# The role of foreign direct investment in the renewable electricity generation and economic growth nexus in Portugal: a cointegration and causality analysis

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# The role of foreign direct investment in the renewable electricity generation and economic growth nexus in Portugal: a cointegration and causality analysis

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## Abstract

This study attempts to investigate a supply function for electricity in Portugal through cointegration and causality analysis over the sample period of 1970 to 2008 to test hypotheses related to the electricity-economic growth nexus in the literature. Evidence is found in favour of cointegration among electricity generation from renewable sources, real gross domestic product, inward foreign direct investment, carbon emissions from electricity production and population size in Portugal by using the bound testing approach to cointegration and error correction models developed within an autoregressive distributed lag (ARDL) framework. Evidence from Granger causality tests show that unidirectional causality is running from renewable electricity production to foreign direct investment in the short-run, and indicate the presence of bilateral causality among renewable electricity production, inward foreign direct investment, real income and population. The joint short- and long-run Granger causality tests provide further support for the feedback hypothesis. These findings have important policy implications, since the promotion of appropriate structural policies aiming at attracting

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foreign direct investment can induce conservation and efficient electricity use without obstructing economic growth. The promotion of foreign direct investment is crucial in boosting Portugal's socio-economic development towards a more efficiency-orientated and less resource-depleting economy.

Keywords: Renewable electricity production, Economic growth, Foreign direct investment, ARDL cointegration, Granger causality, Portugal

## 1. Introduction

The Portuguese economy has witnessed important inflows of foreign direct investment (hereafter FDI) and sustained economic growth since joining the European Union in 1986, being able to benefit from large gains over the last three decades. Portugal has also become one of the top attractive countries for energy sector investment in new energy development and utilization technologies. One of the main objectives of the new Portuguese Energy Strategy, launched in 2010, by means of its 2020 targets and action commitments, is the establishment of favourable business conditions aiming at attracting foreign investors and reinforcing Portugal's leadership in sustainable energy. The new energy strategy acts on the demand side to control the increases in energy consumption through the promotion of energy efficiency, but also on the supply side to increase energy production through renewable energy sources. These have received increased attention in the last 15 years and renewable electricity generation is expected to continue its rapid growth. Between 2005 and 2008, Portugal has trebled its hydropower capacity, quadrupled its wind power, and is investing in flagship wave and photovoltaic plants, leading Europe's clean-tech revolution including some of the most ambitious targets and timetables for renewable energies. Undoubtedly, the energy sector has become a vital sector for socio-economic growth and development in Portugal.

This study attempts to investigate a supply function for electricity in Portugal through cointegration and causality analysis over the sample period of 1970 to 2008 to test several hypotheses from the energy economics literature on the nexus between electricity generation and economic growth. The main contribution of this study is an investigation on the short- and long-run causality issues in the sense of Granger between renewable electricity production and economic growth together with FDI in between to understand the link. The multivariate analysis is addressing a crucial omission in the literature, since it is the only know study to date on the electricity-growth-nexus incorporating the role of FDI in the case of Portugal. Understanding the role of FDI is important since FDI is capable to affect directly and indirectly economic growth and renewable electricity generation in both directions. Foreign investments are central in providing important resources to develop Portugal's renewable energy strategy and the electric energy demand from renewable energy resources. Answering the question of whether the renewable electricity generation affects economic growth or vice-versa is an important issue in order to develop and implement policies that are conducive to the socio-economic development.

The reminder of this paper is organized as follows. Section 2 presents the energy milestones and explains the current status of renewable electricity generation in Portugal. Section 3 discusses the associated hypotheses with the literature on the electricity-growth nexus and summarizes the electricity-economic growth literature. Section 4 deals with the dataset and the econometric methodology. The empirical results are discussed in section 5. Concluding remarks and policy implications are given in section 6.

## 2. Energy milestones and current status of renewable electricity generation in Portugal

Important milestones in the evolution of energy strategies and action plans include the launch of the hydropower plan in the fifties, the construction of large fossil-fuel power stations in the sixties, the consequences of the two oil price crisis in the seventies and the establishment of the *National Energy Plan* in 1983. The option of imported coal based power generation in 1986, the distribution and commercialization of natural gas and the signature of the Kyoto Protocol in 1989 are further steps taken in the Portuguese energy sector in the eighties. The third demand-driven oil price shock is accompanied by an implementation of the *National Energy Strategy* issued in 2003, which contains until 2005 the major political guidelines and relevant measures in the energy area. These procedures aimed at guarantying the security of energy supply through diversification of primary resources and energy services and the promotion of energy efficiency actions, thereby contributing to reduce energy intensity and the external energy bill; to liberalise the energy market and open-up market competition and private investment; to promote the use of endogenous energy sources, namely hydro, wind, biomass, solar (both thermal and photovoltaic) and waves; and to reduce environmental impacts to comply with the Kyoto Protocol ratified in 2002, the *National Programme for Climate Change* launched in 2004 and the *National Plan for the Allocation of Greenhouse Gas Emissions Licenses* approved in 2006. Furthermore, the *Programme for the Modernisation of the Economy* combines a number of tools for the industrial sector to improve energy efficiency and efficient co-generation during the period from 2000 to 2006. The *Energy Efficiency Programme in Buildings* (2004-2005) is carry out to support energy policy in implementing technical energy efficiency standards and energy systems for the services and residential sectors and regulations are put into force about the characteristics of thermal behaviour and the air-conditioning system in buildings. In order to further promote energy efficiency in the industrial sector, the *Regulations for the Management of Energy Consumption* are issued in 2006 and the *National Action Plan for Energy Efficiency* is enacted in 2008.

The new *National Energy* Strategy, issued in 2010, sets out the strategic direction for the energy sector and the role energy will play in the Portuguese economy over the period 2010-2020. The goal is to establish favourable business conditions in the energy sector aiming at attracting foreign investors and reinforcing Portugal's leadership in sustainable energy by containing specific targets for hydropower, wind and solar energy (including micro-generation), biomass, bio-fuels, geothermal and wave energy, and hydrogen as energy carriers. The objectives of securing energy supply through diversification of primary energy resources and energy efficiency promotion, stimulating competitiveness and ensuring environmental sustainability are among the main objectives of the energy strategy, which targets and action commitments are listed in Table 1. The revisions of the *National Action Plan for Renewables* (2010-2012) have yet deferred incentives and tax benefits in electricity micro-generation and cut investments in wind power, solar thermal and wave energy, other than the promotion of energy efficiency improvements in residential and transport sectors and smart energy management (e.g. economic lamps and micro-production for electricity and heat in hospitals).

The organization of the Portuguese electricity sector is defined since 1995, but the revision process of the National Electricity System is started in 2003 to address the adaptation of the Portuguese system to the liberalization of the natural gas and electricity markets, i.e. the creation of MIBEL – Iberian Energy Market founded in 2006, which establishes common rules for the domestic market of electricity. Unlike the previous regime, it is accompanied by the *New Electricity Regime*, which launches the new basis, principles and model of organization of the electricity sector including generation, transmission, distribution, commercialization of electricity and electricity market regulation. In the electric sector, *EDP - Energias de Portugal* (formerly

*Electricidade de Portugal*) ranks among Europe's leading electricity operators, as well as being one of Portugal's largest business groups. *EDP Renováveis* has become one of the largest players worldwide in wind-generated electricity output. Portugal is among the leading IEA member countries in terms of both hydro and wind power generation (IEA, 2009).

In an attempt to diversify the energy mix, Portugal has implemented a variety of projects and actions in most areas of the renewable energy sector (hydropower, wind, solar, geothermal, wave energy, biogas and micro-generation), together with concerns about energy efficiency. In recent years, there has been a growth in the capacity of renewable sources for electricity production. Table 2 shows that the share of renewables in total electricity power generation is around 28 per cent in 1995 and 55 per cent at the end of 2010. This achievement has not been without significant cost effectiveness because of the construction of dam's reservoirs to store energy in the form of water to level the fluctuations output of intermittent power sources. Managing the intermittence electricity generation, namely from wind power farms, has become a major challenge for grid operators. According to APREN (2009), the macroeconomic impact of renewable energies in Portugal yields a series of economic, environmental and social benefits, namely a large number of new jobs, increased energy independence, climate change mitigation and technology exports, profitability returns from international operations and support for the entry of foreign investments. The renewable energy sector is important to Portugal, because it can generate employment and make a growing contribution to the socio-economic development, and reduce environmental impacts.

## 3. Electricity production-growth hypotheses and literature

Following Ozturk (2010), four hypotheses from the empirical literature are tested. The *conservation hypothesis* is supported if unidirectional causality is found running from economic growth to electricity production, and, the *growth hypothesis* if the one-way causality direction is established from electricity production to economic growth. The former case states that economic growth plays an important role in electricity production; hence environmental policies for electricity conservation would not unfavourably affect economic growth. The latter hypothesis postulates that electricity conservation policies, which reduce electricity consumption, might have a negative impact on the economic growth and development. In the absence of causality between the variables, the premise behind the *neutrality hypothesis* specifies that electricity production have a relatively unimportant role in the economic growth process. The *feedback hypothesis* is supported when a two-way causality in a Granger sense is found between the variables. Energy conservation policies, which aim at decreasing electricity production and consumption, may as well have an effect on economic growth and similarly such changes in economic growth may be transmitted back to electricity generation.

In the light of existing literature, the main focus has been on analysing the causal relationship between energy consumption and economic growth either within a bivariate model or a multivariate modelling approach for single country studies and country panel studies (Payne, 2010b). A majority of studies rely on bivariate causality tests of electricity consumption measures and real income. In recent multivariate analysis, the relationship between electricity consumption and economic growth has been further examined in a production function with labour and capital variables. This empirical literature provides mixed results in terms of the four aforementioned hypotheses, while there is plentiful evidence supporting unidirectional and bidirectional causality between electricity consumption and economic growth (Payne, 2010a).

The relation between electricity consumption and economic growth has been the subject of intense studies, but the causal relationship between electricity generation and economic growth is less investigated in the literature. A study on the impact of the electricity supply on economic growth in Sri Lank with simple ordinary least square regression analysis has concluded that current and past changes in electricity output have a significant impact on a change in real GDP in the period of 1954-1997 (Morimoto and Hope, 2004). Another study has found unidirectional causality running from economic growth to electricity generation without any feedback effect for Indonesia using time series techniques for the period of 1971-2002 (Yoo and Kim, 2005). These studies have been carried out within a bivariate model and consequently may suffer from the potential omitted variable problem, which can be surpassed by employing a superior approach such the multivariate analysis to enable more reliable results for policy orientation.

The present multivariate analysis will address the previous omission and, in order to extend the current literature, it will shed some light on the role of FDI in the electricity-economic growth nexus. A consensus view in the empirical literature is reached on the clear positive impact of FDI on overall economic growth in less developed countries (Nair-Reichert and Weinhold, 2001), while research that has focused exclusively on developed countries has found ambiguous results (De Mello, 1999). Empirical studies have focused on the impact of FDI over the productivity and technology transfer on economic growth (Borzenstein *et al.*, 1998). FDI might improve energy efficiency via transfer of new cleaner, environmental friendly (low pollution and waste recycling) and more energy efficient technologies in the economy, hence reduce green gashouse emissions. Generally, in order to meet demand for electricity, electricity generation may be induced by FDI in many ways: industrialisation, transportation and manufacturing industry development, while electricity is required for the endorsement of manufacturing processes.

Up till now, the literature on FDI-electricity consumption and production nexus is limited and provides inconclusive direct evidence and the results emerging from this strand of literature are mainly based on empirical evidence from developing countries. Firm- and plant-level analysis has found a negative impact of foreign ownership on the energy intensity of firms (Eskland and Harrison, 2003). Cross-sectional aggregation of economic data has revealed that FDI has a reducing impact on energy intensity Mielnik and Goldemberg, 2002), while macro level panel data models have not been able to confirm a robust energy reducing effect of FDI (Hübler and Keller, 2010). Besides that, Tang (2009) has estimated an electricity consumption function for Malaysia within a multivariate model where FDI inflows and population size have shown to be positively related to electricity consumption. The role of the country's population size in the electricity supply came out to be important via the residential and commercial usage and Granger causality tests provided evidence for the feedback hypothesis among electricity consumption, income and FDI.

A closer inspection of Table 3, summarizing the empirical studies on electricity-economic growth nexus in the case of Portugal, reveals that empirical evidence provides mixed results and that the electricity-economic growth relationship is examined at the country specific level with cointegration analysis and error correction modelling, but also at the multi-country level with cross-country panel data sets. Narayan and Prasad (2008) provide evidence for a one-way causality running from electricity consumption to economic growth in the long-run run. Ciarreta and Zarraga

(2010) report that economic growth Granger cause electricity consumption instead of the other way around. Shahbaz *et al.* (2011) provide evidence for a two-way long-run causality between economic growth and electricity consumption in Portugal. Murray and Nan (1996) sustain the neutrality hypothesis. On top of that, country panel studies have reported a bidirectional short- and long-run causality between renewable electricity consumption and economic growth (Apergis and Payne, 2012) and long-run causality between renewable electricity generation and economic growth (Bayraktutan *et al.*, 2011).

## 4. Data and econometric methodology

The econometric analysis involves first testing for the order of integration of the series. The next step applies cointegration testing and error correction modelling to ascertain the presence of cointegration among the underlying variables. Then, the causal relation between the variables in the sense of Granger is examined. The weighted symmetric ADF test (ADF-WS) of Park and Fuller (1995) and the generalized least squares version of the Dickey-Fuller test (ADF-GLS) proposed by Elliot, Rothenberg and Stock (1996) are employed to overcome the low power problems associated with conventional unit root tests since the former tests attain the same statistical power with much shorter sample sizes. The optimal lag structure of these tests is selected based on Akaike information criterion, which takes into account sample size by, essentially, increasing the relative penalty for model complexity with small data sets. Inferences from unit root tests are more powerful vis-à-vis the low power of conventional ones, if the small sample simulation of the critical values of the unit root tests is computed (Pesaran and Pesaran, 2009). A robustness check of the findings is completed with the endogenous one-break of Zivot and Andrews (1992) unit root test which allows for one break in the intercept and trend.

In this study, the bound testing approach of cointegration proposed by Pesaran *et al.* (2001) is used to investigate the long-run cointegration relationship between the underlying variables in the supply function for electricity. The Autoregressive Distributed lag model or ARDL model refers to a model with lags of both the dependent and explanatory variables. This technique is suitable when the sample size is small. The ARDL bounds testing procedure can be applied regardless whether underlying regressors are purely integrated of order zero or one, but the order of integration of the dependent variable has to be one. This means that the pre-testing problems associated with conventional cointegration, which requires that all variables must be integrated of order one can be overlooked. This approach has the merit of dealing with the likely endogenous problem of the repressors and as such provides unbiased parameter estimates and valid *t*-statistics of the long run model (Pesaran and Shin, 1999). The critical bounds values provided for the ARDL modelling approach are only valid if the order of integration of the variables is not greater than one. The ARDL unrestricted autoregressive distributed lag error correction model can be specified as:

$$\begin{aligned}\Delta \ln EPR_t &= \alpha_1 + \delta_1 \ln EPR_{t-1} + \delta_2 \ln GDP_{t-1} + \delta_3 \ln FDI_{t-1} + \delta_4 \ln C_{t-1} + \delta_5 \ln P_{t-1} + \sum_{i=1}^{n} \delta_{6i} \Delta \ln EPR_{t-i} \\ &+ \sum_{i=0}^{n} \delta_{7i} \Delta \ln GDP_{t-i} + \sum_{i=0}^{n} \delta_{8i} \Delta \ln FDI_{t-i} + \sum_{i=0}^{n} \delta_{9i} \Delta \ln C_{t-i} + \sum_{i=0}^{n} \delta_{10i} \Delta \ln P_{t-i} + \varepsilon_t \qquad (1)\end{aligned}$$

where $\varepsilon_t$ and $\Delta$ are the first difference operator and the white noise error term, respectively, and *ln* denotes the natural logarithm. The multivariate framework includes electricity production from renewable sources ($EPR_t$) measured in kilowatt-hour, real gross domestic product ($GDP_t$) expressed in 2000 constant US dollars, foreign direct investment net inflows as a percentage of gross domestic product ($FDI_t$), and the control variables such as total carbon dioxide emissions from electricity production ($C_t$) measured in million metric tons, and population size ($P_t$). The sample covers the period from 1970 to 2008. All data is annual and taken from *The World Bank World Development Indicators*.

Equation (1) is estimated by ordinary least squares (OLS) to ascertain the existence of a long-run relationship among the variables by testing the joint significance of the subset of coefficients of the lagged level variables with an F-test or Wald test. The null hypothesis of having no cointegration ($H_0$: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$) is tested against the alternative hypothesis ($H_1$: $\delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq 0$). The two sets of critical values for the bounds test are those tabulated by Narayan (2005) for small sample sizes rather than Pesaran *et al.* (2001), which are based on large sample sizes. The upper bounds critical values are for I(1) regressors and the lower bounds critical values are for I(0) regressors. These are compared between the ARDL model with an unrestricted intercept and no trend, and the ARDL model with an unrestricted intercept and unrestricted trend. If the computed F-statistic exceeds the upper bound of the critical values, then the null hypothesis of no cointegration is rejected regardless of the order of integration. If the F-statistic falls below the lower critical values, the null hypothesis of no cointegration cannot be rejected. The bounds test of cointegration is inconclusive if the F-statistic lies between the two bounds. When the order of integration of all the variables is one, then inference would be based on the upper bound. Likewise, if all the variables are integrated of order zero, then hypothesis testing is based on the lower bound critical values.

The residual-based diagnostic for the multivariate model and tests of parameter stability are conducted to assess the goodness of fit of the ARDL model. The diagnostic checks include the Breusch-Godfrey serial correlation test, the autoregressive conditional heteroskedasticity (ARCH) test, the Ramsey regression equation specification error (RESET) test, and Jarque Bera test of normality. The constancy of the cointegration space is checked with the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of square of recursive residuals (CUSUMQ), and with Hansen (1992) parameter instability test. Under the alternative hypothesis of no cointegration, one should expect to see evidence of parameter instability. If all variables are I(1) processes, the parameter non-constancy $L_C$ test, which arises from the theory of Lagrange Multiplier tests for parameter instability, is an additional robustness check to evaluate the structural change of the parameters and the stability of the cointegration results by testing the null hypothesis that the parameters are stable over time. The trend component of the Hansen parameter instability test is taking one of three forms. The first form of the test is specified with only stochastic trends. Then, the trend component includes a constant term and stochastic trends in the test specification. Finally, the trend component of the cointegration test considers as well the case of stochastic and deterministic trends. The null hypothesis that the parameters are stable, i.e. that the series are cointegrated, cannot be rejected if the probability value for the test is greater than conventional levels.

If evidence for cointegration is found, then there must be Granger causality in at least one direction, but the cointegration analysis does not indicate the direction of temporal causality between the underlying variables. Inferring causal relations among variables if the cointegration analysis does not yield conclusive results can be carried out with a vector autoregressive (VAR) model by using the conventional first difference forms proposed by Engle and Granger (1987). Since the Granger representation theorem relates cointegration to error correction models and provided time series are cointegrated, the short-term disequilibrium relationship between them can be expressed in the error correction form. When cointegration among the variables in the underlying model is detected, the Granger causality analysis can be augmented with a lagged error-correction term and the causality tests can be carried out under the vector error correction model (VECM) representation, which is capable to capture short-run deviations from its long-run equilibrium path through the error correction mechanism. If evidence for a long-run relationship among the variables is found, then a multivariate *pth*-order vector error-correction model can be formulated to ascertain the causality directions of the series with the following form:

$$(1-L)\begin{bmatrix}\ln \mathrm{EPR}_{\mathrm{t}}\\ \ln \mathrm{GDP}_{\mathrm{t}}\\ \ln \mathrm{F}DI_{\mathrm{t}}\\ \ln \mathrm{C}_{\mathrm{t}}\\ \ln \mathrm{P}_{\mathrm{t}}\end{bmatrix} = \begin{bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\\ \alpha_5\end{bmatrix} + \sum_{\mathrm{i=1}}^{\mathrm{p}}(1\text{-L}) + \begin{bmatrix}A_{11,1} & A_{12,1} & A_{13,1} & A_{14,1} & A_{15,1}\\ A_{21,i} & A_{22,i} & A_{23,i} & A_{24,i} & A_{25,i}\\ A_{31,i} & A_{32,i} & A_{33,i} & A_{34,i} & A_{35,i}\\ A_{41,i} & A_{42,i} & A_{43i} & A_{44,i} & A_{45,i}\\ A_{51,i} & A_{52,i} & A_{53,i} & A_{54,i} & A_{55,i}\end{bmatrix} \times \begin{bmatrix}\alpha_1\\ \alpha_2\\ \alpha_3\\ \alpha_4\\ \alpha_5\end{bmatrix}$$

$$+\begin{bmatrix}\ln \mathrm{EPR}_{\mathrm{t-i}}\\ \ln \mathrm{GDP}_{\mathrm{t-i}}\\ \ln \mathrm{F}DI_{\mathrm{t-i}}\\ \ln \mathrm{C}_{\mathrm{t-i}}\\ \ln \mathrm{P}_{\mathrm{t-i}}\end{bmatrix} + \begin{bmatrix}\delta\\ \gamma\\ \lambda\\ \varphi\\ \psi\end{bmatrix} \times \left[\mathrm{ECT}_{\mathrm{t-1}}\right] + \begin{bmatrix}\varepsilon_{1\mathrm{t}}\\ \varepsilon_{2\mathrm{t}}\\ \varepsilon_{3\mathrm{t}}\\ \varepsilon_{4t}\\ \varepsilon_{5\mathrm{t}}\end{bmatrix} \qquad (2)$$

where *(1-L)* is the difference operator and the residual terms $\varepsilon_{1t}$, $\varepsilon_{2t}$, $\varepsilon_{3t}$, $\varepsilon_{4t}$ and $\varepsilon_{5t}$ are independent and normally distributed with zero mean and constant variance. $ECT_{t-1}$ is the one period lagged error-correction term obtained from the cointegrating equation. This term is included if the variables in the underlying model are cointegrated. The appropriate lag order *p* is chosen with Akaike information criterion because of its superior properties in small samples. The speed of adjustment to long-run equilibrium, in the context of cointegrated vector autoregressive processes, can be expressed in terms of years by taking the reciprocal of the estimated absolute value of the error correction coefficient. Equation (2) is used to test three different Granger causality models. First, weak Granger causality is tested on the sum of the lagged right-hand side variables through the *F*-test or Wald test for the significance of the relevant coefficients on the first differenced series. It is known as short-run causality in the sense that the dependent variable responds only to short term shocks to the stochastic environment. Second, another possible source of causation is through the $ECT_{t-1}$ term and the error correction model offers an alternative test of causality or weak exogeneity of the dependent variable. The coefficients on the $ECT_{t-1}$ represent how fast deviations from the long-run equilibrium are eliminated following changes in each variable. Long-run causality is examined through the *t*-test or Wald test for the significance of the related coefficients on the lagged error-correction term. Third, it is also desirable to check whether the two sources of causation are jointly significant, i.e. to test for joint short- and long-run Granger causality referred to as strong Granger causality test. The joint significance test indicates which variable(s) bear the burden of short-run adjustment to re-establish long-run equilibrium, following a shock to the system. Strong Granger causality is detected through joint hypotheses testing of significance with *F*-test or Wald test on both $ECT_{t-1}$ term and lagged explanatory variables. A statistically significant $ECT_{t-1}$ term determines the long-run causality going from all of the explanatory variables toward the dependent variable. This approach is implemented in this study because the variables are cointegrated.

## 5. Empirical results

Table 4 summarizes the unit root tests of the generalized least squares version of the Dickey-Fuller test (ADF-GLS) and of the weighted symmetric augmented Dickey-Fuller test (ADF-GLS) for all the series in level form and in their first differences.

Table 5 summarizes the Zivot-Andrews unit root test with one structural break allowing for a change in the intercept and trend. Both unit root tests confirm that all variables are integrated of the same order, hence I(1). Considering structural breaks in all series, all variables are found to be integrated of order one, hence they are difference stationary with one endogenous break. The breakpoints seem to coincide with the end-eighties and end-nineties, which correspond to Portugal's entry into the European Union and the beginning of the Economic Monetary Union. The 1978 time break is possibly related to post-WWII immigration processes. In the following five years after the political, social and economical changes initiated with the 1974 Revolution, the foreign population almost doubled due to the arrival of new population from the ex-colonies. These events have probably been translated into either shocks or structural breaks.

A closer inspection of Table 6 reveals that $F_{EPRt}$ $(EPR_t|GDP_t, FDI_t, C_t, P_t)$ passes the cointegration tests on the basis of 1 percent significance level. The bounds F–test for cointegration test yields evidence of a long-run relationship between renewable electricity production, real income, FDI, carbon emissions and population size. The calculated *F*-statistic for the ARDL (1,0,1,0,0) model is 6.036 and greater than the critical values of the top level of the bound provided by Narayan (2005). The null hypothesis of no cointegration is rejected and the bounds cointegration test is regarded as conclusive since the computed *F*-statistic falls outside the upper bound critical values in significance levels of 1, 5 and 10 percent. This result holds for both the unrestricted intercept and no trend, and for the unrestricted intercept and unrestricted trend cases. The Jarque-Bara test indicates that the residuals are normally distributed. The serial correlation Lagrange Multiplier (LM) test cannot reject the null hypotheses of no serial correlation. There is also an absence of heteroskedasticity problems in the residuals. The Ramsey RESET conveys that the test has not been able to detect any missspecification. Overall, the model has the correct functional form and the model's residuals are serially uncorrelated, normally distributed and heteroskedastic. A closer look at the plot of the CUSUM of squares test to the recursive residuals of the estimated ARDL in Figure 1 reveals parameter constancy over the sample period. The CUSUMSQ statistics are always within the 5 percent critical bounds of parameter stability. The parameter non-constancy tests for I(1) variables corroborate the CUSUMSQ test, since the probability value of >0.2 is greater than 0.05 in all test specifications. Hence, the null hypothesis that the parameters are stable cannot be rejected and cointegration is present. The $L_C$ statistics are 0.272, 0.335 and 0.503, when the trend component specification includes only stochastic trends, an intercept term and stochastic trends and both stochastic and deterministic trends, respectively. This indicates that the structure of the parameters have not diverged abnormally over time.

Table 7 reports that the long-run coefficients on the error correction terms are statistically significant in the VECM at 1% and 5%, which confirms the result from the bounds test for cointegration. Additionally, they have all a negative sign, which is the expected correct sign, implying that there is bidirectional causality among all the variables in the long-run run, the only exception being carbon emissions. The significance of the error correction mechanisms indicate that if the system is exposed to shocks, the speed of adjustment to the equilibrium occurs at a relatively high convergence speed for renewable electricity production (-0.891) and FDI (-0.814). The speed of adjustment parameter is relatively low for income (-0.294), carbon emissions (-0.211) and population size (-0.119). These findings imply that changes in the renewable electricity production and FDI are the main function of disequilibrium in the cointegration relationship. The weak exogeneity of carbon emissions indicate that this variable does not adjust towards long-run equilibrium. Turning to the short-run estimations, the results vary among the vector error correction models. The population size is significant at the 10% level in the real income and FDI equations and renewable electricity production is significant at 5% in the FDI equation, but neither are FDI and income, nor carbon emissions. This suggests that in the short-run there is a weak Granger causality running from population size to both income and FDI and from renewable electricity production to FDI, but there is neutrality between electricity production and income and vice-versa. Renewable electricity generation plays a positive and statistically significant impact on FDI in the short-run. Given the statistical significance of the error correction term at the 1 per cent level, the speed of adjustment to long-run equilibrium is 1.22 years.

The main findings are summarized as follows. Unidirectional causality running from renewable electricity generation to FDI is found in the short-run. In other words, when a shock occurs in the system, electricity production from renewable sources would make the short-run adjustment to restore the long-run equilibrium. The feedback hypothesis is confirmed since there is evidence for bidirectional causality between renewable electricity generation, economic growth, FDI and population size in the long-run model and joint causality implies the same as in long run. The results of the Granger-causality tests obtained with the error correction mechanisms are in accordance to those of Bayraktutan *et al.* (2011), since these authors also find bidirectional causality in the long-run between electricity generation from renewable sources and economic growth. In the error correction model, the statistical significance of the error correction terms suggest that renewable electricity generation responds rapidly to deviations from long-run equilibrium with an adjustment of about 1.12 years, whereas economic growth presents a slowest adjustment towards equilibrium with 3.40 years.

Apart from that, the findings highlight the importance of renewable electricity sources within Portugal's energy portfolio and indicate that FDI is an important catalyst and complement to electricity generation in driving economic growth. Likewise, economic growth and FDI are important in providing the essential resources for sustained economic development and use of renewable energy.

## 6. Conclusions

This study has attempted to investigate a supply function for electricity in Portugal through cointegration and causality techniques to test hypotheses related to the electricity-economic growth nexus in the literature. The empirical findings confirm the hypothesized two-way causality or feedback hypothesis among the underlying variables. Long-run causality runs from FDI and economic growth to renewable electricity production with feedback. Short-run causality runs from renewable electricity production to FDI. Joint causality implies the same as in long-run. The direction of causality sheds some light on energy policies relating generation, transmission and distribution of electricity in Portugal. The enhancement of renewable electricity production capacity and its efficient utilization can be promoted keeping in view the predictability of changes in real economic activity. Renewable electricity generation and FDI may serve as a catalyst for the modernization of the energy sector in meeting sustainability objectives specified by policy makers. Therefore, the future targets and planning for renewable electricity production need to be synchronized with the promotion of foreign investments not only in renewable electricity generation, but also in other key areas such as recycling and manufacturing of environmental technology products. The central government and local authorities have to share roles in effectively promoting FDI to reduce sector-specific environmental impacts and gashouse gas emissions.

Developments and future research should look at critical success factors for foreign direct investment and technology transfer at the industry and sector level, including the adoption of adequate measures for business facilitation and investment promotion. It is important to emphasize the importance of this type of studies for policy makers. This is necessary in Portugal to meet the challenges of the Kyoto Protocol on carbon emissions, the electricity conservation policies and the use of more efficient generation technologies without obstructing sustained socio-economic growth.

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## Appendix

**Figure 1.** Plot of the CUSUM of squares from bounds tests.

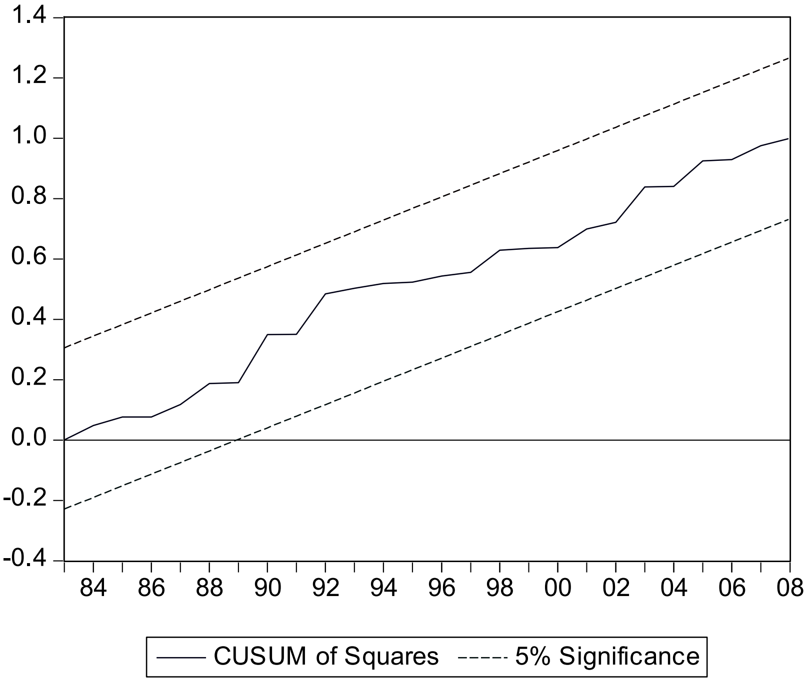

**Table 1**
The Portuguese Energy Strategy.

| ***Strategic lines*** | ***2020 targets*** |
|---|---|
| Agenda for competitiveness, economic growth, energy and financial independence | Development of renewable energy cluster generating 3800 million € gross value added and the creation of 100 thousand new jobs |
| Invest in renewable energy | 31% total energy demand from renewable energy sources (60% of electricity consumption)<br>10% reduction in energy consumption in the transport sector<br>25% reduction in oil imports from endogenous sources (annual cost reduction of 2000 million €) |
| Promote energy efficiency | 20% reduction in final energy consumption<br>Creation of 21 thousand new jobs<br>Overall investments of 13000 million €<br>Additional exports of 4000 million € |
| Ensure security of supply | Diversification of energy-mix<br>Reduction of external energy dependence from 83% in 2008 to 74% in 2020 |
| Sustainability of the energy strategy | Economic and environmental sustainability by reducing house gas emissions and managing efficiently costs and benefits of implementation plan |

**Table 2**
Electricity generation from renewable sources.

| Year | Hydro | Biomass | Wind | Thermal | Solar | Renewables |
|---|---|---|---|---|---|---|
| 1995 | 88.98 | 10.40 | 0.17 | 0.44 | 0.01 | 28.56 |
| 1996 | 93.52 | 6.03 | 0.13 | 0.31 | 0.01 | 46.05 |
| 1997 | 92.13 | 7.24 | 0.27 | 0,36 | 0.01 | 41.81 |
| 1998 | 91.77 | 7.19 | 0.63 | 0,41 | 0.01 | 36.49 |
| 1999 | 84.13 | 13.64 | 1.34 | 0.88 | 0.02 | 20.96 |
| 2000 | 86.66 | 11.50 | 1.24 | 0.59 | 0.01 | 30.89 |
| 2001 | 87.99 | 9.79 | 1.57 | 0.64 | 0.01 | 35.13 |
| 2002 | 79.02 | 16.58 | 3.46 | 0.92 | 0.02 | 22.66 |
| 2003 | 87.70 | 9.08 | 2.71 | 0.49 | 0.02 | 39.07 |
| 2004 | 78.98 | 13.99 | 6.35 | 0.65 | 0.02 | 28.48 |
| 2005 | 57.24 | 22.10 | 19.83 | 0.79 | 0.03 | 19.20 |
| 2006 | 69.57 | 12.14 | 17.75 | 0.52 | 0.03 | 33.61 |
| 2007 | 62.01 | 12.70 | 23.96 | 1.19 | 0.14 | 35.66 |
| 2008 | 47.32 | 13.83 | 37.34 | 1.25 | 0.27 | 33.54 |
| 2009 | 46.64 | 12.30 | 39.23 | 1.00 | 0.83 | 38.47 |
| 2010 | 55.97 | 11.59 | 31.05 | 0.67 | 0.72 | 54.66 |

Notes: The numbers are shares. The first five columns indicate the shares of hydro, biomass, wind, thermal, and solar in renewable electricity generation capacity. The last column reports the shares of renewables in annual electricity power generation.

**Table 3**
Summary of single-country and multi-country studies on electricity-growth nexus for Portugal.

| Authors | Time period | Variables | Methodology | Direction of causation |
|---|---|---|---|---|
| *I. Country specific studies* | | | | |
| Shabaz et al. (2011) | 1971-2009 | Electricity consumption per capita, total employment, real GDP per capita | ARDL Bounds testing;<br>Granger causality–VECM | EC → GDP (short run)<br>EC ↔ GDP (long-run and strong causality) |
| *II. Country panel studies* | | | | |
| Murray and Nan (1996) | 1970-1990 | Electricity consumption, real GDP | Granger causality–VAR | EC ≠ Y |
| Narayan and Prasad (2008) | 1960-2002 | Electricity consumption, real GDP | Toda-Yamamoto's test for causality with bootstrapping approach | EC → GDP (long-run) |
| Ciarreta et al. (2009) | 1970-2004 | Electricity consumption, real GDP | FMOLS panel cointegration,<br>Granger-causality–VAR | GDP→EC |
| Bayraktutan et al. (2011) | 1980-2007 | Electricity production from renewable sources, real GDP | Holtz-Eakin test for causality, VAR | EPR ↔ GDP (long-run) |
| Apergis and Payne (2012) | 1990-2007 | Renewable and non-renewable electricity consumption, real GDP, real gross fixed capital formation, total labour force | FMOLS panel cointegration;<br>Granger causality–VECM | EC, ECR ↔ GDP (short and long-run) |

Notes: the symbols →, ↔ and ≠ represent to one-way or unidirectional, two-way directional or no Granger causality, respectively. Abbreviations of variables are defined as follows: EC = electricity consumption, ECR = electricity consumption from renewable sources, EPR = electricity production from renewable sources and GDP = real gross domestic product. Abbreviations for models: FMOLS = fully modified ordinary least squares, VAR = vector autoregressive model and VECM = vector error correction model. Numbers in squared brackets indicate references of authors.

**Table 4**
Results of ADF-GLS and ADF-WS unit root tests.

| *Variable* | *Model* | *In levels* | | *In 1st differences* | |
|---|---|---|---|---|---|
| | | ADF-GLS | ADF-WS | ADF-GLS | ADF-WS |
| $EPR_t$ | *c* | -0.192(4) | -0.594(4) | -5.435(3) | -5.984(3) |
| | *c+t* | -3.228(4) | -3.681(4) | -5.343(3) | -5.885(3) |
| $GDP_t$ | *c* | 0.247(4) | 0.875(2) | -3.915(0) | -3.837(0) |
| | *c+t* | -0.933(4) | -0.937(4) | -4.712(3) | -4.200(0) |
| $FDI_t$ | *c* | -2.161(0) | -1.304(4) | -5.228(1) | -7.421(1) |
| | *c+t* | -4.238(0) | -3.295(3) | -6.560(1) | -7.301(1) |
| $C_t$ | *c* | -0.086(0) | 0.144(0) | -4.249(1) | -6.273(1) |
| | *c+t* | -1.780(0) | -1.958(0) | -6.272(1) | -6.965(1) |
| $P_t$ | *c* | -0.578(3) | -1.315(3) | -7.962(2) | -2.854(3) |
| | *c+t* | -1.559(4) | -2.915(3) | -7.093(2) | -3.744(1) |
| *Critical values* | *c* | -2.388(0) | -2.610(0) | -2.347(0) | -2.576(0) |
| | | -2.445(1) | -2.686(1) | -2.349(1) | -2.677(1) |
| | | -2.279(2) | -2.600(2) | -2.283(2) | -2.630(2) |
| | | -2.267(3) | -2.610(3) | -2.240(3) | -2.667(3) |
| | | -2.257(4) | -2.708(4) | -2.233(4) | -2.685(4) |
| | *c+t* | -3.299(0) | -3.381(0) | -3.407(0) | -3.406(0) |
| | | -3.429(1) | -3.520(1) | -3.279(1) | -3.456(1) |
| | | -3.128(2) | -3.359(2) | -3.158(2) | -3.356(2) |
| | | -3.135(3) | -3.448(3) | -3.122(3) | -3.471(3) |
| | | -3.074(4) | -3.488(4) | -3.040(4) | -3.429(4) |

Notes: the null hypothesis of a unit root is tested against the alternative of stationarity in the series in level form and in their first differences. The figure in the parenthesis is the optimal lag structure for ADF-GLS and ADF-WS unit root tests selected by Akaike information criterion. The symbols *c* and *c+t* denote that the Dickey-Fuller regressions include, firstly, only an intercept term, and, secondly, both a constant and a linear trend. The critical values are 95% simulated critical values using the small sample size and computed by stochastic simulations for relevant numbers of lags in parentheses using 1000 replications. All variables are in natural logarithms.

**Table 5**

Results of Zivot-Andrews test for unit roots in the presence of one structural break.

| | $EPR_t$ | $GDP_t$ | $FDI_t$ | $C_t$ | $P_t$ |
|---|---|---|---|---|---|
| *TB* | 1996 | 2000 | 1988 | 1989 | 1978 |
| $\delta$ | -1.498 | -0.560 | -0.764 | -0.791 | -0.218 |
| | (-4.262) | (-3.808) | (-2.746) | (-3.779) | (-3.358) |
| $\theta$ | -0.011 | -0.011 | -0.042 | -0.042 | 0.001 |
| | (-0.534) | (-3.004) | (-1.046) | (0.011) | (-0.582) |
| $\gamma$ | 0.408 | 0.023 | 0.699 | 0.418 | -0.009 |
| | (2.059) | (1.165) | (1.521) | (3.865) | (1.491) |
| $\beta$ | 0.016 | 0.017 | 0.044 | 0.055 | 0.001 |
| | (1.792) | (3.751) | (1.285) | (3.162) | (0.784) |

Notes: TB denotes the estimated breakpoint and their corresponding *t*-statistics are compared to the critical values tabulated by Zivot and Andrews (1992), which are at 1% and 5% significance levels -5.570 and -5.080, respectively. The unit root test allows for one structural break in both intercept and trend. The optimal number of lagged first differenced terms included in the unit root tests to correct for serial correlation is selected based on Akaike information criterion and *k*=2 for all series. The *t*-statistics of the related coefficients are given in parenthesis. The time of break is chosen at the point that minimizes the one-sided *t*-statistic in equation $\Delta y_t = \mu + \alpha y_{t-1} + \beta_t + \Theta DU_t + \gamma DT_t + \sum_{j=1}^{k=1} c_j \Delta y_{t-j} + \varepsilon_t$. The first difference operator $\Delta$ and the residuals $\varepsilon_t$ are assumed to be normally distributed and white noise. $DU_t$ and $DT_t$ are dummy variables that capture a structural break in the mean shift and slope shift occurring at time of break, respectively. Let's TB denote the time of break, then $DU_t$=1 if *t*>TB and zero otherwise. $DT_t$ is equal to (*t*-TB) if *t*>TB and zero otherwise. The null is rejected if the coefficient is statistically significant.

**Table 6**
Results of bounds test for cointegration.

| *I. Bounds test for cointegration* | | |
|---|---|---|
| F-statistic: $F_{EPRt}$ $(EPR_t \mid GDP_t, FDI_t, C_t, P_t)$ | 6.036*** | |
| Significance level | Critical values (T=40)[#] | |
| | Lower bounds I(0) | Upper bounds I(1) |
| 1% | 4.045 | 5.898 |
| 5% | 2.962 | 4.268 |
| 10% | 2.483 | 3.647 |
| | Critical values (T=40)[##] | |
| | Lower bounds I(0) | Upper bounds I(1) |
| 1% | 4.885 | 6.550 |
| 5% | 3.577 | 4.923 |
| 10% | 3.032 | 4.213 |
| *II. Diagnostic tests* | | |
| R-Squared | 0.608 | |
| R-Bar-Squared | 0.457 | |
| F-statistics | 4.037 (0.000) | |
| Breusch-Godfrey serial correlation LM test | 0.444 (0.511) | |
| Heteroskedasticity test ARCH | 1.757 (0.193) | |
| Ramsey RESET | 0.102 (0.752) | |
| Jarque-Bera test | 2.557 (0.278) | |

Notes: the asterisks ***, **, and * denote the significance at the 1, 5 and 10 per cent levels, respectively. The optimal lag structure is one. The critical values bounds for [#] unrestricted intercept and no trend and for [##] unrestricted intercept and unrestricted trend are taken from Narayan (2005). The probability values for the diagnostic tests are given in parentheses. Abbreviations: ARCH = autoregressive conditional heteroskedasticity and RESET = Ramsey regression equation specification error test.

**Table 7**
Granger causality tests results.

| *Dependent variable* | Type of Granger causality | | | | | |
|---|---|---|---|---|---|---|
| | *I. Short-run* | | | | | *II.Long-run* |
| | $\sum\Delta EPR_{t-i}$ | $\sum\Delta GDP_{t-i}$ | $\sum\Delta FDI_{t-i}$ | $\sum\Delta C_{t-i}$ | $\sum\Delta P_{t-i}$ | $ECT_{t-1}$ |
| | *F*-statistics (*p*-values) | | | | | [*t*-statistics] |
| $\Delta EPR_t$ | - | 0.122 | 0.076 | 0.056 | 0.349 | -0.891 |
| | | (0.728) | (0.783) | (0.813) | (0.558) | [-2.410]** |
| $\Delta GDP_t$ | 0.893 | - | 1.123 | 1.070 | 3.742 | -0.294 |
| | (0.352) | | (0.297) | (0.309) | (0.062)* | [-3.184]*** |
| $\Delta FDI_t$ | 6.096 | 0.491 | - | 0.584 | 3.446 | -0.814 |
| | (0.019)** | (0.488) | | (0.450) | (0.073)* | [-3.743]*** |
| $\Delta C_t$ | 0.692 | 0.355 | 0.056 | - | 0.004 | -0.211 |
| | (0.411) | (0.555) | (0.813) | | (0.950) | [-0.781] |
| $\Delta P_t$ | 0.187 | 0.370 | 0.486 | 0.101 | - | -0.119 |
| | (0.667) | (0.547) | (0.490) | (0.752) | | [-3.304]*** |
| | *III. Joint short-run and long-run* | | | | | |
| | $\Delta EPR_t$, $ECT_{t-1}$ | $\Delta GDP_t$, $ECT_{t-1}$ | $\Delta FDI_t$, $ECT_{t-1}$ | $\Delta C_t$, $ECT_{t-1}$ | $\Delta P_t$, $ECT_{t-1}$ | |
| | *F*-statistics (*p*-values) | | | | | |
| $\Delta EPR_t$ | - | 2.919 | 2.967 | 3.042 | 2.950 | |
| | | (0.069)* | (0.066)* | (0.062)* | (0.067)* | |
| $\Delta GDP_t$ | 5.214 | - | 5.602 | 5.205 | 5.746 | |
| | (0.011)** | | (0.008)*** | (0.011)** | (0.007)*** | |
| $\Delta FDI_t$ | 9.555 | 8.582 | - | 7.321 | 7.737 | |
| | (0.000)*** | (0.001)*** | | (0.002)*** | (0.002)*** | |
| $\Delta C_t$ | 0.472 | 0.703 | 0.403 | - | 0.350 | |
| | (0.627) | (0.502) | (0.671) | | (0.707) | |
| $\Delta P_t$ | 5.787 | 5.465 | 5.486 | 5.585 | - | |
| | (0.007)*** | (0.009)*** | (0.009)*** | (0.008)*** | | |

Notes: Δ is the first difference operator. ECT is the lagged error correction term. The asterisks ***, **, and * denote the significance at the 1, 5 and 10 per cent levels, respectively. The null hypothesis is that of no causal relationship between variables. Figures in parentheses are *p*-values for Wald tests with a $X^2$ distribution. Values in [ ] indicate the *t*-statistics of the ECM coefficients. All variables are in natural logarithms.