ϑ_i, the statistics of Westerlund ECT based panel cointegration tests can be determined as follows:

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\vartheta_i}{SE\left(\vartheta_i'\right)} \tag{10}$$

$$G_\alpha = \frac{1}{N}\sum_{i=1}^{N}\frac{T\vartheta_i}{\vartheta_i'(1)} \tag{11}$$

where G_τ and G_α are group mean statistics, and judges the null hypothesis, which states that there is no presence of cointegration in the cross-sectional panel. The rejection of this hypothesis implies the presence of cointegration for at least one cross-sectional unit in the panel. On the other hand, the panel statistic can be calculated as follows:

$$P_\tau = \frac{\widehat{\vartheta}_i}{SE\left(\widehat{\vartheta}_i\right)} \tag{12}$$

$$P_\alpha = T\widehat{\vartheta}_i \tag{13}$$

The rejection of the null hypothesis implies no cointegration for the whole panel.

3.3.4. Panel cross-sectional augmented distributed lags (CS-DL)

Due to this study uses panel data, which are mostly suspected to have the cross-sectional dependence across countries, the panel CS-DL test proposed by Chudik et al. [37] and CCEMG proposed by Pesaran [48] and extended by Chudik et al. [38], allow the possible cross-sectional dependence have employed. CCEMG can be estimated in equation (14) and CS-DL in (16), respectively, and written as follow:

$$y_{it} = \alpha_i + \sum_{l=0}^{p}\beta_{il}y_{it-l} + \sum_{l=0}^{q}\delta_{il}x_{it-l} + \sum_{l=0}^{Z}\mu_{il}\overline{z}_{it-l} + u_{it} \tag{14}$$

Where $\overline{z}_t = (\overline{y}_t,\, \overline{x}_t)'$, $\overline{y}_t = n^{-1}\sum_i^N y_t$ and $\overline{x}_t = n^{-1}\sum_i^N x_t$, for (p, q, z) are the lags (l).

The long-rung coefficients can be estimated in this equation:

$$\widehat{\theta}_{cs-DL} = \frac{\sum_{l=0}^{q}\widehat{\delta}_{il}}{1-\sum_{l=1}^{p}\widehat{\beta}_{il}} \tag{15}$$

$$y_{it} = \alpha_i + \beta_i y_{it-1} + \delta_{0i}x_{it} + \delta_{1i}x_{it-1} + \sum_{l=0}^{PT}\sigma_{il}'\overline{z}_{it-l} + u_{it} \tag{16}$$

For $i = 1, 2, \ldots, N$, and $\overline{z}_t = N^{-1}\sum_{i=1}^{N} z_{it} = (\overline{y}_t,\, \overline{x}_t, \overline{f}_t)'$, where β_0 and δ_0 obtained by arithmetic averages of least squares estimators of β_i and δ_{0i} based on the Pesaran [48], and f_t is the unobserved common factor with heterogeneous factor; α_i and u_{it} are intercept and error term, respectively. In the CCEMG estimator, the combinations of the cross-sectional averages of the variable of interest and regressors, which are the observed common effects are employed with coefficients presented in Kapetania et al. [49]. Therefore, the estimated confident interval of each regression coefficient in the model indicates that CS-DL and CCEMG provide similar conclusions. Particularly, CS-DL is sensible to the multicollinearity between the cross-sectional averaged variables and able to drop them out in the estimation process, see [55].

3.3.5. Causality test

The causality test proposed by Dumitrescu Hurlin [56] is used to determine the directional causal relationship among economic growth, total energy, and renewable energy consumption at the regional levels and global level within income groups. This directional causal relation is visible in three ways: Two-way directional causal relations, which runs from one variable to the other, and vice-versa; one-way directional causal, which runs from one variable to the other; and neutral causal relationship between variables. Thus, the causality test expressed as follows:

$$y_{i,t} = \alpha_i + \sum_{h=1}^{H}\delta_i^h y_{i,t-h} + \sum_{h=1}^{H}\beta_i^h x_{i,t-h} + \varepsilon_{it} \tag{17}$$

Where *y and x* are inter-related variables, α is the fixed effect, δ and β are the autoregressive parameter and regression coefficient, respectively, which are different across groups. *H* gives the information on the optimal lag and identical for all cross-sectional units. The hull hypothesis of this test is based on the regression coefficient (slope), and linked with the individual Wald statistics of Granger non-causality averaged across the cross-sectional units, which is written as follows:

$$W_{i,T} = \widehat{\theta}_i' R' Z_i' Z_i\Big)\Big(Z_i' Z_i\Big)\left(Z_i' Z_i\right)^{-1} R'\Big]^{-1} R\widehat{\theta}_i \tag{17a}$$

For more detail about parameters, see [56].

4. Results and discussion

This section presents the results of the energy-growth nexus. The effect of labor and capital on economic growth is used for control. The findings are obtained from cross-sectional dependence

Table 3
Cross-sectional dependence results.

Region	Variable	LI		LMI		UMI	
	Estimate	BLM-1	PLM-2	BLM-1	PLM-2	BLM-1	PLM-2
Africa	lnGDP	786.832*	78.196*	967.973*	97.289*	115.995*	31.752*
	lnREC	626.484*	61.293*	269.230*	23.635*	33.648*	7.981*
	lnEC	428.527*	40.427*	552.428*	53.487*	80.101*	21.391*
	lnL	483.724*	42.831*	573.682*	61.386*	46.172*	32.825*
	lnK	592.563*	58.291*	625.473*	72.963*	51.342*	19.861*
Europe and Central Asian	lnGDP	–	–	113.722*	31.096*	158.521*	44.029*
	lnREC	–	–	12.261***	1.807***	45.220*	11.322*
	lnEC	–	–	36.820*	8.897*	69.119*	18.221*
	lnL	–	–	31.927*	9.726*	63.977*	15.523*
	lnK	–	–	42.873*	13.391**	59.297*	14.933*
East, South and Middle-east Asia	lnGDP	–	–	1195.080*	136.598*	335.326*	58.483*
	lnREC	–	–	379.900*	40.529*	228.845*	39.042*
	lnEC	–	–	966.927*	109.710*	194.982*	32.860*
	lnL	–	–	539.753*	73.942*	103.871*	27.975*
	lnK	–	–	836.382*	97.396*	146.822*	31.197*
North- Central-South America	lnGDP	–	–	139.397*	38.508*	1010.706*	101.794*
	lnREC	–	–	28.629*	6.532*	607.527*	59.295*
	lnEC	–	–	185.363*	51.777*	711.518*	70.257*
	lnL	–	–	46.820*	9.899*	79.229*	15.341*
	lnK	–	–	65.291*	46.737*	682.224*	72.982*
Global panel	lnGDP	4081.411*	211.450*	6546.710*	279.789*	5854.104*	248.999*
	lnREC	2195.809*	109.489*	1956.211*	75.716*	2910.860*	118.156*
	lnEC	2606.662*	131.705*	5021.234*	211.973*	3761.877*	155.677*
	lnL	1818.274*	172.840*	2185.931*	271.850*	2976.911*	143.362*
	lnK	3297.382*	149.692*	3831.822*	229.284*	3199.283*	139.881*

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, -: no results due to few observations, BLM-1: Breusch LM, and PLM-2: Pesaran LM.

tests, panel unit tests, Westurland cointegration, CS-ARDL, and CCEMG estimators, and causalities at regional and global levels across the low-, lower and middle-, and upper-middle-income.

4.1. Cross-sectional dependence results

Table 3 presents the results from Breusch LM [52] and Pesaran LM [51] cross-sectional dependence tests. From this table, except where there is an absence of observations, the null hypothesis of no cross-sectional independence is rejected at a 1 % significance level for all selected variables, and indicating the presence of cross-sectional dependence in regional levels and global level within all three income groups. By knowing this, very recent methods, which consider cross-sectional dependence have been prioritized to analyze the relationship between selected variables at the regional levels and global level across the low-, lower and middle-, and upper-middle-income countries. In this case, the Pesaran CIPS panel unit root test has been used to examine the stationarity and integration levels of all selected variables.

4.2. The CIPS pesaran panel unit root test results

Table 4 presents the results from the CIPS panel unit root test by ignoring and considering cross-sectional dependence in the panel. From this table, except when there are no observations, the null hypothesis of the unit root is rejected for all selected variables at the first difference at regional levels and global level in three income groups of countries. This indicates that all the selected variables are integrated on the first order, I (1) of integration; implies that the appropriate approach to examine whether there is a long-run equilibrium relationship among variables is the error-correction term-based panel cointegration tests proposed by Westerlund [54].

4.3. Westurland ECM cointegration results

Table 5 shows the results from the Westerlund panel cointegration test [54] for the regional levels and global level across the low-, lower and middle-, and upper-middle-income countries. In the case of regional levels, except the African region where the null hypothesis of no cointegration is failed to be rejected in low-income, other regions do not present observations; Westerlund test statistics confirmed the long-run cointegration relationships among the selected variables in all regions across lower and middle- and upper-middle-income groups. In the case of the global level, except in the low-income group, the cointegration test confirms the long-run relationship among the selected variables in lower and middle- and upper-middle-income groups.

These findings imply the presence of a long-run equilibrium causal relationship of total energy and renewable energy consumption on economic growth within the regional levels and global level in lower and middle- and upper-middle-income countries over 1980–2016. The presence of a panel cointegration causal link among selected variables assists the prior aim of this study and allows us to examine the effects of total energy and renewable energy consumption on economic growth at regional and global levels across the income groups.

4.4. CS-DL and CCEMG estimators results

After the presence of cross-sectional dependence, panel unit root, and cointegration tests; the next step is to estimate the long-run relationship between economic growth and total energy and renewable energy consumption at regional and global levels across the three income groups. Tables 6 and 7 present the long-run equilibrium coefficients between economic growth and total and renewable energy, obtained from CS-DL and CCEMG estimators. From these tables, the African region has presented observations in the low-income group, while other regions do not present enough observations. The results are volatile across the income groups,

Table 4
CIPS Pesaran Unit root test results at the first difference.

Region	Variable	LI		LMI		UMI	
		ICSD	CCSD	ICSD	CCSD	ICSD	CCSD
Africa	lnGDP	−3.274*	−3.117*	−2.881**	−2.975**	−3.065*	−2.736***
	lnREC	−3.551*	−3.850**	−3.067**	−2.769***	−3.992*	−4.734*
	lnEC	−1.529	−2.927**	−2.278*	−3.736*	−2.381**	−3.750*
	lnL	−3.349*	−3.923**	−3.964**	−4.760***	−4.178*	−4.982*
	lnK	−3.233*	−3.226*	−3.891**	−3.970**	−4.068*	−4.733*
Europe and Central Asian	lnGDP	–	–	−2.651***	−2.671***	−3.705*	−3.804*
	lnREC	–	–	−3.374*	−3.354*	−4.719*	−4.652*
	lnEC	–	–	−3.797*	−3.637*	−4.835*	−3.778*
	lnL			−3.652***	−3.644***	−5.729*	−4.814*
	lnK			−3.249*	−3.992*	−4.925*	−4.778*
East, South and Middle-east Asia	lnGDP	–	–	−5.640*	−4.221*	−4.060*	−4.019*
	lnREC	–	–	−5.921*	−5.435*	−4.072*	−4.147*
	lnEC	–	–	−4.043*	−3.533*	−6.827*	−6.890*
	lnL			−4.991*	−4.919*	−4.922*	−4.652*
	lnK			−4.197*	−4.522*	−6.924*	−6.119*
North- Central-South America	lnGDP	–	–	−3.620*	−3.845*	−3.550*	−3.468*
	lnREC	–	–	−4.598*	−4.628*	−4.214*	−4.210*
	lnEC	–	–	−4.629*	−4.722*	−4.136*	−4.179*
	lnL			−4.639*	−4.865*	−4.643*	−5.442*
	lnK			−4.762*	−5.328*	−5.211*	−5.082*
Global panel	lnGDP	−3.910*	−3.882*	−3.648*	−3.703*	−3.762*	−3.672*
	lnREC	−4.263*	−4.222*	−4.394*	−4.419*	−5.380*	−4.441*
	lnEC	−4.404*	−4.426*	−4.407*	−4.393*	−4.266*	−4.223*
	lnL	−4.752*	−4.955**	−4.971**	−4.653***	−4.979*	−4.862*
	lnK	−4.211*	−4.292*	−4.842**	−4.978**	−4.982*	−4.672*

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, CCSD: consider cross-sectional dependence, and ICSD: ignore cross-sectional dependence, -: no results due to insufficient observations.

Table 5
Westurland ECM cointegration results.

Region	LI				LMI				UMI			
	Gτ	Gα	Pτ	Pα	Gτ	Gα	Pτ	Pα	Gτ	Gα	Pτ	Pα
Africa	−1.468	−3.305	−3.050	−3.349	−2.523	−9.637**	−6.981**	−10.240**	−2.349	−7.662**	0.058	0.150
ECA	–	–	–	–	−1.632	−5.431	−4.784	−4.142	−3.423**	−7.449**	−6.216**	−2.973
ASM	–	–	–	–	−1.250	−2.971	−3.059**	−1.846	−2.573***	−9.514**	−3.185	−6.359**
America	–	–	–	–	−3.434*	−13.707**	−5.670**	−13.320**	−1.901	−6.951**	−5.422	−6.229**
Global	−1.787	−5.792	−6.238	−5.780	−2.236	−8.370**	−9.149**	−8.303***	−2.212***	−7.558**	−2.581**	−2.588

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, -: no results due to insufficient observations, ECA: Europe and central Asia, ASM: Asia (East, South, and middle-East), and America: North, Central, and South America.

Table 6
CS-DL estimates.

Dependent: ln GDP												
Regional	LI				LMI				UMI			
	lnREC	lnEC	lnL	lnK	lnREC	lnEC	lnL	lnK	lnREC	lnEC	lnL	lnK
Africa	0.320**	0.230*	0.223*	0.421*	−0.080***	0.398*	0.281*	0.492*	0.065	0.915*	0.319**	0.429*
ECA	–	–	–	–	−0.058***	0.245	0.529*	0.374*	0.036**	0.647*	0.186*	0.513*
ASM	–	–	–	–	0.022	0.747*	0.331*	0.192*	−0.032	0.308*	0.297**	0.369*
America	–	–	–	–	0.005	0.807***	0.511*	0.471*	−0.033	0.522*	0.388*	0.421*
Global panel	0.029	0.417*	0.472*	0.519*	0.043**	0.291*	0.619*	0.817*	0.056**	0.645*	0.462*	0.573*

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, -: no results due to insufficient observations, ECA: Europe and central Asia, ASM: Asia (East, South, and middle-East), and America: North, Central, and South American regions.

production function, energy proxy at the global and regional levels. These findings seem to be different from those reported in other studies that used a short spanning and ignore effect in various regions, see Ozturk et al. [19] and Huang et al. [25]. On the other hand, labor and capital significantly and positively affect economic growth at regional and global levels across the income groups.

In the case of regional levels (Table 6), using the CS-DL estimator; total energy and renewable energy consumption significantly and positively affects economic growth in low-income for the case of the African region. In the lower and middle-income, renewable energy significantly and negatively affects growth in the ECA and Africa regions; and positive effect in ASM and America regions, which is significant in the America region. The total energy positively affects growth in both ECA, ASM, and American regions; this effect is significant in both the ASM region and American regions. In upper-middle-income countries, total energy and renewable energy significantly and positively affect growth in ECA; total energy significantly and positively affects growth, while

Table 7
CCEMG estimates.

Dependent: ln GDP												
Regional	LI				LMI				UMI			
	lnREC	lnEC	lnL	lnK	lnREC	lnEC	lnL	lnK	lnREC	lnEC	lnL	lnK
Africa	0.094**	0.346*	0.216*	0.328*	−0.103***	0.515*	0.331*	0.481*	−0.022	0.490*	0.482*	0.539*
ECA	–	–	–	–	−0.077**	0.293	0.316*	0.296*	0.043**	0.926*	0.824*	0.626*
ASM	–	–	–	–	0.019	0.587*	0.483*	0.447*	−0.042	0.389*	0.772*	0.581*
America	–	–	–	–	0.089**	0.225	0.532*	0.621*	−0.024	0.413*	0.582*	0.622*
Global panel	0.035	0.326*	0.381*	0.497*	0.048**	0.519*	0.573*	0.598*	0.062**	0.510*	0.938*	0.739*

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, -: no results due to insufficient observations, ECA: Europe and central Asia, ASM: Asia (East, South, and middle-East), and America: North, Central, and South American regions.

renewable negatively affects growth in ASM and American regions. These results are consistent with those reported by Apergis et al. [57,58] in South America and Vidyarthis [59] in South Asia, By using CCEMG for the case of regional levels (Table 7); total energy and renewable energy significantly and positively affects growth, in the low-income group, and also, total energy significantly and positively affects growth, and renewable energy significantly and negatively affect growth in the lower and middle-income group in the African region. In ECA regions, renewable energy negatively affects growth, while total energy positively affects growth. In the ASM region, both total and renewable energy positively affects growth, with significant for total energy; and renewable energy significantly and positively affects growth, with insignificant effect for total energy in American regions in the lower and middle-income group. This negative effect of renewable energy on growth may be described by the possible inequality between investment and renewable energy production among countries. These findings are similar to those reported by Ozturk and Bilgili [24] for positive effects from renewable energy to growth in 51-African countries, and Dogan et al. [40] for OECD countries.

In the upper-middle-income group, renewable energy negatively affects growth, while total energy significantly and positively affects growth in the African region; total and renewable energy significantly and positively affect growth in the ECA region; and total energy significantly and positively affects growth, while renewable negatively affects growth in ASM and American regions. These findings from CCEMG are consistent with those reported by Salim et al. [35] in 29 OECD countries by using similar estimators, even though this study used very recent estimators.

Lastly, in the case of global level, except in low-income group, where renewable energy is insignificantly and positively affects economic growth; total energy and renewable energy significantly and positively affect growth in all income groups. These findings are consistent with Adams et al. [58] showed that renewable energy positively contributes to economic growth in 30 African countries, and Ozturk et al. [19] and Huang et al. [25] for 51- and 82-low and middle-income countries, respectively.

4.5. Causality results

Table 8 shows the causality test results, which confirm four hypotheses tested between economic growth and total and renewable energy consumption at regional and global levels. In the case of regional levels, the neutral hypothesis is noted between renewable and growth, and the bidirectional causal link is noted between economic growth and total energy in low-income; one-way directional caul relationship is noted between renewable energy and total energy and economic growth, which is running from energy consumption to economic growth in the lower and middle-income group; and conservative hypothesis is noted between total and renewable energy and economic growth, which is running from economic growth to energy consumption in the African

Table 8
Causalities and hypotheses.

Region	variables	LI		LMI		UMI	
		Statistic	hypothesis	Statistic	Hypothesis	Statistic	Hypothesis
Africa	*GDP→REC*	1.437	N	0.409	N	3.604**	C
	REC→GDP	1.372	N	2.519***	G	0.949	N
	GDP→EC	7.146*	Feedback	0.594	N	13.224*	C
	EC→GDP	3.175**		8.229*	G	0.761	N
Europe and Central Asia	GDP→REC	4.969**	Feedback	1.736	N	0.437	N
	REC→GDP	5.003**		2.473***	G	0.119	N
	GDP→EC	1.412	N	0.817	N	5.381*	Feedback
	EC→GDP	9.577*	G	0.370	N	3.772**	
Asia (East, South, and middle-East)	GDP→REC	–	–	1.736	N	0.863	N
	REC→GDP	–	–	2.473**	G	4.934*	G
	GDP→EC	–	–	0.817	N	0.753	N
	EC→GDP	–	–	0.3706	N	3.913**	G
America (North, central and south)	GDP→REC	–	–	2.939***	C	1.130***	C
	REC→GDP	–	–	2.104	N	0.246	N
	GDP→EC	–	–	2.939***	Feedback	1.786***	C
	EC→GDP	–	–	3.559**		0.147	N
Global panel	GDP→REC	0.789	N	1.754***	C	1.266	N
	REC→GDP	7.721*	G	0.308	N	5.130	G
	GDP→EC	1.640	N	7.087*	Feedback	19.713*	C
	EC→GDP	14.122*	G	4.324*		1.781	N

*, **, and *** indicate significance level at 1 %, 5 %, and 10 %, respectively, G: growth hypothesis, C: conservative hypothesis, N: neutral hypothesis, and feedback: bi-directional hypothesis.

region. These findings are consistent with those reported by Ozturk and Bilgili [24], and Akinlo [29], which noted the bidirectional and unidirectional causations between renewable energy and total energy and economic growth in African countries.

In the case of Europe and Central Asia region, the bidirectional causal relationship is noted between renewable energy and economic growth, the one-way directional causal link is noted between total energy and economic growth, which is running from energy to growth in the low-income group; the unidirectional causal link between renewable energy and growth, which is running from renewable energy to economic growth in lower and middle-income; and a bidirectional causal relationship is noted between total energy and growth in upper-middle-income. These results are similar to those obtained by Narayan and Doytch [30] in 89 countries, Tugcu and Topcu [39] in G7 countries, Ntanos et al. [60] for 25 European countries, and [47].

In the case of East, South, and middle-East Asia regions, the unidirectional causal link is noted between renewable energy and growth, which is running from renewable energy to growth, while a neutral hypothesis is noted between total energy and growth in lower and middle-income; and the one-way directional causal link is noted between growth and renewable and total energy, which is running from energy to economic growth in the upper-middle-income group. On the other hand, for the case of the American region, the bidirectional causal link is noted between total energy and growth, while unidirectional causal is noted between growth to renewable energy, which is running from growth to energy in lower and middle-income; and the unidirectional causal link is noted between total and renewable energy and growth, which is running from growth to energy in upper and middle-income countries. These results are consistent with Omri et al. [16] in developing and developed countries, Rahman et al. [14] for South Asia, Zafar et al. [61] for 16 Asia-Pacific countries, which have noted bi-directional, neutral, and unidirectional causations between renewable and total energy and economic growth.

Lastly, in the case of global level, the unidirectional causal relationship is noted between total and renewable energy and growth, which is running from energy to growth in low-income countries; the bidirectional relationship is noted between total energy and growth, while the unidirectional causal link is noted between renewable energy and growth, which is running from growth to renewable energy in lower and middle-income countries; and unidirectional causation is noted between growth and total and renewable energy, which is running from renewable to growth and from growth to the total energy. These findings are similar to those reported by Ozturk et al. [19] and Huang et al. [25], which confirmed that energy consumption positively affects growth in low and middle-income groups. Furthermore, the findings show that the coefficients of total and renewable energy are irregularly distributed in regional levels across the income groups; this implies the irregularly effect of total and renewable energy on economic growth. In contrast, the coefficients are successively increase related to the income groups, which implies that as the total and renewable energy consumption increase, their effects to economic growth relatively increase.

4.6. Robustness analysis check and policy implication

This study examines the effect of total energy and renewable energy on economic growth at regional and global levels across the 75 countries classified in the three income groups (low-, lower and middle-, and upper-middle-income) according to the World Bank classification. The variables, such as labor and capital are used as control variables in the mathematical model. From income groups, some countries grouped in low-income groups from ECA, ASM, and America regions do not present the observations, such GDP, total energy, or renewable energy, have, however, excluded in the analysis.

The empirical findings illustrated in the preceding section can be employed for energy-oriented policy and economic growth analysis across the low-, lower and middle-, and upper-middle-income countries at the global level and regional levels. Besides, comparing the findings of this study with those of recent literature could assist policymakers, investors, and government officials to recognize the historical effect (negative or positive) of total energy and renewable energy consumption on economic growth at the regional levels and global level, with lead to the country-specific view. This may help to establish energy policies and mobilize investors to intensively invest in the energy sector for gaining more income.

The empirical analysis was initiated by examining the levels of the variables (cross-sectional dependence and panel unit root); however, we rejected the null hypothesis of no cross-sectional dependence at 1 % of significance level at regional levels and global level in all three income groups, see (Table 3). Again, we reject the null hypothesis of the unit root by ignoring and consider cross-sectional dependence at the first differencing CIPS unit root test at regional and global levels in all income groups, see (Table 4). The null hypothesis of no cointegration was rejected in lower and middle-, and upper-middle-income in the global level and regional levels, and failed to be rejected in the low-income group, see (Table 5).

Our findings from CS-DL and CCEMG estimators for regional levels and global levels are shown in Tables 6 and 7 These estimators provide the robustness analysis, which leads to similar conclusions even though the effect degree in terms of coefficients is different. At the regional levels, renewable energy negatively affects growth in some regions in lower and middle-income countries (Africa and ECA in lower and middle-income, and ASM and America in upper-middle-income), while total energy positively affects growth in all income groups. On the other hand, total energy and renewable energy consumption positively affect economic growth at the global level. These findings are consistent with those reported by Ozturk et al. [19] and Huang et al. [25] in low-lower and middle-, and upper-middle-income countries. Although in some regions, total and renewable positively affect growth, coefficients for total energy are bigger than those for renewable energy; implies that the effect from total energy is higher than that from renewable energy on economic growth. Furthermore, our results are mixed in the regional levels, which indicates that the effect of total and renewable vary irregularly, while at the global level, the effects successively increase relative to the income groups. On the other hand, labor and capital contribute to economic growth at regional and global levels in all income groups.

Based on the findings of Table 8 and Fig. 3, the brief representation of the causal link between growth and total and renewable energy in regional levels in low-, lower and middle-, and upper-middle-income groups are mixed; while they are strategically presented at the global level across the level of income groups.

Based on the findings, this study suggests some policy implications not only focused on the relationship between energy and economic growth but also increased energy production. One main implication is that renewable energy use in all income groups should be addressed as a prior input in income generation for motivating private investors to intensively invest in the energy sector. The effect that total energy consumption has on growth can differ concerning the economic growth function as well as energy proxy. Although all countries need to concentrate on renewable energy for moving forward to reach higher income as well as increasing total energy generation, low-income and lower and

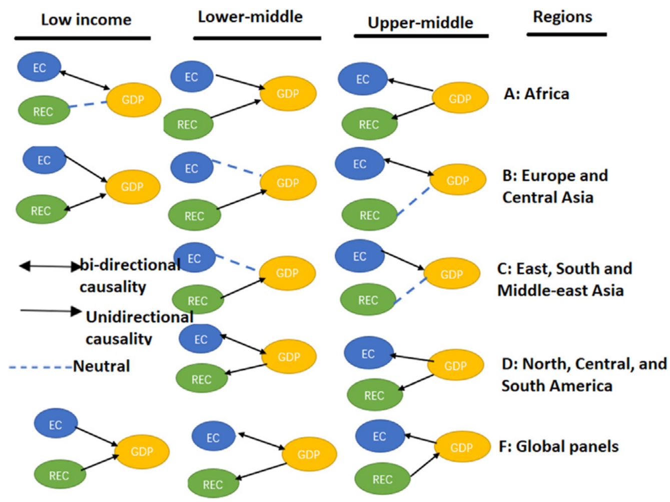

Fig. 3. Graphical representation of hypotheses tested.

middle-income countries should establish efficacy policies in which renewable energy will positively affect economic growth. Therefore, policymakers need to reflect on cause-led negative effects from renewable energy use to economic growth, motivate investors to intensive investment in renewable energy in the low, lower and middle-income countries to increase global energy satisfaction as well as increase growth; the energy market liberation and energy policies may also be established in those countries.

5. Conclusion

Existing studies that examined the total and renewable energy-growth nexus in low and middle-income countries, few of them considered the global level, however, this study aims to investigate the effect of total energy and renewable energy consumption on economic growth at regional and global levels across the low-, lower and middle-, and upper-middle-income groups.

The cross-sectional augmented Autoregressive distributed lagged (CS-DL) and common correlation error means group (CCEMG) have employed and using data from 1980 to 2016 in 75 countries. The findings reveal that in the regional levels, total energy consumption positively affects growth in the considered income groups, while renewable energy negatively affects growth in some regions in lower and middle-income countries (Africa and European and Central Asia in lower and middle-income, and Asia South and Middle-east and America in upper-middle-income). At the global level, total energy and renewable energy consumption positively affect economic growth. Besides, the feedback hypothesis is noted between total energy consumption and economic growth in African and European and Central Asia regions in low-income, in the American region, and global level in lower and middle-income and in European and Central Asia in upper-middle-income. One-way directional causal (growth and conservative hypotheses) is noted between total, and renewable energy and economic growth at the regional and global levels. Furthermore, the neutral hypothesis between total and renewable energy and economic growth is highly supported. Based on findings, this study suggested policy implications, which could boost economic growth in the countries involved in the study. The next study will evaluate the energy policy implementations to meet the Sustainable Development Goals (SDGs) at the global level and regional levels.

Declaration of competing interest

The authors declare that there is no conflict of interest and approve the submission to your reverence journal.

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Appendix

Table A
List of Countries

Regions	Low income	Lower and middle income	Upper middle income
Africa	Burundi, Rwanda, DRC, Cote d' Ivoire, Mali, Sudan, Uganda, Chad, Niger, Madagascar, Malawi	Nigeria, Algeria, Egypt, Marocco, Tunisia, Ghana, Kenya, Senegal, Zimbabwe, Tanzania	Botswana, Gabon, Equatorial Guinea, Namibia, South Africa, Libya
Europe and Central Asia	Tajikistan	Kyrgyz Republic, Moldova, Ukraine, Uzbekistan	Albania, Armenia, Azerbaijan, Bulgaria, Bosnia, Belarus, Georgia, Russia, Turkey, Kazakistan
America	—	Bolvia, El Salvador, Honduras, Nicaragua	Algentine, Belive, Brazil, Colombia, Cuba, Ecuador, Mexico, Jamaica, Peru, Paraguay
East, South, Middle East Asia		Bangladesh, Bhutan, India, Sri Lanka, Nepal, Pakistan, Philippines, Myanmar (Burma), Mongolia, Vietnam	China, Fiji, Indonesia, Malaysia, Iraq, Jordan, Thailand, Lebannon, Maldives,

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