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Abstract: Using a sample of quarterly data, we investigate the effect of electricity consumption, capital formation and financial development on economic growth in Portugal. A positive (negative) shock of electricity consumption is estimated to have increased (decreased) economic growth. Economic growth is positively affected by positive shock stems in capital. A positive (negative) shock in financial development declines (increases) economic growth. These findings reveal that (a) Portugal is still an energy-dependent economy; (b) energy is one of the major inputs for economic growth and development; (c) a conservation energy policy should not be implemented because energy is an important driver of growth; (d) economic growth enhances capital formation and not the opposite. Hence, it appears more relevant to boost economic growth before enhancing capital formation; (e) financial development does not appear to be an important catalyst for economic growth. Findings also highlight (f) the relevance of the recent energy policy implemented in Portugal and (g) the need to limit energy imports by means of producing electricity through renewable energy to reduce the external debt level in Portugal, especially after the 2008 crisis.
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I. Introduction

Energy plays a fundamental role in sustainable economic development for both developing and developed countries. It is a key input in most of the production processes. In particular, due to its importance for the economy, numerous researchers have focused on examining the relationship between electricity consumption and economic growth (e.g., Squalli, 2007, Apergis and Payne 2011, Shahbaz et al. 2013, Wolde-Rufael 2014, Rafindadi and Ozturk 2016, Sarwar et al. 2017). Manufacturing industries rely heavily on the production of electricity. Indeed, electricity shortages may cause serious distortions to the gross domestic product (GDP) and subsequently destabilize a country's economy (Shahbaz and Ali, 2016). As a result, electricity consumption can be viewed as a relevant factor of domestic production and, hence, economic growth. Costantini and Martini (2010), among others, argue that electricity consumption should be a component of the production function in the same way as capital and labor. Therefore, policy makers have habitually been highly concerned by the causal links between electricity consumption and economic growth. These links have significant energy policy implications for the government in different ways. An important way concerns electricity conservation policies. These policies should be developed to avoid the wastage of electricity and reduce electricity consumption whenever possible (Shahbaz and Ali, 2016).

Portugal produced 5.6 million tonnes of oil-equivalent (Mtoe) energy in 2014. Energy is essentially provided by renewables, including biofuels and waste, because Portugal has limited access to fossil fuel production. The final demand represents approximately 16 Mtoe in 2013. Fossil fuels account for 74.3% (including oil, 45.1%; natural gas, 16.4%; and coal, 12.7%) and renewables account for 25.4%. In view of the large gap between supply and demand for energy, Portugal is an energy-dependent country. Nevertheless, since the implementation of new environmental energy policies proposed by the National Energy Efficiency Action Plan (NEEAP)[1], Portugal has embarked on a series of reforms to produce more renewable energy. The results are not long in coming: in 2014, renewables accounted for 25.4% of Portugal's total primary energy supply and 61.3% of electricity generation. Portugal has become one of the

[1]Since 2008, the European Union has made a set of recommendations that aim at promoting renewable energy deployment and supporting economic and environmental sustainability. The NEEAP has proposed several other energy policy actions that concern market liberalization in the electricity and natural gas sectors. The new NEEAP, established in 2013, has defined targets for reducing energy consumption and developing renewable energy production. These targets are to be achieved by 2020.

leaders in the European Union in terms of renewable energy sources. This specific energy strategy makes it possible to reduce both natural gas and crude oil imports and enhances domestic economic output. Indeed, Portugal has imported 2.8 Mt of oil products in 2014, which represents a decrease of approximately 40% compared to 2004 (International Energy Agency, 2016). Bhattacharya et al. (2016) have found that renewable energy consumption positively affects economic growth in the long term for the Portuguese economy. Economic growth also relies on other important inputs such as financial development and gross fixed capital formation. Financial development can play a role in sustaining energy efficient technology (e.g., Shahbaz et al. 2011, Tang et al. 2013) to enhance domestic production and provide public and private investments to reduce greenhouse gases emissions. Capital formation is another notable driver of domestic economic growth. In a recent empirical investigation, Best (2017) finds that capital (especially private credit from banks) facilitates the transition from fossil fuels to alternative renewable energy sources.

Electricity policy depends on the existence and direction of the causality links between electricity consumption and economic growth. It is possible to consider and discuss at least four hypotheses regarding these causality links. First, the growth hypothesis suggests a unidirectional causality relationship from electricity consumption to economic growth (e.g., Ouedraogo 2013, Shahbaz et al. 2013, Iyke 2015, Acarvci et al. 2015, Tang et al. 2016). In this context, the reduction of electricity consumption negatively affects economic growth. As a result, electricity conservation policies should be counterproductive for the economy because a decrease in electricity consumption can induce a decrease in economic growth. Second, the conservation hypothesis puts forward the existence of an opposing unidirectional causality relationship from economic growth to electricity consumption (e.g., Cheng and Lai, 1997, Narayan et al. 2010, Kasnan and Dunan 2015, Arora and Shi 2016). In other words, an increase in economic growth creates an increase in electricity consumption. In this situation, electricity conservation policies may be implemented without affecting economic growth. Third, the feedback hypothesis evokes a bidirectional causality relationship between economic growth and electricity consumption (e.g., Constantini and Martini 2010, Shahbaz and Lean 2012, Polemis and Dagoumas 2013, Mutascu 2016, Sarwar et al. 2017). This feedback effect can serve to implement both energy conservation and efficiency policies without negatively affecting economic growth. Additionally, this reduction of energy use could be more appropriate if policy makers promote a shift from less efficient energy consuming sectors to more efficient counterparts. Fourth, the neutrality hypothesis does not consider any causal relationship between electricity consumption and economic growth. Hence, the neutrality hypothesis suggests that electricity consumption plays a limited role in the economic growth of a given country (e.g., Wolde-Rufael 2009, Smiech and Papiez 2014). In this case, any increase or decrease in electricity consumption has no effect on the economic output. At the energy policy level, this neutrality effect means that an increase or decrease in energy consumption would not have any effect on the national income.

Currently, examination of the causal links between electricity consumption and economic growth is an ongoing concern and is more important than ever. Indeed, around the world, economists and governmental authorities place a large amount of importance on reducing greenhouse gas emissions. This objective constitutes the priority of contemporary energy policies. However, the implementation of such energy policies obviously depends on the impact of electricity consumption on economic growth. Various non-stationary econometric methodologies have been deployed in numerous empirical studies to determine long-term and short-term links between electricity consumption and economic growth (Chen et al. 2007, Narayan and Prasad 2008, Iyke 2015, Mutascu 2016, Streimikiene and Kasperowicz 2016, Tang et al. 2016, Shabhaz et al. 2016 to name a few). In a recent survey, Omri (2014) investigates different empirical study results of the casual links between electricity consumption and economic growth. The author notes the mixed conclusions: 29% of previous empirical studies corroborate the growth hypothesis; 27% support the feedback hypothesis; 23% confirm the conservation hypothesis; and 21% validate the neutrality hypothesis.

Some recent empirical studies on the energy-growth nexus have extended the production function or Solow's growth model by incorporating some additional variables of interest. Narayan and Smyth (2009) study the relationship between energy consumption and exports. They confirm that the causality direction may be different if economists incorporate another relevant factor in the production function. Similarly, Sadorsky (2011a) reveals a positive causality running from export to energy consumption and a feedback effect between import and energy consumption. Shabhaz et al. (2013) argue that the exclusion of some relevant variables in the empirical model clearly causes two main drawbacks. First, the econometric specification may induce inconsistent and biased estimates. Second, the potential omitted variables in the econometric modeling may lead to confirming the only neutral hypothesis. Consequently, the authors add a set of macroeconomic variables to the model, such as financial development, trade openness (imports, exports), international trade and capital[2]. Their results show that these variables have a positive impact on economic growth in China over the period of 1971 to 2011. In the short run, their findings corroborate the growth hypothesis, meaning that China is an energy-dependent country. Tang et al. (2016) investigate this relationship for Vietnam by using an extended neoclassical Solow growth model for the period from 1971 to 2011. The particularity of this study is the use of foreign direct investment (FDI) associated with capital stock in the production function. The main reason for this choice is that capital stock and FDI are two important variables affecting economic growth, especially for developing countries[3].

Economists and policy makers are aware that the use of electricity consumption may be a powerful economic tool to sustain economic growth. However, they face conflicting results from an academic standpoint. The ambiguity in the empirical results may be due to the ignorance of asymmetry or non-linearity arising in time series due to structural reforms; regimes shifts; financial, economic and energy reforms; and regional and global imbalances. This presence of asymmetry in time series may change the impact of electricity consumption on economic growth and the direction of causality between both variables (Shahbaz et al. 2017). Few studies in the existing energy economic literature employed the production function in the case of Portugal (Tang et al. 2011, Tang and Tan 2012 and, Marques and Fuinhas 2015). These studies provide conflicting empirical results. The main reason for the conflicting empirical results may be the presence of asymmetries in times series. The presence of asymmetry in time series leads us to examine how positive (negative) fluctuations in electricity consumption impact economic growth. This paper aims at narrowing the gap between the literature and practice by reconsidering the relationship between electricity consumption and economic growth in the particularly interesting case of Portugal. Portugal is an interesting case study for many reasons.

[2] Cole (2006) investigates the link between trade liberalization and energy consumption for 32 developed and developing countries. The study findings suggest a positive relationship between trade liberalization, energy consumption and economic growth, meaning that trade liberalization is likely to increase energy consumption. Lean and Smyth (2010) investigate the energy-growth nexus by incorporating international trade for Malaysia during the period from 1971 to 2006. Their empirical results are in line with those of Sadorski (2011a).

[3] Rafindadi and Ozturk (2016) examine the growth-electricity nexus for the Japanese economy by incorporating the financial development, capital and trade openness variables in an extended Cobb-Douglas production function.

First, Portugal has established a clear strategic energy plan for the coming years. Indeed, the council of ministers of Portugal has recently formulated an ambitious national energy strategy for 2020 (Prêcidencia do Conselho de Ministros, 2010). This strategy aims at reducing the energy dependence to 74% and increasing the share of renewable energy resources in final energy consumption to 31%. Portugal targets a level of electricity generation from renewable energy sources of 60% by 2020. Second, Portugal imports 83% of its energy needs (Eurostat, 2009). This led the country to diversify its energy sources. Portugal has significantly shifted its electricity production system by introducing natural gas power plants, new hydroelectric power plants and wind energy. Third, Portugal provides a relevant case study as it represents a transitional economy (Niza and Ferrao, 2006). Its development pattern in the last decades shows a linear correlation between natural resources consumption and economic growth. Therefore, analyzing its electricity consumption and demand structure can provide relevant insights for the global effort of sustainable development.

The contributions of the present study are as follows: (i) This study employs a Portuguese-augmented Cobb-Douglas production function to examine the asymmetric effect of electricity consumption on economic growth. (ii) This study considers the vital role of financial development in production function along with capital as an additional factor of production. Financial development may contribute to economic growth directly and indirectly via capitalization (Shahbaz et al. 2017). Financial development affects electricity consumption via consumer, wealth and business effects (Sardosky 2010, Shahbaz and Lean 2012). (iii) Due to the low explanatory power of traditional unit root tests such as ADF, PP and NP, we have applied an advanced unit root test per Kim and Perron (2009) to examine the order of integration of the variables. This unit root test accommodates information from a single unknown structural break that arises in the series. (iv) The BDS test developed by Brock et al. (1996) is applied to test whether non-linearity is present in the series. (v) We also enrich the existing energy economics literature by employing the NARDL bounds testing approach developed by Shin et al. (2014) to examine the asymmetric cointegration between economic growth and its determinants. Numerous studies have sought to explain the electricity-growth nexus by using symmetric causality tests (Narayan and Singh 2007, Ghosh 2009, Shahbaz and Lean 2012, Polemis and Dagoumas 2013). (vi) This study considers an asymmetric causality test recently developed by Hatemi-J (2012) to examine the asymmetric causal relationship between electricity consumption and economic growth. Our empirical findings provide evidence of an asymmetric cointegration association between economic growth and its determinants. A positive (negative) shock in electricity consumption increases (decreases) economic growth. Economic growth is positively affected by positive shock stems in capital. A positive shock in financial development decreases economic growth, but a negative shock in financial development increases it. The causality analysis shows that positive shock in electricity consumption causes economic growth (positive shock). A symmetric unidirectional causality exists that runs from economic growth to capital. Financial development causes economic growth symmetrically. Overall, these findings clearly provide a new basis to discuss and implement the appropriate design of environmental and energy policies for Portugal and other medium-sized economies with similar characteristics. Indeed, Portugal is an energy-dependent economy with energy considered as one of the major inputs for economic growth and development. Consequently, a conservation energy policy should not be implemented in this country. The latter needs to limit energy imports by means of producing electricity through renewable energy which, in turn, would reduce the need for external debt and thus may help reduce Portugal's high debt level, especially after the 2008 crisis. Economic growth is found to enhance capital formation. Hence, it appears more relevant to boost economic growth before enhancing capital formation. Finally, financial development does not appear to be an important catalyst for economic growth in Portugal.

The rest of the paper is structured as follows. Section 2 presents the related literature on the electricity consumption-economic growth nexus. Section 3 describes the data, offers a preliminary analysis of the considered times series and develops the methodology used for the estimations. Section 4 discusses the empirical findings. Section 5 concludes the study and provides a set of energy policy implications.

II. Literature review

The pioneering study of Kraft and Kraft (1978) introduced the question of causality between energy consumption and economic growth. These authors found evidence of a unidirectional causal relationship running from gross national product to energy consumption in the US market over the period of time from 1947 to 1974. The first generation of empirical studies investigate the energy-growth nexus in a stationary econometric framework by using both traditional causality measures, i.e., the so-called Granger and Sims causality tests based on the VAR methodology (Akara and Long 1980, Yu and Wang 1984, Yu and Choi 1985 among others). In the last two decades, the relationship between energy consumption and economic growth has been extensively investigated in a non-stationary setting by using a Vector Error Correction Model (VECM) to test for Granger causality (Cheng and Lai 1997, Stern 2000, Narayan and Singh 2007, Ghosh 2009). For example, Cheng and Lai (1997) confirm the presence of a unidirectional Hsiao's Granger causality running from economic growth to electricity consumption for Taiwan in the period from 1955 to 1993. The same causal relationship is obtained by Narayan and Singh (2007) when applying a production function, in which they incorporate the labor factor as an additional component of the relationship on Fiji for the period from 1971 to 2002. Shahbaz and Lean (2012) investigate the causal links between electricity consumption and economic growth in Pakistan. Their findings suggest in the long run that electricity consumption has a positive effect on economic growth. In the short run, their empirical evidence provides a bidirectional Granger causality between electricity consumption and economic growth. In this situation, electricity conservation policies may not be implemented by the government because they are likely to cause a decline in economic growth. Polemis and Dagoumas (2013) examine the electricity consumption-economic growth nexus for the case of Greece over the period from 1970 to 2011. Their empirical findings reveal that electricity demand appears to be price inelastic and income elastic. They also confirm the feedback hypothesis by obtaining a bidirectional causality between electricity consumption and economic growth. Their results strengthen the fact that Greece is an energy dependent country. As a result, Greek policy makers could put in place energy conservation policies to boost economic activity.

Another strand of research considers panel methods to test for cointegration and Granger causality (Al-Iriani 2006, Narayan and Smith 2009, Costantini and Martini 2010, Acaravci and Ozturk 2010, Wolde-Rufael 2014, Karanfil and Li 2015, among others). Costantini and Martini (2010) suggest that the adoption of recently developed panel techniques related to unit root, cointegration and causality tests could eliminate the problems associated with the low power of the traditional unit root and cointegration tests. Acaravci and Ozturk (2010) reach similar conclusions. They empirically examine the electricity consumption-growth nexus using data from 15 transitional countries for the period from 1990 to 2006. Their results suggest that the Pedroni panel cointegration tests do not confirm the long term equilibrium relationship between electricity consumption per capita and economic growth that is measured as GDP per capita. Hence, for these transitional countries, the implementation of electricity conservation policies would affect negatively economic growth. In the same vein, Apergis and Payne (2011), investigate a panel of 88 countries by using a panel ECM. Their findings clearly corroborate the feedback hypothesis for high- and upper-middle income country panels and validate the growth hypothesis for the lower-income country panel. Similarly, Wolde-Rufael (2014) investigates the electricity-growth relationship by applying a bootstrap panel Granger causality test for 15 European transitional countries for the period from 1975 to 2010. The results are sparse and depend on the investigated country. The empirical findings indicate a unidirectional causality running from electricity consumption to economic growth in Belarus and Bulgaria and from economic growth to electricity consumption in the Czech Republic, Lithuania, Latvia and Russian Federation. The feedback effect is valid only for Ukraine, whereas no causality is also found for the rest of the country panel[4]. From the database of a 45-developing country panel covering the period from 1971 to 2009, Das et al. (2012) investigate the links between electricity consumption and economic activity. By using a system-generalized method of moments (GMMs), they validate the growth hypothesis for the full panel. They also emphasize the finding that a positive growth-electricity nexus exists for the Asia, Pacific and Sub-Saharan African regions, while no relationship is found for the Latin America and the Caribbean panels. Karanfil and Li (2015) examine both the long-term and short-term relationships between electricity consumption and economic growth using a large panel of 160 countries for the period from 1980 to 2010. In line with the previous studies, causal links differ considerably across subsamples. The empirical studies report the conflicting results, and no consensus appears to exist (see the literature surveys by Ozturk 2010, Payne 2010). These discrepancies are probably due to differences in data sets, country characteristics, periods of time and econometric methodologies used to investigate the causal links. The electricity consumption and economic activity

[4] Our work differs from that of Wolde-Rufael (2014) in many directions. First, his bootstrap panel Granger causality methodology tests for linear causality between electricity consumption and economic growth while we employ the asymmetric Hatemi-J (2012) causality test that allows testing for nonlinear causality between electricity consumption and economic growth by testing for causalities between positive (negative) components of the considered variables. Second, the author considered the short-run influences between variables only while our methodology allows assessing short- and long-run influences between variables. Third, we estimate an augmented production function for Portugal which is not included in the sample of countries considered in Wolde-Rufael (2014). Fourth, we include additional variables in the production function which has the advantage of avoiding the omitted variables bias. Fifth, Wolde-Rufael (2014) uses annual data in their empirical study while we use a higher frequency (quarterly) data to consider more variability/patterns in the data.

relationship appears to be particularly sensitive to regional differences (Das et al. 2012), income levels (Apergis and Payne, 2011) and urbanization levels (Karanfil and Li 2015, Shahbaz et al. 2016).

< Insert Table 1 here >

Another possible explanation revealed by part of the related literature is the problem of omitted variables in the production function. Few empirical studies in the extended literature on the electricity-growth nexus have incorporated additional relevant macroeconomic variables into the econometric modeling. Financial development constitutes an interesting variable considered in some recent empirical studies. In certain previous studies, financial development has a positive effect on energy consumption because this variable is positively related to economic growth (Sadorski 2011b, Aslan et al. 2014, Rashid and Yousaf 2015 for among others). According to Sadorski (2011b), this positive causality can be explained by three effects: the direct effect (households consuming), business effect (industrial production) and confidence effect (known as the wealth effect). Financial development is measured by banking variables such as bank deposits, financial system deposits and liquid liabilities. This is a relevant measure for Central and Eastern European countries, where the vast majority of investment projects are financed by bank loans. Xu (2012) finds similar results for China when financial development is measured by both financial institutions and FDI loans, which are scaled by the GDP. In contrast, some previous studies have reported the negative effect of financial development on energy consumption. An increase in financial development may induce a technological outcome (Jalil and Feridun 2011, Shahbaz et al. 2013, Mahalik and Mallick 2014). Some empirical studies have instead found bidirectional causality between financial development and energy consumption (Shahbaz and Lean, 2012). Others have found no causality between financial development and energy consumption (Ozturk and Acaravci 2013). For instance, Coban and Topcu (2013) report an absence of links between financial development and energy consumption in the 27 European Union countries where financial development is computed alternatively as bank loans and stock market values. A positive causal effect exists only for older European Union countries (including Portugal). Only banking variables have a significant relationship with electricity for the panel of new country members. Rafindadi and Ozturk (2016) employ the ARDL bounds test and VECM Granger causality test to determine the long-term and short-term relationship between electricity consumption and a set of macroeconomic variables. The long term analysis supports the presence of a positive relationship between financial development, economic growth, exports, imports and electricity consumption. More precisely, they argue that financial development stimulates electricity consumption and trade openness. These variables create a significant increase in electricity demand. In the short term, their findings clearly indicate a feedback effect between most of the macroeconomic variables used in this analysis and electricity consumption. Only the capital factor negatively affects energy consumption in both the long and short term. Likewise, Tang et al. (2016) use a neoclassical Solow-growth model to investigate the energy-growth nexus in Vietnam for the period of 1971- 2011. Their results confirm the existence of a positive long-term relationship between energy consumption, FDI, capital stock and economic growth, respectively. They find a unidirectional Granger causality running from electricity consumption to economic growth, confirming that Vietnam is an energy-dependent economy. Shahbaz et al. (2016) used a recent econometric methodology to test for both long-term and short-term relationships between energy, growth, financial development and urbanization for India covering the period of 1971-2012. Their findings also underline the fact that financial development increases economic growth in accordance with environmental sustainability. On the whole, financial development is likely to have an important impact on energy consumption. Nevertheless, the related empirical results are sparse and mixed. Therefore, this paper attempts to fill this gap by providing new, accurate econometric modeling, which makes it possible to test for nonlinear and asymmetric relationships between electricity consumption and economic growth for the Portuguese economy.

< Insert Table 2 here >

III. Estimation Strategy and the Data

The NARDL approach, recently developed by Shin et al. (2014), is employed to investigate the asymmetric and nonlinear long-term and short-term influence of electricity consumption on economic growth while controlling for capital and financial development as additional factors of domestic production function in Portuguese economy. The NARDL model represents an extension of the linear ARDL of Pesaran et al. (2001) that allows the capture of asymmetries in the long-term and short-term linkages between variables. These asymmetries may be allowed in the long term and short term separately or jointly. The NARDL approach is well adapted to model the complex relationship between economic and financial variables in a complex system characterized by several sudden events such as economic and financial crises, political changes, and revolutions, among others, which lead to the deficiency of linear approaches to capture all the patterns driving the relationships among economic and financial times series data. Furthermore, the NARDL approach represents a powerful instrument to test for cointegration among a set of time series variables in a single equation. It is now well documented that financial and economic time series data are cointegrated and follow a common long-term equilibrium trend. However, linear cointegration tests/models such as the Johansen cointegration test and linear ARDL approach fail to properly detect these cointegrating relationships. The NARDL approach allows for the detection of these omitted cointegration relationships because it enables the testing of hidden cointegration (Granger and Yoon, 2001). Additionally, previous conventional cointegration tests require that all variables in the system be I(1). The NARDL relaxes the previous condition and permits testing cointegration between I(0), I(1) or a mix of I(0) and I(1) variables. The linear ARDL model is written as follows:

$$\Delta GDP = \mu + \rho GDP_{t-1} + \theta_E E_{t-1} + \theta_K K_{t-1} + \theta_F F_{t-1} + \sum_{i=1}^{p-1} \alpha_i \Delta GDP_{t-i} + \sum_{i=0}^{q-1} \beta_i \Delta E_{t-i} + \sum_{i=0}^{q-1} \gamma_i \Delta K_{t-i} + \sum_{i=0}^{q-1} \varphi_i \Delta F_{t-i} + \varepsilon_t \quad (1)$$

where GDP, E, K and F denote respectively real GDP per capita, electricity consumption, capital and financial development, Δ is the first difference operator, θ_i denotes the long-term parameters, α_i, β_i, γ_i and φ_i are short-term parameters, p and q are lag orders selected by the AIC information criterion, and ε_t is an error term.

Estimation of the linear ARDL model allows testing of the null of no cointegration ($\rho = 0$) against the alternative of linear cointegration ($\rho \neq 0$) using the non-standard F bounds test of Pesaran et al. (2001). In particular, the bounds test consists of computing lower bound critical values for a given confidence level, assuming that all variables are stationary. The test then computes an upper critical bound for the same confidence level, assuming that all variables are I(1). The decision rule is as follows: if the empirical F-statistic is lower than the lower bound critical value, the test fails to reject the null of no cointegration, while it rejects the null of no cointegration in case the empirical F-statistic is higher than the upper bound. The test remains inconclusive if the empirical calculated F-statistic is between the lower and upper bounds. To construct the NARDL model that accounts for long-term and short-term asymmetries, Shin et al. (2014) define the multiple long-term equilibrium relationship between the dependent variable — GDP — and independent variables — E, K and F — as follows:

$$GDP_t = \pi_E^+ E_t^+ + \pi_E^- E_t^- + \pi_K^+ K_t^+ + \pi_K^- K_t^+ + \pi_F^+ F_t^+ + \pi_F^- F_t^- + u_t \quad (2)$$

where $\pi_E^+, \pi_E^-, \pi_K^+, \pi_K^-, \pi_F^+$ and π_F^- are the associated asymmetric long-term parameters and u_t measures deviations from the long-term equilibrium. Finally, each of the regressors among E, K and F is decomposed into its positive and negative partial sums as follows: $y_t = y_0 + y_t^+ + y_t^-$, where $y_t^+ = \sum_{i=1}^{t} \Delta x_t^+ = \sum_{i=1}^{t} \max(\Delta x_t, 0)$ and $y_t^- = \sum_{i=1}^{t} \Delta x_t^- = \sum_{i=1}^{t} \min(\Delta x_t, 0)$. Introducing equation 2 in equation 1 leads to the following NARDL model with long-term and short-term asymmetries:

$$\Delta GDP = \mu + \rho GDP_{t-1} + \theta_E^+ E_{t-1}^+ + \theta_E^- E_{t-1}^- + \theta_K^+ K_{t-1}^+ + \theta_K^- K_{t-1}^- + \theta_F^+ F_{t-1}^+ + \theta_F^- F_{t-1}^- + \sum_{i=1}^{p-1} \alpha_i \Delta GDP_{t-i} + \sum_{i=0}^{q-1} (\beta_i^+ \Delta E_{t-i}^+ + \beta_i^- \Delta E_{t-i}^-) + \sum_{i=0}^{q-1} (\gamma_i^+ \Delta K_{t-i}^+ + \gamma_i^- \Delta K_{t-i}^-) + \sum_{i=0}^{q-1} (\varphi_i^+ \Delta F_{t-i}^+ + \varphi_i^- \Delta F_{t-i}^-) + \varepsilon_t$$
(3)

where $\theta_E^+ = -\rho\pi_E^+$, $\theta_E^- = -\rho\pi_E^-$, $\theta_K^+ = -\rho\pi_K^+$, $\theta_K^- = -\rho\pi_K^-$, $\theta_F^- = -\rho\pi_F^-$ and $\theta_F^- = -\rho\pi_F^-$. The short-term influence of the respective explanatory variables on economic growth are captured by $\beta_i^+, \beta_i^-, \gamma_i^+, \gamma_i^-, \varphi_i^+$ and φ_i^-. The NARDL model allows testing the null of no cointegration between each of the explanatory variables and economic growth against the alternative of cointegration. Statistically, this is achieved by performing the test $\theta_E^+ = \theta_E^- = 0, \theta_K^+ = \theta_K^- = 0$ and $\theta_F^+ = \theta_F^- = 0$ against the corresponding following alternatives $\theta_E^+ \neq 0 \ and \ \theta_E^- \neq 0, \theta_K^+ \neq 0 \ and \ \theta_K^- \neq 0$ and $\theta_F^+ \neq 0 \ and \ \theta_F^- \neq 0$. Once the previous test detects the presence of cointegration, it is then straightforward to test for symmetric $(\theta_E^+ = \theta_E^+, \theta_K^+ = \theta_K^+ \ and \ \theta_F^+ = \theta_F^+)$ against asymmetric cointegration, which is also called long-term asymmetry $(\theta_E^+ \neq \theta_E^+, \ \theta_K^+ \neq \theta_K^+ \ and \ \theta_F^+ \neq \theta_F^+)$. The short-term asymmetries $\left(\sum_{i=1}^{q-1} \beta_i^+ = \sum_{i=1}^{q-1} \beta_i^-\right), \left(\sum_{i=1}^{q-1} \gamma_i^+ = \sum_{i=1}^{q-1} \gamma_i^-\right)$ and $\left(\sum_{i=1}^{q-1} \varphi_i^+ = \sum_{i=1}^{q-1} \varphi_i^-\right)$ are tested using the standard Wald test.

Based on the results of the Wald test for long-term and short-term asymmetries, we select the most appropriate ARDL model that may fit our data. Three possibilities are conceivable. The best model for our data might include both long-term and short-term asymmetries or either long-term or short-term asymmetry or none. Afterwards, we calculate the asymmetric dynamic multipliers that measure the impact of one unit change, respectively, in $E_t^+, E_t^-, K_t^+, K_t^-, F_t^+$ and F_t^- on economic growth. The dynamic multipliers are computed as follows:

$m_{E,h}^+ = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial E_t^+}, m_{K,h}^+ = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial K_t^+}$, $m_{F,h}^+ = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial F_t^+}$, $m_{E,h}^- = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial E_t^-}$, $m_{K,h}^- = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial K_t^-}$ and $m_{F,h}^- = \sum_{j=0}^{h} \frac{\partial GDP_{t+j}}{\partial F_t^-}$, $h = 0,1, \ldots$

Note that as $h \to \infty$, then $m_{i,h}^+ \to \beta_i^+$ and $m_{i,h}^- \to \beta_i^-$, where i~~it~~ indicates E, K and F, respectively. The dynamic multipliers depict the evolution of the dynamic of economic growth following a one-unit shock hitting one of the determinants of economic growth, thus providing the path to the new equilibrium (Fousekis et al. 2016).

According to the results of the long-term and short-term symmetry tests, we re-estimate the NARDL model with the respected symmetry condition imposed (long-term symmetry of capital) to avoid any potential misspecification of either the long-term relationship or the new adjustment path. We thus estimate the following new NARDL model with symmetry imposed in the long-term impact of capital on economic growth:

$$\Delta GDP = \mu + \rho GDP_{t-1} + \theta_E^+ E_{t-1}^+ + \theta_E^- E_{t-1}^- + \theta_K K_{t-1} + \theta_F^+ F_{t-1}^+ + \theta_F^- F_{t-1}^- + \sum_{i=1}^{p-1} \alpha_i \Delta GDP_{t-i} + \sum_{i=0}^{q-1} (\beta_i^+ \Delta E_{t-i}^+ + \beta_i^- \Delta E_{t-i}^-) + \sum_{i=0}^{q-1} (\gamma_i^+ \Delta K_{t-i}^+ + \gamma_i^- \Delta K_{t-i}^-) + \sum_{i=0}^{q-1} (\varphi_i^+ \Delta F_{t-i}^+ + \varphi_i^- \Delta F_{t-i}^-) + \varepsilon_t \quad (4)$$

The equation-4 can be bounds tested for a long-run relationship among the variables. Indeed, Shin et al. (2011) propose the following tests for the existence of an asymmetric (cointegrating) long-run relationship. If $\rho = 0$ in Eq. (4) the NARDL model reduces to the linear regression involving only first differences, implying that there is no long-run asymmetric relationship between the levels of $GDP_t, E_t^+, E_t^-, K_t, F_t^+$ and F_t^-. In the linear case, this can be tested by testing the null $\rho = 0$ or the joint null hypothesis $\rho = \theta_E = \theta_K = \theta_F = 0$.

The study covers the period of 1960-2015. We collect data on the electric power consumption (kWh) measure of electricity consumption, real GDP (constant 2010 LCU), gross fixed capital formation (constant 2010 LCU) measure of capital, and domestic credit to the private sector (constant 2010 LCU) proxy for financial development from world development indictors (CD-ROM, 2017). Indeed, one of the indications or signs (but not the only one), of economic development and prosperity is the development and increasing share (role) of private sector in the national economy or GDP of certain countries. Referring to data from the world Bank, an economic measure of so called domestic credit to the private sector (% to GDP) means that financial resources like loans and non equity securities are provided to the private sector by financial institutions like banks and other financial corporations all measured as percentages with respect to GDP (or national size of economy). The higher this measure is, the higher financial resources or financing is to private sector in a country and so the greater opportunity and space for the private sector to develop and grow. The better the private sector gets and bigger role it has in national economy, the better is generally the health and development of the economy of this country is. Overall, the level of the financial market development affects domestic funding opportunities for firms and, therefore, their demand for foreign credit and their ability to service foreign debt.

We use total population to transform all variables into per capita units. We have transformed the annual data to into a quarter-based frequency by applying the quadratic match-sum method following Shahbaz et al. (2017).[5] To the best of our knowledge the variable financial development which we proxied by domestic credit to the private sector is available only at the annual frequency as it is computed as a weighted average of balance sheet data such as loans, purchases of nonequity securities, and trade credits and other accounts receivable, that establish a claim for repayment. Even if GDP, electricity consumption and capital formation are available for download at the quarterly frequency we find it more appropriate to use the same

[5] A mechanism of data transformation from a low frequency into a higher frequency is said to enable the quadratic match-sum method that is used to adjust seasonal variations in the raw data used in the analysis. Similarly, Cheng et al. (2012) also noted that the quadratic match-sum method easily captures the point-to-point variations in the data to address the seasonality problem. Hence, we prefer the quadratic match-sum method because it transforms the annual data into quarterly data following Denton (1971).

methodology, adopted by Shahbaz et al. (2017) to transform annual into quarterly data to avoid the common-method variance due to the use of different data transformation methods.

IV. Results and Discussion

Table 3 reports the descriptive statistics for the natural logarithm of electricity consumption, capital, financial development and economic growth. The quarterly average prices range from \$3.2699 for electricity consumption to \$4.0076 for GDP. On a quarterly basis, GDP and financial development reached their maximum values respectively in 2008 and 2009, while the highest peak in electricity consumption and capital are observed in 2010 and 2001, respectively. All the variables are negatively skewed, meaning that they have longer right tails than a normal distribution. Economic growth, electricity consumption and financial development have platykurtic distributions because their kurtosis is inferior to that of a normal distribution, while capital displays significant excess kurtosis, indicating that it has a fatter distribution than a normal distribution. The Jarque-Bera test strongly rejects the null of normality for capital, weakly rejects the null of normality for economic growth and electricity consumption, and indicates the normality of financial development. The empirical results in Table 3 also indicate a medium to high correlation between the variables meaning that there is a strong positive association between the variables. A positive correlation exists between electricity consumption and economic growth. Capital and financial development are positively correlated with economic growth. A positive correlation is found between capital (financial development) and electricity consumption. Financial development and capital are positively correlated. The previous findings regarding the correlation between our variables indicate that rising electricity consumption is favorable for economic growth. In addition, higher levels of capital formation and financial development lead electricity consumption to move up which, in turn, improves economic growth.

< Insert Table 3 here >

The NARDL model relaxes the condition that all variables should be integrated for order 1 and is invalid for I(2) variables. Hence, it is necessary to check the order of integration of the variables. In doing so, we applied the conventional unit root tests such as ADF and PP, and the results are reported in Table 4. The results show that electricity consumption, capital, financial development and real GDP per capita are nonstationary while they are stationary at their first difference. Unfortunately, conventional unit root tests have poor explanatory power in the presence of structural breaks in the series, which leads to a high risk of incorrectly accepting the null of non-stationarity. We thus perform the KP (Kim and Perron, 2009) unit root test that accounts for a possible structural break in both the level and slope of the series. The main advantage of the KP unit root test is that knowledge of the break date is not required since the test consists of an iterative procedure that endogenously determines the break date. The KP unit root test confirms the results of the conventional ADF and PP unit root tests. Indeed, our variables are nonstationary in level, but their first differences are stationary and are indeed I(1). This implies that all the variables have a unique order of integration.

< Insert Table 4 here >

< Insert Table 5 here >

To detect further patterns in the dynamics of our data variables, we investigate the presence of nonlinearity in their dynamics by using the BDS test (Brock et al. 1996). The results of BDS test (Table 5) indicate the presence of nonlinearities in the dynamics of economic growth, capital and financial development. The test fails to reject the null of linearity for electricity consumption. The lag order of the best suited NARDL model is selected based on the general-to-specific approach. Specifically, we started with $p = 4$ and $q = 4$ and based our selection of optimal lags on the AIC information criterion. In addition, the diagnosis of residuals provides a satisfactory conclusion because the respective null hypotheses of the absence of serial correlation, homoscedasticity and normality could not be rejected, indicating that the estimated NARDL model is correctly specified. Moreover, the CUSUM and CUSUMsq tests of change point detection (Figure 1) confirms that all nonlinearity is accounted for with the NARDL model and that no remaining nonlinearity is left in the filtered residuals.

The results in Table 6 show that the loading of $lnGDP_{t-1}$ is significantly negative, indicating that the estimated NARDL is stable and fits our data well. Additionally, the bounds test rejects the null hypothesis of no cointegration at the 5% level of significance. This confirms the adequacy of the NARDL for our framework. The results of the long-term and short-term symmetry are also reported in Table 6. The Wald test strongly rejects the null of long-term symmetry electricity consumption and financial development; it does not, however, reject the null of long-term symmetry for capital. In addition, the Wald test strongly rejects the null of short-term symmetry for all the considered variables such as electricity consumption, capital and financial development. The estimated long-term coefficients related to electricity consumption, L_{E^+} and L_{E^-} , which capture the long-term relationship between economic growth and electricity consumption, are statistically significant at the 1% and 10% significance levels, respectively. An increase of electricity consumption leads to an increase of economic growth, while a decrease of electricity consumption leads economic growth to decrease. A negative change of electricity consumption has a more pronounced impact on economic growth than a positive change. This indicates that there is a positive relationship between electricity consumption and economic growth in the long term. The empirical findings of long-term unidirectional causality between electricity use and economic growth are consistent with those of Ouedraogo (2013) for West African countries, Iyke (2015) for the Nigerian economy, Shahbaz et al. (2013) and He et al. (2017) for China, and Wolde-Rufael (2014) for fifteen European countries.

The increase of capital has a positive and significant influence on economic growth in the long term, but a negative change of capital does not impact economic growth in the long term[6]. This confirms that capital is positively linked with economic growth. This result is similar to that of Sahoo and Dash (2009) and Shahbaz et al. (2017) for the case of the Indian economy. This causal direction can be explained by the fact that policymakers in emerging and upper-middle-income countries ensure that public and private investments are achieved to sustain long-term economic growth and employment. Financial development also has a highly significant impact on economic growth in the long term. Contrary to electricity consumption, the increase of financial development reduces economic growth, but the decrease of financial development increases economic growth[7]. This result indicates that any positive shock in financial development hampers economic growth in Portugal. This finding is in contrast with that of Tang et al. (2013), suggesting a unidirectional causality running from financial development to electricity consumption. For them, financial development positively affects GDP. However, this

[6]Note that the increase of electricity consumption has a higher impact on economic growth than an increase of capital.
[7]Negative changes of financial development have a stronger effect on economic growth than positives changes.

same finding is in line with a number of previous studies. Indeed, this finding supports the neo-structuralist position of Lucas (1988), Mauro (1995) and Singh (1997), to name a few, which can be prominently explained by the European macroeconomic context and the recent financial crisis effects. Portugal has experienced rapid growth in credit starting from 1995. Due to easier access to external bank financing during this period, Portugal assists the rapid expansion of household credit. This level of debt has surged from 13% of GDP in 1991 to 61% in 2000 (Sirtaine and Skamnelos, 2007). This access has been reinforced by the European monetary policy. A few factors have enhanced debt. Among these factors, the reduction of the volatility of inflation, decline in interest rates, and financial liberalization have played a key role. The 2008 crisis has impacted financial companies and created instabilities in financial markets, which severely affected the Portuguese economy. In line with Singh (1997), financial development impedes economic growth in the context of economic and financial instabilities. Hence, risk-adverse investors are discouraged from investing in positive net present value projects. According to Mauro (1995), the introduction of specific financial tools allowing investors to hedge against risks may reduce the precautionary saving and thus impede economic growth. In our case, our financial development proxy is based on the ratio of domestic credit to the private sector. Thus, this negative effect may be explained by the fact that credit leads to unproductive consumption and investment activities. These results imply that financial development does not lead to economic growth and energy efficiency either. This same phenomenon has been recently observed by Shahbaz et al. (2017) for the Indian economy. Based on these results, policy makers can consider a few subsequent recommendations. For instance, they can place a special emphasis on implementing policies that result in promoting legal measures to strengthen creditor and investor rights and contract enforcement. They can also reduce loans to non-performing economic sectors by improving the risk management system. There is a need in Portugal to properly realign financial reforms to boost productive investment and thus economic growth.

The positive change of electricity consumption has a positive contemporaneous influence on economic growth, but a negative change of electricity consumption does not exert any influence on economic growth in the short term. For the case of Portugal, this result is in line with some previous empirical studies. For example, Narayan and Prasad (2008) reveal a unidirectional causality from energy consumption to GDP. Shahbaz et al. (2011) report a feedback effect between energy use and economic growth. This finding is consistent with the development of renewable energy sources to produce electricity in Portugal and spur economic growth. Fuinhas and Marquez (2012) validate the feedback effect between energy consumption and economic growth in both the long term and short term for Portugal and similar countries such as Turkey, Greece, Spain and Italy. Tang et al. (2013) corroborate the same hypothesis in the long term and short term. The authors justify these relationships by indicating that energy consumption is an important source of economic growth in Portugal, meaning that any conservation and efficiency energy policy should not be implemented because it would harm the growth and development in this country. The impact of the dummy variable is positive and statistically significant on economic growth. This indicates that the implementation of electricity (energy) reforms since 1986 has been effective in stimulating economic activity; hence, economic growth has increased.

Positive or negative changes in capital lead alternatively to an immediate increase or decrease of economic growth in the short term, indicating a significant association between economic growth and capital. In addition, even though financial development changes do not immediately influence economic growth, the results show that a one-lagged period negative change of financial development reduces economic growth significantly but that a one-lagged period positive change of capital prompts economic growth to increase.

< Insert Table 6 here >

The dynamic effects of electricity consumption, capital and financial development on economic growth can be further investigated using the dynamic multipliers. Figure 2 depicts the cumulative dynamic multipliers computed on the basis of equation 4. The dynamic multipliers show the dynamic asymmetric adjustment from an initial long-term equilibrium to a new long-term equilibrium after a positive or negative unitary shock affecting electricity consumption, capital or financial development for any horizon h. The asymmetry curve represents a linear combination $(m_h^+ - m_h^-)$ of the dynamic multipliers associated with positive and negative shocks. However, the continuous black curve and dashed black curve depict the dynamic adjustment paths following a positive and negative shock to the corresponding explanatory variable, respectively. Finally, the dashed red lines are the lower and upper bounds of the confidence interval associated with the asymmetry curve. Figure 2.a shows the asymmetric adjustment paths of economic growth following a positive and negative shock of electricity consumption. The graph shows that the effect of a negative shock dominates that of a positive shock starting from the beginning of the third quarter. In addition, an increasing asymmetric positive response of economic growth to shocks in electricity consumption is shown and stabilizes after approximately six quarters.

Figure 2.b reports the dynamic response of economic growth to a positive and negative shock in capital. The graph shows that the effect of a negative shock in capital slightly dominates that of a positive shock in capital for approximately 2 quarters, while starting from the third quarter, the reverse dominance is observed. The asymmetric response of economic growth to shocks in capital is insignificantly different from zero both in the short term and long term, except at the 10-quarter horizon, where a significantly positive response is recorded. The dynamic adjustment of economic growth to a positive or negative unitary shock in financial development variable is illustrated in Figure 2.c. The graph shows that the effect of a positive shock in financial development dominates its counterpart of a negative shock in the second and third quarters, while the effect of a negative shock dominates that of a positive shock afterwards. The asymmetric response of economic growth to shocks in financial development is increasingly significantly negative starting from the second quarter and stabilizes from quarter 8 and beyond.

< Insert Figure 1 here >

< Insert Figure 2 here >

We have applied the Hatemi-J asymmetric causality test to examine the direction of the causal relationship between economic growth and its determinants. The results are reported in Table 7, and we find that economic growth linearly generates capital at a 5% significance level. In contrast, economic growth does not cause electricity consumption and financial development at the conventional significance levels. Electricity consumption and financial development cause economic growth, but capital does not cause economic growth. This confirms the presence of the growth hypothesis. This finding is consistent with a few empirical studies in the field (Shahbaz et al. 2013, Wolde-Rufael 2014, Iyke 2015, He et al. 2017, among others). The supply-side hypothesis is also confirmed, i.e., economic growth is the cause of financial development. This is in line with Rashid and Yousaf (2015) for the Indian economy, Sadorsky (2011b) for the USA, Xu (2012) for China and Rafindadi and Ozturk (2016) for Japan. Thus, capital is caused by economic growth. Concretely, gross fixed capital formation does not have any effect on economic growth in the short term. In other words, economic growth drives investment in Portugal and not *vice versa*. This is in line with the findings of Apergis and Payne (2010) for OECD countries and Shuyun and Donghua (2011) for China. He et al. (2017) recently reported a similar result. The causal link between capital stock and economic growth is consistent with the idea that improving electricity infrastructures and services is likely to enhance economic growth without affecting the sustainable environmental development. In the Portuguese economy, policymakers can adopt relevant fiscal policies without affecting economic growth. From the policy point of view, it appears more relevant to boost economic growth before enhancing the capital formation.

The asymmetric Granger causality test shows that the positive cumulative sum of electricity consumption causes a positive cumulative sum of economic growth. In addition, the positive (negative) cumulative sum of capital and financial development causes the positive (negative) cumulative sum of economic growth. In contrast, the positive (negative) cumulative sum of economic growth does not cause a positive (negative) sum of capital and financial development, respectively. This confirms the adequacy of the NARDL model in modeling the long-term and short-term influence of electricity consumption, financial development and capital on economic growth.

The results of our paper could be transposed to other countries besides Portugal. In fact, some E.U countries adopted similar renewable energy support policies to those adopted by Portugal. Indeed, Denmark, France, Germany, Italy, Portugal and Switzerland adopted the Feed-in Tariffs or Premium Payment mechanism; Austria, Italy and Portugal embraced the Electric Utility Quota Obligation or Renewable Energy Standard strategy; Denmark, France, Portugal and Spain considered the public tenders for wind power connection licenses. These policies led to an enormous success in terms of having a large share of renewables providing electricity services. Also, like other European countries Portugal acts under the E.U directive on Renewable

Resources with common targets regarding the generation of energy based on renewables by 2020.

Consequently, our findings on Porteguese data are comparable to those of other European countries and our policy recommandations for Portugal could be useful to other European countries acting under the same E.U directive on renewable resources. In addition, Wolde-Rufael (2014) used a sample of 15 European transition economies to investigate the causal link between electricity consumption and economic growth.

< Insert Table 7 here >

V. Conclusion and Policy Implications

This paper uses an augmented Cobb-Douglas production function to examine the asymmetric effect of electricity consumption on economic growth for the Portuguese economy. Additional control variables, such as financial development and capital, are included to avoid the omission variable bias. The study employs quarterly data over the period 1960Q1 to 2015Q4. Numerous studies have sought to explain the electricity-growth nexus by using symmetric causality tests. To the best of our knowledge, asymmetric causal links between electricity consumption and economic growth have not yet received attention with regard to the Portuguese economy. To address this issue, our paper offers new insights into these connections. First, short-and long-term relationships between these variables of interest have been investigated through the nonlinear and asymmetric ARDL cointegration framework recently developed by Shin et al. (2014). Second, we also perform the Hatemi-J (2012) symmetric and asymmetric procedures to test for the short-term causality between our variables.

The empirical analyses and findings reveal important and useful results for economists and policy makers. In the Portuguese economy, the positive change of electricity consumption has a positive contemporaneous influence on economic growth, but a negative change of electricity consumption does not exert any influence on economic growth in the short term. Portugal is an energy-dependent economy because it has a relatively small energy market and limited energy resources. Electricity consumption is one of the major inputs for economic growth and development in Portugal. Historically, electricity was generated by fossil fuel, coal and natural gas and renewable energies, such as hydro power, solar power, geothermal power, wind power and others, for the past two decades. Indeed, the Portuguese government has enacted energy and environmental policies to both reduce greenhouse gases and enhance electricity capacity production. In the electricity sector, renewable energy sources account for approximately 63% of the generated capacity for the year 2014, providing a contribution of approximately 62% to the electricity supply compared to only 17% in 2005 (IEA, 2016). According to our results, electricity consumption positively impacts economic growth. Thus, a conservation energy policy should not be implemented because energy is an important driver of growth for the Portuguese economy. In other words, the economic growth and development process greatly depends on energy use (Fuinhas and Marques 2012, Tang et al. 2013). Our findings confirm the relevance of the recent energy policy implemented in Portugal, which aims at enhancing the production of electricity through renewable energy such as hydroelectricity and biomass. This strategy makes it possible to limit energy imports and, therefore, the need for more capital. The limitation of energy imports by means of producing electricity through renewable energy is also beneficial to reduce external debt and thus may help reduce Portugal's high debt level, especially after the 2008 crisis. In addition, the current Portuguese strategy to enhance the production of electricity through renewable energy allows the attainment of the further governmental objective of improving environmental quality by limiting CO_2 emissions. Capital and economic growth are positively related in the long term, while economic growth Granger-causes gross fixed capital formation in the short term. This result implies that economic growth enhances capital formation and not the opposite. From a policy perspective, it appears more relevant in this context to boost economic growth before enhancing capital formation. As for the interaction between financial development and economic growth, the findings reveal asymmetric and negative short- and long-term links. The unidirectional causality running from financial development to economic growth is found. More precisely, a positive shock in financial development hampers the growth of the Portuguese economy. In contrast, a negative shock increases the domestic economic output. Moreover, a negative change in financial development has a more pronounced effect on economic growth than that of positive change. Financial development does not appear to be an important catalyst for economic growth. On the whole, this research depicts important energy policy channels to promote growth and sustainable development in Portugal. Energy alone is insufficient to boost national revenues. To the extent possible, this research should be supported by relevant private and public investments, especially in research and development (R&D), to encourage the "green" production of electricity, design new energy-saving technologies and limit environmental degradation while increasing Portuguese economic growth at the same time.

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Tables

Table 1[8]: Economic Growth-Energy Consumption Nexus

Growth hypothesis (EC → GDP)	**Conservative hypothesis** (GDP → EC)	**Feedback hypothesis** (GDP ↔ EC)	**Neutrality hypothesis** (GDP ≠ EC)
Das et al. (2012) for Asia, Pacific and Sub-Saharan countries, Ouedraogo (2013) for West African countries, Shahbaz et al. (2013) for China, Iyke (2015) for Nigeria, Wolde-	Cheng and Lai (1997) for Taiwan, Narayan and Singh (2007) for Fiji, Narayan et al. (2010) for 10 Asian countries, Kasnan and Dunan (2015) for European Union members and candidate countries, Wolde-	Constantini and Martini (2010) for Italy; Squalli (2007) for OPEC countries; Fuinhas and Marques (2012) for Portugal, Italy, Turkey and Spain; Tang et al. (2013) for Portugal;	Wolde-Rufael (2009) for African countries, Smiech and Papiez (2014) for European Union countries

[8]A brief literature review highlights the relevant empirical studies on energy consumption (the economic growth nexus is in Table 1) and empirical studies on financial development (the energy consumption nexus is in Table 2. To the best of our knowledge, Omri (2014), Ozturk (2010) and Payne (2010) have compiled a comprehensive survey of the related literature.

Rufael (2014) for Belarus and Bulgaria, Acarvci et al. (2015) for Turkey, He et al. (2017) for China	Rufael (2014) for Russian, Lithuania, Latvia and Czech Republic	Shahbaz and Lean (2012) for Pakistan; Polemis and Dagoumas (2013) for Greece; Apergis and Payne (2011) for high- and upper-middle income countries	

Note: EC and GDP for energy consumption and economic growth respectively. ↔, → and ≠ indicate the feedback effect, unidirectional causality and neutral effect between the variables.

Table 2: Financial Development-Energy Consumption Nexus

Positive effect (FD →(+) EC)	**Negative effect** (FD →(-) EC)	**Conservative effect** (EC → FD)	**Feedback effect** (FD ↔ EC)	**Neutrality effect** (FD ≠ EC)
Rashid and Yousaf (2015) (1980-2011, India, credit), Sadorsky (2011b) (1996-2006, EU, Bank, stocks), Xu (2012) (1999-2009, China, credit, FDI), Coban and Topçu (2013) (1999-2011, old EU members, credit, bank), Ozturk and Acaravci (2013) (1960-2007, Turkey, credit, SR), Rafindadi and Ozturk (2016), (1970-2012,	Shahbaz et al. (2016) (1971-2012, credit, Pakistan) Mahalik and Mallick (2014) (1971-2009, India, credit), Chang (2015) (1999-2008, 53 countries, stocks)	Chtoui (2012) (1972-2010, Tunisia, credit, SR), Tang et Tan (2014) (1972-2009, Malaysia, bank)	Shahbaz et al. (2016) (1971-2012, Pakistan, credit), Shahbaz and Lean (2012) (1971-2008, Tunisia, credit, LR)	Coban and Topçu (2013) (1999-2011 new EU members, credit, bank), Shahbaz et al. (2013) (1971-2011, China, credit)

Japan, credit)				

Note: EC and FD for energy consumption and financial development respectively. ↔, → (+), → (-) and ≠ indicate the feedback effect, unidirectional positive or negative causality and the neutral effect between the variables. The second set of parentheses incorporate the period investigated and the variable used to measure financial development. “Credit” denotes domestic credit to the private sector, “Stocks” denotes the stock market index, and “Bank” denotes financial institutions variables. LR and SR denote long term and short term, respectively.

Table 3: Descriptive Statistics and Correlations

Variables	$\ln Y_t$	$\ln E_t$	$\ln K_t$	$\ln F_t$
Mean	4.0076	3.2699	3.2948	3.8735
Median	4.0389	3.3280	3.3506	3.8152
Maximum	4.2364	3.6954	3.6260	4.4265
Minimum	3.5317	2.5053	2.2442	3.1281
Std. Dev.	0.2096	0.3658	0.3122	0.3746
Skewness	-0.7492	-0.5410	-1.7715	-0.1440
Kurtosis	2.4847	2.0758	6.2157	2.1416
Jarque-Bera	5.8593	4.7247	53.4211	1.9126
Probability	0.0534	0.0941	0.0000	0.3843
$\ln Y_t$	1.0000			
$\ln E_t$	0.7220	1.0000		
$\ln K_t$	0.3831	0.4096	1.0000	
$\ln F_t$	0.3679	0.5425	0.3445	1.0000

Table 4: Unit Root Analysis

Variables	ADF	PP	KP	Breaks
$\ln Y_t$	-1.6870	-1.2656	-2.1986	1986
$\Delta \ln Y_t$	-4.3193***	-5.1053***	-6.1774***	1975
$\ln E_t$	1.3809	1.1896	-2.7708	2012

$\Delta \ln E_t$	-5.7371***	-5.7057***	-4.7903**	2006
$\ln K_t$	-2.0874	2.7393	-2.4808	1985
$\Delta \ln K_t$	-4.9852***	-4.7351***	-5.3023***	1997
$\ln F_t$	-1.9348	-1.6904	-2.7091	1990
$\Delta \ln F_t$	-3.2277*	-3.8966**	-4.5289**	2008

Notes: The entries indicate the BDS test results based on the residuals of the dependent variable in a VAR. *m* denotes the embedding dimension of the BDS test. The asterisks***, ** and * indicate rejection of the null of residuals being *iid* at 1%, 5%, and 10% levels of significance, respectively.

Table 5: BDS Nonlinearity Test

Variable	*m*=2	*m*=3	*m*=4	*m*=5	*m*=6
$\ln Y_t$	1.6962*	2.1046**	2.5979***	2.4904**	2.6679***
$\ln E_t$	-1.3565	-0.6830	-0.4127	-0.2876	-0.6924
$\ln K_t$	3.3006***	3.1399***	2.44926**	1.3361	0.4822
$\ln F_t$	4.6772***	5.6450***	5.7805***	5.4430***	5.0564***

Notes: The entries indicate the BDS test results based on the residuals of dependent variable in a VAR. *m* denotes the embedding dimension of the BDS test. The asterisks***, ** and * indicate rejection of the null of residuals being *iid* at 1%, 5%, and 10% levels of significance, respectively.

Table 6: Dynamic Asymmetric Production Function in Portugal

Dependent Variable: $\ln Y_t$				
Variable	Coefficient	T-Statistic	Std. Error	Prob.
Constant	1.8452	0.3775	4.8877	0.0000
$\ln Y_{t-1}$	-0.5533	0.1110	-4.9809	0.0000
$\ln E_t^+$	0.3834	0.1190	3.2204	0.0025
$\ln E_t^-$	-0.7439	0.3961	-1.8776	0.0677
$\ln K_t^+$	0.1793	0.0362	4.9445	0.0000
$\ln K_t^-$	0.1019	0.0645	1.5790	0.1222
$\ln F_t^+$	-0.1111	0.0336	-3.3012	0.0020
$\ln F_t^-$	0.3043	0.0968	3.1424	0.0032
D_{1986}	0.0137*	0.0078	1.7478	0.0875
$\Delta \ln K_t^+$	0.2701	0.0616	4.3788	0.0001
$\Delta \ln K_t^-$	0.1700	0.0830	2.0471	0.0473
$\Delta \ln E_t^+$	0.4386	0.1319	3.3245	0.0019
$\Delta \ln F_{t-1}^-$	-0.2452	0.1203	-2.0376	0.0482
$\Delta \ln K_{t-1}^+$	0.1649	0.0731	2.2559	0.0296
R^2	0.8592			
Adj-R^2	0.8169			

D-W Test	2.0079			
χ^2_{SC}	0.1705	[0.8438]		
χ^2_{FF}	1.0804	[0.2808]		
χ^2_{HET}	1.4318	[0.2042]		
χ^2_{NORM}	0.4820	[0.7747]		
L_E^+	0.6929*	L_E^-	-1.3444**	
L_K^+	0.3241*	L_K^-	0.1842	
L_F^+	-0.2008***	L_F^-	0.5499***	
$W_{LR,E}$	7.5123*	$W_{SR,E}$	11.0525***	
$W_{LR,K}$	9.9533**	$W_{SR,K}$	15.699***	
$W_{LR,F}$	13.4747*	$W_{SR,F}$	4.1520**	
F-Bound	7.122**			
Asymmetry	-4.981**			
Note: ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.				

Table 7: Hatemi-J (2012) Symmetric and Asymmetric Causality Analysis

Null hypothesis	Test value	Bootstrap CV at 1%	Bootstrap CV at 5%	Bootstrap CV at 10%
$lnY_t \neq> lnE_t$	0.035	9.230	4.815	3.014
$lnY_t^+ \neq> E_t^+$	0.894	7.620	4.026	2.917
$lnY_t^- \neq> E_t^-$	0.511	20.284	5.759	3.123
$lnE_t \neq> lnY_t$	3.997*	8.836	4.451	3.021
$lnE_t^+ \neq> lnY_t^+$	4.752**	8.352	4.648	3.181
$lnE_t^- \neq> lnY_t^-$	0.255	29.268	6.319	3.397
$lnY_t \neq> lnK_t$	5.374**	8.274	4.080	2.656
$lnY_t^+ \neq> lnK_t^+$	0.431	8.223	4.833	3.122
$lnY_t^- \neq> lnK_t^-$	2.374	13.855	5.412	3.202
$lnK_t \neq> lnY_t$	0.265	9.116	4.230	2.844
$lnK_t^+ \neq> lnY_t^+$	7.513***	7.192	4.255	2.989
$lnK_t^- \neq> lnY_t^-$	7.708**	22.644	6.802	3.604
$lnY_t \neq> lnF_t$	0.061	8.647	4.576	2.835
$lnY_t^+ \neq> lnF_t^+$	0.486	8.061	3.779	2.817
$lnY_t^- \neq> lnF_t^-$	0.904	13.625	7.339	5.572
$lnF_t \neq> lnY_t$	5.961**	9.585	5.283	3.626
$lnF_t^+ \neq> lnY_t^+$	3.320*	7.934	4.692	2.963

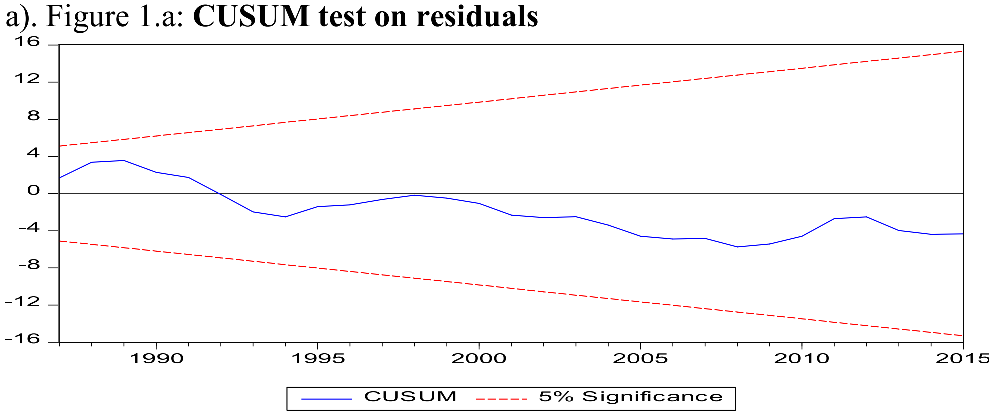
$lnF_t^- \neq> lnY_t^-$	76.459***	36.359	11.460	6.844

Note: The denotation CV is an abbreviation for the critical values that are obtained through 1000 bootstrap repetitions. An extra unrestricted lag was included in the VAR model to account for the effect of a unit root, as suggested by Toda and Yamamoto (1995).

Figures

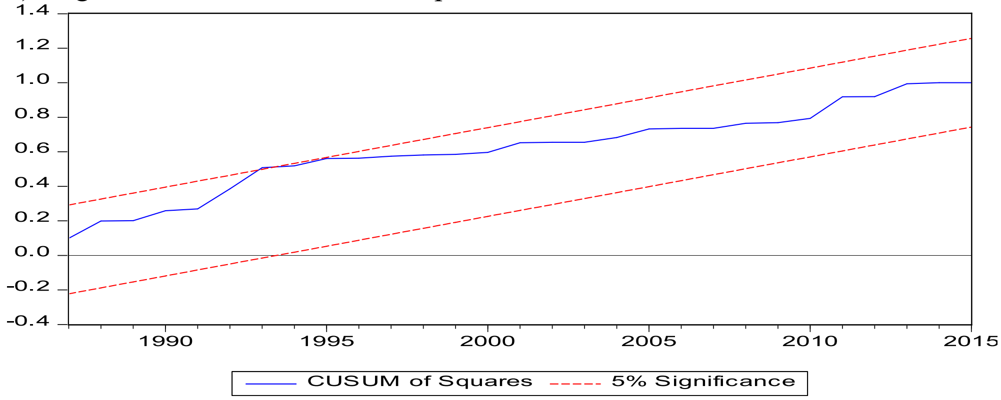
Figure 1: CUSUM and CUSUMsq for Economic Growth in Portugal

a). Figure 1.a: **CUSUM test on residuals**



Note: The blue line plots the sequence of sum of the recursive residuals issued from equation (4). In the CUSUM test residuals are ordered chronologically rather than according to the values of an explanatory variable. The dashed red lines represent the 95% critical bounds.

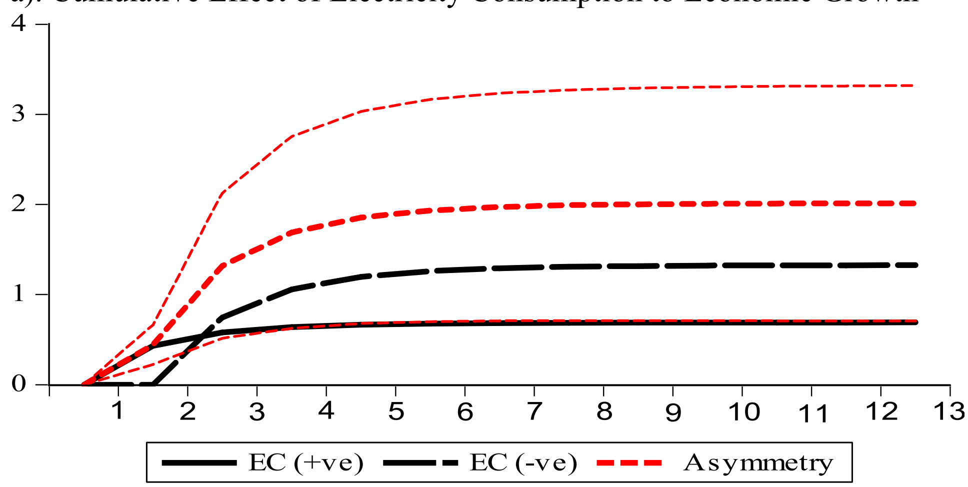
b). Figure 1-b: CUSUM test on squared residuals



Note: The blue line plots the sequence of sum of the recursive squared residuals issued from equation (4). In the CUSUMsq test residuals are ordered chronologically rather than according to the values of an explanatory variable. The dashed red lines represent the 95% critical bounds.

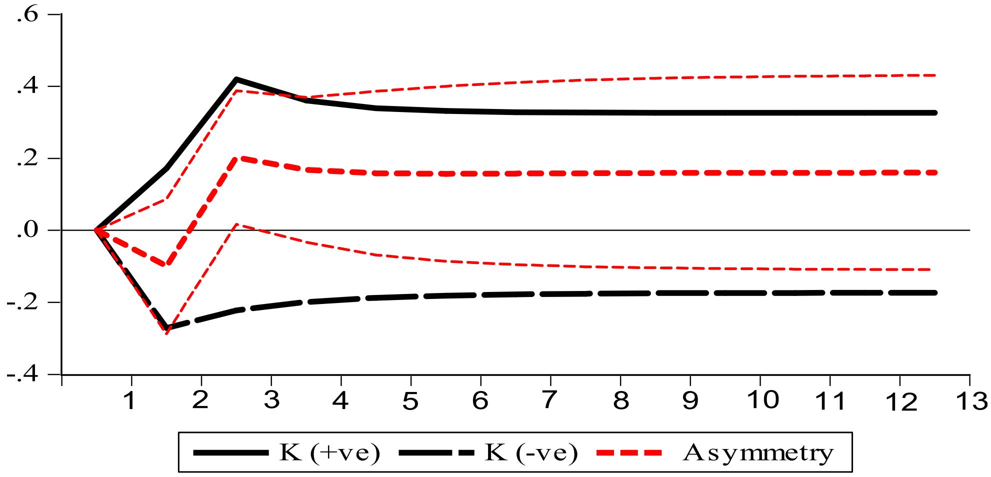
Figure 2: Asymmetric multipliers – NARDL model

a). Cumulative Effect of Electricity Consumption to Economic Growth



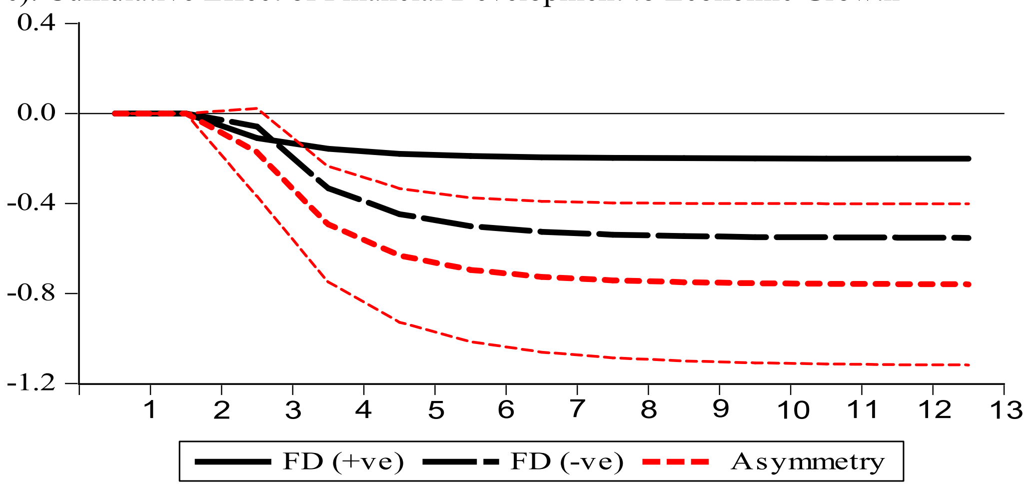
Note: The straight (dashed) black line represents the effect of a one positive (negative) unit shock of electricity consumption on economic growth. The dashed bold red line represents the asymmetry curve computed as a linear combination of the dynamic multipliers associated with positive and negative unit shocks. The dashed red lines represent the 95% critical bounds.

b). Cumulative Effect of Capital to Economic Growth



Note: The straight (dashed) black line represents the effect of a one positive (negative) unit shock of capital formation on economic growth. The dashed bold red line represents the asymmetry curve computed as a linear combination of the dynamic multipliers associated with positive and negative unit shocks. The dashed red lines represent the 95% critical bounds.

c). Cumulative Effect of Financial Development to Economic Growth



Note: The straight (dashed) black line represents the effect of a one positive (negative) unit shock of financial development on economic growth. The dashed bold red line represents the asymmetry curve computed as a linear combination of the dynamic multipliers associated with positive and negative unit shocks. The dashed red lines represent the 95% critical bounds.