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Economic Growth and Electricity Consumption in 12 European Countries: A Causality Analysis Using Panel Data

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Abstract

We apply recent panel methodology to investigate the relationship between electricity consumption and real GDP for a set of 12 European Union countries using annual data for the period 1970-2004. Recently developed tests for panel unit roots, cointegration in heterogeneous panels and panel causality are employed. The results show a long-run relationship between the series. We estimate this relationship and test for causality. We find no short-run causality in any direction. These results might help to design appropriate electricity consumption policies in the sample countries, as well as investment policies in interconnections to build a single European market for electricity.

JEL classification: C33; Q40

Keywords: Electricity consumption; economic growth; panel cointegration; panel causality.

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1 Introduction

European Union countries are entering a new energy scenario unlike that of previous periods. Fossil fuel import dependence is increasing mainly due to the depletion of domestic hydrocarbon reserves. Several solutions have been proposed to mitigate the potential negative effects on economic growth. These include increases in energy efficiency, improvement of infrastructures, R&D investments and effective enforcement of competition law and regulation.

These challenges are shared by all European countries, so they require a coordinated response. At the end of 2005, the European Heads of State and Government called for a true European energy policy. As a result, the European Commission published on 8 March 2006 a Green Paper about the development of a *common, coherent European Energy Policy.* The Green Paper of the Commission of the European Communities (A European Strategy for Sustainable, Competitive and Secure Energy, 2006) also set out to help the European Union to reach efficient use of energy resources, security, competitive markets and sustainable energy development. In particular, it is recognized that security of energy procurement is a necessary condition for a balanced growth path to be followed.

Under this scenario electricity plays a key role. Our study focuses on the implications for economic growth of the creation of a single European electricity market. The deregulation of the European electricity sector began on 19 December 1996, when Directive 96/92/EC "concerning common rules for the internal market in electricity" was adopted. In order to create a single, competitive European electricity market, interconnection lines between European countries need to be developed to manage congestion. We therefore choose 12 European countries which have moved fastest towards this target over the past thirty years.

Several studies have examined the relationship between energy or electricity consumption and economic growth in different countries and sample periods (Altinay and Karagol (2005), Lee and Chang (2005), Soytas and Sari (2003), Oh and Lee (2004), Yoo (2005), Ciarreta and Zarraga (2007), among others). However, these studies are driven at country level and the conclusions reached are mixed, mainly because the econometric methods used are different. The main failure of these studies is that the time series sample size is usually small, so the results of the econometric tests might be not reliable.

Recently, panel data techniques have been used to analyze that dynamic relationship. Lee (2005) uses the two-step procedure from Engle and Granger (1987) in a panel-based error correction model and finds evidence of causality running from energy consumption to Gross Domestic Product (GDP) for a panel of 18 developing countries in the period 1975-2001. Lee and Chang (2008) use a similar methodology for 16 Asian countries for the period 1971-2002 and find evidence of long-run unidirectional causality running from energy consumption to economic growth. Lee et al. (2008) also use the two-step procedure of Engle and Granger (1987) to estimate a panel vector error correction model for 22 OECD countries covering the period 1960-2001 and find a bi-directional causal relationship between energy consumption, capital stock and GDP.

Lee and Chang (2007) estimate a panel VAR using the GMM techniques developed by Arellano and Bond (1991) and find evidence of causality from GDP to energy consumption in a sample of 18 developing countries and bidirectional casuality in a sample of 22 developed countries. Using similar techniques, Al-Iriani (2006) finds a unidirectional causality from GDP to energy consumption for panel data on the six countries of the Gulf Cooperation Council in the period 1971-2002. More recently, Huang et al. (2008) estimate a panel VAR model using GMM-SYS approach, which provides a more efficient estimator. They divide a sample of 82 countries for the period 1972-2002 into 4 groups according to their income levels and find different results depending on the group considered.

Panel estimation techniques have been applied to a lesser extent to study the dynamic relationship between electricity consumption and GDP. Chen et al. (2007) choose a sample of 10 developing countries in Asia. They find significant long-run causality in both directions and uni-directional short-run causality running from economic growth to electricity consumption. Böhm (2008) considers a sample of 15 European countries and tests for the long-run relationship between the variables in question. However, the existence and direction of causality in the short- and long-run is tested at country-level by using vector error correction models and Granger causality tests.

If electricity consumption causes economic growth, then policies encouraging a reduction in electricity consumption will have an effect on growth. If electricity consumption does not cause economic growth or economic growth causes consumption, then electricity conservation policies will have no impact on growth. Finally, if results suggest that there is a mutual relationship between electricity and GDP, then any global policy to reduce electricity consumption in order to reduce emissions would have an impact on the GDP of overall countries. In this paper, we use a panel approach on a set of European countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Luxembourg, the Netherlands, Norway, Sweden and Switzerland. This group of countries is selected because from 1970 to 2004 electricity trading (imports or exports) accounts for around 10 percent of total consumption. Moreover, these countries have moved forward faster than other neighbouring countries towards building a single market during the period under analysis.[1] Therefore, unlike Böhm (2008) we do not include some EU member countries such as the UK, Greece, Ireland, Spain and Portugal.

The methodology includes testing for unit roots, cointegration and a dynamic panel estimation approach to identify the Granger causal relation in our panel data. The use of panel techniques enables the power of the tests to be increased and makes it possible to include heterogeneity between countries. In this way we overcome some of the problems associated with single country studies. We apply system GMM estimation for a panel-VAR as in Huang et al. (2008). This methodology is more efficient than that in Arellano and Bond (1991) when using lagged differenced dependent variables as instruments (see Blundell and Bond, 1998). To our knowledge, there is no other study on that relationship for these countries and these two variables.

The rest of the paper is structured as follows. Section 2 explains the panel methodology. Section 3 describes the data. We provide arguments to justify the choice of the countries used in the study. Section 4 summarizes empirical results. Section 5 concludes and proposes some policy implications that emerge from the study.

2 Methodology

In this paper we investigate the causal relationship between electricity consumption and economic growth (GDP) in three steps. First, we identify the order of integration of the series using panel unit root tests. Second, we employ panel cointegration tests to examine the existence of a long-run relationship between the series and estimate the long-run equation using fully modified OLS (FMOLS). Finally, we study the size and direction of the causal relation between the series following a dynamic panel estimation approach.

2.1 The panel unit roots tests

Conventional unit roots tests for individual series (Augmented Dickey Fuller (ADF) and Phillips and Perron, among others) are known to have low power against the alternative of stationarity of the series, especially for small samples. The power of these tests may be increased by using panel data. Panel data provide a larger number of point data than single time series, increasing the degrees of freedom and reducing the collinearity between the regressors.

[1] We have not included other countries because interconnections with the selected sample countries were not sufficiently developed in the period. For instance, in the case of Spain the average was below 5 percent.

Therefore, panel data allow for more powerful statistical tests. Another advantage of using panel data unit root tests is that the test statistics asymptotically follow a normal distribution instead of nonconventional distributions.

Studies on panel unit root tests include Hadri (2000), Maddala and Wu (1999), Levin et al. (LLC) (2002) and Im et al. (IPS) (2003). The most popular tests in recent applications are LLC and IPS.

The IPS test is based on the following model[2]:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{i,t-j} + \epsilon_{it} \qquad i = 1, ..., N; \;\; t = 1, ..., T \quad (1)$$

where y_{it} is the series for country i in the panel over period t, p_i is the number of lags selected for the ADF regression and ϵ_{it} are independently and normally distributed random variables for all i and t with zero means and finite heterogeneous variances, σ_i^2.

IPS tests the null hypothesis of the unit root for each individual (country) in the panel, that is, $H_0 : \beta_i = 0 \;\; \forall i$, against the alternative $H_1 : \beta_i < 0, \;\; i = 1, ..., N_1; \;\; \beta_i = 0, \;\; i = N_1 + 1, ..., N$, which allows for some of the individual series to be integrated.

IPS develops the $t - bar$ statistic calculated as a simple average across groups of the individual ADF t statistics:

$$t - bar_{NT} = \frac{1}{N} \sum_{i=1}^{N} t_{iT}(p_i, \rho_i) \quad (2)$$

The standardized $t - bar$ statistic, $Z_{tbar}(p, \rho)$, converges in distribution to a standard normal variate sequentially, as $T \to \infty$ followed by N.

The LLC unit root test is also based on model (1) but it differs from IPS in some ways. On the one hand, IPS allows the coefficients of the autoregressive term, β_i, to differ across cross-section units, while LLC is more restrictive in the sense that it considers the coefficients of the autoregressive term as homogeneous across all individuals, that is, $\beta_i = \beta \;\; \forall i$. On the other hand, LLC tests the null hypothesis that each individual in the panel has integrated time series, that is, $H_0 : \beta_i = \beta = 0 \;\; \forall i$, against the alternative $H_1 : \beta_i = \beta < 0 \;\; \forall i$. Therefore, under the alternative, all single series are stationary.

LLC considers pooling the cross-section time series data and suggests a three-step procedure to implement the test. In step 1 a separate ADF regression for each individual in the panel is carried out and two orthogonalized residuals are generated. In step 2 the ratio of long-run to short-run innovation standard deviation is estimated for each individual. Finally, the pooled

[2] The model can be generalized by introducing linear time trends.

t-statistic is calculated. The resulting statistic, t^*, asymptotically follows a standard normal distribution.

Hadri (2000) extends the test by Kwiatkowski et al. (1992) of the null hypothesis of stationarity of a single time series against the alternative of a unit root to panel data. Hadri (2000) proposes a residual-based Lagrange Multiplier test for the null of level or trend stationarity allowing the case of heterogeneous disturbance terms across i.

In this paper Hadri, IPS and LLC tests are used to test for unit roots in the panel data.

2.2 Panel cointegration tests

If the series are individually integrated of the same order they might be cointegrated, i. e. there might exist some linear combination of these series which is made up of a smaller order than the individual series. Traditional cointegration tests (Johansen (1988), Engle and Granger (1987)) have been used to detect the presence of long-run relationships between integrated variables in time series data. Unfortunately, these tests have low power when the length of the series is short.

Pedroni (1999) proposes a methodology to test for panel data cointegration that can be considered as an extension of the traditional Engle and Granger (1987) two-step residual-based method. We use Pedroni's (1999) method to test for cointegration in a heterogeneous panel data and consider the following cointegrating regression:

$$LGDP_{it} = \alpha_i + \delta_i t + \beta_i LEC_{it} + \epsilon_{it} \qquad i = 1, ..., N; \;\; t = 1, ..., T \tag{3}$$

where α_i is the country-specific intercept and $\delta_i t$ is a deterministic time trend specific to individual countries in the panel. The slope coefficients β_i can vary from one individual to another allowing the cointegrating vectors to be heterogeneous across countries.

Pedroni (1999) presents seven different statistics[3], four of which are based on pooling along the within-dimension and the other three are based on pooling along the between-dimension. The former, known as panel cointegration statistics, test the null hypothesis of no cointegration, $H_0 : \gamma_i = 1 \;\forall i$, against the alternative $H_1 : \gamma_i = \gamma < 1 \;\forall i$ in the residuals from the panel regression (3), $\hat{\epsilon}_{it} = \gamma_i \hat{\epsilon}_{i,t-1} + \mu_{it}$. By contrast, the latter, known as group mean panel cointegration statistics, test the null hypothesis of no cointegration against the alternative $H_1 : \gamma_i < 1 \;\forall i$, which allows the possibility of an additional heterogeneity source across the countries.

[3] See Pedroni (1999) for details of the form of the statistics.

To calculate the test statistics, one has to estimate equation (3) separately for each country in the panel and then pool the obtained residuals in a different way for each statistic. Each of the seven statistics is asymptotically normally distributed. Therefore, in order to test the null of no cointegration, the statistics must be compared with the appropriate tails of the normal distribution. In the case of the panel variance statistic (the first panel cointegration statistic), large positive values imply the rejection of the null hypothesis, while for the rest of statistics large negative values imply the rejection of no cointegration.

Pedroni (2000) proves that the panel OLS estimator is biased when the variables are cointegrated and suggests estimating and testing hypotheses for cointegrating vectors in dynamic panels by FMOLS (fully modified OLS). In this paper GDP and electricity consumption are found to be cointegrated, so we estimate the long run relationship by FMOLS.

2.3 Panel causality tests

The following panel VAR model is considered to test for causality between electricity consumption and GDP:

$$LGDP_{it} = \alpha_1 + \sum_{j=1}^{m+1} \beta_{1j} LGDP_{it-j} + \sum_{j=1}^{m+1} \gamma_{1j} LCE_{it-j} + \eta_{1i} + \mu_{1it} \tag{4}$$

$$LEC_{it} = \alpha_2 + \sum_{j=1}^{m+1} \beta_{2j} LGDP_{it-j} + \sum_{j=1}^{m+1} \gamma_{2j} LCE_{it-j} + \eta_{2i} + \mu_{2it} \tag{5}$$

where η_{1i} and η_{2i} are country-specific effects for the ith individual and μ_{1it} and μ_{2it} are the disturbance terms.

Applying OLS to equations (4) and (5) provides biased estimates due to the correlation between the lagged dependent variables and the country-specific effect (η_{1i} and η_{2i}). To avoid the bias, first differences are taken in the above equations as:

$$\Delta LGDP_{it} = \sum_{j=1}^{m} \beta_{1j} \Delta LGDP_{it-j} + \sum_{j=1}^{m} \gamma_{1j} \Delta LCE_{it-j} + \Delta\mu_{1it} \tag{6}$$

$$\Delta LCE_{it} = \sum_{j=1}^{m} \beta_{2j} \Delta LGDP_{it-j} + \sum_{j=1}^{m} \gamma_{2j} \Delta LCE_{it-j} + \Delta\mu_{2it} \tag{7}$$

However, differencing introduces correlation between the lagged dependent differenced variable and the new differenced error term, so OLS estimates will be biased and inconsistent. Arellano and Bond (1991) propose a panel GMM estimator for the system (6)-(7) using lagged dependent variables in levels as instruments for the variables in first differences. For the instruments to be valid there must be no serial correlation in μ_{1it} and μ_{2it}. Also, the optimal lag length, m, is selected until no serial correlation is achieved in residuals. This assumption may be tested taking into account the fact that if the disturbances are not serially correlated, there should be evidence of significant negative first order serial correlation and no evidence of second order serial correlation in the differenced residuals.

Blundell and Bond (1998) point out the weakness of the Arellano and Bond GMM estimator for highly autoregressive panel series and suggest the system GMM estimator. They show that there is an important gain in efficiency when using lagged differenced dependent variables as instruments. Therefore, in this paper equations (6) and (7) are estimated using Blundell and Bond (1998) system GMM robust one-step estimator. The Arellano and Bond (1991) m_j statistic is used to test the null of no jth order correlation in the differenced residuals and the Sargan test of over-identifying restrictions is applied in the results of the system GMM one-step estimation to check the validity of the instruments.

In this context, a simple Wald test can be applied to examine the direction of the causal relationship between electricity consumption and GDP. Electricity consumption does not Granger cause economic growth if all the coefficients $\gamma_{1j}, \forall j = 1, ..., m$ are not significantly different from zero in equation (6). Analogously, economic growth does not Granger cause electricity consumption if all the coefficients $\beta_{2j}, \forall j = 1, ..., m$ are not significantly different from zero in equation (7).

3 Data

It is acknowledged (see for instance the Green Paper on a European Strategy for Sustainable, Competitive and Secure Energy, 2006) that completing the internal European electricity market requires sufficient interconnections across borders. This is a crucial mechanism for electricity market competition. The greater the interconnection in the European electricity grid, the lower the need for spare capacity maintenance. There are some countries where the ratio between peak demand load and available capacity is close to one. Therefore, there is an increased probability of blackouts, which raises concerns about market power abuse, especially on the part of larger generators, as well as the need for investments in capacity. As result, countries have to make investments in capacity that could be avoided with sufficient interconnections.

We use a sample of twelve European countries: Austria, Belgium, Denmark, Finland, France, Germany, Italy, Luxembourg, Netherlands, Norway, Sweden and Switzerland. We have data from 1970 to 2004 on real GDP (in millions of dollars at 1996 constant prices) and electricity consumption measured in millions of tonnes of oil equivalent (mtoe).[4] We build a panel of countries that seek to create a unique market to trade a good that is necessary to sustain economic growth. In these countries electricity imports and exports have increased over time and on average represent a significant share of total consumption. This is the basic reason why we do not include the United Kingdom, Spain and Eastern European countries. Table 1 reports the electricity trade of the sample countries. Columns 2 and 4 show the average shares of imports and exports respectively in total electricity consumption. Columns 3 and 5 show the average shares of imports and exports respectively in sample countries.

Table 1: Electricity imports and exports

	% Imports		% Exports	
	Of total	Of sample	Of total	Of sample
Austria	23.2	13.5	22.5	17.6
Belgium	14.1	14.1	9.4	9.4
Denmark	20.6	20.6	27.8	27.8
Finland	14.4	5.5	2.1	2.1
France	1.2	0.9	17.3	12.4
Germany	8.2	4.3	8.2	7.3
Italy	16.3	14.6	0.3	0.2
Luxembourg	110.9	110.9	24.6	24.6
Netherlands	16.9	16.9	2.4	2.4
Norway	5.9	5.1	8.5	5.3
Sweden	9.4	9.1	10.2	10.0
Switzerland	46.1	46.1	55.8	55.8
Mean[(a)]	*10.8*		*10.9*	

Source: IEA and own work.

[(a)] Weighted mean by total electricity consumption in each country.

On average these countries trade 10 percent of the electricity consumed or

[4] National account data are from the OECD and electricity data are from the IEA.

generated. There are differences in the pattern of trading between countries. The net selling position of electricity is not determined only by resource availability but also by the structure of electricity generation. For example, Italy is clearly a net importer of electricity whilst France is a net exporter. The former relies heavily on non-nuclear capacity whereas the latter uses mainly nuclear generation. Switzerland, and to a lesser extent Austria, are at the heart of central Europe and they are used for electricity transmission between central Europe and Italy. The Nordic countries are linked together, especially after Nordpool started operating in 1993. Moreover, we observe how trade involves neighboring countries. However, a small fraction of trade corresponds to non-bordering countries. This situation has emerged after market deregulation and the creation of regional electricity markets. This feature is more apparent in northern European countries, which have grouped in a single market called Nordpool. The same happens with the Benelux countries. The rest of the countries are promoting single markets for electricity.

Table 2 summarizes average rates of growth in electricity consumption, imports, exports and real GDP of the countries during the period.

Table 2: Average growth rates

Country	Electricity			GDP
	Consumption	Imports	Exports	
Austria	1.9	8.4	6.7	3.3
Belgium	2.4	8.7	0.9	2.7
Denmark	1.2	19.5	19.2	2.2
Finland	2.2	6.1	153.6[(a)]	3.0
France	2.3	4.5	2.1	2.8
Germany	0.7	4.2	5.3	1.9
Italy	2.4	2.5	10.5	3.2
Luxembourg	2.7	2.2	21.8	2.8
Netherlands	2.5	7.8	63.7	2.3
Norway	1.1	162.3[(a)]	31.4	2.9
Sweden	0.2	12.3	7.7	2.2
Switzerland	1.3	5.2	2.7	1.9
Mean	1.7	20.3	27.1	2.7

Source: IEA and OECD

[(a)] Significant increase after the creation of Nordpool, 1993

We observe how countries have experienced a more rapid increase in trade, either imports or exports, than in consumption. The case of the Nordic countries is remarkable: trade among them has just rapidly risen. As pointed out above, this is the result of their joining together in NordPool since 1993, the single power market for Norway, Denmark, Sweden and Finland. Security of supply among the European countries is encouraged in line with this model. Figure 1 plots the average rates of growth in electricity and GDP for each country.

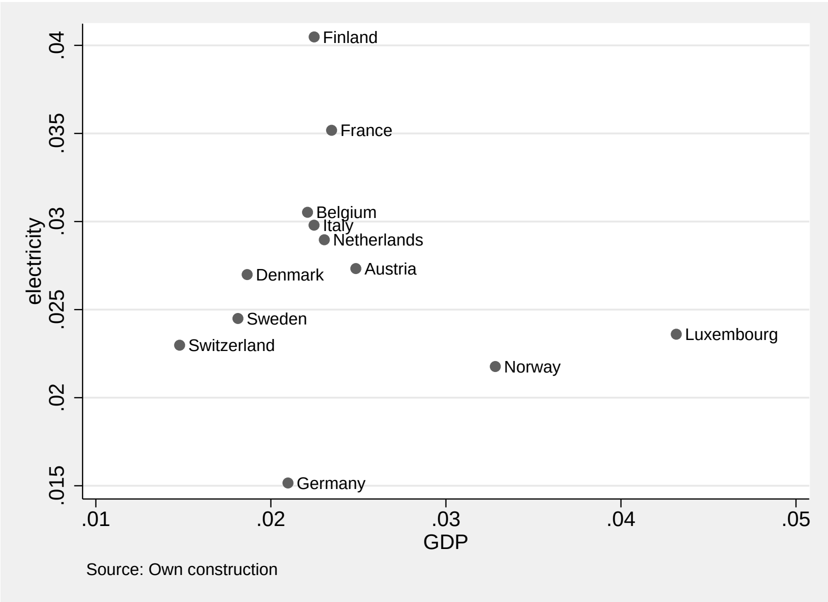

Figure 1: Average Rates of Growth

4 Empirical results

The results of the IPS, LLC and Hadri panel unit root tests are presented in Table 3. As can be seen, with the exception of electricity consumption at levels with no trend, the IPS test shows that both series (LGDP and LEC) are integrated of order one. The Hadri test shows similar evidence except for electricity consumption in first differences with no trend. By contrast, the LLC test cannot reject the null hypothesis of unit root for both differenced series[5].

[5]We consider a maximum of 8 lags in the ADF regressions and select the optimal by using a sequential general-to-specific approach based on the significance of the final lagged term at the 10% level. It should be noted that the tests, specially the LLC, are sensitive to the number of lags selected. For example, if the number of lags decreases, the LLC test shows statistical significance at the 1% level for both differenced series.

Table 3: Results of unit root tests

Variable	IPS		LLC		Hadri	
	No trend	Trend	No trend	Trend	No trend	Trend
LGDP	3.7949	−0.8083	−0.6136	−1.1754	73.258***	20.987***
LEC	−3.1406***	1.0296	−1.6548*	0.8224	70.669***	40.667***
ΔLGDP	−3.8046***	−2.5823***	−1.1662	4.4961	1.483*	1.238
ΔLEC	−2.9203***	−3.3771***	0.3970	4.6607	12.585***	1.290*

IPS, LLC and Hadri represent the panel unit root tests of Im et al. (2003), Levin et al. (2002) and Hadri (2000), respectively.

*** and * indicate rejection of the null hypothesis at the 1% and 10% significance levels, respectively.

We should consider two aspects. On the one hand, as pointed out above, the IPS test allows for heterogeneity across cross-section units in the autoregressive term, which is a more reasonable assumption when using crossed countries. Also, Im et al. (2003) show that under serial correlation and heterogeneity in the underlying data generation process, if the selected order of the underlying ADF regressions is large enough, the IPS test is more powerful than the LLC. On the other hand, the characteristics of the series make it reasonable to include a time trend in the ADF regressions. In fact, both real GDP and electricity consumption exhibit a persistent upward trend for all countries in the panel and have increased over time, as can be seen in Table 2.

Taking into account these results, we conclude that the series are integrated of order one and proceed to test for cointegration. The results of Pedroni (1999) panel cointegration tests based on equation (3) are presented in Table 4. As reported, when time fixed effects are not included in the cointegrating regression (3), none of the statistics can reject the null of no cointegration. However, when the cointegrating regression includes time effects, the results of the tests are misleading. While the null hypothesis of no cointegration cannot be rejected for panel and group ρ and PP statistics, there is evidence of cointegration between the series for the panel variance, panel ADF and group ADF statistics.

As can be seen, the panel cointegration tests are very sensitive to the inclusion of a time trend, but given the characteristics of the series, it seems reasonable to incorporate a deterministic time trend which is specific to each country in the panel[6]. Pedroni (2004) shows that ρ and PP tests tend to under-reject the null of no cointegration in small samples. Therefore, we rely on the results of the rest of the statistics and conclude that real GDP and electricity consumption for the countries in the panel are cointegrated series, that is, there exists a long-run relationship between electricity consumption and economic growth for the countries in the panel, which means that the series move together in the long-run. Following Pedroni (2000), the long run equation (3) is estimated by FMOLS avoiding the bias of the OLS estimator.

Table 4: Results of panel cointegration tests

Statistics	No time effects	Time effects
Panel variance	0.1803	2.3779***
Panel ρ	0.7553	0.1084
Panel PP	0.7026	−0.5243
Panel ADF	1.0110	−1.8247**
Group ρ	1.7284	1.0355
Group PP	1.4832	0.0038
Group ADF	1.5416	−2.1279**

*** and ** indicate statistical significance at the 1% and 5% levels, respectively.

Table 5 reports the results of the estimation of individual and panel FMOLS for the cointegrating relationship. With regard to panel estimation results, the coefficient of LEC is statistically significant and positive at the 1% level. Specifically, a 1% increase in electricity consumption leads to an increase of 0.30% in real GDP in the sample of European countries. The estimates for individual countries show the significance of the coefficient of LEC for all countries except Finland, Germany, Norway, Sweden and Switzerland. For the rest of the countries, the coefficient is positive, except for Denmark, where it is negative. The greatest elasticity of the electricity consumption with respect to real GDP is found in Italy, with a figure of 1.03.

Next, to determine the size and direction of the causal relationship between the series, the VAR in differences (equations (6) and (7)) is estimated using the Blundell and Bond (1998) system GMM estimator. Table 6 shows the results of system GMM panel estimation, the Sargan test results, and m_1 and m_2 statistics. As m_1 and m_2 statistics show, the selection of 1 lag

[6]The time trend is significant in the cointegrating regression for all countries in the panel at a 1% level except for Finland and Italy, where the time trend is significant at the 5% and 10% levels, respectively.

Table 5: Fully modified OLS estimates

Country	LEC
Austria	0.29 (3.27)***
Belgium	0.41 (4.80)***
Denmark	−0.18 (−2.99)***
Finland	0.25 (1.36)
France	0.17 (3.29)***
Germany	−0.08 (−0.97)
Italy	1.03 (7.05)***
Luxembourg	0.72 (1.99)**
Netherlands	0.69 (4.49)***
Norway	0.15 (1.54)
Sweden	−0.04 (−0.72)
Switzerland	0.21 (1.50)
Panel	**0.30 (7.11)*****

t-statistics are in parentheses. *** and ** indicate statistical significance at the 1% and 5% levels, respectively.

is needed for the panel to have no serial correlation in the disturbances μ_{1it} and μ_{2it}. In fact, significant negative first order serial correlation is found in the first differenced residuals, while there is no evidence of second order serial correlation. The Sargan statistics do not reject the validity of the instruments. Granger causality tests indicate the absence of causality in both directions. On the one hand, the coefficient of lagged differenced electricity consumption is not significant in equation (6), and on the other hand the coefficient of lagged differenced GDP is not significant in equation (7). Therefore, we can conclude that past electricity consumption does not help to predict economic growth and, analogously, past economic growth does not help to predict GDP. However, the series are cointegrated and they move together in the long-run along a path. In this context, the absence of causal relationship should be interpretated in the short-run, while in the long-run there exists a stable equilibrium between the series[7].

[7] We also break total electricity consumption down into residential and industrial consumption. The only difference we find is that series are not cointegrated, so there is not a long-run equilibrium relationship between industrial electricity consumption and GDP. Results for industrial electricity consumption are shown in Appendix A.

Table 6: System GMM estimation

Independent	Dependent	
	$\Delta LGDP$	ΔLEC
$\Delta LGDP_{i,t-1}$	0.2536	−0.0307
	(0.00)	(0.68)
$\Delta LEC_{i,t-1}$	0.0639	0.1947
	(0.41)	(0.03)
Sargan test	362.65	352.37
	(0.34)	(0.48)
m_1	−2.7225	−2.9940
	(0.006)	(0.003)
m_2	−0.4334	1.0230
	(0.66)	(0.31)

All tests are based on one-step robust GMM estimates. Sargan test is based on one-step GMM estimates. p-values in parentheses.

5 Conclusions

The study of the causal relationship between electricity consumption and economic growth is of interest in terms of designing appropriate energy policies in different countries. In this paper, we study the causal relationship between electricity consumption and economic growth for a panel of 12 European countries which are related by interconnections and through a common perspective moving towards the creation of a single electricity market.

We use panel data to avoid the problems of standard econometric methods when applied to short-time series, and implement heterogenous panel cointegration tests and panel system GMM estimation to determine the dynamic relationships between the series. We find no evidence of a short-run causal relationship between electricity consumption and economic growth for the European countries in the panel sample, but there is evidence of cointegration between the series, which means that there is a long-run equilibrium relationship between the two variables. This in term means that electricity consumption does not help to predict GDP in the short-run but can do so in the long-run. A 1% increase in electricity consumption would yield a 0.3% increase in economic growth in the long-run.

The implications of our results for a common European electricity market are significant. The long-run electricity policies of the European Commissions can be directed towards a more efficient use of existing capacity and improvement of interconnections in such a way that future economic growth is increased. Therefore, the need for single countries to invest in security of supply maintenance decreases. We may also expect that the single European market for electricity to grow as more countries get interconnected. Thus, our estimation results should be reconsidered to shed light on the causality between electricity consumption and economic growth.

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Appendix A: Industrial electricity consumption

We apply the same methodology to check for causality between industrial electricity consumption and economic growth.

Table 7 shows the results of panel unit root tests for (logarithm) industrial electricity consumption (LIC).

Table 7: Results of unit root tests

Variable	IPS		LLC		Hadri	
	No trend	Trend	No trend	Trend	No trend	Trend
LIC	0.7607	-0.4727	1.2548	2.8541	67.381^{***}	24.012^{***}
ΔLIC	-3.5202^{***}	-3.6356^{***}	8.2049	16.6007	0.450	-0.226

IPS, LLC and Hadri represent the panel unit root tests of Im et al. (2003), Levin et al. (2002) and Hadri (2000), respectively.

*** and * indicate rejection of the null hypothesis at the 1% and 10% significance levels, respectively.

Table 8 shows the results of panel cointegration tests between industrial electricity consumption and GDP. Except for the panel variance statistic when time effects are included, the statistics are not significant and hence the null hypothesis of no cointegration cannot be rejected. Therefore, we conclude that industrial electricity consumption and GDP are non cointegrated series, that is, there is no long-run equilibrium relationship between the series. This result differs from that found when using total electricity consumption. For developed countries, such as our sample countries, the share of total consumption accounted for by industrial electricity consumption follows a decreasing trend. Therefore, the link between electricity consumption for industrial use and economic growth might have weakened over the years, with residential electricity consumption being the key for a long-run equilibrium relationship between total electricity consumption and economic growth.

Table 8: Results of panel cointegration tests

Statistics	No time effects	Time effects
Panel variance	0.2393	7.7416***
Panel ρ	-0.4311	0.9331
Panel PP	-0.4807	0.3793
Panel ADF	0.6771	0.4952
Group ρ	0.4937	1.4956
Group PP	0.1122	0.3699
Group ADF	1.0825	0.4990

*** indicates statistical significance at the 1% level.

Finally, we estimate equations (6) and (7) by system GMM, but considering industrial electricity consumption instead of the total one. Table 9 reports the system GMM panel estimations, the Sargan test results and the value of the m_1 and m_2 statistics. The results are similar to those for total electricity consumption and we find no evidence of a causal relationship between industrial electricity consumption and GDP.

Table 9: System GMM estimation

Independent	Dependent	
	$\Delta LGDP$	ΔLIC
$\Delta LGDP_{i,t-1}$	0.2693	-0.0155
	(0.00)	(0.89)
$\Delta LIC_{i,t-1}$	0.0222	0.0430
	(0.64)	(0.57)
Sargan test	371.27	362.21
	(0.23)	(0.34)
m_1	-2.7925	-3.1778
	(0.005)	(0.002)
m_2	-0.3758	-1.1527
	(0.71)	(0.25)

All tests are based on one-step robust GMM estimates. The Sargan test is based on one-step GMM estimates. p-values in parentheses.