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The electricity consumption and economic growth nexus: Evidence from Greece

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HIGHLIGHTS

- We examine the causality between electricity consumption and economic growth.
- We used cointegration techniques to capture short-run and long-run dynamics.
- The relationship between electricity consumption and GDP is bi-directional.
- Residential energy switching in Greece is still limited.
- The implementation of renewable energy sources should ensure security of supply.

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ABSTRACT

This paper attempts to cast light into the relationship between electricity consumption and economic growth in Greece in a multivariate framework. For this purpose we used cointegration techniques and the vector error correction model in order to capture short-run and long-run dynamics over the sample period 1970–2011. The empirical results reveal that in the long-run electricity demand appears to be price inelastic and income elastic, while in the short-run the relevant elasticities are below unity. We also argue that the causal relationship between electricity consumption and economic growth in Greece is bi-directional. Our results strengthen the notion that Greece is an energy dependent country and well directed energy conservation policies could even boost economic growth. Furthermore, the implementation of renewable energy sources should provide significant benefits ensuring sufficient security of supply in the Greek energy system. This evidence can provide a new basis for discussion on the appropriate design and implementation of environmental and energy policies for Greece and other medium sized economies with similar characteristics.

1. Introduction

The relationship between energy consumption and economic growth has been the subject of thorough research and of great interest to economists as well as to policy makers. Knowledge of the actual causality direction between electricity consumption and income growth has important implications for modeling environmental and growth policies. More specifically, if the causality runs from income growth to electricity consumption, then environmental policies for electricity conservation may not affect income growth. On the other hand, if there is a positive causality running from electricity consumption to income growth, then environmental policies aimed at conserving electricity consumption may negatively affect economic growth and development (Tang and Tan (2012)).

During the last few years, there is a substantial body of literature assessing the determinants and the direction of causality between economic growth and energy consumption. However, the bulk of the literature has so far offered conflicting and inconsistent results concerning the causal relationship between energy consumption and economic growth (Hondroyiannis et al., 2002). Although, the empirical evidence in a study over 100 countries (Ferguson and Wilkinson, 2000) shows a strong correlation between them, this does not necessary imply a causal relationship. The evidence concerning the causality is ambiguous, from bi-directional (in both directions) and uni-directional (from energy consumption to economic growth or the opposite) to no causality. Another extensive study (Payne, 2010) provides a survey of the international evidence on the causal relationship between energy consumption and economic growth, where the empirical results

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are again mixed concerning the causality, even for a specific energy carrier such as the electricity. The variation in results may be attributed to variable selection, model specifications, time periods of the studies, different institutional, structural frameworks in the countries examined, and econometric approaches undertaken (Hondroyiannis et al., 2002; Payne, 2010).

Despite the fact that the relationship between energy consumption and economic growth has been extensively studied over the past three decades, the development of new energy and environmental policies, the new climate regime and the development of new econometric techniques provide enough space for further research. The initial interest in the causality of this relationship, not only in the demand side but also in the production side, was triggered mainly by the energy crises in the 1970s. This has created doubts on the conventional neoclassical production function, where Land, Labor and Capital were recognized as the main factors of production (Obas John, 1996). The energy crises together with fast technological developments have created space for examining the relationship of the energy factor and of endogenous technological change in economic growth.

Over the last two decades, the advance of econometric techniques together with the new climate regime created space and stimulated further empirical research. The increase of global awareness on climate change issues, enhanced mainly through the introduction of the Kyoto Protocol, has placed pressure on designing energy and environmental policies with low marginal abatement costs. Energy efficiency projects have been prioritized in the portfolio of policies for many countries, as those policies have been considered as no regret options, meaning that they provide even gains in the macro-economy. Estimates of the effects of no-regrets efficiency policies have been reported by the International Energy Agency (IzEA WEO, 2006), and synthesized in the IPCC AR4 WG3 report (IPCC AR4, 2007), using detailed bottom-up models but creating also need for examining from a top-down approach.

Therefore, examining the impact of energy efficiency policies on economic growth became a crucial task among researchers and policy makers. Moreover, the extent of the implementation of energy efficiency measures has created doubts on the extent of the rebound effect, which refers to the idea that some or all of the expected reductions in energy consumption as a result of energy-efficiency improvements are offset by an increasing demand for energy services, arising from reductions in the effective price of energy services resulting from those improvements (Barker et al., 2009). This rebound effect is highly influenced by the level of environmental awareness, as a behavioral shift can lock-in or even accelerate the effects of energy savings projects.

The need for directing specific policies has led to the development of “bottom-up” detailed models and on the disaggregation of econometric studies. Recent research does not focus on aggregate energy demand consumption but on specific sectors (Rapanos and Polemis, 2006; Polemis, 2006; 2007; Wolde-Rufael, 2004) and/or on disaggregated energy demand and specific energy carriers (Hu and Lin, 2008; Tang and Tan, 2012; Chandran et al., 2010; Yuan et al., 2007; Altinay and Karagol, 2005) and/or on countries with specific characteristics (Wolde-Rufael, 2009; Narayan and Smyth, 2008; Lee and Chang, 2008). Again in the above mentioned studies, the causality between disaggregated energy demand and economic activity is ambiguous.

The causality between energy consumption and economic growth is ambiguous among countries (Ozturk, 2010; Payne, 2010; Wolde-Rufeal, 2004) or even among studies for the same country, as each country has its own institutional, structural characteristics, different exposure in foreign energy resources and therefore different exposure in energy supply crises, different climatic conditions and behavioral patterns.

Over the last few decades a number of empirical studies for the Greek economy investigated energy demand relationship with economic growth and prices. They have shown mixed results, either observing falling income and price elasticities of energy demand (Samouilidis and Mitropoulos, 1984), either concluding that elasticities behave as a cluster against energy demand (Mitropoulos et al, 1982), either showing that energy demand is rather inelastic with respect to prices (Donatos and Mergos, 1989; Donatos and Mergos, 1991; Christodoulakis and Kalyvitis, 1997; Zonzilos and Lolos, 1996) or showing a bi-directional causality between energy demand and economic growth Hondroyiannis et al., 2002. Other studies (Polemis, 2006, 2007) have examined this causality between energy demand and economic growth, but focused on specific sectors of the economy.

However most of those studies have one or more of the following three main shortcomings: they have not focused on the possible interdependence between energy demand and economic activity, failing therefore to catch the notion of causality and possible rebound effects. They have focused on bivariate or trivariate variable models, and finally they have not focused on electricity consumption. The purpose of this paper is not to resolve this variation in causality, but to provide new evidence and reinvestigate the notion of causality for Greece, considering the latest available data. On the one hand, our aim is to focus on the causality between the electricity demand and the economic growth in a multivariate framework, while on the other hand the novelty of this paper concerns the investigation of the dynamic interactions between the electricity consumption and its main determinants. This can provide a new basis for discussion on the appropriate design and implementation of environmental and energy policies for Greece and other medium-sized economies with similar characteristics.

The rest of the paper is organized in the following way. Section 2 briefly reviews the structure of the electricity sector in Greece. Section 3 deals with methodological issues and the data used in the empirical analysis, while in Section 4 the empirical evidence is presented. Finally, in Section 5, the conclusions of the analysis are summarized and policy implications are discussed.

2. The electricity sector in Greece

The liberalization process of the Greek electricity market started with the law 2773/1999, through which market participants, by obtaining the appropriate Licenses, are enabled to participate in one of the following separate activities: production, trading and supply. This law has eliminated the monopoly of the Public Power Corporation S.A. (PPC) only in the non-interconnected islands. Moreover it has established the Regulatory Authority of Energy and the Hellenic Transmission System Operator S.A. The liberalization processes included the incorporation of a number of European directives and national legislation.

The latest important updates were – through the Law 4001/2011 – the establishment of the Operator of the Electricity Market, of the Independent Transmission Operator S.A. and of the Distribution System Operator S.A. Over the last decade a number of important investments have been made, through the construction of natural gas units and Renewable Energy Resources. Moreover, a significant number of participants have entered the relevant markets, acting either as suppliers of electricity to final customers or as traders of electricity in the interconnections.

During the last few years, there is a process in the EU towards the integration of European electricity and gas markets, through market coupling and the establishment of a common Target Model. The Greek electricity market, already acting as a transit country between cheap north borders and the more expensive Italian market, is considered a mature market and will play an important role for the integration of

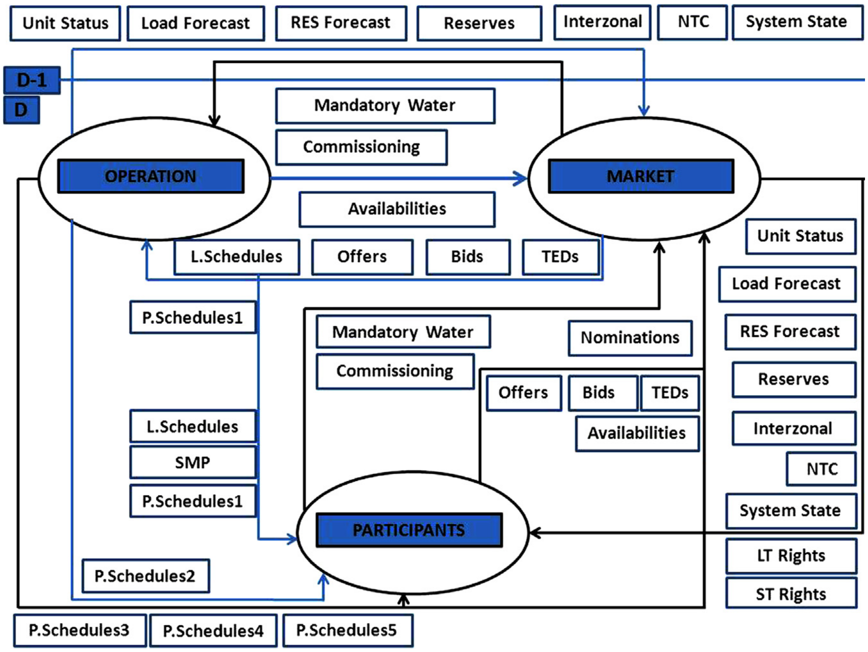

Fig. 1. Overview of the Greek electricity market.

Balkan markets to the European markets. In fact, the Greek electricity market incorporates a complex mathematical algorithm, considering economic and technical characteristics. Fig. 1 provides an overview of the Greek electricity market, showing the linkages between the Day-Ahead market and the real-time dispatch scheduling.

The main responsibility of the electricity Market Operator is the determination of the Day-Ahead electricity price, considering the energy offers and the load declarations of participants as well as the technical characteristics of the system (Dagoumas, 2012). The liberalization of the electricity market and the incentives given by the Greek state have led to a change in the fuel mix through the on-going penetration of natural gas and renewables. Moreover, the operation of the electricity market has led to re-adjustments of the electricity tariffs, as the suppliers were in position to compete with the tariffs of the PPC and have taken an important share of the market. This was highly influenced by the level of demand. In a neoclassical market, as the Greek electricity market is operating, if the demand is decreased, the system marginal price (SMP) either remains stable or is decreased. The decrease can be significant due to the significant difference in the variable cost (and consequently in the energy offers) between lignite and natural gas units. The usage of the interconnection capacity is also playing an important role in the determination of the SMP. Therefore the price is highly dependent on the economic offers of the participants and on the level of the electricity demand. On the other hand, the electricity demand is highly influenced by the electricity prices. Based on the above, we conclude that the understanding of the extent and the causality between the electricity demand and the electricity price is crucial to policy makers and government officials.

3. Data and methodology

The data used in the empirical estimation are national time series expressed in logarithms covering the period 1970–2011. More specifically, the residential electricity consumption (CONEL), measured in kWh, is available from the Hellenic Statistical Authority. Gross domestic product (GDP) measured in Euro is expressed in constant 2005 prices and is obtained from the Annual Macro Economic Database (AMECO) of the European Commission. Employment (EMPL) captures the total number of persons (thousands) employed in the total economy and is available from the AMECO database. Low voltage residential electricity price (PRICE) expressed in Euro/MW h is taken from the Public Power Corporation (PPC) and has been deflated by the Consumer Price Index (2005 = 100) extracted from the World Bank Database. The price of light fuel (LFOIL) measured in Euro/1000 l for the residential sector which has also been deflated by the Consumer Price Index is available from the International Energy Agency. Finally, the variables that measure the heating and cooling degree days (HDD and CDD respectively) are obtained from the Eurostat database.

In order to estimate the short-run and long-run elasticities, we followed the two-step Engle and Granger (1987) methodology by estimating an error correction model (ECM). The main reason for using this approach instead of using a vector autoregression model (VAR) is that the latter is more sensitive to the number of lags that can be used (Kremers et al., 1992), while on the other hand the individual coefficients in a VAR are difficult to interpret, so the analysis must focus on the causal relationships of the endogenous variables. This problem stems from the fact that a VAR model is a-theoretic, because it uses less prior information and thus is less suited for policy analysis (Gujarati, 1995). The basic statistical assumption underlying this approach is that the variables are stationary with the first two moments of the underlying data generation process not depending on time. In fact many time series are not well characterized as being stationary processes and so the first step is to examine the stationarity of the variables. In other words, we have to check for the presence of unit roots. If variables are non-stationary I(1) processes, then there may exist a linear combination which may well be stationary I (0) processes. If this is the case then the variables are cointegrated. Using an ECM, short- and long-run effects can be captured by estimating the short- and long-run elasticities, respectively (Banerjee et al., 1993).

Therefore, according to the methodology applied, in the first step we estimate the long-run equation for the electricity consumption which is expressed by the following formula:

$$CONEL_t = a + b_1\overset{+}{GDP}_t + b_2\overset{-}{PRICE} + b_3\overset{+/-}{LFOIL} + b_4\overset{+}{EMPL} + b_5\overset{+}{HDD} + b_6\overset{+}{CDD} + u_t \quad (1)$$

where all the variables as described above are in natural logarithms and u_t is the disturbance term. The relevant signs above the control variables show the expected impact (positive or negative) of each explanatory variable to the dependent variable (CONEL). In other words, the direction of the causality between the variables (signs) and the magnitude of the relevant coefficients (elasticities) represent the main hypotheses to be tested. It is worth mentioning that the inclusion of the control variable measuring the price of electricity (PRICE) has not been previously tested by other empirical studies (Asafu-Adjaye, 2000; Chandran et al., 2010; Hondroyiannis et al., 2002; Mahadevan and Asafu-Adjaye, 2007; Masih and Masih, 1998; Oh and Lee, 2004; Tang and Tan, 2012). In most of them the consumer price index (CPI) was used as a proxy for the energy price. In the second step, we estimate the ECM, which is written as

$$\begin{aligned}\Delta CONEL_t = a + \sum_{i=1}^{j} b_1 \Delta \overset{+}{GDP}_{t-i} + \sum_{i=0}^{k} b_2 \overset{-}{PRICE}_{t-i} + \sum_{i=0}^{l} b_3 \overset{+/-}{LFOIL}_{t-i} \\ + \sum_{i=0}^{m} b_4 \overset{+}{EMPL}_{t-i} + \sum_{i=0}^{n} b_5 \overset{+}{HDD}_{t-i} \\ + \sum_{i=1}^{o} b_6 \overset{+}{CDD}_{t-i} + \gamma \overset{-}{u}_{t-1} + \delta e_t \end{aligned} \tag{2}$$

where Δ is the first difference operator, u_{t-1} is the lagged disturbance term of the long-run equation and the lag orders j, k, l, m, n, o are chosen so as to make e_t white noise. The coefficient of the error correction term γ measures the speed of adjustment towards the long-run equilibrium and is expected to have a minus sign.

Having estimated the long-run and the short-run elasticities our next step is to investigate the existence of causation between the variables of the model. For this reason we perform the Granger causality tests (Granger, 1988). In order to perform the relevant tests, we estimate the following bivariate regressions of the form for all possible pairs of (x,y) series in the group:

$$y_t = a_0 + a_1 y_{t-1} + \ldots + a_1 y_{t-l} + \beta_1 x_{t-1} + \ldots + \beta_1 x_{t-l} + \varepsilon_t \tag{3}$$

$$x_t = a_0 + a_1 x_{t-1} + \ldots + a_1 x_{t-l} + \beta_1 y_{t-1} + \ldots + \beta_1 y_{t-l} + \varepsilon_t \tag{4}$$

where ε_t is a random error term with mean 0 and constant variance. The empirical implementation of the test proceeds as follows. Y in Eq. 3 is regressed on its past values and on past values of x. Although the choice of lags is arbitrary, in order to avoid omitted variable bias it is customary to start with a high number of lags, choosing the same number of lags for both price series, and then reduce the number of lags by dropping those that are not significant (OFT, 1999). The reported F-statistics are the Wald statistics for the joint hypothesis for each equation:

$$\beta_1 = \beta_2 = \ldots = \beta_l \tag{5}$$

The null hypothesis is that x does not Granger-cause y in Eq. 3 and that y does not Granger-cause x in Eq. 4.

Finally in order to assess the direction of causality between the variables we estimate the impulse response functions (IRF) and variance decomposition (VDC) by employing a vector error correction model (VECM). The VECM takes the following form:

$$\Delta X_t = \Pi X_{t-k} + \Gamma_1 \Delta X_{t-1} + \Gamma_2 \Delta X_{t-2} + \ldots + \Gamma_{k-1} \Delta X_{t-k} + \Phi H_t + u_t \tag{6}$$

where X_t is a (7×1) vector of endogenous variables [CONEL, GDP, PRICE, LFOIL, EMPL, HDD, CDD]′, and Π is a (7×7) matrix which contains information on the long run adjustment among the variables in X_t. If the variables in X_t are integrated of order one, I(1), the cointegrating rank, r, is given by the rank of $\Pi = \alpha\beta'$ where α is the matrix of parameters representing the speed of convergence to the long-run equilibrium and β is the matrix of the cointegrating vector. Γ_i reveals information on the short run adjustment to changes in X_t. H_t is a vector (7×1) made up of the deterministic terms such as intercept, deterministic trend, and seasonal dummies and finally u_t is a (7×1) vector of white noise errors. Since the VECM is a reduced form that includes a system of equations with a common set of lagged regressors on the right hand side, it is not efficient to estimate (6) using OLS. Johansen (1992) develops a technique that allows obtaining maximum likelihood estimations for the components of the multivariate system of equations.

4. Empirical findings

In this section, we present our empirical findings from the estimation of the long-run (cointegrated) equations. The models were estimated incorporating corrections for autocorrelated errors.

4.1. Stationarity and cointegration

Looking at the data over the examined period, we observe that our variables are probably non-stationary I(1). In order to examine the order of integration we have applied a battery of diagnostic tests (Augmented Dickey–Fuller, Phillips–Perron, Ng–Perron and KPSS tests) employed both in levels and first differences of the variables (see Dickey and Fuller, 1979; Phillips and Perron, 1988; Ng and Perron, 2001; Kwiatkowski et al., 1992). The results of the above tests are presented in Table 1. Applying the relevant tests, we observe that the null-hypothesis of a unit root cannot be rejected at 5% critical value for all the relevant variables. In other words all the series are non-stationary. By taking first differences of the non-stationary variables the hypothesis of stationarity cannot be rejected at 5% level of significance for all of the variables. In other words, the variables are integrated of the same order (one) containing one unit root, I(1). This result is in line with the conventional notion that most of the macroeconomic series are non-stationary at levels, but become stationary when first differenced (Nelson and Plosser, 1982). Given that all variables are I(1) series, we proceed to examine the presence of long-run equilibrium relationship between the variables of interest in Greece.

Table 2 presents the maximum likelihood eigenvalue statistics.[1] It becomes clear from the table that the null hypothesis is rejected at 1% level (see Osterwald-Lenum, 1992 for critical values). The estimated likelihood ratio tests and eigenvalues indicate that there is one cointegration vector.

4.2. Empirical estimates

Once the electricity consumption and its determinants are found to be cointegrated, the short- and long-run elasticities should be estimated. In this study, we employ four different cointegrating estimators to estimate the long-run elasticities of Greek residential electricity consumption. Among them are the Ordinary Least Squares (OLS) approach as suggested by Engle and Granger (1987), the Dynamic OLS (DOLS) approach as suggested by Stock and Watson (1993), the Fully-Modified OLS (FMOLS) approach as suggested by Phillips and Hansen (1990) and eventually the Canonical Cointegrating Regression Estimator (CCR) as developed by Park (1992).[2] The reason for using the above methodologies is to check for the robustness of the estimation results and also to provide more efficient estimates in our

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[1] The null hypothesis is that there is no cointegration relationship, so $r=0$.

[2] For a thorough comparison of the finite sample performance of the cointegrating regression estimators see Montalvo (1995).

Table 1
Unit root testing.

Variables	Augmented Dickey–Fuller			Phillips–Perron		KPSS		Ng–Perron				Order of integration
	Lags	τ_t	τ_μ	τ_t	τ_μ	n_t	n_μ	**MZa**	**MZt**	**MSB**	**MPT**	
Levels												
EMPL	0	−2.13 [0.51]	−1.13 [0.69]	−2.42 (1) [0.36]	−1.13 (0) [0.69]	0.07 (3)	0.78* (5)	−10.42 (0)	−2.04 (0)	0.20 (0)	9.84 (0)	I(1)
GDP	0	−1.95 [0.61]	−2.00 [0.28]	−1.70 (2) [0.73]	−3.72* (18) [0.00]	0.18** (5)	0.79* (5)	−6.49 (0)	−1.55 (0)	0.24 (0)	14.07 (0)	I(1)
PRICE	0	−1.48 [0.82]	−1.64 [0.45]	−1.48 (4) [0.81]	−1.69 (11) [0.42]	0.12*** (4)	0.76* (5)	−5.60 (0)	−1.48 (0)	0.26 (0)	15.81 (0)	I(1)
LFOIL	1	−3.15 [0.11]	−2.13 [0.23]	−2.43 (8) [0.35]	−1.88 (11) [0.33]	0.10 (4)	0.37*** (4)	−9.82 (0)	−2.21 (0)	0.22 (0)	9.33 (0)	I(1)
HDD	0	−5.04* [0.00]	−0.07 [0.65]	−3.23** (1) [0.02]	−0.18 (31) [0.61]	0.13*** (5)	0.63** (3)	−14.30 (0)	−2.67 (0)	0.19 (0)	6.37 (0)	I(1)
CDD	0	−2.99** [0.04]	0.48 [0.81]	−2.91*** (2) [0.05]	0.73 (17) [0.87]	0.11*** (2)	0.69** (4)	−18.08 (0)	−3.00 (0)	0.17 (0)	5.06 (0)	I(1)
First differences												
ΔEMPL	0	−4.90* [0.00]	−4.91* [0.00]	−4.85* (2) [0.00]	−4.86* (2) [0.00]	–	0.10 (1)	−19.26** (0)	−2.91** (0)	0.15** (0)	5.88** (0)	I(0)
ΔGDP	0	−9.64* [0.00]	−9.14* [0.00]	−10.53*(5) [0.00]	–	0.36* (32)	0.43 (6)	−17.69** (0)	−2.97** (0)	0.17** (0)	5.15** (0)	I(0)
ΔPRICE	0	−5.59* [0.00]	−5.49* [0.00]	−6.45* (21) [0.00]	−5.45* (12) [0.00]	0.15** (16)	0.22 (9)	−19.86** (0)	−3.15** (0)	0.16** (0)	4.59** (0)	I(0)
ΔLFOIL	1	−6.11* [0.00]	−6.19* [0.00]	−8.26* (35) [0.00]	−8.51* (35) [0.00]	0.50* (40)	0.50** (40)	−47.86* (0)	−4.89* (0)	0.10* (0)	1.90* (0)	I(0)
ΔHDD	0	–	−7.69* [0.00]	–	−21.85* (22) [0.00]	0.50* (31)	0.50** (31)	−14.09* (0)	−2.62** (0)	0.19** (0)	6.64* (0)	I(0)
ΔCDD	0	–	−10.34* [0.00]	–	−27.70* (39) [0.00]	0.16** (17)	0.16 (17)	−15.60** (0)	−2.79** (0)	0.18** (0)	5.86** (0)	I(0)

The calculated statistics are those reported in Dickey and Fuller (1981). The critical values at 5 and 1% for $N=50$ are given in Dickey and Fuller (1981). The optimal lag length structure is determined by minimizing the Schwarz Info Criterion (SIC). The critical values for the Phillips–Perron unit root tests are obtained from Dickey and Fuller (1981). The number in parenthesis denotes the lags using the Newey–West bandwidth. n_μ and n_τ are the KPSS statistics for testing the null hypothesis that the series are I(0) when the residuals are computed from a regression equation with only an intercept and intercept and time trend, respectively. The critical values are given in Kwiatkowski et al. (1992). The Ng–Perron statistic tests the null hypothesis that the series are I(0) including an intercept and a deterministic trend.

[*] Denotes the significance at 1% levels.

[**] Denotes the significance at 5% levels.

relatively small sample. Subsequently, the error-correction model (ECM) is estimated to derive the short-run elasticities.

Panel A of Table 3 shows the long-run elasticities of the Greek residential electricity consumption. Interestingly, all the four cointegrating estimators provide quite similar long-run results thus indicating that the estimated results are robust. Moreover, mostly all of the estimated coefficients are statistically significant at the conventional level and bear theoretically correct signs for the explanatory variables. A key finding of this study is that electricity consumption in Greece is elastic to changes in real income and employment, while it is inelastic to electricity price changes. This is in alignment with other empirical studies for Greece (see for example Polemis, 2007; Rapanos and Polemis, 2006) or other European countries (see for example Tang and Tan, 2012). The real income and employment elasticities range from 4.13 to 4.45 and from 1.16 to 1.88 respectively. This implies that holding other factors constant ceteris paribus, a 1% increase in the level of economic growth (GDP) is likely to increase electricity consumption in Greece by about 4.2% on average. Meanwhile, a 1% increase in total labor force (EMPL) is likely to increase electricity consumption by more than 1% (1.6% on average).

Furthermore, an increase in real electricity price leads to a decrease in the level of electricity consumption. The estimated elasticities range from −0.17 to −0.29, implying that a 1% increase in the energy price is likely to decrease electricity consumption in Greece by less than 0.2% on average. The relevant low magnitude of own price elasticity goes along with expectations in a country where electricity residential demand is in its vast majority dependent on electricity to operate. It is worth mentioning that Greece has the lowest (after Sweden) per capita gas consumption in the EU-15 (Fafaliou and Polemis, 2009). The comparatively low degree of natural gas penetration in the Greek energy balance relatively to other European countries (see for example, United Kingdom, Italy, Germany and Austria) raises serious concerns regarding the long-term energy planning by the Greek government.

In addition, low price sensitivity means that, taxing electricity can be a good source of revenues in the long-run, given the absence of substitutability with respect to light fuel oil. Cross price elasticities (LFOIL) come with the negative sign revealing that electricity and light fuel oil used for heating purposes are not substitutes. Their magnitudes vary from −0.18 (OLS) to −0.35 (DOLS). The variation in their magnitude can be attributed to the different econometric methodologies employed in the empirical analysis.

In the next step, we decompose the short-run elasticities within the ECM framework (see Panel B). The relevant elasticities have been calculated by the estimation of Eq. 2. More specifically, the short-run real income elasticity of electricity consumption is estimated at 0.19 (inelastic demand) and the elasticity with respect to electricity price is below unity (−0.08). The magnitude

Table 2
Johansen's maximum likelihood method test for cointegration relationships.

Null Hypothesis	Alternative hypothesis	Eigenvalue	Critical values	
			95%	99%
No intercept no deterministic trend				
Trace statistic				
$r=0$	$r=1$	96.18[b]	82.49	90.45
$r\leq1$	$r=2$	57.73	59.46	66.52
Maximum eigenvalues				
$r=0$	$r=1$	38.44[a]	36.36	41.00
$r\leq1$	$r=2$	21.30	30.04	35.17
Intercept no deterministic trend				
Trace statistic				
$r=0$	$r=1$	161.11[b]	102.14	111.01
$r\leq1$	$r=2$	94.96[b]	76.07	84.45
$r\leq2$	$r=3$	57.19[a]	53.12	60.16
$r\leq3$	$r=4$	36.14[a]	34.91	41.07
$r\leq4$	$r=5$	16.95	19.96	24.60
Maximum eigenvalues				
$r=0$	$r=1$	66.15[a]	40.30	46.82
$r\leq1$	$r=2$	37.77[b]	34.40	39.79
$r\leq2$	$r=3$	21.05	28.14	33.24
No intercept and linear deterministic trend				
Trace statistic				
$r=0$	$r=1$	150.57[a]	94.15	103.18
$r\leq1$	$r=2$	84.44[a]	68.52	76.07
$r\leq2$	$r=3$	51.22[b]	47.21	54.46
$r\leq 3$	$r=4$	32.03[b]	29.68	35.65
$r\leq4$	$r=5$	16.21[b]	15.41	20.04
$r\leq5$	$r=6$	5.11[b]	3.76	6.65
Maximum eigenvalues				
$r=0$	$r=1$	66.13[a]	39.37	45.10
$r\leq1$	$r=2$	33.21	33.46	38.77
Intercept and linear deterministic trend				
Trace statistic				
$r=0$	$r=1$	157.62[a]	114.90	124.75
$r\leq1$	$r=2$	91.32[b]	87.31	96.58
$r\leq2$	$r=3$	58.01	62.99	70.05
Maximum eigenvalues				
$r=0$	$r=1$	66.30[a]	43.97	49.51
$r\leq1$	$r=2$	33.31	37.52	42.36
Intercept and quadratic deterministic trend				
Trace statistic				
$r=0$	$r=1$	144.68[a]	104.94	114.36
$r\leq1$	$r=2$	78.41[b]	77.74	85.78
$r\leq2$	$r=3$	47.60	54.64	61.24
Maximum eigenvalues				
$r=0$	$r=1$	66.27[a]	42.48	48.17
$r\leq1$	$r=2$	30.81	36.41	41.58

r denotes the number of cointegrating equations, while a denotes significance at $a=0.01$ $a=0.05$. Maximum eigenvalue and trace test statistics are compared with the critical values from Johansen and Juselius (1990).

of the relevant coefficients is lower than their long-run counterparts implying that the Le Chatelier principle is valid as a result of the existence of the fixed-cost constraint in the short-run. Employment appears to be statistically significant in explaining variations of the electricity consumption in the short-run and the relevant magnitude is estimated to 0.61. This means that a 10% increase (decrease) in the total number of labor force will increase (decrease) the level of electricity consumption by about 6.1%. This finding is not in alignment with another similar study (Tang and Tan, 2012) in which the authors did not find a statistically significant relationship between the two variables.

The short-run impact of light fuel oil on the dependent variable comes with a negative as in the long-run but it does not appear to be statistically significant. The coefficient of the cooling degree days (CDD) is statistically significant but comes with an opposite sign (negative). This finding implies that at least in the short-run the households in Greece do not use electricity for cooling purposes (e.g. air conditioning). On the contrary, the use of residential electricity in the short-run is mainly for heating purposes since the relevant coefficient of the heating degree days (HDD) is positive and statistically significant (0.13).

The sign of the error correction term (γ) is negative (-0.318) as expected by the theory and highly statistically significant. This finding implies that in the case we are off the long-run demand curve, electricity consumption adjusts towards its long-run level with about 32% of this adjustment taking place within the first year. In other words, holding other factors constant, the estimated ECT coefficient reveals that if the electricity consumption system in Greece is exposed to a shock, it will slowly converge to the long-run equilibrium (e.g. approximately more than three years).

The results of income and price elasticities are comparable to those reported by earlier studies concerning Greece (see for example Polemis, 2007; Hondroyiannis et al., 2002; Rapanos and Polemis, 2006) which report similar income and price elasticities. Some of the differences in the income and price elasticities may be attributed to the different sources, estimation periods and methodology employed in the various studies.

4.3. *Granger causality tests*

According to the Granger representation theorem, if variables are cointegrated, there must be at least one direction of causality between the variables to sustain the presence of some long-run equilibrium relationship. In other words, Engle and Granger (1987) show that in the presence of cointegration, there always exists a corresponding error-correction representation which implies that changes in the dependent variable are a function of the level of disequilibrium in the cointegrating relationship, captured by the error-correction term (ECT), as well as changes in other explanatory variables (Hondroyiannis et al., 2002). The existence of cointegration vector in the electricity demand model demonstrates that the variables in the model under this study are cointegrated and possess long-run relationship. According to Masih et al. (2009), the vector error correction model (VECM) plays an important role in detecting the endogeneity or exogenity of the variables in the model. Thus, VECM is utilized to obtain the direction and intensiveness of causal effects in the system since the direction of Granger causality is not implied by the cointegration test.

Table 4 shows the summary of the Granger causality test results based on VECM. Specifically, we carry out pairwise Granger causality tests in order to investigate whether an endogenous variable can be treated as exogenous and the direction of the causation. For each equation in the VECM, the output displays (Wald) statistics for the joint significance of each of the other lagged endogenous variables in that equation. It is worth mentioning that the lagged variables that are tested for exclusion are only those that are first differenced. The statistic in the last row (All) is the statistic for joint significance of all other lagged endogenous variables in the equation.[3]

The results show that there is a strong bi-directional relationship between real income (GDP) and electricity consumption (CONEL) since the relevant Wald tests are statistically significant. This means that, Greece is an energy-dependent economy and thus any indiscriminate energy-savings program may adversely affect its economic growth and development. This finding does not confirm previous empirical studies (Narayan, Smyth, 2007; Chontanawat et al., 2008; Shahbaz et al., 2011). There are two plausible explanations for the difference in the empirical outcomes.

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[3] However the lagged level terms in the cointegrating equations (the error correction terms) are not tested.

Table 3
Long-run and short-run elasticities.

Panel A: long-run elasticities	**GDP**	**EMPL**	**PRICE**	**LFOIL**	**CDD**	**HDD**	
OLS	4.20* (6.68)	1.65* (6.30)	−0.22*** (−1.74)	−0.18* (−2.61)	−0.13 (−1.29)	0.33*** (1.73)	
DOLS	4.45*** (1.68)	1.16** (2.04)	-0.29 (-0.63)	-0.35* (−4.07)	-0.65** (−2.39)	-0.57 (−1.13)	
FMOLS	4.13* (4.22)	1.88* (4.60)	-0.17*** (−1.83)	-0.20* (−3.10)	−0.16 (−1.01)	0.35*** (1.52)	
CCR	4.14* (3.02)	1.83* (3.61)	−0.19** (−1.98)	−0.21* (−2.40)	−0.21 (−0.87)	0.28 (0.97)	
Panel B: short-run elasticities	**ΔGDP**	**ΔEMPL**	**ΔPRICE**	**ΔLFOIL**	**ΔCDD**	**ΔHDD**	**ECT**
Dependent variable ΔCONEL	0.19*** (1.89)	0.61** (2.45)	−0.08** (−1.95)	−0.04 (−0.82)	−0.15* (−3.70)	0.13*** (1.71)	−0.32* (−4.66)

All the relevant estimates are corrected for heteroscedasticity and autocorrelation by using the Newey–West (1987) consistent covariance estimator. The numbers in parenthesis denote the *t*-statistic. OLS—Ordinary Least Squares, DOLS—Dynamic OLS, FMOLS—Fully Modified OLS, CCR—Canonical Cointegrating Regression.

* Denotes the significance at 1% level.
** Denotes the significance at 5% level.
*** Denotes the significance at 10% level.

The first is that this study involves a longer sample period and the second is that it has taken into account the effect of real electricity price and employment in the specification of the electricity demand.

Regarding the other variables of the model, it is evident that there is a uni-directional relationship running from electricity consumption to the price of light fuel oil (LFOIL). Similarly, the economic growth (GDP) does Granger cause the price of light fuel oil, since the relevant tests reject the null hypothesis. Lastly, in the employment (EMPL) and heating degree days (HDD) equations the results reveal that there is strong uni-directional Granger causality between all of the lagged endogenous variables in the relevant equations.

4.4. Short-run dynamics

Although the above analysis indicates the existence of causality between electricity consumption and economic growth it does not reveal information of the direction of its causal relationship. Our main interest is to examine the dynamic interactions between electricity consumption and its main determinants. An alternative way to obtain the information regarding the relationships among the variables of the empirical model is through the estimation of the impulse responses functions (IRF) and variance decomposition (VDC).

4.4.1. Impulse responses functions

An impulse response function traces out the response of the dependent variable in the VAR system to shocks in the error terms (innovations). In other words, it traces the effect of a one-time shock to one of the innovations on current and future values of the endogenous variables (Greene, 2000). Provided that the innovations are contemporaneously uncorrelated, interpretation of the impulse response is straightforward. The *i*-th innovation is simply a shock to the i-th endogenous variable. Innovations, however, are usually correlated, and may be viewed as having a common component which cannot be associated with a specific variable. In order to interpret the impulses, it is common to apply a transformation to the innovations so that they become uncorrelated (Hamilton, 1994).

Before conducting IRF and VDC analysis it is important to determine the optimal lag length (k). If the chosen lag length is less than the true lag length, the omission of relevant lags can cause bias. If the chosen lag length is more, the irrelevant lags in the equation cause the estimates to be inefficient (Clark and Mirza, 2006). To minimize some of these problems, we followed Lütkepohl's (1993) procedure where he suggests linking the lag length (m lag) and number of endogenous variables in the system (m) to a sample size (T) according to the following equation:

$$m \times m\,\text{lag} = T^{1/3} \tag{7}$$

with $T=42$, we initially set $k=3$, and we minimize the Akaike Information Criteria (AIC) and the Schwarz Criterion (SC) to select the optimal lag. More specifically, in order to determine the lag length of the VECM, an extensive diagnosing testing of the OLS residuals is employed for various lag lengths. Each equation of the VECM system passes a series of diagnostic tests including serial correlation based on the autocorrelation functions of the residuals as well as the reported Lagrange Multiplier (LM test). According to the empirical results the optimal lag length of the VECM is finally set to $k=3$. The time period of the IRF is over ten years and covers the period 2012–2022, which is long enough to capture the dynamic interactions of the VECM. We set the lag value for the VECM equal to three.

The IRF derived from the VECM are presented in Fig. 2. This diagram reports the response of each variable of the VECM to its own innovation and to the innovations of other variables. At this stage, it is worth emphasizing that the above IRF are based on a VECM in levels with higher than one lag structure as proposed by Toda and Yamamoto (1995), so as to account for the existence of an I(1) underlying data generating process. Solid lines display the point estimates of the coefficients, while the innovations of the VECM are orthogonolized using a Cholesky decomposition of the covariance matrix. From the relevant figure it is evident that the response of electricity consumption to its own innovation (CONEL) is strongly positive and significant for the subsequent period. The response of electricity consumption to a one standard deviation shock of GDP is zero for the first three periods and then becomes positive. Approximately the response of electricity demand after the third period to one standard deviation shock of GDP is nearly 15% per annum, implying that a 1% increase in the level of GDP′s innovation causes a significant increase in the electricity consumption. The peak response of electricity demand to innovations of its own price occurs ten years after the initial shock.

Table 4
Granger causality tests from VECM.

Dependent variables	χ^2 statistic	Degrees of freedom	*p*-value
Δ(CONEL)			
Δ(GDP)	3.159***	1	0.076
Δ(PRICE)	1.010	1	0.315
Δ(LFOIL)	1.168	1	0.280
Δ(EMPL)	0.234	1	0.629
Δ(HDD)	1.400	1	0.237
Δ (CDD)	0.044	1	0.834
All	5.310	6	0.505
Δ(GDP)			
Δ(CONEL)	7.227**	1	0.042
Δ(HDD)	0.310	1	0.578
Δ(PRICE)	1.265	1	0.261
Δ(EMPL)	0.185	1	0.667
Δ(LFOIL)	2.202	1	0.138
Δ(CDD)	1.330	1	0.249
All	9.344	6	0.155
Δ(PRICE)			
Δ(CONEL)	0.084	1	0.772
Δ(GDP)	0.090	1	0.764
Δ(HDD)	0.253	1	0.615
Δ(EMPL)	3.937**	1	0.047
Δ(LFOIL)	0.101	1	0.751
Δ(CDD)	2.368	1	0.124
All	7.117	6	0.310
Δ(LFOIL)			
Δ(CONEL)	3.515***	1	0.061
Δ(GDP)	2.814***	1	0.093
Δ(HDD)	1.167	1	0.280
Δ(PRICE)	0.021	1	0.886
Δ(EMPL)	0.188	1	0.664
Δ(CDD)	0.315	1	0.574
All	7.042	6	0.317
Δ(EMPL)			
Δ(CONEL)	2.154	1	0.142
Δ(GDP)	6.044**	1	0.014
Δ(HDD)	0.769	1	0.381
Δ(PRICE)	0.590	1	0.442
Δ(LFOIL)	2.001	1	0.157
Δ(CDD)	1.958	1	0.162
All	14.614**	6	0.024
Δ(HDD)			
Δ(CONEL)	0.422	1	0.516
Δ(GDP)	0.081	1	0.776
Δ(PRICE)	4.713**	1	0.030
Δ(EMPL)	2.185	1	0.139
Δ(LFOIL)	0.565	1	0.452
Δ(CDD)	6.925*	1	0.009
All	12.296***	6	0.056
Δ(CDD)			
Δ(CONEL)	0.587	1	0.444
Δ(GDP)	0.177	1	0.674
Δ(HDD)	0.114	1	0.736
Δ(PRICE)	0.072	1	0.788
Δ(EMPL)	0.003	1	0.953
Δ(LFOIL)	0.706	1	0.401
All	1.602	6	0.952

Δ is the first different operator.

* Denotes the significance at 1% level.

** Denotes the significance at 5% level.

*** Denotes the significance at 10% level.

The response of electricity consumption to a one standard deviation shock of heating degree days is positive after the first year exhibiting a relatively high annual rate of increase (22.6% per annum). The peak response of electricity demand to innovations of HDD occurs ten years after the initial shock (0.3%). The same result holds for the contribution of cooling degree days. More specifically, the response of electricity consumption to a one standard deviation shock of CDD follows an upward pattern reaching a +8.5% increase annually. Finally, the peak response of electricity demand to innovations of CDD occurs eight years after the initial shock (0.71%) stabilizing thereafter.

A somewhat different picture emerges from the lower part of Fig. 2, where the impact of prices (electricity and light fuel oil prices) on the electricity demand and employment is depicted. For the whole period the price for both the electricity and the light fuel oil exhibits a clear negative trend as expected by the theory. It is worth mentioning that the GDP shock has positive and more persistent effects on the electricity consumption, compared to the negative impact of its own price. Another interesting outcome is that the response of residential electricity consumption to a one standard deviation shock of price of light fuel oil (LFOIL) which is used for heating purposes turns to be negative after the first three years (short-run period). Specifically, the response of electricity demand after the third period to one standard deviation shock of LFOIL is approximately 13% per annum, confirming the absence of substitutability between the two energy inputs (electricity and diesel) in the long-run (see Table 3). Effectively this outcome enhances the argument that the scope of residential electricity switching is still limited (Polemis, 2006).

Lastly, the response of CONEL to a shock in the total labor force (EMPL) is rather ambiguous since the relevant coefficients alternate signs very often for the next ten years. This response appears to follow a rather cyclical pattern over a short period of time, though the pattern response of electricity demand to employment shocks is mostly negative throughout the period.

4.4.2. *Variance decomposition analysis*

While IRF trace the effects of a shock to one endogenous variable on to the other variables in the VECM, variance decomposition separates the variation in an endogenous variable into the component shocks to the VECM. Thus, the variance decomposition provides information about the relative importance of each random innovation in affecting the variables in the VECM. In other words with VDC, we shock the bivariate system and partition the forecast error variance of each variable into contributions arising from its own innovations and the other variables' variance (Masih and Masih, 1996). The forecast error variance decomposition can permit inferences to be drawn regarding the proportion of the movement in a particular time-series due to its own earlier “shocks” vis-à-vis “shocks” arising from other variables in the VECM where it is possible to identify which variables are strongly affected and those that are not.

Table 5 presents the results of the generalized variance decomposition analysis. As we are more interested in the contribution of electricity consumption to the level of economic activity and the other explanatory variables, we only decompose the forecast-error variance of the electricity consumption (see Panel A) and economic growth (see Panel B) in response to a one standard deviation innovation in their main determinants (GDP, PRICE, LFOIL, EMPL, HDD, CDD). However, the empirical results from the other interactions of the VECM are available from the authors upon request.

From the results of the VDC of electricity consumption (CONEL), it is clear that GDP is not the most important factor in explaining innovation to electricity consumption compared to other control variables such as price of electricity (see Panel A). It is noteworthy, that in each of the discrete time periods, the shocks to CONEL due to shocks of economic growth range from 0% to 6.2% compared to 0% and 6.8% respectively of the forecast error variance of PRICE. This finding contradicts with the ones reported by the previous analysis (see IRF and Granger causality testing), revealing a

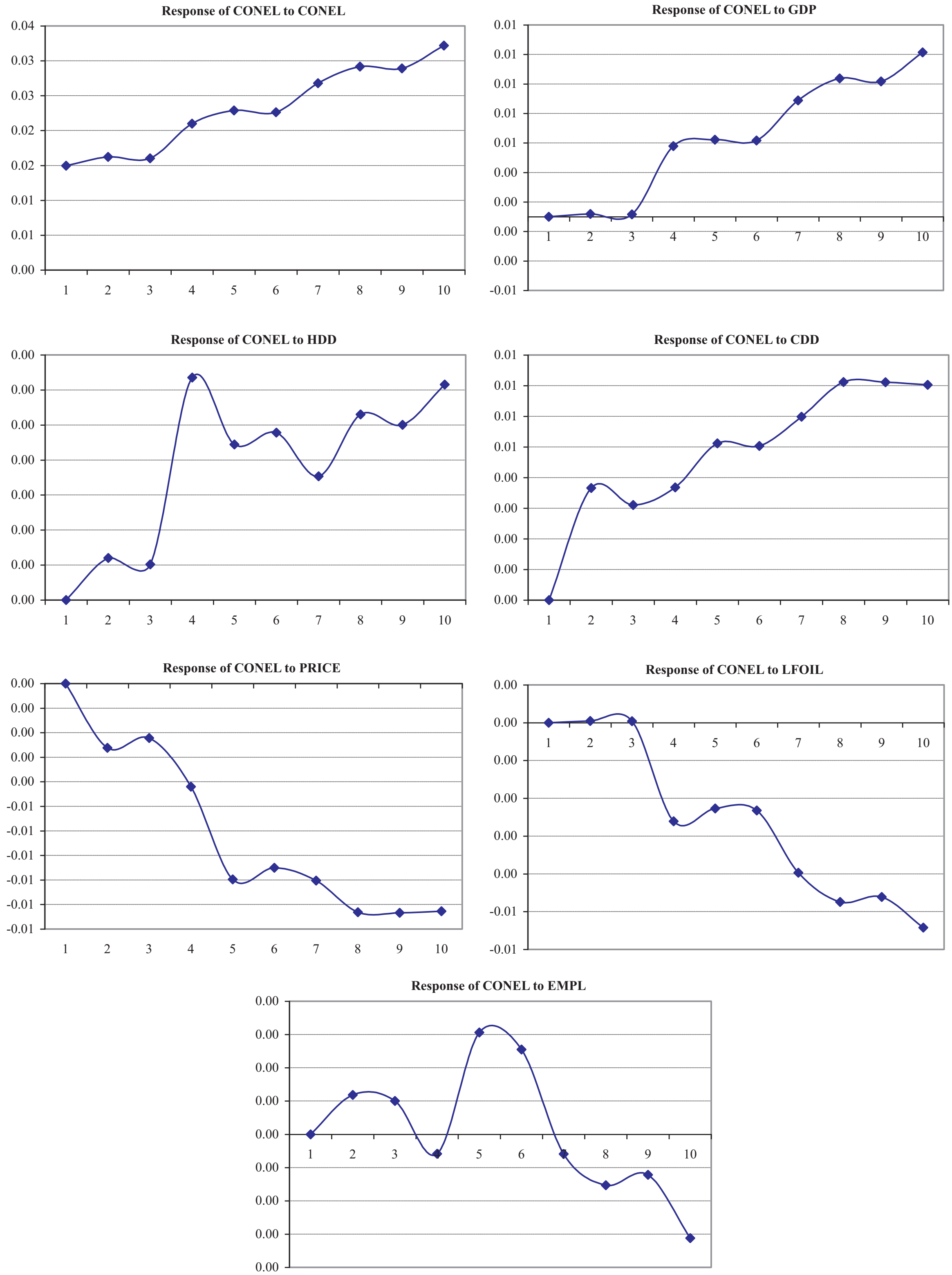

Fig. 2. Impulse response functions of the VECM.
Source: Author's elaboration.

dynamic effect of shocks between CONEL and GDP. However, even though GDP's contribution relative to electricity consumption was not as high as that of electricity price, its contribution to output growth is not negligible compared to other control variables (see for example HDD and EMPL). Regarding the temperature effect, it is worth mentioning that the insignificant contribution of HDD (0–0.7%) in tandem with the low variation levels of CDD (0–4.0%) to the forecast error variance of CONEL may indicate that residential electricity is mainly used for specific energy uses other than heating and cooling (i.e. cooking, lighting, etc.). This finding coincides with other empirical studies (Rapanos and Polemis, 2006; Polemis, 2007; Donatos and Mergos, 1989).

Table 5
Variance decomposition analysis of electricity consumption and economic growth (%).
Source: Authors' elaboration.

Period	CONEL	GDP	HDD	PRICE	EMPL	LFOIL	CDD
Panel A: VDC of CONEL							
1	100.0	0.0	0.0	0.0	0.0	0.0	0.0
2	95.9	0.0	0.1	1.3	0.1	0.0	2.6
3	95.4	0.0	0.1	1.5	0.1	0.0	3.0
4	91.7	1.8	0.8	2.3	0.1	0.5	2.8
5	87.8	2.6	0.8	4.8	0.2	0.6	3.2
6	86.1	3.0	0.8	5.8	0.2	0.7	3.4
7	84.5	4.0	0.7	6.1	0.1	1.0	3.6
8	82.7	5.0	0.7	6.6	0.1	1.2	3.8
9	81.6	5.5	0.7	6.8	0.1	1.4	4.0
10	80.8	6.2	0.7	6.8	0.1	1.5	3.9
Panel B: VDC of GDP							
1	0.36	99.64	0.00	0.00	0.00	0.00	0.00
2	0.22	99.18	0.01	0.20	0.01	0.00	0.38
3	0.19	99.13	0.01	0.22	0.01	0.00	0.44
4	3.51	91.57	0.05	2.88	0.14	0.74	1.11
5	5.67	88.41	0.22	3.49	0.22	1.16	0.84
6	6.91	86.47	0.29	3.96	0.27	1.41	0.69
7	8.64	83.62	0.56	4.37	0.48	1.75	0.58
8	10.58	82.40	0.56	3.74	0.40	1.83	0.49
9	11.85	81.52	0.58	3.37	0.36	1.91	0.42
10	13.26	80.31	0.56	3.10	0.35	2.06	0.37

On the contrary, it is evident that the relatively high level contribution of electricity consumption to output growth in Greece may be an indication that the causal relationship between electricity consumption and economic growth is relatively strong (see Panel B) when compared to either labor (EMPL) and electricity price (PRICE). In all of the cases (periods) electricity consumption is the single most important factor in explaining innovation to economic growth relative to other explanatory variables (employment, temperature variations, own price and price of light fuel oil). More specifically, after the 10-year horizon, the shocks to GDP due to shocks of electricity consumption are still significant and account for nearly 13.3% of the forecast error variance of GDP. To sum up, these results seem to be in line with the ones reported by the IRF providing evidence in favor of the importance of economic growth fluctuations in explaining the variation of electricity consumption and vice versa.

5. Conclusions and policy recommendations

In this paper we try to investigate the relationship between electricity consumption and economic growth in Greece within a multivariate framework. For this purpose we used cointegration techniques and the vector error correction model in order to capture short-run and long-run dynamics over the sample period 1970–2011. In order to estimate the short-run and long-run elasticities, we followed the two-step Engle and Granger (1987) methodology by estimating an ECM. The empirical results of the ECM are quite robust revealing that in the long-run electricity demand appears to be price inelastic and income elastic, while in the short-run the relevant elasticities are below unity. The results of price and income elasticities are comparable to those of other studies for Greece, while any small differences are attributed to the different sources, estimations periods and methodology employed in the various studies.

From the Granger causality testing, we argue that the causal relationship between electricity consumption and economic growth in Greece is bi-directional. However, difference with other studies may be attributed to the longer sample period, the variable selection and the model specifications. This finding strengthens the notion that Greece is an energy dependent country and well directed energy conservation policies could even boost economic growth. This is in alignment with similar studies showing that the rebound effect from energy efficiency projects can be about 50%, while well specified energy projects can even “backfire” the economy, leading to high economic growth.

Moreover, a dynamic impulse response analysis is used to examine the dynamic interactions in the model. The findings are quite plausible and verify previous empirical findings in the literature. Specifically, from the IRF showing the adjustment path after positive and negative shocks in all of the variables, we infer that the response of electricity consumption to a one standard deviation shock of GDP is zero for the first three periods and then becomes positive. Approximately the response of electricity demand after the third period to one standard deviation shock of output is nearly 15% per annum, implying that a 1% increase in the level of GDP's innovation causes a significant increase in the electricity consumption. Furthermore, the response of electricity demand after the third period to one standard deviation shock of price of light fuel oil is approximately 13% per annum, confirming the absence of substitutability between the two energy inputs (electricity and diesel) in the long-run. Effectively this outcome enhances the argument that the scope of residential energy switching is still limited.

Regarding the temperature effect, it is worth mentioning that the insignificant contribution of heating degree days in tandem with the low variation levels of cooling degree days to the forecast error variance of electricity consumption may indicate that residential electricity is mainly used for specific energy uses other than heating and cooling (i.e. cooking, lighting, etc.). Furthermore, GDP is not the most important factor in explaining innovation to electricity consumption compared to other control variables such as price of electricity. On the contrary, electricity consumption is the single the most important factor in the explaining innovation to economic growth.

Finally, as economic growth and environmental protection have been the national aims of Greece, alternative renewable energy sources such as biofuel, biomass, solar power, hydroelectricity, and wind power should be in place to ensure sufficient electricity supply to support economic growth and development. These strategies will also be in line with the EU objective to combat climate change through renewable energy and green technology. In addition, energy price reform will be another important policy element not only to conserve energy but also to encourage initiatives to explore and switch to alternative sources of energy which are more cost-effective and environment friendly.

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