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.
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
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

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

Sources: SEE (several years); UNESA (2016); Prados de la Escosura (2003); National Statistics Institute (several years)
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 |
|---------|-------------|-------------------|------------------------|---------------------|--------------------|
| Morimoto and Hope (2004) | Cointegration Engle Granger | Sri Lanka (1960–1998) | Czech Republic, Latvia, Lithuania and the Russian Federation (1975–2010) | Ukraine (1975–2010) | Transition economies (1975–2010) |
| Altinay and Karagol (2005) | The Dolado–Lütkepohl and the Granger causality tests | Turkey (1950–2000) | Indonesia (1970–1990) | Pakistan (1972–2008) | France, Germany, Portugal, India, Norway, the UK and the USA |
| Tang and Shahbaz (2013) | The Granger causality test | Pakistan (1972–2010) | Indonesia (1971–2002) | Malaysia (1971–1999) | Emerging economies (1970–2011) |
| Wolde-Rufael (2014) | A bootstrap panel causality approach | Bulgaria (1975–2010) | Argelia (1980–2002) | India (1972–2008) | Taiwan (1975–2010) |
| Ali et al. (2020) | Vector error-correction model (VECM) | Pakistan (1961–2015) | | |
| Murry and Nan (1996) | The Granger causality test | | | |
| Narayan and Smyth (2005) | ARDL | | | |
| Yoo and Kim (2006) | Bounds test | | | |
| Squalli (2007) | Cointegration | | | |
| Ang (2008) | Engle Granger | | | |
| Abbas and Choudhury (2013) | ARDL model and Toda–Yamamoto Granger causality test | | | |
| Tang (2008) | Causality tests | | | |
| Yoo and Lee (2010) | Causality tests | | | |
| Bayar and Özel (2014) | ARDL model and Granger causality Model estimated | | | |
| Lu (2017) | The Granger causality tests | | | |
| Ozterk and Acaravci (2011) | The Granger causality test Pedroni panel cointegration and VECM Granger causality | | | |

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

**Table 1.** Economic growth or electricity
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, Ikekami 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:

$$ GDP = f (CAP, EMP, EP) $$

(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 megawatt 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:

\[
\Delta LGDP_t = \alpha_{LGDP} + \sum_{i=1}^{n} (b_i \Delta LGDP_{t-1}) + \sum_{i=1}^{n} (c_i \Delta LEP_{t-1}) + \sum_{i=1}^{n} (d_i \Delta LCAP_{t-1}) \\
+ \sum_{i=1}^{n} (e_i \Delta LEMP_{t-1}) + \sigma_{1LGDP} LGDP_{t-1} + \sigma_{2LEP} LEP_{t-1} \\
+ \sigma_{3LCAP} LCAP_{t-1} + \sigma_{4LEMP} LEMP_{t-1} + dt + \epsilon_{1t} \\
\]

\[
\Delta LEP_t = \beta_{LEP} + \sum_{i=1}^{n} (b_i \Delta LEP_{t-1}) + \sum_{i=1}^{n} (c_i \Delta LGDP_{t-1}) + \sum_{i=1}^{n} (d_i \Delta LCAP_{t-1}) \\
+ \sum_{i=1}^{n} (e_i \Delta LEMP_{t-1}) + \beta_{1LGDP} LGDP_{t-1} + \beta_{2LEP} LEP_{t-1} \\
+ \beta_{3LCAP} LCAP_{t-1} + \beta_{4LEMP} LEMP_{t-1} + dt + \epsilon_{2t} \\
\]

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, \(\Delta\) 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 \(H_1: \sigma_{1LGDP} \neq 0, \sigma_{1LEP} \neq 0\), 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
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 \(t\left(\frac{LGDP}{LEP}\right)\) 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 \(F_{LEP}\left(\frac{LEP}{LGDP}\right)\) and \(t\left(\frac{LEP}{LGDP}\right)\) 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             | 11.28 (1.960) |
| Trend                 | −0.0014 (0.471) |
| \(\Delta LGDP(-1)\)   | 0.099 (0.658) |
| \(\Delta LGDP(-2)\)   | 0.279 (1.808) |
| \(\Delta LEP(-1)\)    | −0.166 (−1.754) |
| \(\Delta LEP(-2)\)    | −0.160 (−1.712) |
| \(\Delta LCAP(-1)\)   | 0.132 (0.479) |
| \(\Delta LCAP(-2)\)   | 0.009 (0.035) |
| \(\Delta LEMP(-1)\)   | 0.557 (3.520) |
| \(\Delta LEMP(-2)\)   | −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 \(\Delta\) 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 \((ALGDP)\) in Spain for the period 1958–2015 (equation 2)
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 $\Delta \text{LEP}(-1)$ 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 Zarraga’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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### Table A1.
Electricity production and electric power installed on December 31st, Spain

| Year | 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 | 17,333                                    | 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                                    | 5,885                                                  | 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 | 99,334                                    | 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 | 112,232                                   | 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              | 7,854               | 45,658        |
| 1991 | 159,022                                   | 17,026                                                 | 21,855              | 7,854               | 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 | 189,581                                   | 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)
| Year | 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.