ENERGY CONSUMPTION AND ECONOMIC GROWTH LINKAGE: GLOBAL EVIDENCE FROM SYMMETRIC AND ASYMMETRIC SIMULATIONS

Wajid Ali [1], Solomon Prince Nathaniel [2,3], Ibrahim Ayoade Adekunle[4], Bezon Kumar [5,6]

[1] Department of Economics, University of Perugia, Italy
[2] Department of Economics, University of Lagos, Nigeria
[3] Lagos State University, School of Foundation, Badagry, Nigeria
[4] Babcock Business School, Babcock University, Ogun State, Nigeria
[5] Department of Economics, Rabindra University, Bangladesh
[6] BK School of Research, Shahjadpur, Sirajganj-6770, Bangladesh

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Abstract: The literature reveals that linear models do not accurately represent the asymmetric relationship between economic growth and energy consumption (EC). To fill this gap, we examined the asymmetric relationship between EC and economic growth in a non-linear panel autoregressive distributed lag (ARDL) framework of 85 countries as a whole sample and of Brazil, Russia, India, China, and South Africa (BRICS), the Next Eleven, Big Four in Western Europe, Asia-Pacific region, Group of Seven, South Asian Association for Regional Cooperation (SAARC), Economic Cooperation Organization (ECO) and the Arab League as a sub-sample analysis from 1977 to 2014. A second generational unit root test has been applied to check the problem of cross-sectional dependency. Asymmetric co-integration was employed to analyse the co-integration between the variables of interest. Long-run and short-run estimates have been calculated using the non-linear panel ARDL method. Results indicate that positive shocks to energy use tend to have a growth-enhancing effect in ECO and the Next Eleven while in the rest of the regions, the effect is growth contraction. Moreover, economic recovery from a positive shock to energy use is the case in the Arab League, Asia-Pacific region, Group of Seven and in the whole sample. However, a negative shock to EC is observed in the Group of Seven, Asia Pacific region, Big Four in Western Europe and ECO, and the whole sample worsens the economic contraction. We can deduct from this study's results that information on the asymmetric relationship between the subject variables is needed to design sound economic policy decisions across different economic regions.

Keywords: energy consumption, economic growth, NARDL, co-integration

JEL Codes: C33, O44, O50, Q43w

Corresponding author: Wajid Ali, Department of Economics, Universita degli Studi di Perugia Economics, Piazza dell'Università, 1, 06123 Perugia PG, Italy; e-mail: wajidkhan2272@gmail.com

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Introduction

A plethora of work has been done across geography and it is high time we examined the relationship between economic growth and energy consumption (EC). Although comprehensive studies on the phenomena have been done using linear regression, they failed to account for the data's hidden cointegrating properties, which lead to spurious, unreliable and myopic outcomes. This empirical irregularity has culminated in the misalignment of energy policies with growth and development objectives almost undesirable. Past studies investigating energy use and economic growth through conventional econometric methods had their own limitations. This paper applies the recent non-linear autoregressive distributed lag (ARDL) procedure of Pesaran (2014) to illuminate and clarify an essential concept that has remained unclear for a long time. This paper examines the asymmetric relationship between energy use and economic growth using panel data for all the countries where data is available as a whole sample and in Brazil, Russia, India, China, and South Africa (BRICS), the Next Eleven, Big Four in Western Europe, Asia-Pacific region, Group of Seven, and South Asian Association for Regional Cooperation (SAARC) region as a sub-sample analysis. The previous studies, in particular, are country-specific, which utilised the non-linear ARDL methodology and/or non-linear co-integration in time-series (Shin et al. 2014; Bayramoglu, Yildirim 2017; Ndoricimpa 2017; Tugcu, Topcu 2018). We specifically use the Pooled Mean Group (PMG) estimator of the dynamic heterogeneous panel (Pesaran et al. 1999) to account for heterogeneity related to country-specific effects of energy use on economic growth but in a non-linear way. Short-run and long-run coefficients of PMG estimates respectively vary across cross-sections in the short run and are constrained to be the same in the long run. Though Huang et al. (2008) believe that EC and economic growth are related only in the long run, Ouedraogo (2013) maintains that it may lead to a false conclusion if we test only the long-run relationship between the two. Therefore, the examination of the dynamic relationship between the two is a must.

We considered precisely 85 countries in this study. However, they are not represented geographically. Therefore, we believe a separate analysis for BRICS, the Next Eleven, Big Four in Western Europe, Asia-Pacific region, Group of Seven and SAARC region as a sub-sample analysis will produce outcomes most inclined to the development objectives of each region. To the best of our knowledge, studies in this field used linear panel data methods to examine the subject relationship. Some panel data studies are conducted on a similar subject in African countries while utilising non-linear threshold models, non-linear Granger causality tests, and panel smooth transition vector error correction models (Huang et al. 2008; Omay et al. 2014). Nonetheless, these studies did not account for asymmetries by decomposing energy use and economic growth in their positive or negative components. Moreover, the framework of threshold models does not consider asymmetries and/or shocks; therefore, the econometric method we choose for this study deals with all the limitations and can produce more meaningful results that can rejuvenate policies towards the realisation of growth and development objectives.

To test for co-integration between the positive and negative energy use components and economic growth, we used the newly developed hidden panel co-integration test of Hatemi-J (2018). This test can be considered an equivalent to Shin et al.'s (2014) hidden co-integration test on time series. There are several advantages of using Hatemi-J's (2018) test. To name a few, it can test for hidden co-integration in a panel data framework and separate the variables in the equations for the positive and negative components to test for the presence of co-integration.

There is a conflicting set of findings on nature, direction, magnitude, and the drivers of economic growth in the context of energy use and economic growth nexus in the literature. These varying results can be attributed to various sets of specifications/explanatory variables and estimation techniques. The examination of modelling and estimation techniques applied in these studies clearly indicates that much of the literature ignores the asymmetries in interest variables. Economic series adapt to different regimes such as financial crises and unexpected changes in economic policy. This analysis has severe implications for the individual economies in general and the group of economies in particular.

Review of literature

EC and economic growth have been a topical issue for the past three decades holding to the increasing energy demand and economic expansion in many developed and developing economies. However, the relationship between both variables has yielded mixed and controversial results. There is still no consensus on which drives which. As a result, four known hypotheses (growth hypothesis, conservation hypothesis, feedback hypothesis, and neutrality hypothesis) have been tested in previous studies. The growth hypothesis posits that EC drives economic growth, while the conservation hypothesis assumes the opposite. The feedback hypothesis argues for bidirectional causality between both variables, unlike the neutrality hypothesis, suggesting no causality between both. Numerous studies (Bayat et al. 2017; Fotourehchi 2017; Hasanov et al. 2017; Lechthaler 2017; Obradovic, Lojanica 2017; Atems, Hotaling 2018; Kumari, Sharma 2018) discovered that EC drives economic growth which is in line with the growth hypothesis mentioned earlier. These studies emphasised the vital role of EC in manufacturing and other production processes, which led to the creation of goods for local consumption and exportation, and hence economic growth. However, the studies mentioned above did not bother much about reverse causality. Studies (like Burakov, Freidin 2017; Kyophilavong et al. 2017; Tatlı 2017; Chen, Fang 2018; Kirikkaleli et al. 2018; Nyasha et al. 2018; Rahman, Velayutham 2020) were able to show that economic growth is capable of increasing EC. This is in line with the conservation hypothesis. According to these studies, economic growth necessitates more energy demand for home appliances, factory machines, waste management, etc. Now, it is also possible that the direction of causality is mutual. That is, EC drives economic growth, and vice versa. This was the major argument of Lin and Wang (2019) for China, Saad and Taleb (2018) for the EU countries, Bazarcheh Shabestari (2018) for Sweden, Zafar et al. (2019) for Asia countries, and Hasan et al. (2017) for Bangladesh. Moreover, Bah and Azam (2017) have a case for the neutrality hypothesis in South Africa.

Besides, most of the existing studies have explored the relationship between both variables within a linear framework (see, for instance, Gozgor 2018; Gozgor et al. 2018; Mensah et al. 2019; Wang et al. 2019; Zafar et al. 2019; Ali et al. 2020; Le et al. 2020). There are a few studies that examined a similar relationship, but within a non-linear framework via various techniques, such as non-linear models (Baz et al. 2019; Awodumi, Adewuyi 2020; Ghosh, Kanjilal 2020; Munir et al. 2020), a panel threshold model (Chen et al. 2020; Wang, Wang 2020) and quantile regression (Shahbaz et al. 2018; Zhou et al. 2019).

Munir et al. (2020) explored the direction of non-linear causality between economic growth and ASEAN countries' EC from 1980 to 2016. They discovered a unidirectional causality from economic growth to EC in Malaysia, Thailand, and Indonesia; unidirectional causality from EC to economic growth in Singapore, and feedback causality between the Philippines' variables. Ivanovski et al. (2020) investigated the impact of renewable and non-renewable energy on OECD (Organisation of Economic Co-operation and Development) countries' economic growth from 1990 to 2015 via a nonparametric method. Their findings reveal that the latter has no adverse effect on economic growth. Also, both energy sources advance economic growth in non-OECD countries. The authors reiterated the need for the transition to renewables to consolidate growth and uphold environmental sustainability. Awodumi and Adewuyi (2020) examined the effect of EC on economic growth and emissions for oil-exporting countries in Africa from 1980 to 2015. Their findings suggest that EC exacts an asymmetric impact on both economic growth and CO_2 emissions. However, the response of both variables to an increase in EC was mixed. Chen et al. (2020) applied a threshold model to examine the link between EC and economic growth for 103 countries from 1995 to 2015. They reported that EC had no significant/positive effect on growth in developed/OECD countries, respectively. However, the consumption of energy above/below a certain threshold will have a significant positive/negative effect on developing countries' growth.

Ali et al. (2020) examined the impact of EC and urbanisation on Nigeria's economic growth after considering structural breaks. The FMOLS (fully modified ordinary least square) and DOLS (dynamic ordinary least square) results confirmed that EC added to economic growth, while urbanisation inhibited growth in Nigeria. Further findings revealed a one-way causality from urbanisation to economic growth and EC. This contradicts Nathaniel and Bekun's (2020) earlier study which discovered no direction of causality; supporting the neutrality hypothesis, for Nigeria, Wang and Wang (2020) investigated the non-linear effect of EC on the OECD countries' economic growth. They discovered that EC has a positive effect on economic growth. Nonetheless, this positive impact changes at different threshold levels.

In summary, the relationship between EC and economic growth remains inconclusive with discrepancies in findings emanating from regional differences, peculiarities about countries, estimation techniques, and choice of variables. The majority of existing studies assumed a linear relationship between both, but recent studies have focused on nonlinearity because most economic variables do not exhibit a linear relationship. This study adds to this argument by examining the relationship between both variables in a non-linear framework for different blocs, regions, and organisations.

Materials and methods

Data

Two different variables (real GDP per capita and EC) are used in this study. The time period, consistent with data availability, spans 1971 to 2014. This study has been carried out for BRICS, Next Eleven countries, the Economic Cooperation Organization (ECO), the Big Four in Western Europe, Asia-Pacific region, Group of Seven, Arab League, SAARC region, and World sample. EC is measured in kg of oil equivalent per capita, while real GDP per capita, our proxy for economic growth, is measured in constant 2010 USD. The data for both variables were obtained from the World Development Indicator (WDI 2020). These two variables are widely used in the energy-economic growth literature (see Ali et al. 2020; Meo et al. 2021; Nathaniel 2020). In all, 836 observations were used for conducting the relevant analysis. See Table A1 in Appendix for the list of countries adopted in this study.

Methods

The globalisation of the world's economy has promoted interconnectivity and the transfer of shocks from one economy to another. Therefore, interdependence among countries is possible. The study proceeds with Pesaran's (2004) cross-sectional dependence (CD) test. The CD test is of utmost importance to ensure unbiased estimates and estimator efficiency. We further applied the Im-Pesaran-Shin (CIPS) test to ascertain the stationarity properties of the variables. The CIPS test is robust amidst CD. Once variables are stationary, a co-integration test is required to ascertain the possibility of a long-run relationship. In this study, the Westerlund (2007) test investigates the presence of co-integration among the variables. Just like the CIPS test, the Westerlund (2007) test is also robust amidst CD and performs better than the traditional first-generation co-integration tests, including the Kao and Chiang (1999) and Pedroni (2000) co-integration tests.

Unlike most previous studies, we examine the asymmetric impact of EC on economic growth (GR) via the non-linear autoregressive distributive lag (NARDL) model. The primary model for this study is given as:

$$GR_t = \varphi_0 + \varphi_1(EC_t) + \mu_t \tag{1}$$

The NARDL model of Shin et al. (2014) can estimate short and long-run dynamics even when the sample size is small (Pesaran et al. 2001; Narayan, Narayan 2005; Meo et al. 2020). The non-linear form of the model is given as:

$$GR_t = \varphi_0 + \varphi_1(EC_t^+) + \varphi_2(EC_t^-) \tag{2}$$

where φ_0, φ_1 and φ_2 are the long-run parameters. The asymmetric effects of EC are incorporated by positive change EC_t^+ and negative changes EC_t^- respectively, whereas EC_t^+ and EC_t^- are the partial sums of positive and negative changes in EC, respectively. Now, to obtain the short-run effect, Eq. (1) can be re-specified as:

$$\Delta GR_t = \textstyle\sum_{k=1}^{m} \theta_{1k}\Delta GR_{t-k} + \sum_{k=1}^{m} \theta_{2k}\Delta EC_{t-k} + \partial_1 GR_{t-1} + \partial_1 EC_{t-1} + \mu_t \tag{3}$$

Eq. (3) is the specification that encompasses both long-run and short-run coefficients. Δ is the short-run coefficient while ∂_1 and ∂_2 are the long-run coefficients. We specify Eq. (4) to derive the asymmetric cointegrating.

$$\gamma_t = \beta^+ x_t^+ + \beta^- x_t^- + \mu_t \quad (4)$$

where x_t are the long term parameters of $kx1$ vector of regressors decomposed as

$$x_t = x_t^+ + x_t^- \quad (5)$$

where x_t^+ and x_t^- are the explanatory variables, decomposed into a partial sum of positive and negative changes. Eqs. (6) and (7) are the partial sums of positive and negative changes in EC.

$$EC^+ = \sum_{i=1}^{t} \Delta EC_i^+ = \sum_{i=1}^{t} \min(\Delta EC_i, 0) \quad (6)$$

$$EC^- = \sum_{i=1}^{t} \Delta EC_i^- = \sum_{i=1}^{t} \min(\Delta EC_i, 0) \quad (7)$$

Replacing EC in Eq. (3) by EC^+ and EC^- gives us the asymmetric ARDL model:

$$\Delta GR_t = \partial_0 + \sum_{k=1}^{m} \phi_k \Delta GR_{t-k} + \sum_{k=1}^{m} \phi_k \Delta EC_{t-k}^+ + \sum_{k=1}^{m} \phi_k \Delta EC_{t-k}^- + \partial_1 GR_{t-1} + \partial_2 EC_{t-1}^+ + \partial_3 EC_{t-1}^- + \mu_t \quad (8)$$

From Eq. (8), the long-run impact of both positive and negative changes in EC are $-\partial_2 / \partial_1$ and $-\partial_3 / \partial_1$. One huge advantage of the NARDL technique is in its ability to accommodate variables with various levels of stationarity whether I (0) or I (1) or I (0) and I (1)

Results and discussions

The descriptive statistics of the regressors used in the NARDL model of this paper have been presented in Table 1 with mean, standard deviation, minimum, maximum, and coefficient of variation.

In Table 1, we report the summary statistics that contain the mean (averages), observations, standard deviation, the minimum (Min) values as well as their maximums (Max). In our joint sample analysis, the coefficient of variation measures the heterogeneity of regressors. With a large coefficient of variation in the whole sample, we established the heterogeneity of regressors with GDP per capita having the more severe sample variances than energy use.

Across the sample period, the averages across varying samples were considered within the study. In the whole model, the averages for energy use are large compared to GDP per capita averages. Apart from the fact that this statistical revelation points to ample energy use among the sample frame, the structural properties of data permit drawing credible inferences in a broad regional specific categorisation but not without controlling for the heterogeneity of regressors (Lewbel 2012). Across the BRICS, Next Eleven, Big Four in Western Europe, Asia-Pacific region, Group of Seven, and SAARC region economic classifications, the heterogeneity of regressors seems relatively weak and the averages of energy use seem predominate their large variances arrangement. Nonetheless, the Arab League shows heterogeneity well above the whole sample, and this implies its heterogeneity properties are greater than those observed in the entire sample. With the data extensive and fraught with the heterogeneity of regressors across samples and a pointer to nonlinearities among regressors, we proceed to test for common factor restrictions leading to the verification of the presence of cross-sectional dependence.

The regional EC pattern and their growth-inducing strategies are almost identical with notable variances (Ahmed, Wahid 2011). These homogenous growth stabilisation approaches, induced by varying EC, ensure that economic indices are fraught with interdependence among cross-sections. It then becomes imperative to test for CD and consider controlling such disturbances to reach conclusions that are non-spurious (Pesaran 2015). We tried the null of no CD using the Pesaran (2004) CD test. In Table 2, Pesaran (2004) confirms the existence of CD with probability values <1%. The presence of CD calls for estimation procedures that control such disturbances. We proceed to estimate the second-generation panel stationarity test of CIPS of Pesaran (2004) because of its high-level precisions and capacity to control CD in panel data econometrics. In consonance with Phillips and Sul (2003), we followed this path to avert spurious outcomes when CD is not controlled.

Beyond the descriptive revelation of heteroskedasticity and nonlinear properties among the regressors, it becomes apt and imperative to adopt the leading stationarity test to set a clear

Table 1. Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max	Coef of variation
Whole sample						
GDPG	3,431	1.715	4.945	−64.99	53.97	2.88
EU	3,431	2,130.886	2,369.316	99.71	18,178.141	0.011
BRICS						
GDPG	114	6.823461	3.996938	−7.3881	13.63833	0.585
EU	114	842.0321	559.7145	279.380	2,236.730	0.664
Next Eleven						
GDPG	418	2.49	4.55	−30.18	22.12	1.82
EU	418	958.1	930.15	99.70	5,248.5	0.97
ECO						
GDPG	114	1.40	6.05	−30.18	22.14	4.32
EU	114	1,064.1	680.6	302.54	2,889.10	0.63
Big Four in Western Europe						
GDPG	152	1.66	1.78	−5.46	5.87	1.07
EU	152	4,053.8	341.3	3,172.8	4,658.3	0.048
Asia-Pacific region						
GDPG	570	3.47	3.47	−14.35	13.64	1
EU	570	944.23	1,122.8	99.71	4,083.8	1.189
Group of Seven						
GDPG	266	1.66	2.10	−7.94	6.33	1.26
EU	266	4,770.7	1,970.9	2,203.8	8,455.5	0.41
Arab League						
GDPG	418	1.148	5.10	−25.61	11.83	4.44
EU	418	1,811.7	1,903.7	235.18	6,871.8	1.05
SAARC region						
GDPG	190	3.01	2.35	−7.39	9	0.78
EU	190	334.7	119.6	99.71	636.5	0.35

BRICS – Brazil, Russia, India, China, and South Africa; ECO – Economic Cooperation Organization; SAARC – South Asian Association for Regional Cooperation; GDPG – GDP growth ; Obs – Observations.
Source: own elaboration.

Table 2. CD test results (Pesaran's test 2004).

Variables	CD-test	*P*-value	Average joint T	Mean Ï	Mean abs (Ï)
GDP growth per capita	21.417	0.000	37.95	0.06	0.18
Energy use	102.57	0.000	37.95	0.27	0.54

Notes: Under the null hypothesis of cross-sectional independence, CD ~ N (0, 1) *P*-values close to zero indicate data are correlated across panel groups.
CD – cross-sectional dependence.
Source: own elaboration.

Table 3. Unit root test results in the presence of cross-section dependence (Pesaran's test 2007).

Variables	Level				First difference			
	CIPS (−1)	CIPS (−2)	CIPS (−3)	Critical value (5%)	CIPS (−1)	CIPS (−2)	CIPS (−3)	Critical value (5%)
No intercept no trend								
GDP growth	−1.231	−3.761	−3.774	−1.52	−5.963	−5.935	−5.934	−1.52
Energy use	−1.134	−1.267	−1.268	−1.52	−5.097	−4.940	−4.883	−1.52
Only intercept								
GDP growth	−1.107	−4.107	−4.107	−2.08	−5.977	−5.977	−5.977	−2.08
Energy use	−1.606	−1.606	−1.606	−2.08	−5.272	−5.272	−5.272	−2.08
Linear trend								
GDP growth	−2.48	−4.470	−4.453	−2.56	−6.206	−6.161	−6.181	−2.65
Energy use	−1.836	−1.936	−1.893	−2.56	−5.537	−5.461	−5.410	−2.65

Notes: H0 (homogeneous non-stationary): bi = 0 for all i.
Source: own elaboration.

line of thought on the stationarity characteristics of the data set to reach non-spurious, policy and theory consistent empirical outcomes. Using the cross-sectionally augmented IPS test of Pesaran (2007) that considers CD when estimating its series, we found impressive stationarity outcomes. Table 3 reports the second generation panel stationarity test from the CIPS test of Pesaran (2007). We found regressors to be stationary at first difference across all the series I (1). These empirical outcomes establish an apparent need to uncover the covariance characteristics of the data. We proceed to estimate the Durbin-Hausman co-integration (Westerlund 2007) test to establish long-run cointegrating relations because of its relative sensitivity to CD.

We prefer the Westerlund (2007) co-integration test to the Pedroni (1999) test due to its relative sensitivity to CD and slope homogeneity of regressors. Westerlund (2007) produces consistent estimates under the mild assumption. Since it disregards lag information about integrating series orders, it is widely applicable in a broader context. By permitting spatial correlation of

Table 4. Panel co-integration test (Westerlund's test 2007).

	Statistics	Model with intercept			Model with trend		
		Value	Z-value	P-value	Value	Z-value	P-value
BRICS	Gt	−4.369	−4.997	0.000	−4.010	−3.504	0.000
	Ga	−23.489	−5. 201	0.000	−24.688	−3.229	0.001
	Pt	−6.332	−3.847	0.000	−5.953	−2.623	0.004
	Pa	−22.190	−7.007	0.000	−22.953	−3.961	0.000
Next Eleven	Gt	−1.728	0.183	0.573	−2.421	−0.222	0.412
	Ga	−4.998	1.307	0.904	−7.746	2.081	0.981
	Pt	−0.595	4.231	1.000	−4.915	2.391	0.992
	Pa	−0.242	2.980	0.999	−2.942	3.241	0.999
ECO	Gt	−0.243	2.959	0.999	−2.033	0.710	0.761
	Ga	−1.599	1.764	0.961	−3.251	2.231	0.987
	Pt	0.770	3.297	1.000	−1.724	2.213	0.987
	Pa	0.587	1.879	0.970	−2.306	1.872	0.969
Big Four in Western Europe	Gt	−2.295	−1.152	0.125	−2.696	−0.812	0.208
	Ga	−12.127	−1.832	0.034	−11.706	0.090	0.536
	Pt	0.697	3.613	1.000	−3.092	1.295	0.902
	Pa	0.828	2.279	0.989	−3.719	1.701	0.956
Asia-Pacific region	Gt	−2.365	−2.530	0.006	−2.421	−0.261	0.397
	Ga	−12.430	−3.762	0.000	−13.242	−0.701	0.242
	Pt	−9.287	−3.702	0.000	−8.028	0.176	0.570
	Pa	−11.345	−6.207	0.000	−11.655	−1.720	0.043
Group of Seven	Gt	−2.633	−2.520	0.006	−2.831	−1.513	0.065
	Ga	−13.333	−3.009	0.001	−12.795	−0.305	0.380
	Pt	−2.293	1.546	0.939	−3.871	1.964	0.975
	Pa	−3.147	0.646	0.741	−4.877	1.750	0.960
Arab League	Gt	−1.629	0.548	0.708	−1.777	2.405	0.992
	Ga	−100.936	−57.145	0.000	−67.851	−27.235	0.000
	Pt	−2.223	2.593	0.995	−1.630	6.147	1.000
	Pa	−1.901	1.740	0.959	−1.806	3.855	1.000
SAARC region	Gt	−2.532	−1.877	0.030	−2.579	−0.584	0.280
	Ga	−14.997	−3.226	0.001	−13.943	−0.635	0.263
	Pt	−5.671	−2.448	0.007	−4.531	0.220	0.587
	Pa	−15.506	−5.679	0.000	−14.606	−2.069	0.019
World sample	Gt	−2.715	−1.807	0.035	−2.331	0.077	0.530
	Ga	−9.223	−0.662	0.254	−9.136	0.733	0.768
	Pt	−2.751	−0.245	0.403	−2.054	1.835	0.967
	Pa	−2.694	0.599	0.726	−4.068	1.374	0.915

BRICS – Brazil, Russia, India, China, and South Africa; ECO – Economic Cooperation Organization; SAARC – South Asian Association for Regional Cooperation.
Source: own elaboration.

CD, the Westerlund (2007) test controls for unobserved heterogeneity of regressors that characterises panel data estimation. To reach meaningful outcomes in the presence of cross-section dependence issues, the Westerlund (2007) test computes P-values robustly based on bootstrap iterations. Through the error correction component, cointegrating properties are revealed in the individual sample and across samples. Westerlund (2008) went further by computing the nullity and otherwise of the cross-section unit using the weighted averages and associative t-stats.

Further evidence is sought into the cointegrating properties when the Westerlund (2007) tests establish the nullity of co-integration across panels by pooling the estimates in a comprehensive panel framework. The result presented in Table 4 shows that variables in different samples do not tend towards their long-run equilibrating position even when CD exists. Our result is robust at a 1% level of significance. We proceed to estimate the asymmetric co-integration in tandem with Hatemi-J's (2020) in Table 5.

The results of no co-integration between energy use and economic growth across the various samples led to the verification of hidden co-integration to reveal the series's negative and positive cointegrating properties of components. Hatemi-J's (2018) test for asymmetric co-integration was employed for this purpose. It revealed (2020) the hidden panel cointegrating properties. The initial analysis presents false outcomes of no co-integration by hidden co-integration, but further examination reveals co-integration between negative and positive components. This hidden composition leading to false cointegrating

Table 5. Asymmetric co-integration results of Hatemi-J's test (2020).

	Variables	Kao test results	
		Im et al. (2003) unit root test results on residuals	Decision regarding residuals
Arab League	Y^+, X^+	−2.4916 (0.0003)	I (0), Stationary
	Y^+, X^-	−2.7552 (0.000)	I (0), Stationary
	Y^-, X^-	−2.7677 (0.000)	I (0), Stationary
	Y^-, X^+	−2.6207 (0.000)	I (0), Stationary
Asia-Pacific region	Y^+, X^+	−2.6571 (0.000)	I (0), Stationary
	Y^+, X^-	−2.9797 (0.000)	I (0), Stationary
	Y^-, X^-	−2.3041 (0.003)	I (0), Stationary
	Y^-, X^+	−2.4447 (0.0001)	I (0), Stationary
Big Four in Western Europe	Y^+, X^+	−4.0673 (0.000)	I (0), Stationary
	Y^+, X^-	−3.2235 (0.000)	I (0), Stationary
	Y^-, X^-	−2.5821 (0.012)	I (0), Stationary
	Y^-, X^+	−2.6298 (0.010)	I (0), Stationary
ECO	Y^+, X^+	−3.5681 (0.0004)	I (0), Stationary
	Y^+, X^-	−2.5875 (0.025)	I (0), Stationary
	Y^-, X^-	−2.8706 (0.013)	I (0), Stationary
	Y^-, X^+	−2.7547 (0.013)	I (0), Stationary
Group of Seven	Y^+, X^+	−3.2938 (0.000)	I (0), Stationary
	Y^+, X^-	−3.3661 (0.000)	I (0), Stationary
	Y^-, X^-	−2.5256 (0.002)	I (0), Stationary
	Y^-, X^+	−2.5917 (0.001)	I (0), Stationary
Next Eleven	Y^+, X^+	−1.9333 (0.081)	I (0), Stationary
	Y^+, X^-	−1.7222 (0.301)	I (0), Stationary at 10%
	Y^-, X^-	−2.0643 (0.021)	I (0), Stationary
	Y^-, X^+	−2.0375 (0.026)	I (0), Stationary
World sample	Y^+, X^+	−2.3252 (0.000)	I (0), Stationary
	Y^+, X^-	−2.6464 (0.000)	I (0), Stationary
	Y^-, X^-	−2.6051 (0.000)	I (0), Stationary
	Y^-, X^+	−2.4566 (0.000)	I (0), Stationary

ECO – Economic Cooperation Organization.
Source: own elaboration.

outcomes could result from unobserved factors in the non-cointegrating relations causing negative and components series to vary differently from idiosyncratic influences. Establishing a clear line of thought on the heterogeneous impact of energy use and economic growth asymmetric relationship informs about the need for this approach. Heterogenous energy pricing, the various institutional setup that moderates policy and content of reforms towards change, trade and export strategies, and so on, influence the output elasticity of the model in a non-linear and different manner. Thus, establishing the asymmetric properties of the model's parameter will produce results that are most inclined to each region's development objectives. Hatemi (2020) assumes the first difference integration test stationary of the series before decomposing regressors into the positive and negative components. It is also important to note that the residual from the series has to be stationary to establish regressors' collinearity. The result in Table 5 reveals nonlinearities in the co-integration relationship between energy use and economic growth for all samples with residuals stationary at the level.

Table 6 presents the linear ARDL result for the model. We relied on the Mean Group estimation procedure because of the high precision and relevance in establishing a clear line of thought on the energy use-growth relations. The convergence term is negative and statistically significant at a 1% level. The convergence terms give the speed of adjustment from long-run tendencies to short-run equilibrating positions. We have found long-run and short-run behavioural movements of the data set in the BRICS and SAARC regions. The Wald test has revealed the asymmetric properties of the model and affirmed no short-run and long-run asymmetric relations. In the search for hidden asymmetric properties of the energy use induced growth model, we proceed to estimate the non-linear ARDL model in consonance with Shin et al. (2014).

To assign numerical weights to the asymmetric relationship between energy use and economic growth within a global analytic framework, we report the non-linear ARDL result in Table 7. Beyond linear relations in the energy use-growth dynamic associations, we rely on the PMG to establish the regressors' independent capacities to predict variations in the response variables. Following Shin et al. (2014), we unravel the energy use-growth dynamic relations' asymmetric properties in an idiosyncratic capacity.

Table 6 rejected the nullity of covariance among economic growth and positive and negative components of energy use. With the Wald test outcomes not statistically significant at any significance threshold, we failed to reject the null of asymmetry in the short run while confirming the presence of asymmetry in the long run across the Arab League, Asia-Pacific region, Big Four in Western Europe, ECO, Group of Seven, Next Eleven and World sample. Across the heterogeneous sample leading to a global framework, the error correction components are appropriately signed (negative) and statistically significant at a 1% level of significance. By intuitions, the convergence from long-run behaviours is gradually adjusted to the short-run equilibrating positions.

Table 6. Linear ARDL results.

ΔY	MG (BRICS)	PMG (SAARC)
ECT	−0.008* (0.043)	−0.0064577 (0.389)
Long-run effect	−0.829* (0.000)	−1.040631* (0.000)
Short run effect	0.054* (0.001)	0.0496974* (0.006)
_cons	4.914* (0.000)	2.895211* (0.000)
Hausman test $H_0 = PMG$ $H_1 = MG$	7.51** (0.0234)	0.21 (0.6462)
Wald test (long-run asymmetry)	1.75 (0.1855)	1.09 (0.2971)
Wald test (short-run asymmetry)	1.26 (0.2616)	0.42 (0.5146)
Log likelihood		−366.9499

Notes: The *P*-values are given [* at 1%, ** at 5%].
ARDL – autoregressive distributed lag; BRICS – Brazil, Russia, India, China, and South Africa; PMG – Pooled Mean Group; SAARC – South Asian Association for Regional Cooperation; ECT – error correction term.
Source: own elaboration.

Table 7. Nonlinear panel ARDL.

Variables	Arab League		Asia-Pacific region		Big Four in Western Europe		ECO	
	ΔY^+	ΔY^-	ΔY^+	ΔY^-	ΔY^+	ΔY^-	ΔY^+	ΔY^-
ECT	−0.585* (0.000)	−0.409* (0.000)	−0.520* (0.000)	−0.455* (0.000)	−0.415* (0.000)	−0.577* (0.000)	−0.260** (0.033)	−0.598 (0.000)
eu_t^+	−0.0080* (0.000)	0.0047* (0.001)	−0.0114 (0.000)	0.014* (0.000)	−0.005** (0.030)	−0.002* (0.992)	0.069 (0.009)	−0.025 (0.012)
eu_t^-	0.003** (0.011)	0.0054* (0.002)	0.0242* (0.000)	−0.028* (0.000)	0.025* (0.000)	−0.011* (0.000)	0.220* (0.001)	−0.065 (0.000)
Δeu_t^+	0.0011 (0.267)	−0.0006 (0.974)	−0.046** (0.052)	0.045** (0.045)	0.001 (0.914)	−0.007 (0.393)	0.036 (0.061)	−0.021 (0.078)
Δeu_t^-	0.952 (0.267)	0.051 (0.242)	0.006 (0.874)	0.001 (0.974)	0.0019 (0.595)	0.028 (0.929)	0.018 (0.490)	0.002 (0.894)
Δeu_{t-1}^+	0.005 (0.703)	−0.006 (0.686)	−0.018 (0.146)	0.018 (0.084)	0.004 (0.318)	−0.002 (0.456)	0.023 (0.166)	−0.020 (0.217)
Δeu_{t-1}^-	−0.103 (0.290)	0.105 (0.269)	0.060 (0.619)	−0.038 (0.689)	−0.002 (0.579)	0.004 (0.238)	−0.012 (0.445)	0.013 (0.424)
Constant	2.328* (0.005)	−6.688 (0.229)	−0.296 (0.862)	−3.550** (0.013)	−1.984 (0.173)	−1.281 (0.368)	3.920 (0.725)	−2.563 (0.783)
Hausman (χ^2) $H_0 = PMG$ $H_1 = MG$	3.17 (0.2054)		1.55 (0.461)		3.56 (0.613)		2.32 (0.192)	
Wald test (long- -run asymmetry)	3.320** (0.0367)		5.69* (0.002)		5.61** (0.020)		7.76* (0.005)	
Wald test (short- -run asymmetry)	0.031 (0.142)		0.29 (0.370)		0.91 (0.213)		0.12 (0.730)	
Log likelihood	−1176.886		−1072.3		−193.7512		−258.049	

Notes: P values are given in [], where eu is energy use; *1%; **5%; ARDL – autoregressive distributed lag; ECO – Economic Cooperation Organization; ECT – error correction term.

Variables	Group of Seven		Next Eleven		World sample	
	ΔY^+	ΔY^-	ΔY^+	ΔY^-	ΔY^+	ΔY^-
ECT	−0.427* (0.000)	−0.5535* (0.000)	−0.458* (0.000)	−0.413* (0.000)	−0.494* (0.000)	−0.446* (0.000)
eu_t^+	−0.006* (0.000)	0.021** (0.036)	0.034* (0.007)	−0.036* (0.000)	−0.001** (0.013)	0.001* (0.003)
eu_t^-	0.021* (0.000)	−0.013* (0.000)	0.440* (0.000)	0.066* (0.000)	0.015* (0.000)	−0.011* (0.000)
Δeu_t^+	−0.061 (0.466)	−0.049 (0.710)	−1.114 (0.264)	1.167 (0.242)	−0.004 (0.577)	0.005 (0.544)
Δeu_t^-	0.026 (0.243)	−0.002 (0.290)	1.337** (0.026)	−1.217** (0.036)	−0.005 (0.480)	0.005 (0.463)
Δeu_{t-1}^+	0.011 (0.992)	−0.009 (0.627)	0.945 (0.257)	−0.955 (0.259)	−0.010 (0.397)	0.011 (0.380)
Δeu_{t-1}^-	−0.001 (0.626)	0.009 (0.396)	−0.339 (0.640)	0.436 (0.556)	−0.003 (0.794)	0.004 (0.747)
Constant	−1.813 (0.075)	−1.394 (0.145)	−296.64* (0.006)	−71.781 (0.121)	1.881744 (0.236)	−5.050* (0.001)
Hausman (χ^2) $H_0 = PMG$ $H_1 = MG$	2.17 (0.250)		2.55 (0.601)		4.17 (0.542)	
Wald test (long-run asymmetry)	4.05** (0.0443)		7.76* (0.005)		5.76** (0.051)	
Wald test (short-run asymmetry)	0.07 (0.7917)		0.12 (0.730)		0.83 (0.305)	
Log likelihood	−284.11		111.42		−3620.302	

P values are given in (), where *eu* is energy use; *1%; **5%.
Source: own elaboration.

The sign and magnitude of the convergence terms established asymmetric properties in the energy use-growth relationship in a broad-based sample. For clarity, positive changes in our response variable ΔY^{+} denote growth expansion while negative changes ΔY^{-} denote growth contraction. Furthermore, positive values of the parameters estimate eu^{+} that are associated with the positive value of the response variables ΔY^{+} imply growth expansion and negative values of parameters eu^{-} associated with positive response variables ΔY^{+} imply economic contractions. Nonetheless, a positive value of parameter estimates eu^{+} with the negative response variable ΔY^{-} implies economic recovery and negative values of parameter eu^{-} estimated in a negative response variable ΔY^{-} imply advance in economic contractions.

The result from Table 7 was analysed based on regional sample categorisation, and the interpretations were presented logically and sequentially. With economic growth expected to

Table 8. The result of Dumitrescu and Hurlin's (2012) panel causality test.

	Null hypothesis	W-stat	Z-bar	P-value	Lag
Arab League	Real GDP per capita does not Granger-cause energy use	3.50237	5.13479	3.E−07	1
	Energy use does not Granger-cause real GDP per capita	1.88856	1.73847	0.0821	1
Asia-Pacific region	Real GDP per capita does not Granger-cause energy use	2.58086	0.74883	0.4540	2
	Energy use does not Granger-cause real GDP per capita	5.58611	5.82965	6.E−09	2
Big Four in Western Europe	Real GDP per capita does not Granger-cause energy use	3.36903	2.92718	0.0034*	1
	Energy use does not Granger-cause real GDP per capita	1.34434	0.35767	0.7206	1
BRICS	Real GDP per capita does not Granger-cause energy use	0.83674	−0.24812	0.8040	1
	Energy use does not Granger-cause real GDP per capita	2.77734	1.88470	0.0595	1
ECO	Real GDP per capita does not Granger-cause energy use	16.2136	16.6519	0.0000*	1
	Energy use does not Granger-cause real GDP per capita	2.49738	1.57701	0.1148	1
Group of Seven	Real GDP per capita does not Granger-cause energy use	10.4306	15.7275	0.0000*	1
	Energy use does not Granger-cause real GDP per capita	2.98822	3.23298	0.0012*	1
Next Eleven	Real GDP per capita does not Granger-cause energy use	4.69690	7.64871	2.E−14	1
	Energy use does not Granger-cause real GDP per capita	5.20540	8.71888	0.0000*	1
SAARC	Real GDP per capita does not Granger-cause energy use	1.02665	−0.05086	0.9594	1
	Energy use does not Granger-cause real GDP per capita	9.77719	12.3651	0.0000*	1
World sample	Real GDP per capita does not Granger-cause energy use	5.74984	26.7688	0.0000*	1
	Energy use does not Granger-cause real GDP per capita	2.23745	6.70996	2.E−11	1

Notes: We computed the probability values using large iterative bootstrap identifications; W-Stat statistic presents the averages from cross-sections of N standard individual Wald statistics of Granger non-causality tests. The Z-bar statistic is a standardised statistic.
BRICS – Brazil, Russia, India, China, and South Africa; ECO – Economic Cooperation Organization; SAARC – South Asian Association for Regional Cooperation.
Source: own elaboration.

react differently to heterogenous positive and negative energy shocks and produce non-linear results that are most inclined to each region's development objective, our result follows a stratified and sample-specific pattern to reach conclusions regionally generalisable. The asymmetric short-run relations are observed for the Arab League, Asia-Pacific region, and Next Eleven. The short-run asymmetric properties in these samples depict energy shocks that could be a result of their extensive energy dependence. There is no observed asymmetric relationship between energy use and growth in the Big Four in Western Europe, ECO, Group of Seven, and World sample with just two of their coefficients significant at established thresholds. Short-run asymmetric relations are a testament to variations in cross-sectional domains that defines a country or regional groupings. The variations in the asymmetric properties across the sample categorisation could result from the heterogeneous level of reliance on energy use by different samples observed in this study.

To establish linearity in reverse causative structure in the energy use-growth relation across varying samples, we reported the Dumitrescu and Hurlin (2012) panel Granger test in Table 8. The Dumitrescu and Hurlin (2012) panel Granger test accounts for the endogeneity of the regressor by computing the probability values of the numerical coefficient matrix. Using a large bootstrap iterative process, we accounted for cross-sections of the country and regional dimensions of the data set. We confirmed stationarity at the first difference before engaging the Panel Causality test in consonance with contemporaneous Granger causality test literature. We rejected the null hypothesis of *Real GDP per capita does not Granger-cause energy use* in the Big Four countries in Western Europe, ECO, Group of Seven and SAARC regions. By rejecting the nullity of the no Granger cause relations in the real GDP-energy use, we established uni-directional causality from real GDP to energy use in the Big Four countries in Western Europe, ECO, Group of Seven, and SAARC regions. In other related but distinct findings, we also rejected the null of *Energy use does not Granger-cause real GDP per capita* in the Group of Seven and SAARC region. This implies that a one-way causality exists from energy use to real GDP per capita in the Group of Seven and SAARC region. In summary, a bilateral causality exists between energy use and real GDP per capita in the Group of Seven.

Conclusion and policy suggestions

This paper investigates the following questions. Is the relationship between economic growth and EC asymmetric? What if we investigate the same connection across a different group of countries? Suppose the relationship between the variables of interest is asymmetric, does it prevail both in the short run and in the long run? Does the impact of EC on economic growth enhance or contract growth across a different group of countries and in the whole sample? These and other relevant questions are answered while examining the impact of EC on economic growth in a non-linear panel ARDL framework.

Using data from 1977 to 2014 for 85 countries (as a whole sample) and seven similar groups of countries, the study first applied the second generational panel unit root test due to cross-sectional dependency. To check for the existence of a long-run relationship between EC and economic growth, Hatemi-J's (2018) test for asymmetric co-integration was employed for this purpose. To determine whether the impact of EC on economic growth is growth-enhancing or growth contracting both in the short run and in the long run, we use the non-linear ARDL model. Using these methods, some interesting results are found.

This paper finds a linear relationship between EC and economic growth in BRICS and SAARC countries while an asymmetric relationship in the rest of the countries, including the whole sample of 85. Furthermore, among those groups of countries where the relationship is asymmetric, we have only found a long-run asymmetry. This confirms the possible impact of changes in EC on economic growth in the short run but not in the long run.

The asymmetric relationship between the subject variables means that the impact of EC on economic growth varies on the phase/state of the economic cycle. In this context, our results suggest that positive shocks on energy use have a positive and significant effect on economic growth only in ECO and the Next Eleven in the periods of economic expansion. This means that in ECO and the Next Eleven groups of countries, a positive shock to energy use is growth-enhancing while in the rest of the group of countries it is growth-contacting. Moreover, the study results suggest that economic recovery is the case in the Arab League, Asia-Pacific region, Group of Seven, and the whole sample. However, a negative shock to EC in the Group of Seven, Asia-Pacific region, Big Four in Western Europe, ECO, and the whole sample worsens the economic contraction. In the short run, the results are mostly insignificant.

Based on the findings, the relationship between economic growth and EC is asymmetric, and this paper suggests adjusting the energy supply and energy demand in a group of countries where a positive shock to energy use is growth-enhancing. Similarly, EC could be encouraged by expanding industrialisation, urbanisation, and transport in countries where a positive shock to EC leads to economic recovery. However, in a group of countries where a positive shock to EC worsens economic growth, EC should be discouraged while encouraging the use of close substitutes of energy, lowering the use of private vehicles, promoting solar and water energy, reducing an excess use of luxurious goods. Although we have tried to carry out this research carefully, there may be some methodological pitfalls. Thus, further research may be carried out to solve these shortcomings.

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W.A and I.A came up with a draft of the introduction S.N and B.K reviewed extant literature on the subject. I.A. and S.N presented the methods and interpretations. W.A concluded and wrote the abstract.

Ethical approval

This manuscript has not been published in whole or elsewhere; the manuscript is not currently being considered for publication in another journal. All authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

Consent to participate

Materials, methods leading to the findings from the study do not require seeking third-party approval from any group or individual (as the case may be).

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Appendix

Table A1. Groupwise list of selected countries for the study.

Group	Countries	Number of countries
BRICS	China, India, Brazil	3
Next Eleven	Indonesia, Pakistan, Bangladesh, Philippines, Vietnam, Egypt, Iran, Turkey, Republic of Korea, Nigeria, Mexico	11
Economic Cooperation Organization	Pakistan, Iran, Turkey	3
Big Four in Western Europe	Germany, France, Italy, United Kingdom	4
Asia-Pacific region	China, India, Indonesia, Pakistan, Bangladesh, Japan, Philippine, Thailand, Myanmar, Malaysia, Nepal, Argentina, Australia, Austria	15
Group of Seven	Japan, Canada, Germany, France, United States, Italy, United Kingdom	7
Arab League	Algeria, Egypt, Saudi Arabia, Sudan, Oman, Morocco, Jordan, Iraq, United Arab Emirates, Syria, Tunisia,	11
SAARC	India, Pakistan, Bangladesh, Nepal, Sri-Lanka	5
World sample	United Arab Emirates, Argentina, Australia, Austria, Belgium, Benin, Bangladesh, Bolivia, Brazil, Canada, Switzerland, Chile, China, Cote d'Ivoire, Cameroon, Democratic Republic of Congo, Republic of Colombia, Costa Rica, Cuba, Cyprus, Germany, Denmark, Dominican Republic, Algeria, Ecuador, Arab Republic of Egypt, Spain, Finland, France, Gabon, United Kingdom, Ghana, Greece, Guatemala, Hong Kong SAR, China, Honduras, Haiti, India, Ireland, Islamic Republic of Iran, Iraq, Iceland, Israel, Italy, Jamaica, Jordan, Japan, Kenya, Republic of Korea, Sri Lanka, Luxembourg, Morocco, Mexico, Malta, Myanmar, Malaysia, Nigeria, Nicaragua, Netherlands, Norway, Nepal, New Zealand, Oman, Pakistan, Panama, Peru, Philippines, Portugal, Paraguay, Saudi Arabia, Sudan, Senegal, Singapore, El Salvador, Sweden, Thailand, Tunisia, Turkey, Uruguay, United States, Zambia.	85

BRICS – Brazil, Russia, India, China, and South Africa; SAARC – South Asian Association for Regional Cooperation.
Source: own elaboration.