www.rericjournal.ait.ac.th

On the Global Energy Consumption and Economic Growth Nexus: a Long Time Span Analysis

Luis Miguel Marques*[1], Jose Alberto Fuinhas*, António Cardoso Marques*

***Abstract* –** There is plenty of research on the energy-growth nexus for individual countries and panels of countries, but none at a global level. For this reason, this paper aims to provide important information for energy policymakers. The global energy consumption and economic growth nexus was analyzed by using an annual time series from 1965 to 2013. An auto-regressive distributed lag (ARDL) approach was followed in the presence of permanent shocks (structural breaks). The ARDL bounds test, as well as both short- and long-run elasticities, was performed. Performing the Johansen co-integration and the Toda and Yamamoto causality testing procedure gives robustness to the results. The results suggest that there is bi-directional causality between energy consumption and growth, both in the short- and long-run. High and positive long-run elasticities were found. Accordingly, conservation policies on energy could reduce economic growth on a worldwide scale. In addition, policies could begin to have a cyclical effect, given that there is bidirectional causality between energy consumption and economic growth.

***Keywords* –** ARDL bounds test, global energy-growth nexus, short- and long-run elasticities, primary energy consumption.

1. INTRODUCTION

The study of the relationship between energy consumption and economic growth has been given extensive attention in the literature. However, it is mainly focused on studies of individual countries and panels of countries. The global nexus, i.e. the energy-growth relationship at a global level, has not been given much attention. Indeed, to the best of our knowledge, there are no studies at this level.

The world is experiencing a period of change in global energy markets. According to BP [1], primary energy consumption will increase 41% between 2012 and 2035. In addition, growth in energy demand will move towards emerging economies. These changes may cause a shift in the set of global policies that are being implemented. Nowadays, achieving universal access to the best and most efficient energy is one of the world's goals. In 2013, more than $1,600 billion was invested worldwide to provide energy and $130 billion to improve energy efficiency [1]. If the amounts spent in energy policies are correlated with world economic growth, there may be bidirectional causality between energy and economic growth. Nevertheless, these effects are not empirically observed in the literature. Given that the energy market is changing, understanding the global nexus can lead to a new insight on energy policies. The similar movements of Crude and Brent prices show the correlation between energy markets. Consequently, energy demand and supply adjustments are being experienced all over the world. The way that these adjustments interact with world growth is not known.

The motivation for this research comes from the need to understand the global nexus. The central question of the study is: Is bi-directional causality present on a global level? And is it stable over time? A causality relationship running from energy to growth is expected due to energy impacts on GDP as a factor in production. Moreover, over a long period of time, cointegration between energy and grow this expected to be found.

This study uses a long time span (from 1965 to 2013), thus lending greater robustness to the econometric analysis. The presence of structural breaks is expected, due to well-known crisis episodes during the period studied. To handle these variables, the ARDL bounds test methodology was used. This approach allows for the use of dummies to accommodate economic shocks and structural breaks, making it possible to capture cointegration.

The results fit into the traditional *feedback hypothesis*, where bi-directional causality between energy and growth is found. Furthermore, the global nexus is an endogenous phenomenon, i.e. energy and growth interact with each other causing an effect of an endogenous adjustment. In addition, the 2008 financial crisis strongly impacted the energy-growth relationship and needed to be controlled.

This paper evolves as follows: Section 2 provides a brief debate of energy-growth nexus literature; Section 3 describes the data, methods and models; Section 4 sets out the results; In Section 5 the robustness of the results is checked; Section 6 discusses the results; and Section 7 states the conclusions.

2. ENERGY - GROWTH NEXUS LITERATURE: AN OVERVIEW

The relationship between energy consumption and economic growth has been studied in literature since the 1970s, when Kraft and Kraft [2] examined this causality relationship for the USA. Nevertheless, the lack of consensus remains. Furthermore, in literature we can find different results for the same country, probably due

*NECE-UBI and Management and Economics Department, University of Beira Interior. R. Marquês de Ávila e Bolama, 6201-001 Covilhã, Portugal.

[1]Corresponding author;
E-mail: luismssmarques@gmail.com.

to the use of different data or methodologies. Both individual countries [3]-[8] and panels of countries [9]-[15] have been studied. However, there is a lack of literature at a global level. Understanding the global nexus could provide a useful tool for the policymakers to handle the increasing number of global energy goals.

In the literature, four types of relationships are identified [16], [17]: (i) the *"neutrality hypothesis"* that asserts that no causality between energy consumption and economic growth is observed; (ii) the *"conservation hypothesis"* that states that there is uni-directional causality from economic growth to energy consumption; (iii) the *"growth hypothesis"* that states that there is uni-directional causality from energy consumption to economic growth; and (iv) the *"feedback hypothesis"* that finds that there is bi-directional causality between energy consumption and economic growth. Recently a different effect of a reversed energy-growth nexus, i.e. a negative relationship between energy and growth, was identified [18]. The empirical knowledge leads us to expect that energy consumption impacts economic growth due to the impact of energy as a factor in production. Nevertheless, no forecast of the effects of growth on energy consumption can be made.

To enhance nexus knowledge, researchers needed to use different methodologies. Four generations of methodologies have been identified over the years [19]: (i) studies based on VAR methodology [20] and Granger causality, assuming stationary [2], [21]; (ii) studies based on non-stationary series and Granger [22] cointegration theory using a correction model to test for causality [23], [24]; (iii) studies using multivariate estimators with more than two variables in the cointegration relationship [25]-[31]; and (iv) studies based on panel cointegration and panel error correction models [32]-[37]. The use of long time span variables is essential, given that this permits the study of both the short- and long-run nexus. To identify cointegration among variables, the use of ARDL bounds test, introduced by Pesaran and Shin [38] and extended by Pesaran, Shin, and Smith [39], is an appropriate methodology. Indeed, the ARDL bounds test allows the use of I (0) and I(1) variables and a diverse number of lags, which makes this technique highly flexible when confronted with different data. In addition, it allows robust results to be obtained, by correcting outliers and structural breaks. In this way, it is possible to develop long-term models to explain the global nexus.

Energy markets have experienced several periods of economic and political turbulence. In particular, there were two periods that could have had a strong impact on the nexus: (i) the 1970s crises with the oil shocks of 1973 and 1979; and (ii) the 2008/2009 financial crisis and the European debt crisis. The 1970s oil shocks affected the growth of well-known industrialized countries. On one hand, these events could have reduced energy consumption thus impacting economic growth. On the other hand, if global economic growth affected global energy consumption, the impacts of the 2008 crisis on the nexus should have been severe. The 2008 financial crisis decreased the capacity of energy markets to fund themselves in capital markets. In addition, strong recessions have been experienced all over the world, which may have had an impact on energy growth. New contributions to nexus literature should focus on new approaches, perspectives and models. The global level is the maximum macroeconomic aggregate level and the nexus at this level remains unexplained.

In nexus literature, three approaches can be pursued: (i) the supply approach, which often includes capital stock and labour, in addition to energy consumption and economic growth [40], [41]; (ii) the demand approach, which adds energy prices to energy consumption and economic growth [35], [42]; and (iii) a neutral approach, which includes bivariate models with energy consumption and economic growth. The use of multivariate models is only preferred when it is not possible to obtain robust bivariate models, or causality is not achieved. Indeed, the introduction of more than two variables will produce results arising from the relationships between all the variables. A good evaluation of the global nexus using a bivariate model will allow new insights into the aforementioned nexus literature.

3. METHODOLOGY

On the long-run, there is expected to be some interaction between global energy consumption and global economic growth. To handle this endogenous phenomenon, the use of an auto-regressive distributed lag (ARDL) model, as in Pesaran, Shin, and Smith [39], is suitable. The recurring use of ARDL models in nexus research is far from new in the literature [43], [18].

3.1 Data

Annual GDP (Y) and primary energy consumption (E) data are used from 1965 to 2013. The variable Y is measured in constant 2005 dollars and its source is the World Bank World Development Indicators. The variable E is measured in tonnes of oil and its source is the BP Statistical Review of World Energy, June 2014. L denotes the natural logarithm and D denotes the first difference operator. Econometric software EViews 9 was used. Summary statistics are presented in Table 1.

Table 1. Descriptive statistics.

	LY	LE	DLY	DLE
Mean	30.9751	22.7495	0.0321	0.0254
Median	31.0232	22.8066	0.0337	0.0249
Maximum	31.6554	23.2673	0.0618	0.0640
Minimum	30.1161	22.0491	-0.0212	-0.0123
Std. Dev.	0.4415	0.32	0.0156	0.0196
Skewness	-0.1942	-0.3488	-0.6908	0.1232
Kurtosis	1.9513	2.3781	4.4406	2.2985
Jarque-Bera	2.5534	1.7831	7.9685	1.1055
Probability	0.279	0.41	0.0186	0.5754
Observations	49	49	48	48

A first appraisal of the variables reveals a strong correlation (0.9946) between LE and LY, as well as between DLY and DLE (0.8566). Despite the presence of high correlation, this does not mean that cointegration exists. To evaluate the cointegration, an ARDL bounds test is performed. For this, the variables must be I(0) or I(1). To analyze the integration order of the variables, we worked on: (i) the graphical analyses of the level variables and their first differences; (ii) the visual examination of the series and their correlograms; (iii) Augmented Dickey-Fuller (ADF), Phillips-Perron (PP); Kwiatkowski–Phillips–Schmidt–Shin (KPSS), and Modified Dickey-Fuller (MDF) tests (Table 2). The latter followed Perron [44], and allowed it to be handled with a single break date.

Table 2. Integration order tests.

	ADF			PP			KPSS		MDF
	a)	b)	c)	a)	b)	c)	a)	b)	d)
LY	-2.9824	-3.5059**	14.0312	-3.7771**	-3.4997**	11.1301	0.1899**	0.9254***	-3.8986
LE	-3.4790*	-3.1743**	8.8723	-3.8178**	-2.5830	6.0813	0.1516**	0.9179***	-4.0847
DLY	-5.3446***	-4.8143***	-2.0650**	-5.2056***	-4.6805***	-1.8436*	0.1020	0.5970**	-6.1244***
DLE	-4.4574***	-4.2601***	-2.5601**	-4.4574***	-4.2601***	-2.5601**	0.1636**	0.3651*	-5.4796***

Notes: a) denotes the test statistic with trend and constant; b) denotes the test statistic with constant; c) denotes the test statistic without tendency and constant; d) for LY denotes the test with trend and intercept and break at the intercept, for LE denotes the test with trend and intercept and break at the intercept, for DLY denotes the test with trend and intercept and break at the intercept, for DLE denotes the test with trend and intercept and break at the trend. ***, ** and * denote statistical significance at 1%, 5% and 10% level, respectively.

The graphical examinations of the variables and their correlograms (not shown to preserve space) suggest that all variables are I(1). The Schwarz criterion is used in the ADF test with a maximum of 9 lags. In the PP test, as well as in the KPSS test, the Bartlett kernel spectral estimation method and Newey-West Bandwidth were used. The null hypothesis rejection of the ADF, PP and MDF tests means that variables are stationary. In contrast, the rejection of the KPSS null hypothesis means that the variables are not stationary. The results of the three tests (see Table 2) indicate that all variables are I(1), or at least near I(1). As a result, the ARDL bounds test is the best choice for test cointegration because it does not impose a restrictive assumption that all variables should have the same integration order. Moreover, the MDF test shows for LY a trend and intercept break in 2007, for DLY a trend and intercept break in 2009, for LE a trend and intercept break in 2009, and for DLE it only shows a trend break in 1981. The possible presence of these structural breaks in the variables were initially expected, given the effects of the 2008 economic and financial crisis. It should be noted that international energy markets need to fund themselves in the capital market to meet their high capital investments. This need may have caused several impacts on the nexus.

3.2 Model

To handle lengthy series and their possible breaks, the ARDL bounds tests approach [38], [39] is performed. The general equations for relating LE and LY are:

$$LY_t = \theta_0 + \theta_1 t + \theta_2 LE_t + \mu_{1t} \quad (1)$$
$$LE_t = \varphi_0 + \varphi_1 t + \varphi_2 LY_t + \mu_{2t} \quad (2)$$

where θ_0 and φ_0 means the intercepts, t the trends, θ_1 and φ_1 the trend coefficients, θ_2 and φ_2 the LE and LY coefficients, respectively, and μ_{1t} and μ_{2t} are the disturbance terms assuming white noise and normal distribution. These equations provide information about long-run elasticities. Furthermore, if there is cointegration then the presence of causality is assured.

Equations (1) and (2) could be converted into their equivalent ARDL, as presented in Equations (3) and (4):

$$LY_t = \gamma_0 + \gamma_1 t + \sum_{i=1}^{k} \gamma_{2i} LY_{t-i} + \sum_{i=0}^{k} \gamma_{3i} LE_{t-i} + \mu_{3t} \quad (3)$$
$$LE_t = \delta_0 + \delta_1 t + \sum_{i=1}^{k} \delta_{2i} LE_{t-i} + \sum_{i=0}^{k} \delta_{3i} LY_{t-i} + \mu_{4t} \quad (4)$$

where, k represents the number of lags defined by empirical knowledge of the variables. If the variables are co integrated, the ARDL could be transformed into an unrestricted error correction model (UECM). Equations (5) and (6) (hereinafter model 1 and model 2, respectively) which represent the general UECM in its equivalent ARDL bounds test:

$$DLY_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{k} \alpha_{2i} DLY_{t-i} + \sum_{i=0}^{k} \alpha_{3i} DLE_{t-i} + \alpha_4 LY_{t-1} + \alpha_5 LE_{t-1} + \mu_{5t}, \quad (5)$$

where the expected parameter signs are $\alpha_0 \neq 0$, $\alpha_1 \neq 0$, $\alpha_{2i} \neq 0$, $\alpha_{3i} \neq 0$, $\alpha_4 < 0$, $\alpha_5 < 0$. The parameters α_{2i}, α_{3i} explain the short-run dynamic coefficients, while α_4, α_5 explain the long-run multipliers.

$$DLE_t = \beta_0 + \beta_1 t + \sum_{i=1}^{k} \beta_{2i} DLE_{t-i} + \sum_{i=0}^{k} \beta_{3i} DLY_{t-i} + \beta_4 LE_{t-1} + \beta_5 LY_{t-1} + \mu_{6t}, \quad (6)$$

where the expected parameter signs are $\beta_0 \neq 0$, $\beta_1 \neq 0$, $\beta_{2i} \neq 0$, $\beta_{3i} \neq 0$, $\beta_4 < 0$, $\beta_5 < 0$. The parameters β_{2i}, β_{3i} explain the short-run dynamic coefficients, while β_4, β_5 explain the long-run multipliers.

A battery of diagnostic tests was performed: (i) Jarque-Bera normality test; (ii) Breusch-Godfrey serial correlation LM test; (iii) ARCH test for heteroskedasticity; (iv) Ramsey RESET test for model specification; and (v) CUSUM and CUSUM of Squares tests for stability. The residuals of models 5 and 6 confirm the need to control for the 2008 crisis period. To do so, the introduction of dummy variables to handle the structural breaks was followed. The ARDL bounds test is robust to the inclusion of dummies [39]. As expected, it was observed that the introduction of shift dummies, from 2009 onwards in model 5 and from 2008 onwards in model 6, is statistically highly significant. The robustness of the results was tested by the Johansen cointegration test and by theToda and Yamamoto [45] causality testing procedure.

4. RESULTS

To analyze the series, we initially carried out a general UECM version of ARDL with constant and trend (model 1), as in Pesaran, Shin, and Smith [39]. Model 2 (see Table 3) becomes highly significant, excluding the trend. In the presence of structural breaks, lag selection using levels of information, such as the Akaike Information Criterion, Hannan-Quinn or Bayesian Information Criterion, should not be pursued. A general-to-specific modelling approach was followed, such as that by Hendry [46]. Parsimonious models were achieved with one lag. The introduction of additional lags was shown as not being statistically significant. The estimated models are shown in Table 3.

Table 3. Estimated ARDL.

	Model 1 (Dep. Var. DLY)	Model 2 (Dep. Var. DLE)
Constant	8.2961***	0.3465***
Trend	0.0089***	
DLY		0.9718***
DLE	0.6231***	
DLY(-1)	0.3422**	-0.5846***
DLE(-1)	-0.2325*	0.4402***
LY(-1)	-0.4812***	0.0841***
LE(-1)	0.2814***	-0.1296***
Time dummies		
SD0913	-0.0298***	
SD0813		0.011**
Diagnostic Tests		
ARS	0.8425	0.8391
SER	0.0061	0.0078
JB	[0.9918]	[0.5469]
LM	[0.3839]	[0.3268]
ARCH	[0.1418]	[0.8828]
RESET	[0.4982]	[0.4804]

Notes: Diagnostic test results are based on F-statistic. represents p-value. ARS means adjusted R-squared. SER means standard error of regression. JB means Jarque-Bera normality test. LM means Breusch-Godfrey serial correlation LM test. ARCH means ARCH test. Reset means Ramsey RESET test. Estimated method: least squares. ***, ** and * denote statistical significance at 1%, 5% and 10% level, respectively.

Globally, the battery of diagnostic tests indicates that the two models have the desired econometric proprieties of no normally distributed errors, no serial correlation in the residuals and no auto-regressive conditional heteroskedasticity. All coefficients are statistically significant. The ECM in model 1 (coefficient of LY_{t-1}) has a magnitude of -0.4812 revealing a fast speed of adjustment from short-run disequilibrium to the long-run equilibrium. In Model 2, the ECM (coefficient of LE_{t-1}) has a magnitude of -0.1296, revealing a moderate speed of adjustment. To verify the existence of cointegration between variables, an ARDL bounds test was performed (see Table 4).

Table 4. Bounds test.

	Model 1	Model 2
F-statistic	10.6025***	7.4385**
K	1	1

Notes: k represents the number of independent variables in equation estimated. Critical values obtained from Pesaran, Shin, and Smith [39], tables CI(iii) and CI(v). Critical values for unrestricted intercept and no trend for bottom and top are, respectively, 6.84 and 7.84, for 1%; 4.94 and 5.73, for 5%; and 4.04 and 4.78 for 10%. Critical values for unrestricted intercept and unrestricted trend for bottom and top are, respectively, 8.74 and 9.63, for 1%; 6.56 and 7.3, for 5%; and 5.59 and 6.26 for 10%. ***and ** denote significance at 1% and 5% level, respectively.

The bounds test proves that there is a long-run relationship between energy and growth by rejecting the null hypothesis of non-cointegration. In model 1 the null hypothesis is rejected at the significance of 1%, and in model 2, rejection of the null hypothesis occurs at the significance of 5%. In short, the existence of a long-run relationship between energy and growth is confirmed. To analyze the speed of adjustment between LY and LE, we estimated both short- and long-run elasticities, which are shown in Table 5.

Table 5. Short-run semi-elasticities and long-run elasticities.

	Model 1	Model 2
Short-run (DLE+DLE(-1))	0.3907***	
Long-run (LE)	0.5848***	
Short-run (DLY+DLY(-1))		0.3872*
Long-run (LY)		0.6483***

Notes: ***and * denote statistical significance at 1% and 10% level, respectively.

The short-run semi-elasticities were calculated by adding the coefficients of variable in its first differences. The joint significance is tested by using the Wald coefficient test. The long-run elasticities are calculated by dividing the coefficient of lagged independent variable by the coefficient of the lagged independent variable, multiplied by -1.All the elasticities have the expected signs and are highly significant. Model 1 shows that in both the short- and long-run, energy exerts a positive impact on growth. A 1% increase in energy leads to economic growth of 0.391 in the short-run and 0.585 in the long-run. In model 2 it is also observed that in both the short-and long-run, economic growth exerts a positive impact on energy. A 1% increase in economic growth leads to energy growth of 0.387 in the short-run and 0.648 in the long-run.

5. ROBUSTNESS OF RESULTS

The results from the previous section suggest the existence of: (i) a strong global nexus, in the long-run; and (ii) endogeneity between energy consumption and economic growth. To assess the robustness of results, the introduction of crude oil prices (P) in the models was tested. The LR omitted variables test (Table 6) shows that the bivariate model is the preferred one. Only the variable LP(-1) revealed statistical significance at 10% for Model 1. However further tests such t-statistic and f-statistic do not confirm the statistical significance.

Table 6. LR omitted variables test.

	Model 1	Model 2
DLP	0.6397	0.0114
DLP(-1)	0.4166	0.8404
LP(-1)	2.8571*	0.0142

Notes: χ^2-statistic. * denotes statistical significance at 10% level.

To compare it with the ARDL model results, a VECM with 2 lags was carried out. The optimal number of lags was achieved by Schwarz information criteria and VEC lag exclusion Wald test. The model residuals revealed a possible structural break in 2009, controlled by introducing the dummy variable SD0913 as exogenous, which was revealed to be statistically significant. The Johansen cointegration test is presented in Table 7.

Table 7. Johansen Cointegration tests.

Eigenvalue	H_0: r	Trace	Max-Eigen
0.4526	0	41.1138***	27.722***
0.2526	1	13.3918**	13.3918**

Notes: r indicates the number of cointegrating relationships. *** and ** denote: significance at 1% and 5% level, respectively. Deterministic trend of test: Intercept and trend in Co integration Equation and no intercept in VAR. MacKinnon-Haug-Michelis (1999) p-values.

The Johansen cointegration test reveals the existence of two co integrating relationships between DLY and DLE. Both the Trace statistic and the Max-Eigen statistic are highly significant. The results agree with those previously obtained by the ARDL bounds test. The Toda and Yamamoto [45] causality testing procedure was also performed. To do so, a VAR model with LY and LE was carried out. The lag selection criteria set 2 lags as the optimal lag number and the VAR model residuals revealed a possible structural break in 2009 for model 1, and in 2008 for model 2. These dummies were introduced as exogenous variables, which were shown to be statistically significant. Furthermore, one lag was added to the model as in the Toda and Yamamoto [45] procedure. The results are shown in Table 8.

Table 8. Toda and Yamamoto causality tests.

Dependent variable	Model T-Y 1 (DLY)	Model T-Y 2(DLE)
Excluded	Chi Square	Chi Square
DLY	-	10.9231***
DLE	6.5114**	-

Notes: *** and ** denote statistical significance at 1% and 5% level, respectively. In Model T-Y 1 and Model T-Y 2 the alternative shift dummies SD0913, and SD0813 were used, respectively

The Toda and Yamamoto [45] procedure shows the presence of endogeneity. It is worthwhile to note that the Granger Causality tests were also performed within the VECM framework and they are in line with those from Toda-Yamamoto. Thus, there is evidence of Granger causality running from DLE to DLY and from DLY to DLE. These results point in same direction as those previously obtained by the ARDL bounds test. A global *feedback hypothesis* was verified. The range of results is discussed in the next section.

6. DISCUSSION

This study proves the existence of stable relationships between energy and growth, from 1965 to 2013. The application of the UECM version of the ARDL model is adequate, given that the bounds test showed cointegration between energy and growth. The model was adjusted from the 2008 crisis onwards, by introducing shift dummies. In addition, the statistical significance of ECM for both models proved the presence of a long-run equilibrium, which is in line with the existence of cointegration [47]. The cointegration was reinforced by the Johansen procedure.

As expected, a causality relationship running from energy to growth was found. Moreover, evidence of causality running from growth to energy was found. The elasticities revealed stronger nexus in the long-run. However, the short-run elasticities also confirm the nexus. The partial elasticities showed the endogeneity between the variables, where energy consumption leads to economic growth and the reverse is also true. In short, from the results it can be affirmed that the *feedback hypothesis* is present on a global level. Despite the presence of endogeneity, when an ARDL framework is free from correlation, endogeneity is not a problem [38] which contributes to robust results. Moreover, the Toda and Yamamoto [45] causality tests reinforced the results. In consequence, the use of restrictive energy consumption policies raises some concerns. Indeed, any energy consumption reduction should be followed by an increase in efficiency. Although a regulatory authority does not exist at a global level, these conclusions are important globally, where: (i) there are attempts to achieve the same goals in several countries, for example, increase energy efficiency and reduce pollution levels; and (ii) the implementation of policies in large groups of countries, such as the European Union, can cause global impacts through a contagion effect. In spite of the fact that small effects could be experienced in the short-run, the impacts in the long-run could be amplified by the endogenous nature of the variables.

The 2008 crisis negatively impacted the nexus. The addition of two shift dummies was needed to control for the crisis. In contrast, there was no need to control for the 1970s oil crises. This is in line with what is expected, given that the 2008 crisis impacted on a global level through the bankruptcy of financial companies and the creation of instability in financial markets, particularly the impact on the sovereign debts of some countries. In its turn, in the 70s, the effects of the oil crises on the global level was diluted by income transfers between oil producers and consumers. On one hand, in model 1 the effects of the 2008 crisis needed to be controlled by a shift dummy from 2009 to 2013. On the other hand, model 2 needed to be controlled from 2008 onwards. This behaviour reveals the different speeds that the shocks from the crisis are experienced by the dependent variable. Economic growth decelerated faster than energy consumption, which explains the positive coefficient dummy in model 2. This finding goes against what was expected, given that energy is one of the most essential goods and one of the last that consumers choose to reduce.

The research revealed that the nexus is stable over the time. Changes in world economies have been observed. Developing countries have turned into developed countries, countries with strong economies have become more fragile, but the nexus remained. These conditions give robustness to the explanation that the global nexus is stable.

7. CONCLUSION

This research adds to the literature on the energy-growth nexus by studying the phenomenon at a worldwide level. Using the ARDL bounds test approach, with time series data from 1965 to 2013, the feedback hypothesis was verified. Furthermore, the nexus is verified both in short- and long-run. Overall, the energy-growth nexus proved to be robust over a long time span. The ARDL bounds test proved to be a suitable tool to examine the nexus in the context of permanent shocks.

On a global level, the causal relationship running from energy to growth was expected. However the research also concluded that there is causality running from economic growth to energy consumption. Indeed, the former result suggests that the dynamic effects on both directions are huge. The model elasticities revealed that the nexus is present in both the short- and long-run. Moreover, long-run elasticities are larger than those in the short-run in the two models, which allows it to be concluded that the nexus is stronger in the long-run. The endogenous phenomenon is important in these results. The results also revealed that the 2008 financial crisis impacted negatively on the energy-growth nexus. In contrast, no significant impacts were detected for the 1970s oil crises.

Some caution is required in the policies involving constraints. In the short-run, a reduction on energy consumption has effects on economic growth and in the long-run these effects will be stronger. Any reduction in energy consumption will negatively impact growth and vice versa. Therefore, energy efficiency policies are required. Expanding on and confirming the results of this research by using studies with variables measuring the total energy and growth of some country aggregates could be an interesting future path of research. This would differ from previous country aggregate studies that used panels of countries. In addition, the examination of the endogenous effects on the energy-growth nexus at a worldwide level, is a direction for future research.

ACKNOWLEDGMENTS

The financial support of the NECE-UBI – Research Unit in Business Science and Economics, sponsored by the Portuguese Foundation for the Development of Science and Technology, Ministry of Education and Science, project UID/GES/04630/2013, is acknowledged. We thank the anonymous reviewer for the useful comments and suggestions.

REFERENCES

[1] BP. 2014. "BP Energy Outlook 2035." In *January 2014*: BP. http://www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/Energy_Outlook_2035_booklet.pdf (accessed 19 December 2014).

[2] Kraft J. and A. Kraft. 1978. On the relationship between energy and GNP. *The Journal of Energy and Development* 3(2): 401-403.

[3] Ahmed M., Riaz K., Khan A.M., and Bibi S., 2015. Energy consumption–economic growth nexus for Pakistan: Taming the untamed. *Renewable and Sustainable Energy Reviews* 52: 890-896.

[4] Han Z.-Y., Fan Y., and Wei Y.-M. 2004. Study on the cointegration and causality between GDP and energy consumption in China. *International Journal of Global Energy Issues* 22(2): 225-232.

[5] Kyophilavong P., Shahbaz M., Anwar S., and Masood S., 2015. The energy-growth nexus in Thailand: Does trade openness boost up energy consumption? *Renewable and Sustainable Energy Reviews* 46: 265-274.

[6] Lau E. and C.C. Tan. 2014. Econometric analysis of the causality between energy supply and GDP: the case of Malaysia. *Energy Procedia* 61(0): 203-206.

[7] Shahbaz M., Zeshan M., and Afza T., 2012. Is energy consumption effective to spur economic growth in Pakistan? New evidence from bounds test to level relationships and Granger causality tests. *Economic Modelling* 29(6): 2310-2319.

[8] Wolde-Rufael Y., 2010. Bounds test approach to cointegration and causality between nuclear energy consumption and economic growth in India. *Energy Policy* 38(1): 52-58.

[9] Ahmed M. and M. Azam. 2016. Causal nexus between energy consumption and economic growth for high, middle and low income countries using frequency domain analysis. *Renewable and Sustainable Energy Reviews* 60: 653-678.

[10] Ajide K., Bekoe W., Yaqub J., and Adeniyi O., 2013. Energy consumption and financial development in Sub-Saharan Africa: a panel econometric analysis. *International Journal of Global Energy Issues* 36(2): 225-241.

[11] Akinlo A.E., 2008. Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries. *Energy Economics* 30(5): 2391-2400.

[12] Fuinhas J.A. and A.C. Marques. 2012. Energy consumption and economic growth nexus in Portugal, Italy, Greece, Spain and Turkey: An ARDL bounds test approach (1965–2009). *Energy Economics* 34(2): 511-517.

[13] Mohammadi H. and M.D. Amin. 2015. Long-run relation and short-run dynamics in energy consumption–output relationship: International evidence from country panels with different growth rates. *Energy Economics* 52, Part A: 118-126.

[14] Ozturk I. and A. Acaravci. 2011. Electricity consumption and real GDP causality nexus: Evidence from ARDL bounds testing approach for 11 MENA countries. *Applied Energy* 88(8): 2885-2892.

[15] Usama A.-M. and S.C.N. Che. 2013. Energy consumption, pollution and economic development in 16 emerging countries. *Journal of Economic Studies* 40(5): 686-698.

[16] Apergis N. and J.E. Payne. 2009. Energy consumption and economic growth in Central America: Evidence from a panel cointegration and error correction model. *Energy Economics* 31(2): 211-216.

[17] Payne J.E., 2010. Survey of the international evidence on the causal relationship between energy consumption and growth. *Journal of Economic Studies* 37(1): 53-95.

[18] Fuinhas J.A. and A.C. Marques. 2013. Rentierism, energy and economic growth: The case of Algeria and Egypt (1965–2010). *Energy Policy* 62(0): 1165-1171.

[19] Mehrara M. 2007. Energy consumption and economic growth: The case of oil exporting countries. *Energy Policy* 35(5): 2939-2945.

[20] Sims C.A. 1972. Money, Income, and Causality. *American Economic Review* 62(4): 540-52.

[21] Yu, E.S.H., and B.-K. Hwang. 1984. The relationship between energy and GNP: Further results. *Energy Economics* 6(3): 186-190.

[22] Granger C.W.J., 1988. Causality, cointegration, and control. *Journal of Economic Dynamics and Control* 12(2–3): 551-559.

[23] Cheng B.S. and T.W. Lai. 1997. An investigation of co-integration and causality between energy consumption and economic activity in Taiwan. *Energy Economics* 19(4): 435-444.

[24] Glasure Y.U. and A.R. Lee. 1998. Cointegration, error-correction, and the relationship between GDP and energy: The case of South Korea and Singapore. *Resource and Energy Economics* 20(1): 17-25.

[25] Ishida H. 2012. Causal relationship between fossil fuel consumption and economic growth in the world. *International Journal of Global Energy Issues* 35(6): 427-440.

[26] Jammazi R. and C. Aloui. 2015. On the interplay between energy consumption, economic growth and CO_2 emission nexus in the GCC countries: A comparative analysis through wavelet approaches. *Renewable and Sustainable Energy Reviews* 51: 1737-1751.

[27] Lee C.-C. and C.-P. Chang. 2005. Structural breaks, energy consumption, and economic growth revisited: Evidence from Taiwan. *Energy Economics* 27(6): 857-872.

[28] Ocal O. and A. Aslan. 2013. Renewable energy consumption–economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews* 28: 494-499.

[29] Oh W. and K. Lee. 2004. Causal relationship between energy consumption and GDP revisited: the case of Korea 1970–1999. *Energy Economics* 26(1): 51-59.

[30] Pao H.-T. and H.-C. Fu. 2013. Renewable energy, non-renewable energy and economic growth in Brazil. *Renewable and Sustainable Energy Reviews* 25(0): 381-392.

[31] Stern D.I. 2000. A multivariate cointegration analysis of the role of energy in the US macro economy. *Energy Economics* 22(2): 267-283.

[32] Al-Iriani M.A. 2006. Energy–GDP relationship revisited: An example from GCC countries using panel causality. *Energy Policy* 34(17): 3342-3350.

[33] Caraiani C., Lungu C.I. and Dascălu C., 2015. Energy consumption and GDP causality: A three-step analysis for emerging European countries. *Renewable and Sustainable Energy Reviews* 44: 198-210.

[34] Ciarreta A. and A. Zarraga. 2010. Economic growth-electricity consumption causality in 12 European countries: A dynamic panel data approach. *Energy Policy* 38(7): 3790-3796.

[35] Damette O., and M. Seghir. 2013. Energy as a driver of growth in oil exporting countries? *Energy Economics* 37(0): 193-199.

[36] Mohammadi H. and S. Parvaresh. 2014. Energy consumption and output: Evidence from a panel of 14 oil-exporting countries. *Energy Economics* 41(0): 41-46.

[37] Sadorsky P., 2011. Trade and energy consumption in the Middle East. *Energy Economics* 33(5): 739-749.

[38] Hashem P.M. and Y. Shin. 1999. An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis." In *Econometrics and Economic Theory in the 20th century*, edited by Steinar Strom and Steinar Strom, 371-413. Cambridge: Cambridge University Press.

[39] Hashem P.M., Shin Y., and Smith R.J., 2001. Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics* 16(3): 289-326.

[40] Lee C.-C. and M.-S. Chien. 2010. Dynamic modelling of energy consumption, capital stock, and real income in G-7 countries. *Energy Economics* 32(3): 564-581.

[41] Payne J.E., 2009. On the dynamics of energy consumption and output in the US. *Applied Energy* 86(4): 575-577.

[42] Fatai K., Oxley L., and Scrimgeour F.G., 2004. Modelling the causal relationship between energy consumption and GDP in New Zealand, Australia, India, Indonesia, The Philippines and Thailand. *Mathematics and Computers in Simulation* 64(3–4): 431-445.

[43] Bildirici M.E. and T. Bakirtas. 2014. The relationship among oil, natural gas and coal consumption and economic growth in BRICTS (Brazil, Russian, India, China, Turkey and South Africa) countries. *Energy* 65(0): 134-144.

[44] Perron P., 1989. The Great Crash, the Oil Price Shock, and the Unit Root Hypothesis. *Econometrica* 57(6): 1361-1401.

[45] Toda H.Y. and T. Yamamoto. 1995. Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics* 66(1–2): 225-250.

[46] Hendry D.F., 1995. *Dynamic Econometrics, Advanced Texts in Econometrics*. Oxford: Oxford University Press.

[47] Banerjee A., Dolado J., and Mestre R., 1998. Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis* 19(3): 267-283.