Article

The Development of Wind Farms Business and the Central Control of Smart Grid in Spain: Making a Virtue of Necessity

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Abstract: This paper lays out the role of, on the one hand, the first center in the world for the integration in the electrical grid of electricity coming from renewable energy (CECRE by its Spanish acronym) and, on the other hand, the industrial development of large energy suppliers and wind turbine manufacturers in the growth of renewable energies. These two initiatives enabled, in Spain, the development of one of the first integrated markets for this type of energy sources. With respect to CECRE and from a technological point of view, the key contributions were the development of two software programs (wind management and management of solar light incidence) and their visual implementation and centralized digital control.

An economic and business history approach is used to show the rise and relative failure of the Spanish wind industry during the period between 2004-2015, when Spain became the fourth country after China, the US and Germany in installed capacity of renewable energies and, in relative terms, the second country after Denmark. This study is unique in that it provides an integrated vision of the reasons for the relative fall of Spain in the world ranking of wind energy producers. The methodology of the economic analysis of industrial policies makes it possible to explain the fall in the relative importance of Spain in the international panorama of wind farms. There were no reasons related to technological obsolescence or inability of the CECRE managing renewable energies to explain the fall.

Keywords: regulatory economics; smart grids; wind farms

1. Introduction

Spain became a global power in the production of wind energy, in both absolute and relative terms, from the end of the 1990s to the Great Recession (Figures 1, 2 and Table 1). Three reasons have been argued:

1. Strong government incentives (premiums) for the installation of wind and solar farms.
2. The positive attitude of Spanish society as regards renewable energies.
3. A suitable geographical situation for using wind energy.

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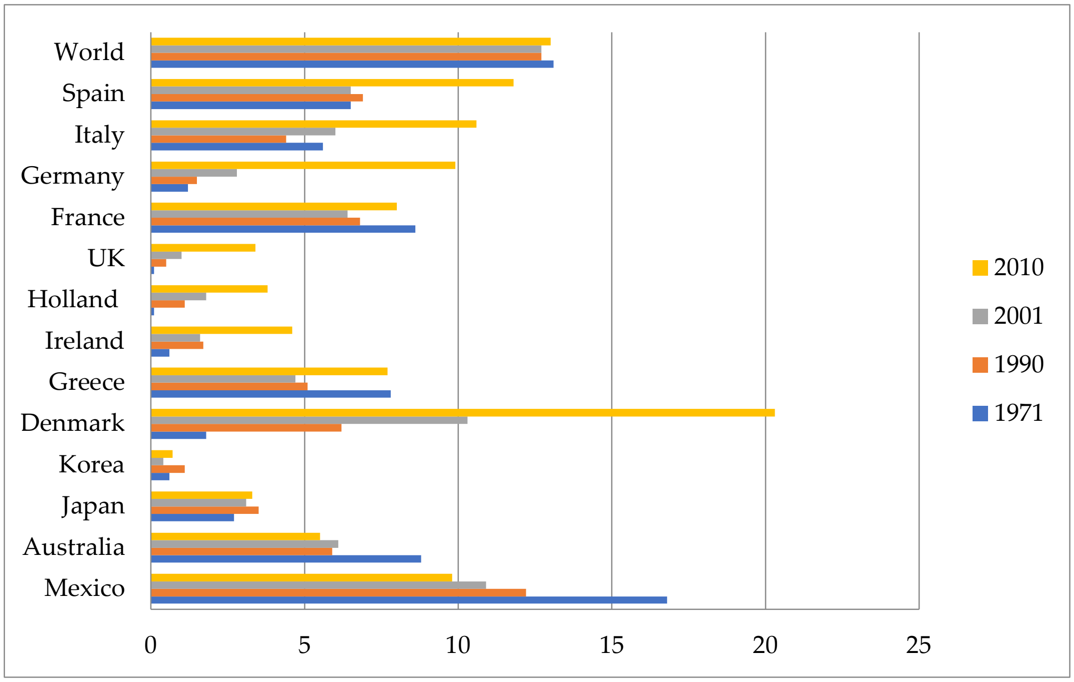

Figure 1. Contribution of renewable energies to energy supply as a percentage of total primary energy supply. Source: http://www.oecd.org/statistics/ (Electricity - Electricity generation).

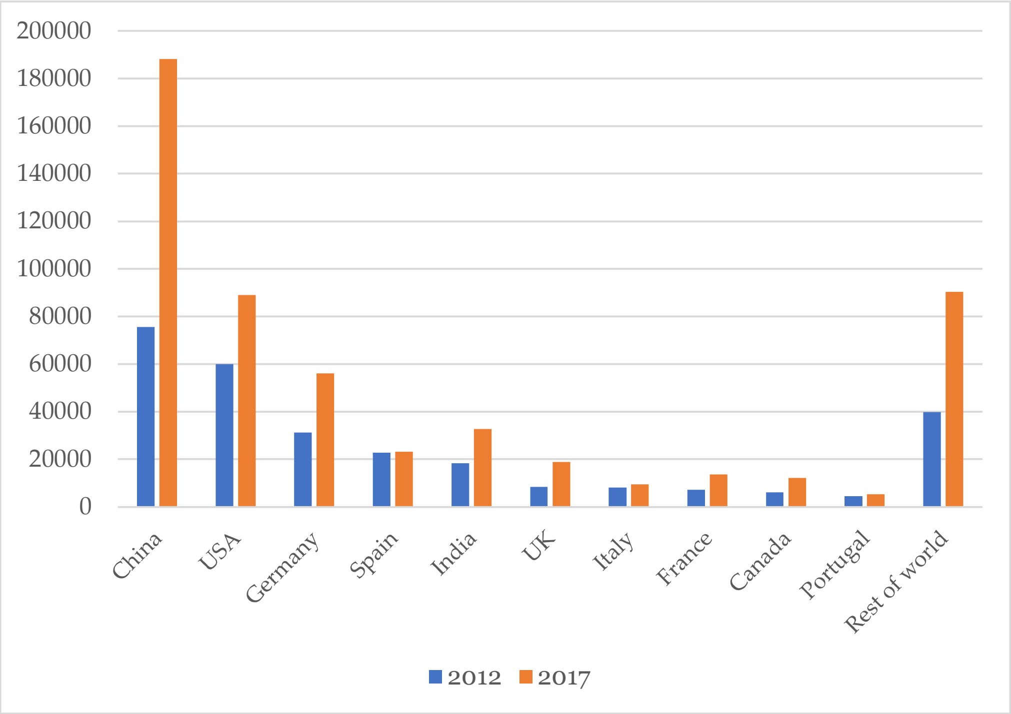

Figure 2. Installed capacity of wind power in MW. Years 2012 and 2017. Source: GWEC, 2013, 2018 [27, 28].

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Table 1. Wind energy penetration levels in some European countries in 2010.

	Denmark	Portugal	Spain	Ireland	Germany
1. Maximum Demand (GW)	6.4	9.4	45.4	4.5	80
2. Minimum Demand (GW)	1.8	3.5	18	1.6	34.6
3. Wind Installed Capacity (GW)	3.7	3.9	20	1.4	26.4
4. Total Wind Energy Produced (TWh)	7.8	9	42.7	2.9	36.5
% MPIP (4/2)	204	111	110	86	76
% Penetration Capacity (3/1)	58	42	44	32	33
% Wind Energy Penetration (4/TED)	22	17	16	10.5	6.7

MPIP = Maximum Possible Instantaneous Penetration, TED = Total Energy Demand

Source: Holttinen et al. [29].

From the above, point three is usually cited as the main reason behind the country's strong achievements in matters of wind energy. Spain's success is easy to confirm by reviewing the Renewable Energy Country Attractiveness Index (RECAI). The RECAI has been compiled by the firm Ernst & Young since 2003. It is an index that allow to measure the profitability of investments in renewable energies in 40 countries around the world. In RECAI, variables directly related to the economic retribution of investments—the "bankability of renewables"—weigh strongly on the position of the countries included. In 2004, RECAI situated Spain in the first place. In 2007 Spain held second place, starting to plummet from there in 2011 and achieving its worst result in 2014 when it was located at position 24. Currently, in 2020, Spain has recovered somewhat in the index, gaining several places to rank eleventh [1].

Point two—the interest of citizens in renewable energies—may be measured using the Special Eurobarometer on Climate Change for the period 2008–2018. Relative to European citizens, Spaniards have always been little worried about renewable energies, particularly when measuring their individual actions in favour of using renewable energy sources [2].

As regards point three, it bears noting that the regime and intensity of winds in the Iberian Peninsula is not particularly good. Only a small part of the North-West coast offers a high wind speed regime, similar to that of the whole of Ireland or central and northern UK [3]. Consequently, it seems that Spain could really only count on premiums as a suitable explanation for its accomplishments.

In order to understand why Spain facilitated investments in wind and solar farms, we must go back to the mid-1980s. Spain had managed to financially recover and grow after the 1970s oil crisis and the nuclear moratorium in 1983. However, its energy production still relied extensively on imported petrol. Although the effort to use available energy more efficiently has never been put to aside, the problem has truly been of such magnitude that, at the time, it was only practicable to work on finding a substitute. It became obvious, then, that Spain required large-scale production of electrical energy from renewable

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energy sources. The development of the necessary technological knowledge and know-how required to make a virtue of necessity became a priority.

The relation of knowledge to the concept of making a virtue of necessity is found in *The Canterbury Tales*, written by Geoffrey Chaucer at the end of the XIV century. Chaucer writes: "Then is it wisdom, as it seems to me, to make a virtue of necessity". However, in our current postindustrial society, we'd probably do well to substitute "technological knowledge" for the term "wisdom".

Our hypothesis is that two windows of opportunity for catching up in matters of renewable energies were opened thanks to two different types of technological knowledge which had accumulated in the Spanish industry. These windows of opportunity were those which allowed the country to make virtue of necessity and overcome two obstacles: a low social demand for the use of renewable energies, and a relatively low primary (potential) wind energy. It was the two different types of specific technological knowledge which we will mention that made it so attractive to invest in renewable energies in Spain—scientific rigor and its excellent implementation ensured the solvency of the investment.

This article describes, in Sections 2 and 3, these two types of technological knowledge. Before that, however, we ought to clarify what we mean by "windows of opportunity for catching up." The concept of "window of opportunity" was defined by Perez & Soete in 1988 [4]. According to them, in the very early stages of a new technology, relatively backward countries may enter in or bring about a new industry given enough human capital or a lack of barriers to entry. Barriers to entry exist when a technology is already patented or when a new technology substitutes some previous activity with a solid presence of firms with strong market power (monopolies or oligopolies). Section 4 discusses whether the technological advancements described were indeed those which originated the high production of wind energy in Spain or, alternatively, whether it was the government's economic incentives that propitiated the massive set-up of wind farms. In the conclusions we stress the importance of technological advancements in explaining why Spain became one of the main producers of wind energy before the Great Recession. On the other hand, we give little weight to the impact of institutional economic incentives for the construction of wind turbines and wind farms.

The theoretical foundations of our work lay on such economic literature as highlights the importance of scientific and technological aspects in the electric industry, which were already underlined by Hughes in his volume *Networks of Power* [5]. There is also much scientific literature on technological change which focuses on the importance of technological advancements. We will find good theoretical support, on the more orthodox side, in the economic models of both Solow and Romer [6, 7]; and, from a different angle, on the evolutionary or neo-Schumpeterian school with Nelson and Winter at its head [8].

The two possibilities that countries have of reducing their technological and wealth gap with more advanced countries are: a) to import technology and combine it with cheap but increasingly better educated labour, or b) to take advantage of the birth of a new technology (window of opportunity) to develop it, adapt it to the conditions of their country and export it afterwards. The catching-up phenomenon is achieved because one of the leaders eventually "plateaus", choosing to continue to redeem a prior technology and thus opening up the possibility for another country to take its place [9].

For relatively poorer countries, such as Spain, the second option always comes hand-in-hand with the necessity of solving an urgent technological problem. In the Spanish case, and in the case of wind energy, the problem was that the degree of efficiency in management needed to be very high, since there was no back-up energy, not enough linkage with European grids, nor is Spain a particularly windy country. The development of a central control for the integration in the electrical grid of electricity coming from renewable energy and the adaptation of wind turbines to these requirements synthesised all this effort and generation of new knowledge, hence making virtue of necessity. The first of the countries acquiring the knowledge required for an efficient management of thousands of wind farms would take the place of one of the traditional leaders in the field.

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2. First Window of Opportunity: A Digital Control Centre for the Electricity Grid

As has been noted in the introduction, Spaniards are not strongly disposed towards the use of renewables; however, along with Portuguese citizens, they are the ones to worry the most, in the European Union, about a lack of energy sources and, particularly, about being unable to meet their increasing prices. The first case—energy reliability—concerns more than 20% of the Spanish population; the second—energy affordability—more than 70% [10]. In both items, Spaniard's score doubles the average for the whole of the European Union.

Such a negative perception comes from a generalised understanding on the part of the population of the Iberian Peninsula of one of their greatest needs: that they have no energy reservoirs of their own. Coal sources are depleted or very low-quality, and their hydroelectric yield is already one of the highest in the world. The building of nuclear reactors was also paralysed in Spain in 1984, and in Portugal it never really took off. Feelings of vulnerability are heightened by the fact that the Peninsula's main energy reservoir is actually outside of it, as it depends on two pipelines transporting natural gas from Algiers. These started operating, respectively, in 1996 and 2011.

Energy sovereignty is precarious on the side of the Peninsula's own supply. The Spanish population is very conscious of this, as well as of the fact that overcoming this difficulty is Spain's greatest technological challenge. In 2010, the Spanish Foundation for Science and Technology (FECYT by its Spanish acronym) conducted the Citizens' Agenda for Science and Innovation [11]. This social experiment was aimed at uncovering what where thirteen most important technological challenges for the Spanish society, mid- and long-term. More than 100,000 people took part in this experiment. The most-voted option, with 14% of the votes, was "acquiring more efficient energy storage".

Along the whole period of installation of wind and solar farms, and up until now, the Spanish population has been conscious that when there is no light nor wind, electrical demand relies on combined cycle gas turbine plants (Figure 3). In fact, for every MW installed in wind or solar energy, another combined cycle needed to be built to cover situations of high electrical demand in conditions of lack of sun and wind as the figure 3 shows. This is not the case for any other European leader in the construction of wind farms, who have always benefited from their own or geographically close backup energy sources given the high integration of their medium- and high-voltage electrical grids. In contrast, the linkage of the Iberian Peninsula with the European grid, which happens through France, amounts only to a 3% of the installed energy production in Spain.

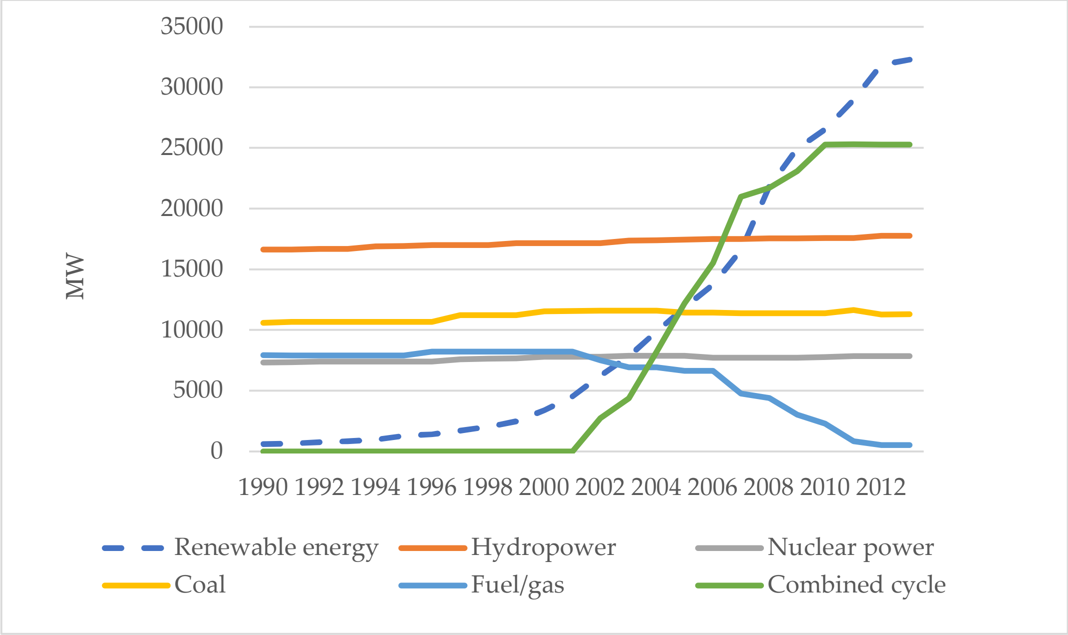

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Figure 3. Instaled power by source of energy (1990-2013). Source: REE data.

It is certainly very difficult to explain how Spain got to be a leader in the production of renewable energies taking into account the following three points:

Social perception of having no energy backup in situations of lack of wind
Scarcity of backup given by a lack of connectivity with the rest of Europe
Little societal interest in renewable energies

The answer to this paradox lies also in the editions of the Special Eurobarometer on Climate Change [2]. It was not the Spanish population which pushed, as it was the case in Denmark or Germany, towards renewable energies, but the oligopoly of the producer firms of electrical energy.

Between 2008 and 2017, the percentage of private (at-home) solar panel installations in Spain always was small or null. By contrast, at the beginning of 2018, there were more than 1,000,000 small-scale installations for the private production of electrical energy in Germany—in Spain, this number barely reached 1,000. What this situation evidenced was that, in Spain, renewable energies had only been developed in the form of great installations (farms). Against the reality of many European countries, it is difficult to find small wind generators, solar installations, or photovoltaic panels in Spanish homes. This is due to a lack of economic incentives for their installation, the presence of many administrative obstacles, and the opposition of the oligopoly made up by the great energy firms, as well as the difficulties in incorporating the resulting surplus energy from individual producers to the medium- and high-voltage grid.

The number of obstacles peaked in 2015, when the Spanish government became one of the world's few in adopting a double tax on energy. Consumer-producers had to pay for using the grid to consume as well as to put out energy. These obstacles were lifted in 2018 and immediately and positively reflected on the growth of photovoltaic energy sources for self-consumption. Of 263MW of photovoltaic energy sources installed, 236 came from small individual and community installations [12].

However, this solution for homes did not solve the macroeconomically current problem present since the installation of the first wind farms, that is, that there is no large-scale electricity storage for energy from renewable sources. Furthermore, as the installed capacity of renewable energies grows, the Spanish linkage with the European grid diminishes in percentage.

Following Chaucer ("Then is it wisdom, as it seems to me, to make a virtue of necessity"), in the face of a necessity for electricity storage, the second-best option in Spain for solving the problem at hand appeared to be the technological development of a digital centre for the national control of wind and solar farms—the CECRE (Centro de Control de Energías Renovables) [Control Centre for Renewable Energies].

2.1 Software Development for the Management of Wind Energy: GEMAS and SIPREOLICO

The need to create the CECRE became manifest at the beginning of the 21st century, when REE (Red Eléctrica Española) [Spanish Electrical Grid] detected a difficulty in integrating the amount of energy coming from wind turbines without assuming the high costs for the operation of the grid (see figure 4) [13, 14]. REE did not know about the wind power that might be entering the system and predicting the potential wind power input on the spot had become imperative.

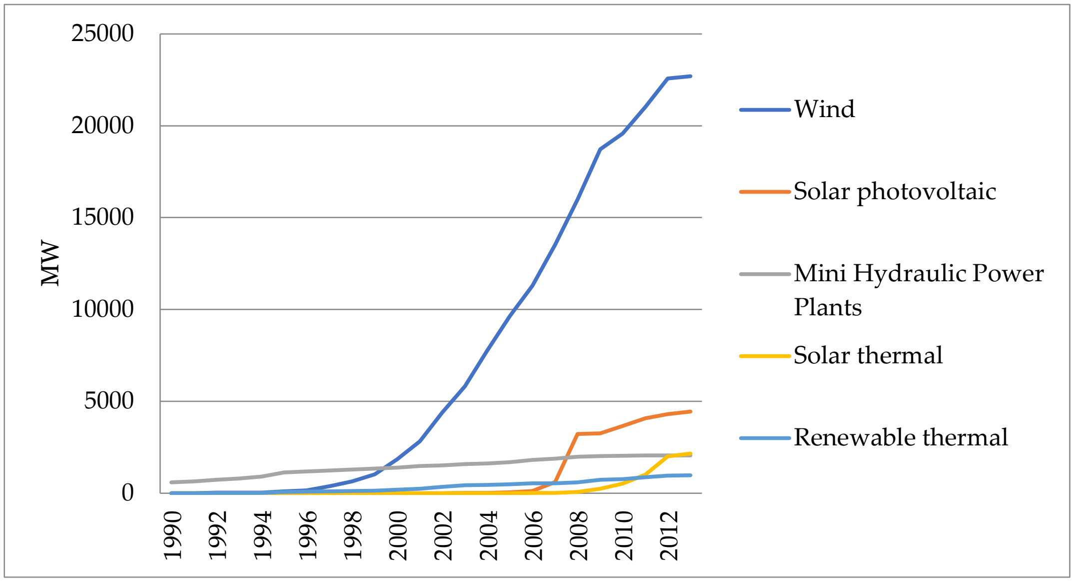

Figure 4. Installed power in renewable energies (1990-2013). Source: REE data. http://www.ree.es/sistema_electrico/series_estadisticas.asp

Both pieces of software—GEMA (Generación Eólica Máxima Admisible en el Sistema) [Maximum Wind Energy Generated Tolerable by the System] and SIPREÓLICO (a wind power prediction tool)—enabled the prediction of worst-case scenarios for the state of the electrical grid. They were developed and made operational between the years 2000-2006, born from the teamwork of the firm REE (Red Eléctrica Española) and the Universities Carlos III and ICAI School of Engineering (Escuela Técnica Superior de Ingeniería - ICAI in Spanish). To this day, current versions of both programs are still used and have become an international standard for managing centralized operations for the electrical grid.

These programs were developed as a way of confirming whether the total of generated wind energy could be integrated to-the-minute into the electrical grid without negatively affecting the reliability¡ of the supply. The control screens at CECRE were able, from 2004 onwards, to conduct simulations on the environmental conditions of wind and light in Spain. Since this made data of wind predictions and state of generators for the different locations available, the commissioning of wind farms could be foreseen; thus, the CECRE could write instructions that could solve eventual problems in the grid, such as an eventual increase or lack of wind, voltage drops, overproduction and overloads and congestion. It should be noted that the CECRE was already capable of evaluating the availability of backup energies which could be used at any time (and that mostly consisted of cogeneration plans) and supply the secondary market with information to make the best use of the available plants. This was the first large-scale solution to the problem of variability in renewable energies.

2.1.1 Gemas [15]

The Spanish acronym GEMAS, as has been previously noted, indicates that this is a piece of software which analyses the maximum wind energy generated that the system may withstand. GEMAS is able to calculate in real time the maximum energy capacity that the system is safely able to absorb. It uses various functions which indicated is or may be affected by the input or output of energy from renewable sources, particularly from wind and solar farms. This tool, thus, optimizes the energy generation by maximising energy from renewable sources and preventing eventual problems in the system. GEMAS is based on the constant calculation of the minimum reduction in energy production, which is used to solve, among others, voltage dips, overproduction of energy with respect to demand, congestions, and grid overload.

The calculation is done at the level of each independent farm and each aggregation per node (of the transport network) and is sent to the generation control centers to be then transmitted to individual generators. All of these procedures are automatically executed without needing the intervention of an operator at a minimum timeframe of up to one minute.

2.1.2 Sipreolico [16]

The SIPREOLICO software began its development in the year 2001. Its first version was launched in 2002 and presented at various conferences as well as to the IEA (International Energy Agency). SIPREOLICO's first version was trialed in the Canary Islands in 2005 and it was already in full operation the following year [17]. This is a software that updated, in real time, the data used for the prediction of wind energy generated hourly within a 24-48h timeframe, using data relative to the forecast of wind speeds, the characteristics of individual energy farms, power curves and other historical data. The strength of its predictive abilities made it possible to match its previsions with the estimates in energy demands [18].

2.2 The coming into operation of the CECRE

The CECRE allowed the growth rate in renewable energy sources for the next 5 years to spike. At that moment, there was no parallel increase in government incentives for the installation of wind power, nor did technology have unprecedented efficiency increments (with the subsequent reduction in fabrication and installation costs). If anything, the opposite was true, given that wind turbines had to be adapted to the norms of the REE (Red Eléctrica Española, the Spanish electricity grid and name of the company) in order to be controlled and subsequently supply their energy production to the network. Furthermore, as an investment, wind power installations had to compete with photovoltaic ones, which, conversely, were being supported by state investments, as well as being much more subsidized (Figure 5).

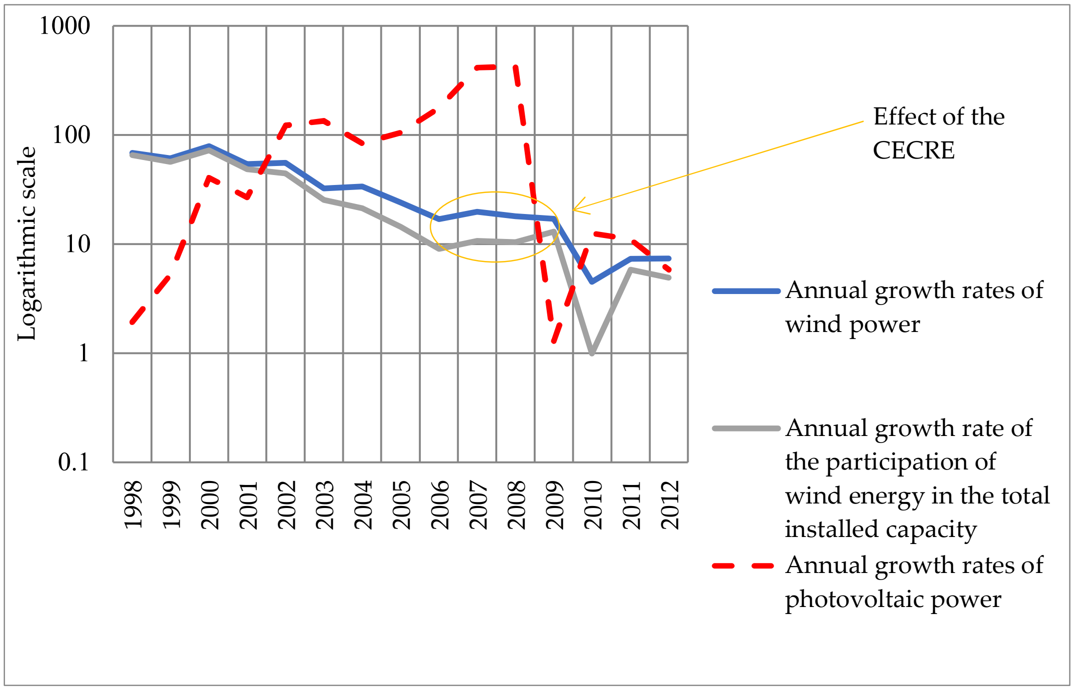

Figure 5. Annual growth rates of wind and photovoltaic power. Source: REE data.

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The maintenance of an annual growth rate of around 18% in installed capacity and 11% in relation to the total installed capacity for the period between 2006–2009 is unrivalled globally in function of the energy demands in the Spanish market. There was a rise from 11,000MW to 19,000MW in installed wind power, and, within four years, 15% of the demand was covered, a sharp contrast to the previous 9%. Not only had the CECRE managed to maximise the integration costs of wind power in a strong and constant manner, but, in the process, it had moved on to dismantle all installations based on different sources of energy which, although still profitable, were not as much so in relation to the dynamics of wind power (Figure 5). Quite literally, wind power had paralysed any option that was not complementary to it growth. From the time that the CECRE was set up, its objective of maximising the integration of wind power without affecting the security of the system was accomplished, which led to the maintenance of growth rates in the installation of wind turbines (Effect of the CECRE, Figure 5). This was how the installed capacity in wind power rose from 15% in 2006 to 17.5% in 2007 and sustained its growth rate until 2009.

Investment in renewable energies started to decrease in 2010 as the Great Recession made these investments expendable (Figure 5). The sector's problems were heightened in 2013, when the government refused to continue paying the mid- and long-term premiums which had been agreed on in 2008. An avalanche of complaints in the international courts ensued, leading to unfavourable judgements that, at the beginning of 2020, already amounted to around 800M Euros, and which could reach the sum of 10,000M Euros, according to the incumbent for the Ministerio para la Transición Ecológica (Spanish Ministry for the Ecological Transition).

3. Second Window of Opportunity: Wings and Blades

The CECRE's improvements were spectacular. In the year 2009, Nobuo Tanaka, Executive Director of the International Energy Agency, pointed out that "The CECRE is, globally, the most important experiment in its field." In the same year, John Podesta, former Assistant to President Bill Clinton and president of the Center for American Progress, asserted that "Visiting the CECRE is seeing the future."

Without the CECRE, Spain would not have become, in 2013, the fourth country after China, the US and Germany in installed capacity of renewable energies, and, in relative terms, the second country after Denmark (Figure 2). In 2007 Spain surpassed Japan and the US—which ranked, respectively, second and third—in terms of photovoltaic energy installed. However, the combined existence of the CECRE and government premiums are not sufficient to explain the growth in the installation of wind farms. The answer rather lies in the degree to which the Spanish electrical market was an oligopoly.

Three firms, Iberdrola, Endesa and Naturgy (Gas Natural Fenosa), have controlled since the mid-XXth century up until today the segments of production, distribution, and commercialization to different degrees, but always with majority holdings [13, 14]. Without their endorsement, participation, and push in the business of renewable energies, the growth of the latter would have been impossible. Iberdrola is probably the firm with the greatest market power, given that it is strategically well situated in its relationships with central and regional governments, to which is added its good standing in the UK and US markets. Above all, however, Iberdrola participates in industrial firms and technological incentives associated to the regional government of the Basque Country (Spain). It was in this region of northern Spain when at the end of the 80s a great window of opportunity for the aerospace industry was opened.

Metallurgy, a traditional industry in the Basque Country, was in crisis, and its government spearheaded many incentives for the industrialization of the region. One of the possibilities was entering into the production of parts and components for the aerospace industry, which was a completely new sector to Basque firms [19]. However, its industry was already knowledgeable in matters of special alloys and new compound materials. In little time, many firms appeared capable of creating parts and components of planes, in particular, plane wings. The most representative firm in this new industry was Aernnova, which currently owns factories in the US, Mexico, Brazil, and Romania.

In 1993, Aernnova entered to participate in a small metallurgic firm named Gamesa (Grupo Auxiliar MEtalúrgico S.A.), born in the 1970s. In 1990, Iberdrola had also entered its capital. In 1994, Gamesa entered the business of wind turbines and established Gamesa Eólica.

The idea was simple: manufacturing the blades of the wind turbines was very similar to manufacturing plane wings. Gamesa Eólica signed several contracts for the transfer of technology with the number one firm in wind turbines, the Danish Vestas. Vestas entered Gamesa in 1996 with a capital participation of 40%, but abandoned it in 2001 after conflicts, precisely, around the ownership of technological developments. From that moment on, both firms would compete in the market.

In the following years, Gamesa Eólica became the fourth or fifth world manufacturer of wind turbines. Vestas would still hold first place in the business, but Gamesa continued to open firms around the world until it almost reached the level of the German firm Siemens, the North American General Electric and the Chinese GoldWind. In 2011, Gamesa came into popular knowledge when President Obama visited their factory in Pennsylvania and deemed it an example of a "firm of the future".

Gamesa Eólica represents Spain's success in wind energy production. And this success cannot be explained without understanding the importance of the tandem Gamesa Eólica–Iberdrola. This tandem worked as a single firm at the time of acquiring the greater part of the best installation contracts for wind farms around the world. Whereas Gamesa Eólica cared for the technological aspects, Iberdrola used the whole of its commercial and financial power to win contracts. In Spain, Endesa tried to create a similar structure to the Gamesa–Iberdrola tandem creating the firm of wind turbines MADE, which was taken over in 2003 by Gamesa Eólica. Meanwhile, Naturgy, which specialized in gas plants, saw its business grow until 2013 merely because it provided a backup to the increasing installations of wind farms.

4. Discussion: Squandering VS. Technological Advancement

In 2012 Spanish politicians and many economic analysts thought that renewable energy premiums had created a speculative bubble ought to be eliminated. In this section, firstly, we will look at the reasons that led to this idea. Secondly, we will state that it was technological advancements which originated the high production capacities, which means that premiums, at least in the case of wind farms, were justified.

4.1 The Association *of the Idea of the Speculative Bubble with Renewable Energies*

At the beginning of the Great Recession in 2008, the Spanish economic press accused the government of creating a financial investment bubble around photovoltaic energy. This bubble would have been produced by the facilities given for the installation of solar farms since 2004 and the high premiums on the production of photovoltaic farms since 2007 (Real Decreto [Royal Legislative Degree] 661/2007).

The government had foreseen at the beginning of this plan that the demand would lead to installing a power of around 400MW per year. However, the Government found itself with 3,500 new MW coming from photovoltaic energy sources. When the installations were inspected, one in four presented administrative irregularities, although the cases of fraud were very few. However, many investors and citizens outside of the energy sector had decided to enter it, often falling into debt in the process. This situation coincided with the beginning of the Great Recession.

Throughout the year 2008, as the Great Recession advanced, the notion that a financial bubble had been created around to photovoltaic energy invaded both the field of polity and academic analysis. Articles based on the study of premiums, rates and prices in renewable energies reached the conclusion that that there had been a small—in size—but notable—in degree—economic inefficiency. In mid-2008, the government which had

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played a leading role in supporting renewable energies, accepted these ideas. The Real Decreto [Royal Legislative Degree] 1578/2008 inaugurated the actions of the government against renewable energies.

At the time it was only a matter of dismantling premiums on photovoltaic power stations. To that end, premiums were reduced, the type of installations to which they could apply decreased, and the country's total installed power was limited. However, there was no need to worry as the amount of photovoltaic power installed photovoltaic energy was small but the criticism on governmental aid spread to the rest of renewable energies. These accusations were, however, difficult to sustain. The premiums to the production of photovoltaic energy per MW/h were more than nine times higher than for wind energy. Furthermore, in 2009, the cost of production of wind energy began to be able to compete against hydroelectric energy—Spain's cheapest. Premiums had stopped being essential to new wind installations. Analysts indicated that the so-called learning curve for technology with respect to wind energy was peaking [20][1].

The crisis continued, electricity consumption fell, and its production decreased by 5,1% in 2009. The percentage share of renewable energies increased, as did the cost of the electric bill. This resulted in a simple analysis: after years of solid growth in the production of wind energy the price of energy in Spain had continued to increase, and consequently, the deficit paid by consumers increased as a result of the premiums paid to wind farms.

Wind farms were not accused of creating a bubble, as in the case of the premiums to photovoltaic energy. The argument was the following: If a country with a per capita income half that of Germany or Denmark had jointly spearheaded the growth of wind energy and, in turn, consumers had not seen their electricity bill decrease, then there had doubtlessly been a social cost or opportunity cost overrun. In holding this view, it was therefore assumed that Spaniards should have only invested in cost-efficient energies because, being half as rich as the Germans or Danish, they were making a double effort. From this perspective, Spain had made an excessive contribution (its opportunity cost) to the reduction of the learning curve of wind energies. It was concluded that the installation of wind farms should have started from 2009 and all that had come before had merely been a case of squandered money.

In a situation of non-payment of premiums to solar farms, it was only a matter of time and depending on the intensity of the Great Recession that the government would extend the idea of a bubble or "splurge" to the rest of renewable energies. Large investors were already anticipating this by way of not building any new combined cycle plants.

Even though in 2010 almost half of the electrical consumption lost in the year 2009 was recovered, at the end of the year the Real Decreto Ley [Royal Legislative Degree - Act] 14/2020 established that renewable energies—in particular photovoltaic energy—had caused the increase in electricity production costs. In order to mitigate this increase, the use of photovoltaic farms was further limited and, for the first time, producers of wind, solar thermal and CHP (Combined Heat and Power) energy were forced to participate, like the rest of conventional energies, in the maintenance costs of the grid the management of the CECRE.

The measure did not seem very forceful, but confidence in Spain's environmental politics crumbled. New investments in wind farms also plummeted and Spain lost its standing in the RECAI. In any case, during the whole of 2011, with the declining electricity demand, wind farms, whose investment and premiums corresponded to agreements prior to RD - Law 14/2010, continued to come into operation.

After little over a year, on January 27th, 2012, the Real Decreto Ley 1/2012 was enacted, suspending the procedures for the pre-allocation of remuneration and abolishing

[1] The learning curve is the relationship existing between the quantity of installed capacity and the reduction in the cost of installing a new unit. For terrestrial wind energy at this period a reduction of 12% was applicable each time that the installed capacity doubled.

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the economic incentives for the installation of electric energy plants using cogeneration, renewable energy sources and waste.[2]

This Decree was retroactive, entailing a 40% reduction in already agreed-on premiums for the installation of farms which had just finished construction or barely started operating. In a short period of time, Spain became one of the countries with the greatest number of complaints in the International Economic Courts, and it crashed in the RECAI.

Between 2007 and 2012, the accumulated State deficit with energy supply firms surpassed 20,000M€, around 2% of the GDP. However, the premiums to wind farms were not to blame for this. In 2013, when premiums were cut, they were practically in line with the extra cost which comes from optimizing of optimising a wind turbine in Spain in comparison to Ireland, the UK or Denmark, countries with better and more constant wind endowments. Though, thanks to the integral management strategy developed by REE in the CECRE and to the continuous process of innovation in wind turbines by part of Gamesa and the rest of producers, that differential was small and diminishing.

However, on February 1st, 2013, the government published the Real Decreto Ley 2/2013 with urgent measures for the electrical system. This Real Decreto-Ley suspended the system of premiums that had been established in 2007. It justified this measure because of the premiums that had to be paid for renewable energies. The negative consequences for the sector were immediate. Acciona, Spain's most vulnerable operator, lost more than 14% of its stock market value and thought of selling the business. The sector lost 3,641 workers that year, accounting for almost 15% of all employment in the sector, and nine wind component factories closed [21, 22].

The real reason to eliminate premiums was stated in the preamble to the Decreto Ley: "…New deviations in the cost and income estimates driven by different factors, both at the closing of 2012 and for 2013, in the current economic climate, make breaking even practically unfeasible in light of electric tolls and expected funds as allocated in the Presupuestos Generales del Estado [National Budget]."[3]

The deficit was, however, not due to the premiums. It had arisen because the system of remuneration to producer firms was, and still is, based on keeping nuclear and hydroelectric power plants in operation all the time. From this point on, priority is given to the use of renewable energies. With this array of available energy sources, the Spanish electricity bill is very cheap, as long as no other power plants have to be turned on. But when there is no wind nor enough turbines, then combined cycle power plants and small-scale thermal power plants need to be set in motion. These plants are technically much easier to turn on and off than larger ones. However, the cost per KW/h produced is very high. Finally, the last plant in entering the system sets the price at which the KW will be switched off for all producers fixes the price per KW to the rest of producers. Therefore, supplier firms have a perverse incentive to push the entry of renewable sources to the limit and then put thermal power plants with high production costs into operation.

In a situation of recession (since 2008), renewable energies took an increasing share of the production, but from a decreasing demand. The demand for thermal energies remained relatively low and, for a long time, did not budge, but when winds were scarce, they were set in motion, circumstantially increasing the deficit. As long as the price of petrol was low—until 2012—the situation was bearable. However, as oil prices rose when the small thermal power plants came on stream, the deficit soared.

2 Original text in Spanish: La suspensión de los procedimientos de preasignación de retribución y a la supresión de los incentivos económicos para las instalaciones de producción de energía eléctrica a partir de cogeneración, fuentes de energía renovables y residuos.

3 Original text in Spanish: "…Las nuevas desviaciones en las estimaciones de costes e ingresos motivadas por distintos factores, tanto para el cierre de 2012 como para 2013, en el contexto económico actual, hacen casi inviable la cobertura de los mismos con cargo a los peajes eléctricos y a las partidas previstas provenientes de los Presupuestos Generales del Estado."

The Government needed, paradoxically, to make great producers to stop relying on premiums to set their wind farms in motion and, conversely, convince them to turn on large, efficient thermal plants before the situation became even more urgent. The government's objective changed into being that of increasing the time of operation of large-scale thermal and combined cycle plants.

The government's Real Decreto-Ley (RD-Law) worked. The deficit in the electrical sector decreased in 2013, and it achieved a surplus of more than 500M€. In return, the lower CO2 production, which had been decreasing since 2007, was reducecd, and the consumption of oil and natural gas increased in the following years. Even the burning of coal increased again, after 25 years in a row of reduced consumption.

4.2 The Entrepreneurial *Context: The Importance of the Historical Trajectory*

The situation of investments in solar farms did meet the requirements for its consideration as a financial bubble in which novice and even some experienced investors got caught. However, the case with wind farms is far from having been so. In our mind, what happened with wind farms has more to do with the dynamics of Spanish multinationals in their attempts to grow and occupy exterior markets.

This model was inaugurated by the company Telefónica-Movistar [23] and has been replicated by firms such as Repsol and Iberdrola. It originates from the firm's domestically holding a monopoly or oligopoly, which allows for a great accumulation of capital. From there, the firm develops a solid group of small to medium technological firms in which it participates as shareholders or through the establishment of trust-based relationships. These firms, again, are ensured with their technology of a central position in their domestic markets, once they open up and become liberalized. In turn, they receive aid to compete with their cheap and efficient technologies in the international market. This phenomenon was christened that of "the Spanish technological mini-multinationals." Once these "mini-multinationals" have taken up positions in foreign markets the large companies also enter into market liberalisation processes in other countries or through tenders, leaning on some of these technological mini-multinationals which are already established.

In the case of wind farms, the first main Spanish firms which entered the market—Iberdrola, Endesa and Acciona—did follow this model. Iberdrola, as has been mentioned in Section 3, created, and partnered with Gamesa and ultimately turned Gamesa into the world's third largest wind turbine manufacturer and into one of the main wind farm management companies. Endesa tried to follow suit with the firm Team, but Gamesa finally absorbed it. Acciona developed Acciona Windpower, whose technological strength was in wind farm construction and management, and in 2015, it merged with the German wind turbine manufacturer Nortex, creating the world's sixth largest wind turbine group. Of course, the fourth Spanish operator, Naturgy, simply reaped the benefits derived from the installation of combined cycle plants which served as backup to the growth of wind farms. At last, in 2016 Siemens and Gamesa announced their plan to merge their wind businesses.

In support of this strategy, the State itself made available the knowledge developed in the CECRE. All firms had collaborated in its development, in particular Iberdrola and Acciona, which meant that when these firms began to compete in the exterior market these not only provided the technology of their technological mini-multinationals, but also their knowledge in the management of smart grids.

5. Conclusions

From the beginnings of the CECRE, its teams have made possible the maximum integration of renewable energies in the coverage of electrical demand in Spain, making it possible for these energies to supply as much as possible to the system. The software programs GEMAS and SIPREOLICO increased the effectiveness of the electrical, so that energy production from wind farms has been optimized and increased, increasing, in turn, the profitability of such installations. The CECRE has allowed energy producers to know in advance that there will be no technical problems for the integration of their energy production into the system.

At times, in the economic analysis that is made of the regulatory framework, too much emphasis is made on tariffs, premiums, and the law. However, technological and organizational innovations on a large scale, such as the CECRE, are also fundamental. Besides, without the endorsement, participation and push of the electrical power companies in the business of renewable energies, the growth of the latter would have been impossible. The investment generated was in function of the business strategies of electrical firms. REE did not invest in the CECRE for speculative purposes. Its action generated a new and growing field of investment. Gamesa, Iberdrola, Endesa and Acciona did not develop their technologies to artificially increase their stock market listing.

The Great Recession ended with the dream of continuing to increase the capacity of renewable energies. The shattering of this dream was clear already in 2008 with the fall in the growth rates of the installations. From then on, Spain has lost positions in international rankings related to renewable energies. A great amount of debt with foreign investors has been generated, industrial firms have been absorbed or have moved abroad and the large companies of electricity management have installed themselves in other markets.

Today, despite of the problems generated by the Great Recession in the State's public debt, Spain is the fifth exporter of wind technologies, almost tied with the US. However, if considerations on management are added to the hardware side of the equation, Spain would probably jump some places higher in the ranking [24, 25, 26]. We might thus conclude that it was ultimately the technological knowledge and not the premiums which kept Spain reasonably well situated throughout and have contributed to its return to being an attractive market for the investment in renewable energies.

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