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Economic growth or electricity, what came first in Spain after 1958?

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Abstract

Purpose – With the opening up of the economy since the 1959 Economic Stabilization Plan, was it the production of electricity that drove the growth of gross domestic product (GDP) in Spain or, on the contrary, was it the growth of GDP that drove the production of electricity well into the 21st century? The purpose of this paper is to answer this question.

Design/methodology/approach – A cointegration approach based on the studies conducted by Pesaran and Shin (1999) and Pesaran *et al.* (2001) is applied, as it is suitable for short data series like those used in this paper.

Findings – The results of this paper allow us to conclude that electricity production boosted economic growth in Spain during the period under study, confirming the growth hypothesis.

Research limitations/implications – The results of this paper should be interpreted with caution, as electricity today amounts to less than a quarter of the total amount of energy used in Spain. It was not possible to incorporate other inputs to the production function (such as other energy inputs, technological or human capital), but the methodology used avoids the problems of omitted variables and of autocorrelation.

Practical implications – The results show that a small economy with limited resources, such as the Spanish one, is more vulnerable to energy shocks than other energy-sufficient economies. As Spain is a country with high energy dependence from abroad, the government must first ensure the electricity supply. Increased availability and access to different sources of electricity will improve the outlook for the Spanish economy. Conversely, a shortage in supply of electricity will constrain the regular pace of economic growth.

Social implications – Spain should investigate and explore more efficient and cost-effective sources of energy, in particular the renewable energies, as traditional energy sources will be scarce before long.

Originality/value – This paper differs from previous ones carried out for Spain in several aspects: it considers a broader period of time, from 1958 to 2015; the relationships between electricity production and GDP are analysed for the first time in a neo-classical production function where electricity, capital and employment are considered as separate factors; and a cointegration approach based on the studies conducted by Pesaran and Shin (1999) and Pesaran *et al.* (2001) is applied, as it is suitable for short data series like those used in this paper.

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Paper type Research paper

1. Introduction

Since the beginning of the industrial revolution, changes in production and the consumption of energy have been basic elements of successive transformations in the world economy. As is well known, electricity was swiftly adopted in Western countries, and activities related to it soon became economic sectors, leading to the modernization of the production system.

In Spain, this form of energy followed the same steps as in other developed countries, although with delays and peculiarities. In the early 1950s, Spain's energy production (and energy consumption) was weak with an absolute pre-eminence of coal and a scarce external dependence. The low energy consumption was coherent with the backwardness of Spanish economy, which had a predominantly agricultural productive system and a still incipient industry.

Circumstances changed during the 1950s and the electricity sector became the engine of Spanish industrial expansion. The intense industrialization process, based on heavy industry sectors that are great consumers of energy, raised the energy intensity. This increase was also a consequence of a higher standard of living. The result was that electricity production since 1958 grew at a faster rate than gross domestic product (GDP).

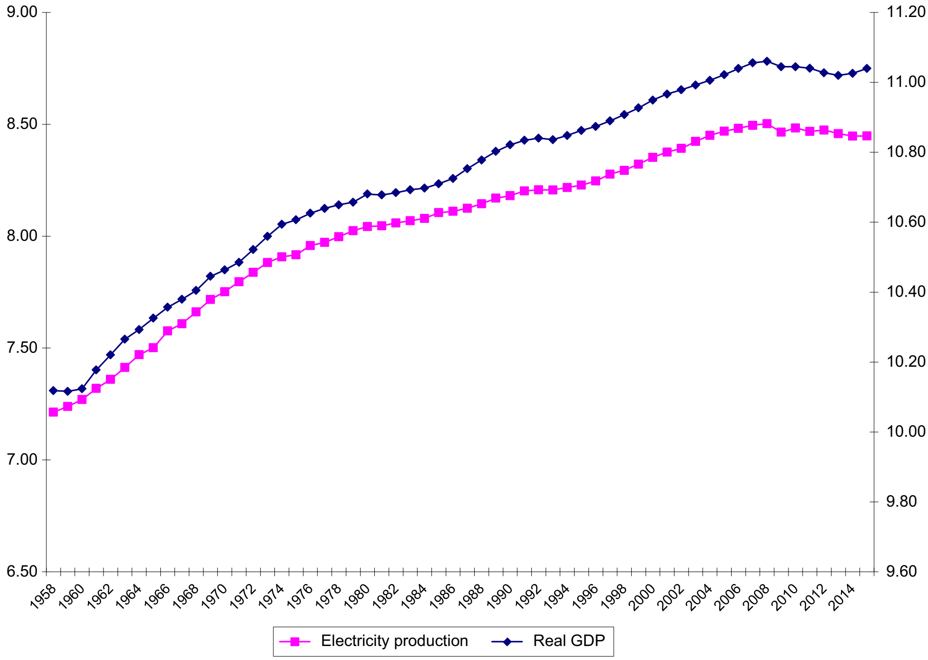
The aim of this research is to determine whether the increase in electricity production preceded Spanish GDP growth after 1958 when the Economic Stabilization Plan was implemented and the Spanish economy entered a phase of greatest economic growth or, on the contrary, whether GDP growth boosted electricity production. For that purpose, the relationships between electricity production and GDP are researched for the first time in Spain in a neo-classical production function where electricity production, capital and employment are considered as separate factors. A longer time span than that studied by Ciarreta and Zárraga (2010), Fuinhas and Marques (2012), Pirlogea and Cicea (2012) and Sanz-Villarroya and Sanaú (2016) is analysed here. Moreover, a cointegration approach based on the studies conducted by Pesaran and Shin (1999) and Pesaran *et al.* (2001) is applied, as it is suitable for short data series like those used in this work. The results of an autoregressive distributed lag (ARDL) model allow us to conclude that electricity investments were called for economic growth in Spain since the late 1950s.

The paper is organized as follows. Section 2 concisely describes the evolution of the electricity sector in Spain since the late 1950s. Section 3 summarizes the literature that analyses the relation between GDP growth and electricity consumption or production. Section 4 gives an account of the methodology used and provides the data and empirical evidence for the Spanish case. The paper ends with a report of the main findings obtained.

2. Evolution of the Spanish electricity sector since 1958

Since 1958, two important stages can be distinguished in the evolution of growth of Spanish GDP and electricity sector. The first lasts until the mid-seventies and reflects the period of expansion and modernization of the electricity sector as well as the take-off of the Spanish economy. This marks the beginning of the second stage in which two subperiods can be differentiated: 1975–1984 and 1985–2015.

Figure 1 summarizes the trajectory of GDP and electricity production between 1958 and 2015. Note that the evolution of electricity production coincides with the evolution of GDP. However, it cannot be concluded from the figure whether the growth of electrical production



Sources: SEE (several years); UNESA (2016); Prados de la Escosura (2003); National Statistics Institute (several years)

Figure 1. Real gross domestic product and electricity production in Spain (1958–2015). Evolution in logarithms

preceded GDP growth or, conversely, whether it was GDP growth that boosted electricity production.

Between 1958 and 1974, there was a strong GDP growth (at an annual average rate of 6.7% cumulative) and a higher expansion of electricity production (10.5% cumulative annual average) (Appendix 1). In these years, the capacity of power generation and oil refining rose very quickly and the energy sector managed to meet the energy demands by relying on imported oil and natural gas (since the late 1960s).

During this first stage, many power plants were projected and partially financed, through public funds, under the Spanish National Electricity Plan (NEP) 1971–1981. This favoured a large expansion of hydroelectric power and, above all, of conventional thermoelectric power, both of which exhibited a very similar installed capacity in 1974. In these years, the transmission and distribution network was tripled and completed, achieving a full interconnection between the various electricity production enterprises.

The second stage begins around 1975, when the effects of the economic crisis (originated by the sudden, sharp increase in oil prices and raw materials in 1973) begin to affect the Spanish economy. The economic crisis was a turning point in the Spanish evolution given that, from then until 2015, the last year with available data, the average annual GDP growth rate declined to 2.7% and the average annual growth rate of electricity production fell to 2.6%.

The early years of this second stage were very hard because the lower GDP growth was accompanied by a sharp rise in unemployment and inflation. Energy policy aimed to satisfy demand, at minimum cost and with maximum safety, and energy planning was initiated through the Spanish NEP. After 1979, these plans also pursued diversification and energy saving.

Until 1984, the increase in electric power was led by nuclear power plants (whose power increased at an annual rate cumulative average of 17.8% between 1975 and 1984) and, to a much lesser extent, by conventional thermal power plants (5.4%). The growth of hydroelectric power was lower, 1.9% (annual cumulative average). The extension of the installed power capacity enabled electricity production to advance between 1975 and 1984 at an annual cumulative average rate of 4.8% (less than half of that achieved in the first phase).

After 1985, the Spanish economy experienced a new growth period, slower in some years (early 1990s) and abruptly stopped in 2008. The growth of the installed capacity is explained by the increase of renewable energy (at a cumulative rate of 4.2% per year between 1985 and 2015) and conventional thermoelectric power (2.9%), rather than by nuclear power (1.0%).

3. Economic growth and electricity

Energy, besides allowing for the satisfaction of the consumers' needs, is a necessary input to transform materials into products and transport them, that is, to carry out any productive activity.

Traditionally, the economic growth theory has hardly paid attention to the role of energy. The most renown models do not include resources or energy as relevant factors. By contrast, economic historians [(such as Allen (2009) or Carreras and Tafunell (2010)] believe that energy has played a crucial role in economic growth as well as in industrialization processes.

Stern (2010) states that when energy is scarce, it imposes a strong constraint on economic growth; however, when energy is abundant, its impact on the growth of the economy is reduced. In other words, energy can be more important for economic growth in developing countries than in developed countries.

Stern and Kander (2012) add energy as an input to Solow's growth model that has low substitutability with capital and employment, allowing the elasticity of substitution between capital and employment to remain one. Their model considers innovations that directly increase the productivity of energy and those that increase the productivity of employment (*labour-augmenting technological change*). As all economic processes require energy and there are limits to the substitution of other production factors for energy, the latter is an essential production input (Stern, 1997).

Consequently, the relationship between energy and the aggregate output can be affected by substitution between energy and the other inputs, by total factor productivity and even by shifts in the composition of the energy input and in the composition output (Stern, 2010).

Empirical evidence suggests that energy intensity has declined during the past decades in developed countries. A part of the reduction in energy intensity can be explained by the development of electricity because electricity allows a more efficient use of the energy.

As Burke *et al.* (2018) argue, electricity has offered advantages over other energy sources, enabling far more efficient technologies (like the information and communications technologies), a more productive organization of manufacturing and a more efficient lighting and providing productivity gains. To make the best of these advantages, a reliable supply of electricity and an adequate electricity network that answers to the volatile demand of electricity will be necessary.

For all these reasons, the relationship between electricity and economic growth is an important issue to research, and the empirical evidence is inconclusive. Camarero *et al.* (2015) classify the research approaches into groups based on different estimations.

The paper written by Kraft and Kraft (1978) initiated the debate on the direction of causality between energy and GDP. Some of these analyses, included in the so-called *growth* *hypothesis*, find a unidirectional causality that runs from electricity consumption or production to economic growth. This means that in countries that follow this pattern, a reduction in electricity consumption or production could lead to lower economic growth. This hypothesis is found to be prevalent in the developed world, as suggested by Chontanawat *et al.* (2008) and Narayan and Prasad (2008). However, Morimoto and Hope (2004) highlight that the increase in electricity supply played an important role in explaining economic growth in Sri Lanka. Altinay and Karagol (2005) provided evidence for unidirectional causality running from the electricity consumption to the real GDP in Turkey during the period 1950–2000. Tang and Shahbaz (2013) concluded that electricity consumption Granger-caused output for economy as a whole and also for the manufacturing and services sectors in Pakistan from 1972 to 2010 (not for the agricultural sector). More recently, Wolde-Rufael (2014) confirmed the growth hypothesis in Belarus and Bulgaria during the period 1975–2010 and Ali *et al.* (2020) in Pakistan from 1961 to 2015 (Table 1).

Other studies, on the contrary, reveal the opposite relationship. That is, a higher rate of growth leads to a higher electricity consumption (or electricity generation), a result that fits into the *conservation hypothesis*. If this were the case, then policies implemented to stimulate or to reduce electricity consumption would not have any effects in terms of economic growth. This happens, for example, in countries such as Indonesia and Mexico or in Australia, a fact reflected in the analysis of Murry and Nan (1996) and Narayan and Smyth (2005), respectively. Yoo and Kim (2006) found a unidirectional causality that runs from economic growth to electricity generation in Indonesia. Squalli (2007) presented empirical evidence indicating that policies for energy conservation can have little to no impact on economic growth in Argelia from 1980 to 2002. Ang (2008) found a strong support for causality running from economic growth to energy consumption growth in Malaysia. Finally, Wolde-Rufael (2014) proved the conservation hypothesis in the Czech Republic, Latvia, Lithuania and the Russian Federation for the period 1975–2010.

In other papers, there are some evidences of the *feedback hypothesis*, that is, of a bidirectional causality between electricity consumption and economic growth, with the consequent beneficial effects. Tang (2008), with quarterly data from 1972 to 2003, suggested that electricity consumption and economic growth in Malaysia Granger-causes each other. Yoo and Lee (2010) found this relationship in their sample of a large set of economies that included the OECD countries and other developing countries. Their results showed a statistically significant inverted-U-shaped relationship between per-capita income and electricity consumption. Bayar and Özel (2014) found that electricity consumption had a positive impact on the economic growth in emerging economies and that there was bidirectional causality between economic growth and electricity consumption (during the period 1970–2011). Wolde-Rufael (2014) found bidirectional causality in Ukraine during the period 1975–2010 and Lu (2017) found it in Taiwan.

Some of the economies analysed point to the absence of a causal relationship between these variables, supporting the *neutral hypothesis*, as in the case of France, Germany, Portugal, India, Norway, the UK and the USA (Murry and Nan, 1996); in 11 Middle East and North Africa countries (Ozturk and Acaravci, 2011); or in transition economies (Wolde-Rufael, 2014).

Finally, some studies have found seemingly contradictory empirical evidence. Abbas and Choudhury (2013), for instance, examined the causality between electricity consumption and economic growth in India and Pakistan at aggregated and disaggregated level. At the aggregated level, India confirmed the *conservation hypothesis*, while Pakistan confirmed the *feedback hypothesis*.

Authors	Methodology	Growth hypothesis	Conservation hypothesis	Feedback hypothesis	Neutral hypothesis
Bivariate models					
Morimoto and	Cointegration Engle	Sri Lanka	Czech Republic, Latvia,	Ukraine (1975–2010)	Transition economies (1975–2010)
Hope (2004)	Granger	(1960–1998)	Lithuania and the Russian	Pakistan (1972–2008)	France, Germany, Portugal, India,
Altinay and	The Dolado–Lütkepohl	Turkey	Federation (1975–2010)	Malaysia (1972–2003)	Norway, the UK and the USA
Karagol (2005)	and the Granger causality	(1950–2000)	Indonesia (1970–1990)	88 countries (1975–2004)	(1970–1990)
Tang and	tests	Pakistan	Australia (1966–1999)	Emerging economies	11 MENA countries (1971–2006)
Shahbaz (2013)	The Granger causality	(1972–2010)	Indonesia (1971–2002)	(1970–2011)	
Wolde-Rufael	test	Belarus and	Argelia (1980–2002)	Taiwan (1975–2010)	
(2014)	A bootstrap panel	Bulgaria	Malaysia (1971–1999)		
Ali *et al.* (2020)	causality approach	(1975–2010)	India (1972–2008)		
Murry and Nan	Vector error-correction	Pakistan			
(1996)	model (VECM)	(1961–2015)			
Narayan and	The Granger causality				
Smyth (2005)	test				
Yoo and Kim	ARDL				
(2006)	Bounds test				
Squalli (2007)	Cointegration				
Ang (2008)	Engle Granger				
Abbas and	ARDL model and Toda–				
Choudhury	Yamamoto Granger				
(2013)	causality test				
Tang (2008)	Causality tests				
Yoo and Lee	Causality tests				
(2010)	ARDL model and Granger				
Bayar and Özel	causality				
(2014)	Model estimated				
Lu (2017)	The Granger causality				
Ozturk and	tests				
Acaravci	The Granger causality test				
(2011)	Pedroni panel				
	cointegration and VECM				
	Granger causality				

(*continued*)

Table 1.
Selection of papers analysing the relationship between economic growth and electricity consumption/production

Table 1.

Authors	Methodology	Growth hypothesis	Conservation hypothesis	Feedback hypothesis	Neutral hypothesis
Multivariate models					
Iyke (2015) Sun and Anwar (2015) Ikegami and Wang (2016) Tang and Tan (2013) Tang *et al.* (2013) Polemis and Dagoumas (2013) Mohammadi and Parvaresh (2014) Ohler and Fetters (2014) Karanfil and Li (2015) Shahbaz *et al.* (2017)	Trivariate VECM Trivariate vector autoregressive framework ARDL and Granger causality test Granger causality test Granger causality test within VECM VECM and Granger causality test Panel estimations techniques Panel error correction model Panel data techniques Estimation of panel regressions	Nigeria (1971–2011) Singapore (1983–2014) North America (1960–2014)	Germany (1983–2014) Lower-middle-income, Middle East and North Africa and South Asia countries (1960–2014)	Malaysia (1970–2009) Portugal (1974–2009) Greece (1970–2011) 14 oil-exporting countries (1980–2007) 20 OECD countries (1990–2008) 160 countries Upper-middle income, high income, OECD, East Asia & Pacific and Europe and Central Asia categories (1960–2014)	Low-middle-income, the non-OECD, Latin America and Caribbean and Sub-Saharan Africa countries (1960–2014)
Bivariate models for Spain					
Ciarreta and Zárraga (2010) Sanz-Villarroya and Sanaú (2016)	Standard and non-linear Granger causality Cointegration model for short time series	Renewable sources and nuclear power (1958–2011)	1973–2008 Conventional power plants (1958–2011)		

Apart from total electricity consumption, attention has also been paid to the role of the different types of electricity (Payne, 2010; Dogan, 2015a, 2015b; Cerdeira Bento and Moutinho, 2016; Cardoso Marques *et al.*, 2016 or Sanz-Villarroya and Sanaú, 2016).

A common criticism is that many studies concentrate on the bivariate relationship of energy consumption and economic growth. In these cases, there may be an omitted-variable bias problem (when one or more relevant explanatory variables are ignored in the estimated model) and results may be biased and inconsistent. Many authors try to mitigate this criticism using control variables, that is, considering other potential variables such as electricity prices, export and import, capital, employment, inflation, entrepreneurship [. . .] that affect energy consumption and economic growth (multivariate models). Although this approach has limitations deriving from the selection process of the control variables, it highlights the importance of a disaggregate analysis of economic activity.

The papers that incorporate new variables on examining the electricity–GDP growth relationship have limitations deriving from the selection process of the control variables and also provide mixed results, the direction of causality between these variables being controversial. Iyke (2015) and Sun and Anwar (2015) conclude that there is a positive causality running from electricity consumption to real GDP that supports the growth hypothesis in Nigeria and Singapore, respectively. Conversely, Ikegami and Wang (2016) find evidence that there is a unidirectional and positive causality running from real GDP to combustible fuels electricity supplied in Germany, supporting the conservation hypothesis. The evidence in favour of the feedback hypothesis is very common. Tang and Tan (2013) show that electricity consumption and economic growth Granger-cause each other in the short and long term. Tang *et al.* (2013) confirm the same results in Portugal and Polemis and Dagoumas (2013) in Greece in a multivariate framework.

Mohammadi and Parvaresh (2014), examining the nexus between energy consumption and output in 14 oil-exporting countries over 1980–2007, support bidirectional causality in both long and short run and the robustness of the results to the inclusion of additional variables in the models. Ohler and Fetters (2014) examine the causal relationship between economic growth and electricity generation from renewable sources across 20 OECD countries. Among their results, it is worth highlighting that there is a bidirectional relationship between aggregate renewable generation and real GDP and that the energy conservation policies positively impact GDP, if biomass or waste energy decrease and hydroelectricity and wind energy increase.

Karanfil and Li (2015) find a long-run cointegration relationship between electricity consumption and economic growth, implying a feedback hypothesis in 160 countries for the period 1980–2010. Shahbaz *et al.* (2017) analyse the relationship between economic growth, electricity consumption, oil prices, capital and labour in 157 countries. They find countries where the growth hypothesis is confirmed, others that do not depend on electricity for economic growth (*conservation hypothesis*), others supporting the feedback hypothesis and countries in which the neutrality hypothesis is proved.

In sum, there are a lot of works that deal with this matter, but the results obtained from them are mixed. Although there are studies covering a wide range of countries, the particular case of Spain has hardly been investigated, despite the importance of the electricity sector in explaining the process of industrialization that began in the late fifties. Ciarreta and Zárraga (2010), focusing on the 1973–2008 period, find a unique relationship that runs from economic growth to electricity consumption, supporting the *conservation hypothesis*. On the contrary, Sanz-Villarroya and Sanaú (2016) conclude that renewable sources and nuclear power stimulated GDP growth between 1958 and 2011, but the economic growth led to the production of electricity in conventional power plants. Two other studies, considering energy consumption, obtain support for the feedback hypothesis (Fuinhas and Marques, 2012) and the growth hypothesis (Pirlogea and Cicea, 2012). In other words, the results are not conclusive for Spain either.

4. Methodology, data and empirical results

Several authors [(such as Dogan (2015b), Narayan *et al.* (2008) or Apergis and Payne (2010)] considered energy as an additional factor in the production function. Following this literature, the short- and long-run relationships and the direction of causality between electricity production and GDP are investigated, in a neo-classical production function:

$$GDP = f(CAP, EMP, EP) \tag{1}$$

where *CAP* is the capital stock, *EMP* is the employment and *EP* is electricity production. Including *CAP* and *EMP* in the model changes the direction of causality and the magnitude of estimates in the short and long run as compared to the bivariate models.

Annual data for the period 1958–2000 for real GDP and employment are from Prados de la Escosura (2003) and from the National Statistics Institute (2020) since 2000. Annual data for the net capital stock are from Fundación BBVA e Ivie (Instituto Valenciano de Investigaciones Económicas) (2015, 2019). The necessary information about electricity production (in megawatts hour) for the same time span has been collected from the Secretaría de Estado de Energía (SEE) (2020) and UNESA (2016).

The methodology used in this paper is a vector error-correction model (VECM). The VECM for equation (1) is based on that proposed by Pesaran and Shin (1999) and Pesaran *et al.* (2001). They developed a new cointegration approach, the ARDL bounds testing approach, that has many advantages over the traditional one proposed by Engle and Granger (1987) and Johansen and Juselius (1990). The first and the most important advantage is that the order of integration of the series does not matter, so non-stationary and stationary variables can both be taken into account. The second advantage is that this new methodology produces robust results even in small sample sizes. The third advantage is that this methodology leads us to estimate the short- and long-run equilibrium relationship at the same time, avoiding the problems of omitted variables and of autocorrelation. Moreover, the bounds test permits us to obtain the causal relationship between the variables and distinguish between the dependent and the explanatory variables.

The application of the ARDL model has become very popular in some areas of economics and especially in energy market analysis, a field in which the temporal dimension of the data available is usually short (Narayan and Smyth, 2005; Narayan *et al.*, 2008; Ghosh, 2009).

For all the reasons mentioned above, it seems that this approach is appropriate for studying the case of Spain: we have a relatively small sample (58 observations); we want to

ADF	*LGDP*	LEMP	*LCAP*	*LEP*	*LEC*
Levels	−2.42	−2.60	−0.72	−2.05	−1.58
	−5.03***	−3.03	−2.78	−3.69	−4.34***

Notes: *LGDP* is the level of real GDP in logarithms; *LEMP* is the level of employment in logarithms; LCAP is the level of the stock of capital in logarithms; *LEP* is the level of electricity production in logarithms and LEC is the level of electricity consumption in logarithms. ***; **; * represent the rejection of the null hypothesis of non-stationarity at the 1%, 5% and 10% level of significance, respectively

Table 2.
Results of unit root tests (with constant and trend)

know the direction in which the causality between them operates; and despite of the different order of integration of the variables, we must be careful with these results because the power and the size properties of conventional unit roots are reduced as a consequence of the relative short data span (Table 2).

The ARDL bounds testing approach is based on a dynamic specification that involves separately estimating the following unrestricted error-correction models in which the two variables are considered as the dependent variable:

$$\Delta LGDP_t = \propto_{LGDP} + \sum_{i=1}^{n}(b_{it}\Delta LGDP_{t-1}) + \sum_{i=1}^{n}(c_{it}\Delta LEP_{t-1}) + \sum_{I=1}^{n}(d_{it}\Delta LCAP_{t-1}) + \sum_{i=1}^{n}(e_{it}\Delta LEMP_{t-1}) + \sigma_{1LGDP}LGDP_{t-1} + \sigma_{2LEP}LEP_{t-1} + \sigma_{3LCAP}LCAP_{t-1} + \sigma_{4LEMP}LEMP_{t-1} + dt + \in_{1t} \quad (2)$$

$$\Delta LEP_t = \beta_{LEP} + \sum_{i=1}^{n}(b_{jt}\Delta LEP_{t-1}) + \sum_{i=1}^{n}(c_{jt}\Delta LGDP_{t-1}) + \sum_{I=1}^{n}(d_{jt}\Delta LCAP_{t-1}) + \sum_{i=1}^{n}(e_{jt}\Delta LEMP_{t-1}) + \beta_{1LGDP}LEP_{t-1} + \beta_{2LEP}LGDP_{t-1} + \beta_{3LCAP}LCAP_{t-1} + \beta_{4LEMP}LEMP_{t-1} + dt + \in_{2t} \quad (3)$$

where *LGDP* represents the log of *GDP*, *LEP* is the log of electricity production, *LCAP* is the log of capital stock, *LEMP* is the log of employment, Δ is the first difference operator and t is a deterministic trend.

To determine the existence of a long-run relationship between the variables, Pesaran *et al.* (2001) propose two alternative tests. On the one hand, they compute an *F*-statistic to test the joint significance of the first lag of the level of variables included in the analysis. On the other hand, a *t*-ratio is used to test the individual significance of the first lag of the level-dependent variable.

The null hypothesis of no cointegration among the variables in equation (1) is H_0: $\sigma_{1LGDP} = \sigma_{2LEP} = 0$ and the alternative hypothesis is H_1: $\sigma_{1LGDP} \neq: \sigma_{1LEP} \neq 0$, which we denote as F_{LGDP} (*LGDP*/*LEP*). The hypothesis and the F_{LEP} (*LEP*/*LGDP*) in equation (2) are defined in a similar way. Moreover, we can use a *t*-ratio to test the null hypothesis of $\sigma_{1LGDP} = 0$ in equation (1) and $\beta_{1LEP} = 0$ in equation (2) with and without a trend in the respective error-correction model. Pesaran *et al.* (2001) provide the corresponding critical values. If the *F*-statistic or the *t*-ratio falls outside the band of critical values, then a clear conclusion can be drawn about the existence or not of a long-run relationship between the variables, without needing to know whether the variables are I(1) or I(0). However, if these statistics fall within the band of critical values, then we are not able to reach a clear conclusion without analysing the order of integration of the variables concerned.

In particular, if the estimated values of F_{LGDP} (*LGDP*/*LEP*) and t (*LGDP*/*LEP*) are higher than the superior band of critical values and those of F_{LEP} (*LEP*/*LGDP*) and t (*LEP*/*LGDP*) are below the band of critical values, then it means that there is a unique relationship in the long run in which the dependent variable is the level of income (*LGDP*) and the electricity

Explanatory variables	Coefficient
Intercept	11.28 (1.960)
Trend	−0.0014 (0.471)
Δ*LGDP* (−1)	0.099 (0.658)
Δ*LGDP* (−2)	0.279 (1.808)
Δ*LEP* (−1)	−0.166 (−1.754)
Δ*LEP* (−2)	−0.160 (−1.712)
Δ*LCAP* (−1)	0.132 (0.479)
Δ*LCAP* (−2)	0.009 (0.033)
Δ*LEMP* (−1)	0.557 (3.520)
Δ*LEMP* (−2)	−0.0372 (−0.244)
LGDP (−1)	−0.632 (−4.590)
LEP (−1)	0.252 (3.898)
LCAP (−1)	0.210 (2.317)
LEMP (−1)	0.0834 (2.487)
D2008	0.0360 (−2.608)
R^2	0.856
Adjusted R^2	0.804
DW	2.023
F-statistic	16.563
AIC	−5.405
LM	1.964
ARCH	0.058
Bounds test for cointegration	
FLGDP(LGDP/LEP)	11.786**
t(LGDP/LEP)	−4.590**
ADF (resid)	−7.743 ***

Notes: LGDP is the level of real GDP in logarithms and LEP is the level of electricity production and LCAP and LEMP are the stock of capital and the employment, respectively, in logarithms. The symbol Δ represents the first differences of the variables. D2008 is a dummy variable that takes value one since 2008

Table 3. Ordinary least square estimates of first differences of real GDP in logarithms (ΔLGDP) in Spain for the period 1958–2015 (equation (2))

production (*LEP*) is the explanatory variable. This outcome would confirm that the causality between the two variables runs from electricity production to growth.

As can be seen in Table 3, this is the case obtained in this analysis. The value of the *F*-statistic for the regression in which *LGDP* is the dependent variable, and considering two lags, is 11.79, higher than 5.07, the upper band critical value at the 5% level of significance. Moreover, the *t*-statistic for *t* (*LGDP*/*LEP*) is also higher than its critical value (−4.59 versus −4.16).

Additionally, the residuals are tested for stationary to avoid the production of spurious results and to ensure the existence of the long-run relationship. The ADF test exhibits a value of −7.74 which is higher than the critical value of −4.15 at the 1% of significance. So, residuals are stationary, indicating a stable long-run relationship between the variables.

On the contrary, as Table 4 shows, the values for F_{LEP} *(LEP/LGDP)* and *t* (*LEP*/*LGDP*) obtained in the alternative regression where *LEP* is the dependent variable are 1.69 and −0.846, respectively, which fall within the critical band.

These results, from Tables 3 and 4, lead to the conclusion that, in Spain, electricity supply explains economic growth in the long run with no feedback effect observed. Therefore, the proper model to explain the relationship between both variables is this showed in Table 3.

As seen in Table 3, long-term coefficients associated to the lagged variables in level – *LGDP(−1)* and *LEP(−1)* – have the expected sign and are significant. The coefficient on the

Explanatory variables	Coefficient
Intercept	−0.872 (−0.785)
Trend	0.005 (0.831)
Δ*LGDP* (−1)	−0.301 (−1.034)
Δ*LGDP* (−2)	−0.036 (−0.120)
Δ*LEP* (−1)	−0.226 (−1.238)
Δ*LEP* (−2)	0.113 (0.625)
Δ*LCAP* (−1)	−0.059 (−0.111)
Δ*LCAP* (−2)	0.326 (0.624)
Δ*LEMP* (−1)	0.475 (1.556)
Δ*LEMP* (−2)	−0.070 (−0.237)
LGDP (−1)	0.083 (0.314)
LEP (−1)	−0.105 (−0.846)
LCAP (−1)	−0.109 (−0.623)
LEMP (−1)	0.100 (1.545)
D2008	−0.062 (−2.316)
R^2	0.733
Adjusted R^2	0.637
DW	2.266
F-statistic	7.662
AIC	−4.091
LM	4.017
ARCH	1.849
Bounds test for cointegration	
FLEP(LEP/LGDP)	1.689
t(LEP/LGDP)	−0. 846
ADF (resid)	−8.287***

Notes: LGDP is the level of real GDP in logarithms; LEP is the level of electricity production in logarithms; and LCAP and LEMP are the stock of capital and the employment, respectively, in logarithms. The symbol Δ represents the first differences of the variables. D2008 is a dummy variable that takes value one since 2008

Table 4. Ordinary least square estimates of first differences of electricity production in logarithms (ΔLEP) in Spain for the period 1958–2015 (equation (3))

lagged income representing the convergence parameter is equal to −0.63 and is significant to 5%. This indicates that 63% of deviations from long-run equilibrium level are corrected for in each year. As a result, it will take approximately a little bit of a year and a half to ensure full correction.

The sign of the variable *LEP(−1)* is positive and significant, indicating a long-term positive effect on the dependent variable, GDP growth. Elasticity amounts to 0.40% (this is minus 0.25 over −0.63, the value of the convergence parameter) in the case of the relationship between electricity generation and GDP. These results indicate that in the long term, an increase in power production can increase growth of GDP by 0.40%, which is not a negligible amount.

With respect to the variables in differences, positive and negative effects are detected in the short-run dynamics. In particular, GDP exhibits positive value in the former, indicating that an increase of 1% in the GDP of the previous year will result in a 0.10% expansion in economic growth, even though this coefficient is not significant. The coefficient of this variable lagged two periods is significant and implies a GDP growth of 0.28%. Electricity production, however, has a negative impact on GDP in the short run.

Moreover, as we can see in Table 3, employment and capital stock, the two main variables in a growth model, have a positive and significant sign, as would be expected. The dummy variable that captures the behaviour difference in the sample since 2008 presents a negative sign, reflecting that the decline in both the dependent and the independent variable is given to enter the crisis.

In addition, based on the coefficient of variation, the model explains 80.4% of the variation in GDP growth and the results from the robustness tests for the model indicate no serial correlation (DW = 2.02) and not a bad specification problem (LM = 1.96 and ARCH = 0.06, the test of autocorrelation and conditional heteroscedasticity, respectively). The residual of the model are stationary with an ADF of −7.74.

Performing the same type of exercise to consider electricity consumption, similar results are obtained and these outcomes remain even when considering the structural change that occurs in the Spanish economy after the year 2008.

5. Conclusion and policy implications

The empirical studies have yielded mixed conclusions in terms of the four hypotheses related to the relationship between electricity consumption and economic growth (growth, conservation, neutrality and feedback). As previous research shows, the variation in the empirical results may be attributed to the selection of variables, model specifications, time periods of the studies, stage of development of the countries or econometric approaches undertaken.

The aim of this study was to re-examine the electricity–GDP nexus in Spain to determine whether or not the increase in electricity production preceded Spanish GDP growth after 1958. For that purpose, the relationships between electricity production and GDP are investigated in a neo-classical production function where electricity production, capital and employment are considered separate factors. A longer time span than the previous papers is analysed here. Moreover, a cointegration approach based on the studies conducted by Pesaran and Shin (1999) and Pesaran *et al.* (2001) is applied, as it is suitable for short data series like those used in this work.

The results of an ARDL model allow us to conclude that the increase in electricity production (which was possible after a large expansion and modernization of the electricity sector) was a stimulus for economic growth. These outcomes support the growth hypothesis, as does Sanz-Villarroya and Sanaú's work (2016) for renewable sources and nuclear power electricity, but contradict Ciarreta and Zárraga's (2010) conclusions. This piece of research uses the same methodology as in Sanz-Villarroya and Sanaú (2016); however, it differs from the latter in several aspects. First, it analyses another period of time, with the main aim of finding out the impact of the electricity sector after the 1959 Economic Stabilization Plan, a time when this sector started to become the basis of Spanish industrialization. In addition, in Sanz-Villarroya and Sanaú (2016), the impact of electricity is analysed according to different generation sources, something that this study does not tackle. Finally, Sanz-Villarroya and Sanaú (2016) is based on a model that considers only two variables, GDP and electricity production. On the contrary, the present work expands this model by introducing capital and employment as control variables, as it corresponds to a production function, which allows us to make a more robust estimate.

In any case, the results of this study should be interpreted with caution, as electricity today amounts to less than a quarter of the total amount of energy used in Spain. It was not possible to incorporate other inputs to the production function (such as other energy inputs, technological or human capital), but the methodology used avoids the problems of omitted variables and of autocorrelation.

This relationship between electricity production and economic grown may provide a basis for a discussion on the appropriate design and implementation of energy policy. The results show that a small economy with limited resources, such as the Spanish one, is more vulnerable to energy shocks than other energy-sufficient economies. As Spain is a country with high energy dependence from abroad, the government must first ensure the electricity supply. Increased availability and access to different sources of electricity will improve the outlook for the Spanish economy. Conversely, a shortage in supply of electricity will constrain the regular pace of economic growth.

To reduce the energy dependency, improve efficiency and ensure uninterrupted energy supply and sustainable growth, Spain should investigate and explore more efficient and cost-effective sources of energy, in particular the renewable energies, as traditional energy sources will be scarce before long.

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Appendix

	Electricity production (in megawatts hour)	Electric power installed at December 31 (in megawatts) Hydroelectric power	Conventional thermal	Nuclear power	Total
1958	16,350	4,195	1,878	0	6,073
1959	17,353	4,436	1,948	0	6,384
1960	18,614	4,600	1,967	0	6,567
1961	20,879	4,768	2,242	0	7,010
1962	22,905	5,190	2,298	0	7,488
1963	25,897	5,895	2,492	0	8,387
1964	29,526	7,020	2,706	0	9,726
1965	31,723	7,193	2,980	0	10,173
1966	37,699	7,680	3,457	0	11,137
1967	40,637	8,227	4,671	0	12,898
1968	45,851	8,543	5,292	153	13,988
1969	52,124	9,335	6,165	153	15,653
1970	56,490	10,883	6,888	153	17,924
1971	62,516	11,057	7,403	613	19,073
1972	68,904	11,136	9,615	1,120	21,871
1973	76,272	11,470	10,617	1,120	23,207
1974	80,857	11,841	11,376	1,120	24,337
1975	82,515	11,954	12,393	1,120	25,467
1976	90,822	12,497	12,974	1,120	26,591
1977	93,804	13,096	13,334	1,120	27,550
1978	99,534	13,530	13,628	1,120	28,278
1979	105,779	13,515	15,267	1,120	29,902
1980	110,483	13,577	16,447	1,120	31,144
1981	111,232	13,579	17,158	2,051	32,788
1982	114,569	13,821	17,637	2,051	33,509
1983	117,196	14,087	17,614	3,911	35,612
1984	120,042	14,119	19,898	4,885	38,902
1985	127,363	14,661	20,991	5,815	41,467
1986	129,149	15,201	20,987	5,815	42,003
1987	133,390	15,269	21,087	5,815	42,171
1988	139,571	15,673	21,119	7,854	44,646
1989	147,842	16,545	21,227	7,854	45,626
1990	151,741	16,924	21,370	7,364	45,658
1991	159,392	17,026	21,855	7,367	46,248
1992	161,105	17,282	21,922	7,400	46,604
1993	160,890	17,294	21,989	7,400	46,683
1994	164,942	17,906	22,346	7,400	47,652
1995	169,094	18,037	22,849	7,417	48,303
1996	176,510	18,279	23,960	7,498	49,737
1997	189,381	18,538	25,339	7,580	51,457
1998	196,792	19,139	26,228	7,638	53,005
1999	209,885	20,201	26,847	7,749	54,797
2000	225,105	20,855	28,180	7,798	56,833
2001	237,684	22,162	28,980	7,816	58,958
2002	246,789	23,758	31,683	7,871	63,312
2003	265,071	25,337	33,818	7,896	67,051
2004	282,209	27,663	37,905	7,878	73,446
2005	294,422	29,355	42,593	7,878	79,826

(*continued*)

Table A1. Electricity production and electric power installed on December 31st, Spain

	Electricity production (in megawatts hour)	Electric power installed at December 31 (in megawatts)			
		Hydroelectric power	Conventional thermal	Nuclear power	Total
2006	303,450	31,437	45,790	7,728	84,955
2007	312,972	34,638	49,209	7,728	91,575
2008	318,238	39,316	49,681	7,728	96,725
2009	291,374	42,022	50,097	7,728	99,847
2010	304,618	43,358	51,117	7,795	102,270
2011	293,805	46,036	52,319	7,849	106,204
2012	298,174	48,725	50,425	7,867	107,017
2013	287,162	49,827	50,921	7,866	108,613
2014	280,101	49,867	50,400	7,866	107,615
2015	280,289	50,771	49,203	7,867	107,841

Source: UNESA (2016)

Table A1.