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Energy Transition Towards a Greener and More Competitive Economy: The Iberian Case

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Abstract: In this paper, we analyze the effects of the energy transition process on economic growth in Spain and Portugal, countries that, adhering to European Union (EU) directives, opted to promote clean energies from the very start. On the one hand, we look at the energy transition laws introduced by the EU and other countries. On the other, we conduct a causal analysis of energy consumption and economic growth to confirm whether the change of energy model has generated positive effects on economic growth. The procedure was as follows. First, we conducted an aggregate causality analysis exploring the relationship between growth and energy consumption. As the results were not significant, we repeated the analysis with different disaggregations of renewable energy sources. With respect to solar thermal energy and economic growth, the main conclusion is that the data appear to show a one-way causal relationship for Portugal and EU-26 (European Union without Portugal and Spain) and a two-way relationship for Spain.

Keywords: energy transition; economic growth; renewable energy; Granger causality; Iberian economies

1. Introduction

The causality relationship between energy consumption and GDP (gross domestic product) is a popular theme in energy economics. However, the empirical literature is divided. From the theoretical viewpoint, a quick look at the nexus between energy sector development and economic activity growth would lead us to expect the most intuitive relationship to be one-way causality from the economy to energy. In other words, the energy sector can be expected to grow as it needs to cater for energy demand increases led by increased economic activity. Thus, demand derived from the production sector will grow due to increased activity and the production of new goods. Likewise, there will be energy demand increases from private households insofar as the standard of living increases boosting household energy consumption. In their pioneering article, ref. [1] identified this one-directional causality from aggregate production to energy consumption. Apart from the abovementioned one-way relationship, known as the conservation hypothesis, the literature refers to several other possible relationships between energy consumption and economic growth: growth, neutrality and feedback (e.g., [2,3]). In sum, the causality relationships between energy consumption and economic growth can be classed into four different types:

- No causality (neutrality hypothesis): energy has little or no impact on GDP and vice versa.
- One-way causality from GDP to energy consumption (conservation hypothesis): an increase in the real GDP causes an increase in energy consumption. This is the most intuitive relationship that is to be expected between the two variables as GDP growth due to increased economic activity generates more energy consumption, including energy from renewable sources.

- ○ One-way causality from energy consumption to GDP (growth hypothesis): an increase in energy consumption causes a growth in real GDP. Energy is a limiting factor for economic growth, and energy supply disruptions will have an impact on GDP. Additionally, one might expect a negative impact if the economy evolves towards less intensive energy production.
- ○ Two-way causality between GDP and energy consumption (feedback hypothesis): energy consumption and economic growth are determined by and influence each other. If the feedback hypothesis is true, energy consumption and real GDP are interrelated and possibly complementary. Additionally, energy policies aimed at deploying electricity from renewable energy sources or improvements in energy consumption efficiency would not have a negative impact on real GDP.

In this context, the early empirical studies examined the direction of causality assuming that the underlying variables were stationary ([1,4], among others). Later, empirical analyses accounted for non-stationary data, checking for cointegration relationships ([5,6], among others). Some employed panel methods to evaluate the unit roots and cointegration relationships ([7,8], among others). Generally, as ref. [9] noted, empirical evidence on the causal nexus between energy and growth is ambiguous.

Moreover, far-reaching energy policy developments affecting the electricity market have taken place over recent years. European Union (EU) policies aimed to promote a shift towards a more liberalized, competitive and environmentally friendly electricity market, influencing the energy supply cost and substantially modifying member states' energy mix. The pursuit of the above objectives was based on several pieces of legislation, including the 2001/77/EC Directive [10], on the promotion of electricity produced from renewable energy sources in the internal electricity market. This was followed by Whereas Clause 3 of the 2009/28/EC Directive [11] which stated that there could be opportunities for establishing economic growth through innovation and a sustainable competitive energy policy. The Directive went on to point out that the opportunities for growth and employment brought about by investment in regional and local production of energy from renewable sources in the member states and their regions are important. Renewable energy is expected to play an important role to prevent and reduce environmental pollution and to break the link between economic growth and environmental degradation.

The Spanish and Portuguese cases are two interesting attempts at making the transition towards a more economically and environmentally sustainable economy. Both countries rose to the challenge of leading the process, changing the role played in previous energy transitions like coal or oil. Additionally, the objectives were not confined to the electricity sector. The aim was to take advantage of factors like greener energy, new job opportunities or a lower dependency on imported fuels to spread the effect and build a more sustainable economy. The effectiveness of the implemented policies is unclear. On the one hand, the results were compromised by the economic downturn caused by the financial crisis that hit both countries hard and ultimately called into question the process. On the other hand, the multiplicity of objectives (energy market liberalization, environmental sustainability, economic modernization, job creation, etc.) complicates policy evaluation.

Even so, it is notable that Spain and Portugal have led the efforts towards energy transition, aiming to take advantage of the results of this investment, including economic growth and employment. Our research aims to evaluate the extent to which other objectives, set out by the policies promoting electricity from renewable energy sources, specifically referring to economic modernization and dynamism on the Iberian Peninsula, are achieved.

Focusing on renewable energy, ref. [12] analyzed the literature written so far about the causal nexus between renewable energy and economic growth. The result of this study indicates that only 20% of the papers in this field support the growth hypothesis. Therefore, the other 80% adopt the conservation (40%) and neutrality (40%) hypotheses. Ref. [13] indicate that, in view of the important role that renewable energies play in planning an energetically sustainable future, it is important to understand the dynamics between renewable energy consumption and economic growth. Accordingly, ref. [14] account for the simultaneous use of renewable and non-renewable energy in order to differentiate the relative impact of each one on the economic growth process. The results of the estimations reported in this paper, analyzing data from 80 countries (including Spain and Portugal) in the period 1990–2007, reveal a two-way causality between renewable and non-renewable energy consumption and economic growth in both the short- and long-term. Additionally, there is a short-term two-way causality between renewable and non-renewable energies, suggesting that the two sources of energy are substitutes. Ref. [15] investigated the relationship between renewable energy consumption and economic growth in 25 European countries. They found significant links between GDP and its predictors in the long run, and a differential behavior depending on the country-group (high or low GDP per capita).

With respect to Spain and Portugal, ref. [16] claimed that the deployment of electricity from renewable energy sources may have a negative effect on economic growth in its early stages, an effect that will fade as technologies become more competitive. Ref. [17] recently claimed that investment in renewable energies and energy efficiency is a key issue for stabilizing climate and would lead to greater employment and economic growth opportunities all over the world. High revenue in terms of employment gains through investment in renewable energy are forecast for Spain. The consolidation of the renewable energies sector is a potential opportunity to boost R&D (research and development) and should have positive effects both inside and outside the electricity sector. In a generally favorable climate for innovation, its positive effects can be boosted and improved by investment in the deployment of electricity generated from renewable energies and propagated to all branches of production activity and employment. As far as we know, there is no previous research on the effect of the deployment of renewables on this scale, considering the effort of the Iberian countries and analyzing the links between growth and energy consumption.

The following section briefly reviews the main characteristics of the evolution of the energy sector in Spain and Portugal over the last few years, focusing especially on the promotion of renewable energies. Section 3 sets out a strategy for estimating the relationship between GDP and energy consumption, defining the variables, data used and methodology. The results of the estimations are reported in Section 4. Finally, Section 5 outlines the conclusions.

2. Iberian Energy Transition

In the first half of the 20th century, the Spanish and Portuguese energy sectors differed from the European and OECD (Organization for Economic Co-operation and Development) countries in a number of respects (such as shortage of fossil fuels or the importance of hydroelectric energy), which finally led to a high dependency on external energy and a different sector setup than most developed countries (Figure 1). After the oil crisis, several nuclear power plants were commissioned in Spain. However, the 1982 decision not to authorize any further increase in nuclear power capacity brought this process to an end. Portugal's external energy dependency was even greater, as there had been no such commitment to nuclear power. Hydroelectric power did not have the capacity to meet demand needs and fell behind fossil fuel power generation which continued to grow, thereby consolidating the peninsula's external and climatologic energy dependency.

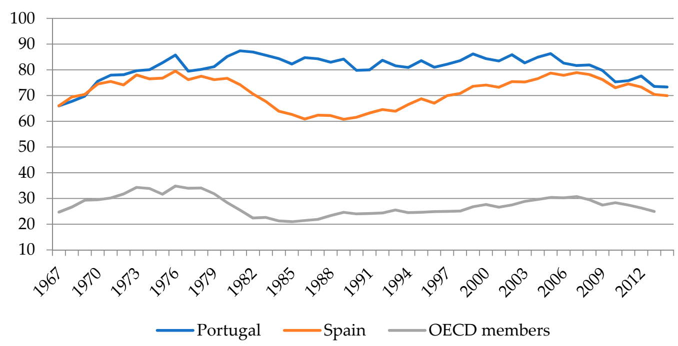

Figure 1. Net Imported energy (% of energy use). Source: Database is from International Energy Agency. Source. IEA Statistics. OECD/IEA [18].

Spain and Portugal's adhesion to the European Economic Community (EEC) led to major economic and social changes on the Iberian Peninsula, including a process of modernization of their system of production that also affected the electricity sector. As of their full EEC membership, governmental decisions on the organization of their electricity sectors were subject to the supranational reference framework of European directives. During the 1990s, the European Union brought in policies to promote a common European electricity market and also to progress towards renewable energies in order to reduce environmental pollution and to break the link between economic growth and environmental degradation. These plans aimed to improve sector efficiency by introducing competition with the aim of preserving quality of supply and focusing especially on environmental protection [19]. There is plenty of literature on this issue with regard to both the setup and characteristics of the competitive electricity market—for example, ref. [20] analyzes whether the legislation to be implemented was consistent with the principles underlying the creation of an integrated single market and conclude that it was indeed insufficient—and the results of the very wide-ranging deregulation processes. Ref. [21] reviews the results of the electricity market liberalization process, with some references to the European markets. Ref. [22] conducted an interesting analysis of the effects of the national incentive policies on renewables and the income transfers due to cross-border interconnections.

European legislation encouraged the creation of regional markets to achieve a more competitive and efficient national energy market. Thus, in 2007, the Iberian Energy Market (MIBEL) [23] started to operate as a common market for Spanish and Portuguese operators.

According to [24], Spain and Portugal embraced the challenge embodied by the 20-20-20 targets as a period during which both economies had experienced the most unprecedented economic growth in modern history drew to its close. These were a set of measures, including legislation for the European Union countries that has been legally binding since 2009, aimed at guaranteeing compliance with the European Union's 2020 climate and energy targets: 20 per cent cut in greenhouse gas emissions from 1990 level; 20 per cent of EU energy from renewables; 20 per cent improvement in energy efficiency. At the time (2009), Portuguese per capita production had reached levels of around 80% of the European average, whereas Spain had, after several years on a par, surpassed the European average. Looking at the figures, this degree of success was unthinkable at the time they joined the EU: in 1985, while Spanish per capita GDP was less than 70 per cent of the European average, Portugal's was under 65%. Rapid growth was mirrored by a continuous increase in energy intensity until the trend turned and continued downwards for the last 12 years, in line with European sustainability goals. This process has had its ups and downs and differences. For example, whereas some highlight the success of promoting a system based on renewable energy, others stress the problems of uncertainty and misjudgments with respect to incentive design. The transformation of the Spanish and Portuguese energy systems is very much limited by the energy policies designed by the EU (where the process of liberalization started in the early 1990s). The creation of the European emissions market (EU emissions trading scheme or EU ETS) or the launch, in 2004, of the Iberian Electricity Market (MIBEL) [23] are factors that have unquestionably conditioned the evolution of the sector in Spain and Portugal.

Note, though, that Spain and Portugal are among the countries leading the energy transition promoted by electricity generation from renewable energy sources. The challenge was to lead the process, changing the role that they played in the more traditional energy transitions, like oil and gas. The aim was to go beyond the mere environmental component, as the commitment to renewable energy sources was expected to have a positive impact on the electricity sector and further advance both economies. The crux was to take advantage of factors like greener energy, new job opportunities or a lower dependency on imported fossil fuels to extend the effect and build a more sustainable economy and society. The electricity sector plays a key role in achieving these aims. The growth of the share of renewable energies in the MIBEL mix led to a 25.5 and 22.0 per cent per capita reduction in greenhouse gas emissions in Spain and Portugal, respectively, from 2000 to 2014 (Eurostat data).

However, the financial crisis hit the economy of the Iberian countries particularly hard, and it had worse effects, on average, than in the other European countries. The data on the evolution of the labor market are very disturbing, with deplorable unemployment rates. Against this backdrop, it is crucial to design energy transition policies that are compatible with job creation and economic growth. In this respect, as already specified above, the transposition of European directives to Spanish and Portuguese legislation has not only included guidelines targeting a reduction in the environmental impact of energy production but has also aimed to boost economic growth through investment in new technology innovation and looking to generate positive effects across the entire economy.

3. Data and Methodology

Our empirical analysis of the relationship between economic growth and energy consumption used several variables, primarily focusing on real gross domestic product (GDP) and gross domestic energy consumption in Portugal, Spain and the European Union. We used a 26-country aggregate for European Union data, namely EU-28 data, from which we subtracted the data for Spain and Portugal. The EU-26 data were included in order to check the existence of a specific performance in the Iberian countries. GDP data are expressed in euro at constant 2010 prices, and energy consumption is shown in million tonnes of oil equivalent (Mtoe). The main data source for the 1990 to 2017 period are the Eurostat AMECO [25] (Annual Macroeconomic Database of the European Commission's Directorate General for Economic and Financial Affairs) and the European Environment Agency [26] (EEA/UNFCCC) databases.

Renewable energies initially include the sum of hydropower, wind power, solar power, biomass energy and geothermal energy. With the aim of estimating the effect of the development of electricity from renewable energies, we used energy consumption data for other categories, singling out any that had potentially more impact in the analyzed countries. Thus, we used a variable that includes only renewable wind and solar energy. Additionally, we considered the effect of wind power, solar photovoltaic and solar thermal energy separately in an attempt to discover the possible effects of diverse technologies, perhaps with different implications for economic activity. Table 1 shows the descriptive statistics of each variable used in this article. The correlation coefficient between GDP and total energy consumption is the highest in Spain and Portugal. In the other 26 countries of the European Union, however, the highest correlation coefficient is found for renewable energies. This is because, although the series have the same trend, total energy consumption has fallen very sharply since 2007, which makes the correlation coefficient with GDP very small. This may be for two reasons: on the one hand, that although GDP growth was slower, consumption decreased since 2007 due to the crisis; on the other hand, since the EU is an agglomeration of countries, it may be that the reality of each one distorts the result.

Firstly, it is necessary to check for unit roots, as the macroeconomic series may not be stationary, and the causality tests are sensitive to the stationarity of the time series [27]. The augmented Dickey-Fuller unit root test (ADF) is used to explore the stationary characteristics of GDP and energy consumption time series, according to the following equation:

$$\Delta X_t = \theta_0 + \varphi_0 t + \varphi_1 X_{t-1} + \sum_{i=1}^{m} \theta_i \Delta X_{t-i} + e_t, \tag{1}$$

where X_t is each variable (*GDP* and energy consumption, *E*) at time t, θ_0 represents the intercept term, e_t is the disturbance (0, σ^2), and m is the lag order. The error term is ε. If φ_1 is significantly less than zero, then the null hypothesis of a unit root is rejected.

Then, we use the Granger causality test [28] to ascertain the relationship between GDP and the consumption variables. Using this test, we can find out what nexus there is between the variables: whether we can predict one variable from the results of another, that is, whether there is a one-way or two-way relationship:

$$\Delta E_t = \alpha_0 + \sum_{i=1}^{m} \beta_{0i} \Delta GDP_{t-1} + \sum_{j=1}^{m} \gamma_{0i} \Delta E_{t-1} + \varepsilon_{0t}, \quad (2)$$

$$\Delta GDP_t = \alpha_1 + \sum_{i=1}^{m} \beta_{1i} \Delta GDP_{t-1} + \sum_{j=1}^{m} \gamma_{1i} \Delta E_{t-1} + \varepsilon_{1t}, \quad (3)$$

where α_0 and α_1 are the intercept terms; m is the optimal lag order, and β and γ represent the estimated coefficients. The error term is ε. The null hypothesis is that *GDP* cannot strictly Granger cause energy consumption (*E*), and energy consumption (*E*) cannot strictly Granger cause *GDP*, in Equations 2 and 3, respectively, which is represented by $\beta_{0i} = \gamma_{1i} = 0$ (i = 1, 2, . . . , m, and j = 1, 2, . . . , m). Table 2 presents the possible relationships between the variables, depending on the estimated values of β and γ.

Table 1. Summary statistics for each variable used in this article.

Country	Var.	Mean	Median	Max.	Min.	Std. Dev.	Corr.
Spain	GDP	921,766.30	973,411.50	1,139,926	659,273.90	168,449.30	
	TEC	120.84	124.61	147.39	88.46	18.06	0.88
	REC	10.19	8.61	18.10	5.11	4.57	0.79
	WPC	1.81	1.19	4.78	0.001	1.79	0.86
	SPPC	0.22	0.002	0.73	0.001	0.31	0.66
	STPC	0.57	0.05	2.62	0.02	0.94	0.54
Portugal	GDP	161,767	169,813.20	181,997.2	124,511.5	18,693.82	
	TEC	23.12	23.58	27.44	17.24	3.01	0.88
	REC	4.14	3.90	5.63	2.85	0.80	0.70
	WPC	0.35	0.06	1.07	8.60×10^{-5}	0.42	0.58
	SPPC	0.02	0.001	0.09	8.60×10^{-5}	0.03	0.40
	STPC	0.03	0.02	0.09	0.01	0.01	0.54
EU-26	GDP	10,438,555	10,587,017	12,588,166	8,192,512	1,443,370	
	TEC	1576	1575.67	1668.95	1472.64	55.39	0.03
	REC	113.32	94.33	199.29	62.67	42.92	0.90
	WPC	5.54	2.721165	20.76	0.07	6.43	0.84
	SPPC	1.53	0.03	8.33	0.001	2.78	0.66
	STPC	0.73	0.52	1.80	0.13	0.56	0.89

Notes: GDP represents real gross domestic product. TEC represents total energy consumption. REC represents renewable energy consumption. WPC represents wind power consumption. SPPC represents solar photovoltaic power consumption. STPC represents solar thermal power consumption. Var. = variable; Max. = maximum; Min. = minimum; Std. Dev. = standard deviation; Corr. indicates the correlation coefficient between each variable and GDP in each country.

Table 2. Causality test. (real GDP growth vs. energy consumption growth).

Tested Hypothesis	Result	Direction	Hypothesis
GDP does not cause energy consumption	Δ GDP does not cause Δ consumption	-	Neutrality
Energy consumption does not cause GDP	Δ consumption does not cause Δ GDP		
GDP does not cause energy consumption	Δ GDP causes Δ consumption	one-way	Conservation
Energy consumption does not cause GDP	Δ consumption does not cause Δ GDP		
GDP does not cause energy consumption	Δ GDP does not cause Δ consumption	one-way	Growth
Energy consumption does not cause GDP	Δ consumption causes Δ GDP		
GDP does not cause energy consumption	Δ GDP causes Δ consumption	two-way	Feedback
Energy consumption does not cause GDP	Δ consumption causes Δ GDP		

Notes: Energy Consumption depends on the different forms of energy: total energy consumption, renewable energy consumption, wind power consumption, solar photovoltaic power consumption, and solar thermal power consumption.

4. Results and Discussion

In the following, we report an empirical analysis of the effectiveness of these policies examining what type of energy produces a growth in the economies of Portugal and Spain, or whether renewable energy consumption is boosted by more state investment. We start with the total consumption variable, including all renewable and non-renewable energies. This is then gradually broken down to provide a full analysis of the causality relationship between consumption and GDP for the analyzed energies.

We report the results of the analysis below. However, the first step of the analysis was to check for unit roots, as the macroeconomic series may not be stationary and the causality tests are sensitive to the stationarity of the time series [27]. We used the augmented Dickey-Fuller test (ADF) to estimate the level of cointegration between series, as shown in Table 3 below.

Table 3. The results of the augmented Dickey-Fuller (ADF) unit root test for each variable.

Country	Differences	GDP	TEC	REC	WPC	SPPC	STPC
EU-26	Level	−1.56 (0)	−0.77 (1)	−0.09 (1)	4.68 (6)	−5.05 (6)***	0.52 (6)
	First Difference	−4.05 (1)**	−6.86 (0)***	−7.23 (0)***	−0.28 (6)	−2.93 (6)	−3.29 (5)*
Spain	Level	−2.37 (1)	−1.35 (1)	−2.28 (0)	−6.79 (5)***	−1.99 (1)	1.87 (5)
	First Difference	−2.06 (0)	−3.28 (0)*	−5.85 (0)***	−0.24 (6)	−2.84 (0)	−2.02 (5)
Portugal	Level	−1.62 (1)	−1.21 (0)	−4.67 (0)***	−3.55 (3)*	2.62 (0)	−1.96 (1)
	First Difference	−2.84 (0)	−4.50 (0)***	−7.21 (1)***	0.18 (2)	−3.34 (0)*	−2.05 (0)

Notes: GDP represents real gross domestic product. TEC represents total energy consumption. REC represents renewable energy consumption. WPC represents wind power consumption. SPPC represents solar photovoltaic power consumption. STPC represents solar thermal power consumption. The regressions include an intercept and trend. All variables are in levels, whereas the optimal lag lengths are determined via the SIC criterion and are reported in parentheses. The numbers in parentheses are the optimal lag order. *, **, or *** denote that the null hypothesis is rejected at the 10%, 5%, or 1% significance levels, respectively.

From these results, the necessary differences have been made so that the series are stationary. Table 4 shows the level of differences for each variable.

Table 4. Level of integration of the variables.

Country	GDP	Total Energy Consumption	Renewable Energy Consumption	Wind Power Consumption	Solar Photovoltaic Power Consumption	Solar Thermal Power Consumption
EU-26	I(1)	I(1)	I(1)	I(2)	I(0)	I(1)
Spain	I(2)	I(1)	I(1)	I(0)	I(2)	I(2)
Portugal	I(2)	I(1)	I(0)	I(0)	I(1)	I(2)

Notes: The number of differencing for each variable was determined from the augmented Dickey-Fuller test (ADF). I represent the level of integration. The numbers in parentheses are the optimal level of integration.

Based on this information, we applied differencing to make the time series stationary. Only in the case of the thermal energy consumption series for Spain, which was heteroskedastic, was it necessary to use log transformation prior to differencing to make this series non-stationary. The photovoltaic energy consumption series for EU-26 is non-stationary, even though we applied several transformations to make it stationary.

We also ran Johansen's cointegration test [29] between the series that had the same level of integration as the GDP in each country. The goal was to assure that results are not biased because the series are cointegrated. The result showed that there was no cointegration with the GDP in any of the countries.

Finally, we applied the Granger causality test [28] to ascertain the relationship between GDP and the consumption variables. In the following, we report the results of the causality test. We start with the total consumption variable, including all renewable and non-renewable energies. This is then gradually broken down to provide a full analysis of the causality relationship between consumption and GDP for the analyzed energies.

As already mentioned, we first tested for causality between GDP and total energy consumption in Europe-26, Portugal and Spain, without taking into account the source of this energy. Additionally, we tested for causality with energy from renewable sources. The significance level for the acceptance of causality was at least 95% (we used a significance level of 90% in one case only). The results are summarized in Table 5 below.

Table 5. Causality test between real GDP growth and energy consumption (total and renewable energy consumption).

Country	Energy	Tested Hypothesis	F-test.	Prob.	Result	Hypothesis
EU-26	TEC	GDP does not cause consumption	0.12	88.47%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	0.50	61.57%	Δ consumption does not cause Δ GDP	
Portugal	TEC	GDP does not cause consumption	1.44	26.13%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	0.06	94.53%	Δ consumption does not cause Δ GDP	
Spain	TEC	GDP does not cause consumption	0.85	44.49%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	0.57	56.96%	Δ consumption does not cause Δ GDP	
EU-26	REC	GDP does not cause consumption	3.98	3.70%	Δ GDP causes Δ consumption	conservation
		Consumption does not cause GDP	0.15	86.13%	Δ consumption does not cause Δ GDP	
Portugal	REC	GDP does not cause consumption	1.41	26.77%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	1.41	26.77%	Δ consumption does not cause Δ GDP	
Spain	REC	GDP does not cause consumption	7.54	0.39%	Δ GDP causes Δ consumption	Conservation
		Consumption does not cause GDP	0.31	73.66%	Δ consumption does not cause Δ GDP	

Notes: GDP represents real gross domestic product. TEC represents total energy consumption. REC represents renewable energy consumption. All variables are transformed in differences. F-test. represents the f-statistics test of the Granger causality test. Prob. represents the p-value of the Granger causality test.

These preliminary results suggest a hypothesis of neutrality for total energy consumption, that is, there is no causality relationship between the variables (in either direction) in any of the three specific cases (EU-26, Portugal or Spain) when there is no discrimination of energy consumed by source. Studies in the literature using a similar methodology have come up with wide-ranging results. For example, in a paper with data for 11 developed countries, accounting for several European member states included in EU-26, ref. [30] reported results favorable to the neutrality (Germany and United Kingdom), conservation (France and Italy), growth (Belgium and the Netherlands) and feedback (Sweden) hypotheses. On the other hand, ref. [31] applied the same methodology, the Granger causality test, to data on six industrialized countries, which output neutrality results for some nations (France and United Kingdom) and evidence in favor of the conservation hypothesis for other countries (Italy and Germany) within our aggregate EU-26. In our case, the neutrality hypothesis can be explained by the heterogeneity of the consumption variable, which includes energy derived from sources with technologies as far apart as hydro, nuclear, wind, solar or fossil fuel-based power. Data heterogeneity is even greater for the EU-26 country aggregate, meaning that the results of EU-26 can only be disaggregated as a control for estimating differences in behavior with respect to Spain or Portugal.

In the case of Spain, the result is in line with [32], that studies the macro-economic impact of renewable energy and alludes that between 2012 and 2017, the contribution of renewable energy to GDP decreased from 1% to 0.8%, with a growth of 9.3% of the contribution to GDP compared to the previous year.

Table 6 below shows the results broken down by renewable energies: wind, solar photovoltaic and thermal energy.

Table 6. Causality test between real GDP growth and energy consumption (wind, solar photovoltaic power and solar thermal power consumption).

Country	Energy	Tested Hypothesis	F-test.	Prob.	Result	Hypothesis
EU-26	WPC	GDP does not cause consumption	5.56	1.31%	Δ GDP causes Δ consumption	conservation
		Consumption does not cause GDP	1.12	34.91%	Δ consumption does not cause Δ GDP	
Portugal	WPC	GDP does not cause consumption	3.14	6.59%*	Δ GDP does not cause Δ consumption	conservation*
		Consumption does not cause GDP	0.22	80.28%	Δ consumption does not cause Δ GDP	
Spain	WPC	GDP does not cause consumption	11.66	0.00%	Δ GDP causes Δ consumption	conservation
		Consumption does not cause GDP	1.72	20.58%	Δ consumption does not cause Δ GDP	
EU-26	SPPC	GDP does not cause consumption	18.98	0.00%	Δ GDP causes Δ consumption	conservation
		Consumption does not cause GDP	0.83	44.97%	Δ consumption does not cause Δ GDP	
Portugal	SPPC	GDP does not cause consumption	0.01	98.98%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	1.51	24.65%	Δ consumption does not cause Δ GDP	
Spain	SPPC	GDP does not cause consumption	1.24	31.15%	Δ GDP does not cause Δ consumption	neutrality
		Consumption does not cause GDP	0.08	92.00%	Δ consumption does not cause Δ GDP	
EU-26	STPC	GDP does not cause consumption	0.18	83.87%	Δ GDP does not cause Δ consumption	growth
		Consumption does not cause GDP	5.83	1.11%	Δ consumption causes Δ GDP	
Portugal	STPC	GDP does not cause consumption	0.95	40.61%	Δ GDP does not cause Δ consumption	growth
		Consumption does not cause GDP	4.98	1.82%	Δ consumption causes Δ GDP	
Spain	STPC	GDP does not cause consumption	6.24	0.82%	Δ GDP causes Δ consumption	feedback
		Consumption does not cause GDP	6.02	0.94%	Δ consumption causes Δ GDP	

Notes: GDP represents real gross domestic product. WPC represents wind power consumption. SPPC represents solar photovoltaic power consumption. STPC represents solar thermal power consumption. All variables are transformed in differences. Prob. represents the p-value of the Granger causality test. F-test. represents the f-statistics test of the Granger causality test. * denotes the significance level of 90%. The significance level is 95% unless otherwise indicated.

Even though some European countries, including Spain, are leading developers and exporters of renewable energy electricity generation technologies (especially wind power), the estimations with disaggregated data did not return the expected causality results. The estimations appear to suggest that wind energy consumption does not lead to economic growth, supporting the conservation hypothesis. The results are consistent across the three analyzed cases, although, for Portugal, the conservation hypothesis is accepted with a significance level of 90% (as opposed to the neutrality hypothesis if we maintain the 95% level established for the other estimates). This result is contrary to expectations, especially for Spain because ref. [33] notes that strong support for wind power in Denmark, Germany and Spain helped build a powerful industry, with beneficial effects for the three economies, as it can be explained by aggregation in the case of EU-26 and by Portugal's lower participation in component production.

Neither did we find any such positive effect on economic growth derived from investment in solar photovoltaic energy. Our estimations support the hypothesis of neutrality for both Spain and Portugal, whereas the conservation hypothesis is observed for EU-26. This result is consistent with the findings for wind power generation. It is not surprising, as, unlike the wind energy industry, European countries are not leading photovoltaic panel technology developers or exporters.

Finally, with regard to solar thermal energy, the estimations using European, Portuguese and Spanish data do return results that support the causality between energy consumption and economic growth. Causality is confirmed in all three cases: it is one-way in the case of EU-26 and Portugal (growth hypothesis) and two-way for the Spanish economy (feedback hypothesis). The causality between energy consumption and GDP is confirmed at the usual significance level. In the case of Spain, however, the hypothesis is confirmed with an even higher probability level (99%).

Apart from the economic question regarding the nexus between consumption energy and GDP, there are other noteworthy econometric issues that could be the source of some of the mixed results for some classes of energy. Our principal concern is related to data linearity. Several authors (including [34–36]) have noted that linear Granger causality modelling is not good at detecting nonlinear links. Moreover, the information captured by linear causality tests may not be suitable for uncovering the energy-growth nexus ([37]). To deal with this issue, we use the BDS independence test [38] as a diagnostic tool to determine series linearity acceptance or rejection. BDS test performance involves the choice of two parameters: ε (the distance determining whether two points are close enough), and d (the value of the embedding dimension). In other words, the BDS test analyzes linearity using the d data background and a distance. Under the assumption of independence, we would expect the distance between any pair of points to be less than or equal to ε. The BDS test is a two-tailed test, and the null hypothesis should be rejected if the BDS test statistic is greater or less than the critical values. Table 7 shows some results.

Table 7. Results of the BDS test.

Embedding Dimension (d)	BDS Statistics for Spain				
	ΔTotal Energy Consumption	**ΔRenewable Energy Consumption**	**ΔWind Power Consumption**	**ΔSolar Photovoltaic Power Consumption**	**ΔSolar Thermal Power Consumption**
2	−0.013	−0.0103	0.075***	−0.003	0.136***
3	−0.019	−0.003	0.141***	−0.009	0.207***
4	−0.020	−0.027	0.162***	−0.0191	0.246***
5	−0.008	−0.039**	0.145***	−0.032	0.254***
6	−0.048	−0.050**	0.155***	−0.049	0.236***
Embedding Dimension (d)	**BDS Statistics for Portugal**				
	ΔTotal Energy Consumption	**ΔRenewable Energy Consumption**	**ΔWind Power Consumption**	**ΔSolar Photovoltaic Power Consumption**	**ΔSolar Thermal Power Consumption**
2	−0.030***	0.002	0.006	0.018	0.048
3	−0.023	0.021	0.017	−0.010	0.134***
4	−0.006	0.028*	0.107**	0.033	0.187***
5	0.0170	0.068***	0.0148	−0.025	0.189***
6	0.0275	0.023	0.087*	0.033	0.148**

Note: *, **, or *** indicate significant nonlinear dependencies at the 10%, 5%, or 1% levels, respectively.

As Table 7 shows, several of the analyzed variables are likely to be subject to nonlinearity. This could explain the inconclusive results for some of the renewable energy sources. To improve the data analysis, the series were log transformed and retested. The results were unchanged, that is, the series were still nonlinear, and Granger's causality continued to return the same results.

Unfortunately, our data sample is not long enough for more thorough testing. Therefore, the results should be interpreted with caution. Further research will analyze additional estimations considering nonlinearity, including different econometric methodologies (neural networks), and more variables, for example, employment, as in Spain, there are several works ([17,39] among others) that conclude with the increase in employment and the creation of qualified employment.

5. Conclusions

Spain and Portugal are two of the countries at the forefront of the energy transition in Europe. The objectives that they pursue are not confined to environmental concerns, since a commitment to renewable sources of energy is expected to transcend the frontiers of the electricity sector and have a positive impact on the advancement of both their economies. The increase in the share of renewable energy sources in the Iberian electricity market mix led to a sizeable reduction in per capita greenhouse gas emissions in Spain and Portugal. However, the decarbonization process has been compromised over recent years by the evolution of the economy and, especially, the financial crisis, which affected the deployment of renewable energies and set back the target of reducing emissions.

In our article, we estimated the relationship between energy consumption and economic growth, analyzing the causality between the energy sector and GDP. Our interest focuses on observing how decarbonization objectives are related to economic growth led by the modernization of the economy and the externalities produced by the development and deployment of renewable energy technologies.

The initial estimations support the neutrality hypothesis, although the observed non-causality can be explained by data aggregation at both country (EU-26) and energy source level. Again, the results with aggregate data for renewable energy sources support the hypothesis of neutrality (Portugal) and conservation (EU-26 and Spain).

With the aim of differentiating the possible impact of each technology on economic activity, we then conducted the analysis with separate energy consumption data for the different renewable sources. The aim was to account for the differences in maturity and deployment of the different technologies in order to single out the possible effects on other economic activity. As they account for the energy sectors and policies of different countries, the results for the EU-26 aggregate do not warrant too much attention.

For the wind power sector, the results indicate that the joint objective of environmental sustainability and economic advancement has not been achieved. According to the estimations, wind energy consumption does not produce any economic growth (conservation hypothesis) apart from the environmental gains of promoting the use of renewable energies as a substitute for fossil fuel alternatives (and other additional advantages related, for example, to the reduction of energy dependency) in either Spain or Portugal. However, as ref. [33] notes, Europe is the world leader in this type of renewable energy technology, where some European countries—Germany, Denmark and Spain—are the biggest exporters of wind power generation components. A possible explanation for this result is that the economic crisis coincided with the commissioning of wind power projects. Although the deployment of renewable energies has stopped in Spain, sector companies have maintained their share of the world wind energy market.

With respect to solar photovoltaic energy, the data support the neutrality hypothesis in both Spain and Portugal. This is not surprising, as Spain, like Portugal and most other EU member countries, is a net importer of photovoltaic equipment, with China being the major exporter of this technology [40].

Our results suggest that solar thermal energy does boost the growth of the Spanish and Portuguese economies (as well as the EU-26 aggregate). In the case of Spain, there is a two-way relationship. This is an interesting result, as Europe is the world leader in concentrated solar power (CSP) technology development, with Spain being the country that has invested most in this sector. European, and especially Spanish, companies are solidly positioned in the marketplace and are engaged in the deployment of this technology all over the world. The scope for cost reduction driven by technological progress, and the potential for solving intermittent renewable energy integration problems thanks to its storage capacity, are an incentive for investment in research and development in the CSP sector.

On the other hand, despite having researched the possibility of the series function being nonlinear, results were inconclusive. Thus, the main shortcoming of this paper is that the series are not long enough. Therefore, future research will focus on a longer series and include other variables and methods of analysis.

In sum, we can say that, despite not having found evidence of the causality between all renewable energy sources and economic growth in either Spain or Portugal, investment in renewable sources has managed to reduce per capita emissions and further diminish energy dependency. The positioning of Spanish companies in the wind and CSP sectors are proof that investment in renewable energy sources has also had positive impacts on the economy. Our results confirm this point for CSP. Future analyses after further deployment of renewable energies and without the disruption of the financial crisis might show up a clear nexus between the promotion of renewable technologies and economic growth.

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