



Research paper

How political decisions affect the economy of a sector: The example of photovoltaic energy in Spain



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ABSTRACT

The economic crisis in Spain (2008–2012) led to a massive decrease in the feed-in tariff on photovoltaic solar energy production, which caused stagnation in the growth of this market. The objective of this paper is to analyze how institutional changes have affected the structure of the market; for this purpose, concentration and stability indices have been calculated. The analysis period is from 2004 to 2018 and data from 5,353 firms in the sector have been used. The results of the analysis show that the incentive policy increased the degree of competition and attracted mostly small companies. This was due to the profitability guaranteed by the premiums. Despite the progressive decrease in the number of companies since the cancellation of the premium policy, concentration in the sector is low. However, from 2016 onwards there has been an increase in the degree of concentration. This is because we are facing the beginning of a new photovoltaic "boom" in Spain, this time led by large companies, attracted both by a new legislative turn and by the low costs of photovoltaic technology.

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1. Introduction

In the last decade of the 20th century, the progressive depletion of fossil fuels and the growing concern for environmental conservation, there has been a change in energy policies (Covert et al., 2016; Kittner et al., 2017). These factors, together with technological improvements in the energy sector, have stimulated policies to promote renewable energy in Europe (Blok, 2006; Saint Akadiri et al., 2019; Li et al., 2020). Spain is one of the European countries with the best climate conditions for photovoltaic energy production (Carrión et al., 2008; Spanish Photovoltaic Union (UNEF), 2016). The number of hours of solar radiation in Spain far exceeds that of the largest European producer, Germany (Šúri et al., 2007).

Since 2007, Spain has established an aggressive policy of incentives for solar energy. This led to disproportionate growth in photovoltaic production, which reached 300% year-on-year growth rates (Movilla et al., 2013). In 2007, the generation of photovoltaic solar electricity in Spain was 507.0 GWh and grew to reach 8193.0 GWh in 2010, stabilizing at the current 7512 GWh generated in 2018 (International Energy Agency (IEA), 2019). The economic crisis and the risk of foreign intervention in the Spanish economy during the spring of 2010 made the Spanish State implement an adjustment policy that slowed down the

bonus policy (Fernández-González et al., 2020). Thus, as the crisis affected the country, the Spanish government's budgets reflected new distribution priorities (Mahalingam and Reiner, 2016). Although this change in public policy did not affect the property rights of the agents, it involved a change in the possibilities of return on investment. Within transactional policy, this is clearly a hold-up problem of an irreversible investment, as classified by Epstein and O'Halloran (1999) or Williamson (2007). The ex-ante conditions on investment returns were not met, since the government changed the institutional framework ex-post, eliminating investment returns and making it impossible for investors to recover their investments (Álvarez-Díaz et al., 2017).

The photovoltaic sector in Spain has attracted the attention of academy. Many studies address different aspects of this industry in Spain, such as the production performance of large solar energy production plants (Carrión et al., 2008; Martín-Martínez et al., 2019; Talavera et al., 2015), the implementation of solar energy at households (Prol and Steininger, 2017; Ordóñez et al., 2010; Rosales-Asensio et al., 2019; Tanil and Jurek, 2020), the comparative analysis between the Spanish and European markets (Tanil and Jurek, 2020; Prol, 2018; Sarasa-Maestro et al., 2013) and the governance of this sector (Mir-Artigues, 2013; Mir-Artigues and Del Río, 2016). However, a concentration analysis reflecting the changes in the business structure of this sector has not been carried out.

This paper analyzes how institutional change in the photovoltaic sector has affected the degree of concentration and

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Nomenclature

Ck	Weight of the largest “k” companies
CNMC	National Commission for Markets and Competition
CNE	National Energy Commission
DI	Dominance Index
GEntryR	Gross entry rate
GExitR	Gross exit rate
HHI	Herfindahl–Hirschman Index
HHI-S	Herfindahl–Hirschman standardized index
I	Instability and volatility index
K	Kwoka dominance index
MR	Market rotation rate
NEntryR	Net entry rate
R	Inverse number of companies
RD	Royal Decree
RD-L	Royal Decree Law
RHT	Rosenbluth, Hall & Tideman Index
SABI	Iberian Balance Sheet Analysis System

stability of the sector and what factors have influenced the level of competition. The aim of this research is to find out the degree of concentration and consolidation of the Spanish photovoltaic sector and what its future prospects are.

The study is organized as follows: Section 2 presents the institutional structure of the sector. Section 3 sets out the methodology used to carry out the empirical analysis of the photovoltaic sector. Section 4 analyzes the results of the degree of concentration and stability, and its evolution in the face of institutional change. The conclusions of this study are provided in Section 5.

2. Legislative framework of the Spanish photovoltaic sector

It was not until 2007 that the photovoltaic sector took off in Spain. This was due to the lower cost of solar technology, the credit facilities for the sector promoted by the banking system, the shift in investment flows from the building sector to the photovoltaic solar energy sector and the proliferation of distribution and grid connection companies (Mir-Artigues et al., 2015). Despite the importance of these factors, the trigger for the sector's growth was the change in premium policy in 2007. In the following sections, we will analyze the trends in the legislative framework and how this framework modified the behavior of the agents involved in it (See Fig. 1).

2.1. The expansion of the sector

The exponential growth of the photovoltaic sector was due to the entry into force of RD 436/2004 (2004), passed on 12 March 2004. The objective of this Royal Decree was to unify existing regulations on renewable energy (de la Hoz et al., 2012). It sought to define a framework that would be conducive to the renewal of the legal and economic system related to the production of renewable energy, paying particular attention to installations. This tariff system was based on RD 2818/1998 (Spanish Ministry of Industry and Energy, 1998) and RD 841/2002 (Spanish Ministry of Economy, 2002) and, as a novelty, it established two channels of remuneration of free choice for the producer. The first of these remuneration methods gave the owner of the installation the option to trade with the electricity companies on its production or surplus, receiving a proportion of the average electricity

tariff (De la Hoz et al., 2010). The second way of remuneration was based on the sale of the production or surplus to the daily market, without intermediaries. Another important point of RD 436/2004 (Spanish Ministry of Economy, 2004) was to guarantee the sustainability and profitability of the installations throughout their useful life and to extend the application of the premiums to 100 kW installations, as it previously only covered 5 kW installations (Salas and Olias, 2009).

The real boost to the sector came with the passing of RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007). Although it maintained the dual remuneration system for production implemented in 2004 and explained above, it created the bottom-top system, which guaranteed a minimum return for photovoltaic companies during the entire lifetime of the plant. Annually, until 2010, the limit amounts would be reviewed based on the Consumer Price Index. From 2010 onwards, reviews would be carried out every four years (del Río González, 2008). In addition, RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007) established a limit on the amount of installed capacity to support the premium system, namely 371 MW. If 85% of the installed power limit was reached, the tariffs would be changed (Mir-Artigues, 2013). It should be noted that in May 2007, production was already close to 71% of the limit (263 MW over the 371 MW limit).

The new legislative framework attracted new producers and investors, making solar PV power grow exponentially (see Fig. 2). In 2008, the annual rate of change of PV power production increased by more than 440% (Álvarez-Díaz et al., 2017). In addition, in 2008 the relative weight of photovoltaic energy in the renewable energy mix quadrupled. Thus, according to data from the REE (Spanish Electricity Network (REE), 2010), in October 2007 photovoltaic energy production was 521 MW, exceeding the limit of 371 MW established by RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007) by 40%. One year later, in October 2008, production exceeded the limit of 371 MW by 900% (Mir-Artigues and Del Río, 2016). As Fig. 2 shows, the number of installations, although still growing, has slowed down since the 2008 boom. The latest available data for 2019 show that since 2012 the number of installations has only increased by 2.6%.

The National Markets and Competition Commission (CNMC), formerly the National Energy Commission (CNE), defines the special regime as the production of electricity with renewable sources, waste or cogeneration, whose installed capacity does not exceed 50 MW. In 2016, 35% of all electricity generated in Spain was under the special regime. Except in specific cases, it is not competitive and its existence is due to the fact that it is subsidized by premiums.

In the Spanish national context, photovoltaic solar energy is the one that obtains more millions of annual remuneration, despite the fact that its production is one of the smallest. In absolute values, it takes twice as much as wind power and produces one fifth (National Commission for Markets and Competition (CNMC), 2020). This is due to the fact that its premium is 10 times that of wind power. Solar FV, in 2018, collected a premium of more than 2500 million euros for 7765 GWh, while wind energy, in 2018, charged a premium of 1480 million euros for 36,143 GWh (4 c€/kWh or 40.9 euros/MWh) (National Commission for Markets and Competition (CNMC), 2020). Fig. 3 shows the evolution of installed power, as well as remuneration, which over a period of 10 years has been multiplied by 2.5. All of this is the result of government policies initiated when José Luis Rodríguez Zapatero was at the helm of the government, which his successors kept going.

Fig. 4 shows the evolution of premium growth, which led to a financially unsustainable situation. Thus, according to data from the REE (Spanish Electricity Network (REE), 2010) and CNMC (National Commission for Markets and Competition (CNMC), 2020),

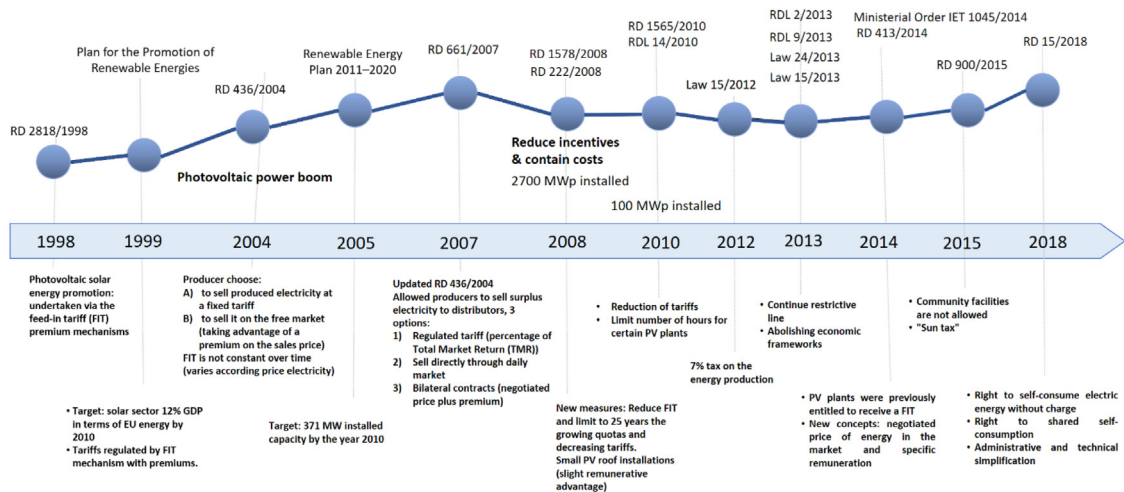


Fig. 1. Graphic summary of the timeline of the regulations that affect the PV solar energy production sector and its impacts. Source: Compiled by authors.

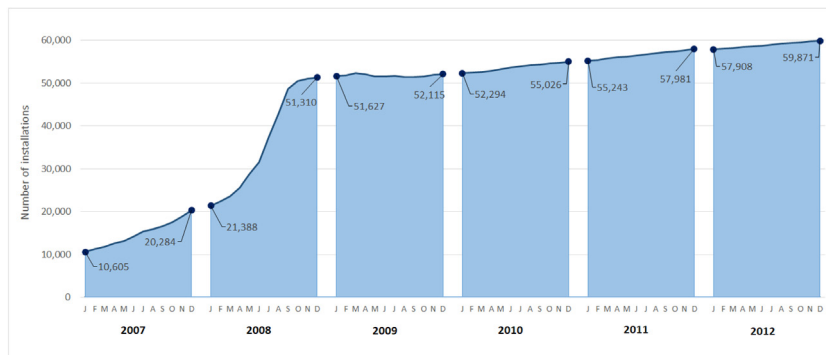


Fig. 2. Photovoltaic solar power total installations in Spain. Source: Compiled by authors. Data from CNMC, 2020.

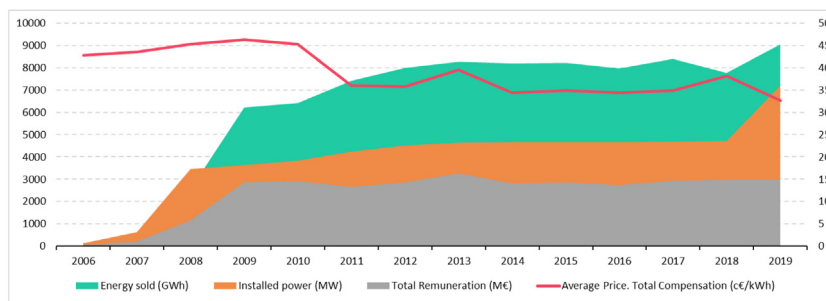


Fig. 3. Evolution of installed power and remuneration obtained from solar photovoltaic installations, 2007–2019. Source: Compiled by authors. Data from CNMC, 2020.

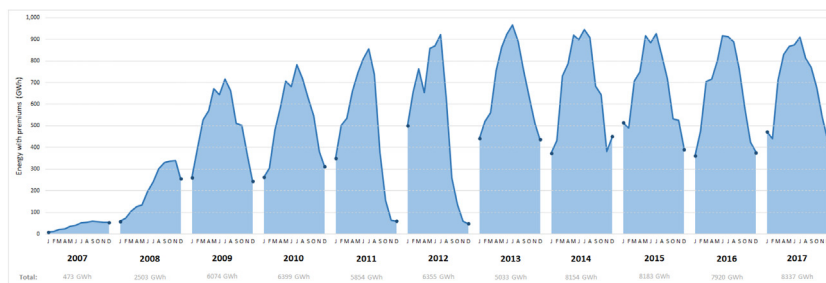


Fig. 4. Premiums and contribution to the special mix of photovoltaic energy. Source: Compiled by authors. Data from CNMC, 2020.

in October 2007 photovoltaic energy production was 521 MW, exceeding the limit of 371 MW established by RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007) by 40%. One year later, in October 2008, production exceeded the limit of 371 MW by 900% (Álvarez-Díaz et al., 2017). The variability in the solar PV contribution data is due to the sensitivity of production to seasonality. The variability observed in the period analyzed is in a range of 400 GWh (Spanish Electricity Network (REE), 2010).

2.2. The contraction of the sector

The Spanish photovoltaic sector achieved such high growth rates that, during 2008, the number of MW produced doubled from one quarter to the next. This phenomenon was brought about by the injection of public funds into the solar energy sector. This situation ended up generating criticism from the rest of the energy sector, since it meant an inequality of opportunities, as well as a high cost for public finances in a crisis scenario (Blok, 2006). Thus, the heavy burden of subsidies, coupled with the change of government in 2011, led to the passing of laws between 2008 and 2014 to restrict the beneficial conditions of this sector.

As indicated above, the policy change began in 2008 with the passing of RD 1578/2008 (Spanish Ministry of Industry, Tourism and Commerce, 2008). In order to moderate the disproportionate growth of the sector, this Royal Decree established a procedure of quarterly calls to establish the price of the kWh received by the producers, which were registered in the Pre-Reward Allocation Register (Fernández-González et al., 2020). The reduction in premiums contained in RD 1578/2008 (Spanish Ministry of Industry, Tourism and Commerce, 2008) and the imposition of a limit on the number of projects benefiting from them led to a decrease in investments in the sector.

Later, in 2010, three new pieces of legislation laws were passed: RD 1003/2010 (Spanish Ministry of Industry, Tourism and Commerce, 2010a), which regularized the payment of the premium under the special scheme according to the date of operation of the plant; RD 1565/2010 (Spanish Ministry of Industry, Tourism and Commerce, 2010b), which required the adoption of various technological measures (1-MW plants had to send telemetrics to the nearest System Operator and 2-MW plants had to be conditioned to withstand voltage dips); and RD-L 14/2010 (Spanish Head of State, 2010), which imposed a toll on access to the electricity grid and reduced the equivalent hours of operation during for which the plants benefited from the photovoltaic tariff. Following the passing of this new legislation, the profitability of some photovoltaic companies was reduced by up to 40% (Fernández-González et al., 2020). This measure made it difficult for producers to meet their financial debts as most of the plants had not yet been paid in full (Photovoltaic Industry Association (ASIF), 2011).

In 2011, RD 1544/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011a) and RD 1699/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011b) were passed, continuing the trend of reducing premiums and making access to the sector more difficult. RD 1544/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011a) established tolls for access to the transport and distribution networks. Specifically, it established a fee of 0.5 euros/MWh for generating companies for the use of the networks (Álvarez-Díaz et al., 2017). These new rates meant a 0.2% increase in the costs of floor plants, while for panels in buildings they would increase by 0.3%. RD 1544/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011a) was intended to discourage the creation of new companies by decreasing their profitability, now that it was recovering due to the decrease in the price of solar panels. RD 1699/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011b) encouraged the implementation of small power installations, to the

detriment of those with a high number of panels. This other measure was intended to change the profile of the sector: more facilities for self-consumption and fewer “solar farms” with a high concentration of solar panels.

The passing of RD 1544/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011a) and RD 1699/2011 (Spanish Ministry of Industry, Tourism and Commerce, 2011b) paved the way for the dismantling of the premium system, but it was RD-L 1/2012 (Spanish Head of State, 2012) that determined the end of this stage. RD-L 1/2012 (Spanish Head of State, 2012) was passed by urgent procedure and was based on the need to approve definitive measures to paralyze the Spanish budget deficit (Spanish Photovoltaic Union (UNEF), 2014). With its passing, the tariffs, premiums and supplements for efficiency and reactive energy were halted indefinitely. Although all the companies in the sector were negatively affected by RD-L 1/2012 (Spanish Head of State, 2012), those facilities that were not registered in the Pre-Allocation Register by 28 January 2012 were most affected, since the 550-MW quota assigned for 2012 was removed (Álvarez-Díaz et al., 2017). Therefore, the year-on-year growth of the sector in 2013 and 2014 fell alarmingly (2.34% and 0.16%, respectively). To appreciate the magnitude of this decline, it is important to emphasize that the same rates for 2010 and 2011 showed values above 10%.

RD-L 2/2013 (Spanish Head of State, 2013a), on urgent measures in the electricity system and the financial sector, annulled the double remuneration system established by RD 436/2004 (Spanish Ministry of Economy, 2004) and consolidated in RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007). Thus, the passing of RD-L 2/2013 (2013) carried on with the dismantling of the premium system (Álvarez-Díaz et al., 2017). From 2013 onwards the producer had to choose exclusively between entering the market and receiving a compensatory premium in case of losses (Ciarreta et al., 2011). This measure led to the value of the production tax on electricity, 7% of the KW generated, being borne by the producer (de la Hoz et al., 2014).

Due to the new measures implemented, the average profitability of the sector decreased (Ramírez et al., 2017). In fact, in 2013 it presented a deficit of 26 billion euros, undermining the appeal of the sector. The destruction of jobs, the slowdown in the creation of companies and the stagnation of production in the sector led to the passing of RD-L 9/2013 in July 2013 (Spanish Head of State, 2013b), with more favorable proposals for the sector (del Río et al., 2015). RD-L 9/2013 (Blanco-Díez et al., 2020) established the specific remuneration system, replacing the previous system contained in RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007), which guaranteed a minimum profitability of 7.5% for all those companies with a negative balance between their sales and investment costs. This Royal Decree was complemented a posteriori with the passing of RD 413/2014 (Spanish Ministry of Industry, Energy and Tourism, 2014a) and Order IET/1045/2014 (Spanish Ministry of Industry, Energy and Tourism, 2014b), which contributed two specific characteristics to the specific remuneration system: the former sought to cover unamortized investment costs and the latter sought to compensate for energy costs that were not covered by sale (Talavera et al., 2016).

In 2015, RD 900/2015 (Spanish Ministry of Industry, Energy and Tourism, 2015) was passed, which turned out to be another unfavorable regulation for the photovoltaic sector. RD 900/2015 (Spanish Ministry of Industry, Energy and Tourism, 2015) contained the so-called “sun tax” which obliged self-consumers of photovoltaic energy to pay a tax to contribute to the Spanish electricity system. This new legislation led to stagnation in low-power building installations (Ibarloza et al., 2018). Numerous allegations were made against this RD (Spanish Ministry

of Industry, Energy and Tourism, 2015), as it was a barrier to consumption. One of them, presented by the regional government of Catalonia, was the one processed by the Spanish Constitutional Court, which led to the annulment of the ban on self-consumption of electricity in neighborhood associations in 2007 (Spanish Photovoltaic Union (UNEF), 2015). The Constitutional Court's ruling was the first step in removing the obstacles to self-consumption. The definitive step was taken by RD-L15/2018 (Spanish Head of State, 2018), passed after a change of government, which simplified the procedures for self-consumption facilities, approved economic compensation for surplus clean energy and definitively repealed the "sun tax". In this way, it is possible to take advantage of the economies of scale derived from the consumption of photovoltaic energy in community homes. Therefore, since 2017 the photovoltaic sector is experiencing a new growth.

3. Methodology

Concentration and stability ratios make it possible to observe the structural characteristics of the market in a simple manner, which are then used in models that try to explain the level of competition in the industry as a result of the structure of the market. In addition, concentration ratios can reflect the entry or exit of companies into and out of the market, or mergers between established companies. This feature is, for example, used in anti-trust legislation in the USA.

Data on Spanish companies in the photovoltaic energy sector were obtained from the SABI (Iberian Balance Sheet Analysis System) database belonging to the Bureau van Dijk Group. From SABI it is possible to access the financial accounts of 2.6 million Spanish and 800,000 Portuguese companies from 1993 to the present year (Ibarloza et al., 2018). The group of companies analyzed was defined using these search parameters:

- Country: Spain.
- Operating income (thousands of euros) min = 0.001 for at least one of the years 2004–2019.
- IAE (Tax on Economic Activities) classification (only primary codes): 1514- "Production of energy from tides, solar energy, etc."
- CNAE 2009 (Primary codes only): 3519- "Other types of electric power production".
- Description of the activity: it had to include "solar" or "photovoltaic".

Finally, the sample is made up of a total of 5353 companies.

The company data collect both legal and financial information and also reflect the administrative structure. However, due to the scarcity of records on the number of workers in each company, this variable has not been included in the analysis. The data obtained from SABI were analyzed on the basis of concentration and stability ratios. This type of tool allows the study of both the structure of a market and the level of competition, as well as reflecting the entry or exit of companies into and out of the market.

There is general agreement that the elements of concentration measurement in a market are based on the number of firms and the distribution of firm size (inequality). In this paper, the concentration indices (CI) are in the following form:

$$CI = \sum_{i=1}^n s_i w_i \quad (1)$$

Where, s_i is the market share of the i th company, w_i is the weight assigned to each company's market share in the index, and n is the number of companies in the sector.

The calculation system used allows, depending on the weight given to the smaller companies, the analysis of temporary changes in the distribution queue. Seven concentration indices were applied and analyzed. The following is an overview of the key ratios used, the method of calculation and how the results are interpreted. There are a great number of concentration indices for economic analysis, but there are no clear theoretical fundamentals for choosing among the different tools. Tables A.1 and A.2 presented in Appendix summarize the concentration and stability ratios used.

4. Results

A quantitative analysis of concentration and stability of the sector was carried out with data obtained from SABI for the period between 2004 and 2019.

As far as concentration indicators are concerned, the results of these indices allow the impact of the institutional and regulatory environment and the economic cycle on the sector to be analyzed. The results of the indicators are shown in Table 1.

In general, the results of the concentration indicators show the following:

- Since 2009, the number of companies in the sector has been reduced due to the impact of government policies. This decline was smooth for three years (period 2009–2011), but with the cancellation of the feed-in tariff policy in 2012, it has been accelerating. In 2018, the number of companies in the sector is close to the number that existed in 2007 (see the value of the concentration indicator R).
- The level of concentration has been decreased from 2004 to 2016. The recent institutional framework, a consequence of the abolition of the "sun tax" and the passing of RD-L 15/2018 (2018), has increased concentration in the sector.
- Despite variations, the degree of concentration in the sector, as of 2007, can be considered low.

From a more thorough analysis of the results, the following lessons can be drawn:

- Policies based on feed-in-tariffs have resulted in no dominant company in the sector. The drastic drop in the value of CR1 in 2007, which continues until 2009, is noteworthy. In 2010 and 2011 the market share of the main companies in the sector increased due to two reasons: the drop in annual installed power and the limitation on the number of hours and rates imposed by RD 1003/2010 (Spanish Ministry of Industry, Tourism and Commerce, 2010a) and RD-L 14/2010 (Spanish Head of State, 2010). However, in recent years the degree of concentration in the sector has increased. A greater commitment of the Spanish executive power (i.e. RD-L 15/2018 Spanish Head of State, 2018), the beginning of the decarbonization of the Spanish economy and the lowering of the costs of photovoltaic energy (Ibarloza et al., 2018) have attracted large companies. In the last two years, the construction of large-scale photovoltaic power plants by large companies has been a trend (Bullich-Massagué et al., 2020). This type of installation has the advantage of exploiting economies of scale, but it also increases the degree of concentration in the sector. In this new photovoltaic "boom", the support of foreign financial institutions (e.g. Natixis S.A., Goldman Sachs Group, Inc. and Société Générale S.A.) is key (Cinco Días and El País, 2020).
- The dominant companies in the sector (CR5 and CR10) in the period 2004–2007 are either extinct or have dramatically fallen in market share. The companies that lead the market today did not exist before 2007. In the time series analyzed,

Table 1
Evolution of concentration indicators in the Spanish solar photovoltaic sector, 2004–2018.

	R	Weight of the largest “k” companies				HHI	HHI-S	RHT	DI	K
		C1 (%)	C3 (%)	C5 (%)	C10 (%)					
2004	0.0084	75.2	85.8	92.7	98.3	5744.46	0.571	0.0646	0.969	0.4793
2005	0.0018	55.7	73.9	85.3	95.4	3368.91	0.336	0.0230	0.850	0.2104
2006	0.0005	37.6	59.8	71.4	82.3	1808.73	0.180	0.0064	0.633	0.0577
2007	0.0003	16.5	34.2	44.6	64.0	612.79	0.061	0.0035	0.242	0.0055
2008	0.0002	11.2	28.9	41.9	59.2	460.08	0.046	0.0042	0.157	0.0012
2009	0.0002	7.2	16.2	23.1	33.6	169.65	0.017	0.0010	0.141	0.0008
2010	0.0002	10.9	22.1	28.4	41.7	274.83	0.027	0.0014	0.239	0.0026
2011	0.0002	15.5	32.6	38.1	45.5	471.11	0.047	0.0014	0.394	0.0090
2012	0.0002	6.8	15.3	19.9	28.8	135.01	0.013	0.0011	0.181	0.0009
2013	0.0002	5.0	12.4	18.0	29.6	118.65	0.012	0.0010	0.100	0.0003
2014	0.0002	5.8	13.6	19.4	31.2	130.29	0.013	0.0011	0.119	0.0006
2015	0.0002	5.2	13.5	19.2	30.5	123.60	0.012	0.0011	0.113	0.0003
2016	0.0003	5.1	12.9	19.2	31.5	127.22	0.012	0.0013	0.099	0.0003
2017	0.0003	8.1	18.2	24.3	36.9	189.23	0.019	0.0015	0.179	0.0010
2018	0.0003	11.0	24.7	33.3	44.7	306.02	0.030	0.0017	0.229	0.0020
2019	0.0003	7.1	16.5	23.6	36.5	178.28	0.017	0.0019	0.132	0.0008

two periods are distinguished: 2004–2007 and 2008–2018. Thus, the first company by market share changes over time (Acciona Solar S.A., between 2004 and 2008, Trina Solar S.L. (Spain), in 2011, Aries Solar Termoelectrica S.L., from 2013 to 2016, and X-Elio Energy S.L. in 2009, 2010, 2012, 2017 and 2018).

- The evolution of HHI and HHIN shows the decrease in the concentration rate in the sector. The market is now deconcentrated (2007 is the turning point year). However, in the years 2004–2005 the HHI exceeded the critical figure of 1500. This shows that, until the implementation of incentive policies, it was a concentrated sector. In 2017 and 2018 there is an increase in the HHI and HHIN index. The growth of the sector in recent years is due to two reasons: the new legislative framework and the emergency auction held by the Spanish government in 2017. This energy auction was carried out due to international pressure over the failure to meet the European energy objectives for 2020 (Gürtler et al., 2019). It is estimated that the large companies that participated will install 4000 MW of solar energy (Fernández-González et al., 2020).
- The RHT, DI and K indices show that currently large companies have no power over small ones. In other words, the market power exercised by companies with a larger market share has diminished considerably. Thus, the influence of the leading companies on the prices, production and strategies of the remaining companies is reduced. The DI in 2004 had a value of 0.969, which indicated that it was a market with a high degree of concentration: large dominant companies and great power over the rest. However, since 2007 there has been a large decrease in the value of the RHT, DI and K indexes. In order to understand the behavior of these indices, it is necessary to describe the two key points of the economic-legal environment since 2007:
 - o The Spanish financial system facilitated the entry of small investors into the photovoltaic sector. For this purpose, Project Finance were created as micro-companies, in which financial expenses were covered through the premiums received (del Río and Mir-Artigues, 2012).
 - o Cheaper and more efficient photovoltaic technology also benefited the more modest investors. Photovoltaic technology was a barrier to entry into the sector for small and micro businesses at the beginning of the

21st century. The new solar modules can be grouped into small parks, making them more accessible to small investors (del Río and Mir-Artigues, 2012).

Concerning the sector stability analysis, the evolution of the sector reflects the financial crisis and the process of legislative reform. The results of stability are highly linked to contestability, understood as the direct relationship between entry and exit barriers and competition in the industry. If we take into account the regulatory changes, it can be said that the restrictions on activity in this sector are very high. As shown in previous studies (Bikker et al., 2007), contestability variables explain market competition. In other words, the greater the appeal of the investment environment, the greater the degree of competition. This justifies stability parameters, through concentration rates.

The main stability indicators in the Spanish PV sector were analyzed:

- Between 2004 and 2017, 5308 companies entered the market (1670 in 2007), while 1694 companies left it. That is, the market has increased by 3551 companies since 2004. Since 2010, more companies have left the market than entered it. The reduction in the number of companies in the last seven years is due to the extinction of small companies which, with the reduction of premiums, were no longer profitable.
- The index of instability and volatility shows higher values since the elimination of the feed-in tariff system (year 2012). The high premiums offered by the legislation passed since 2007 attracted new companies to the market. This made the competitive position of some companies change. A small increase in instability can be observed from 2016 onwards. This is due to the fact that some of the large companies are regaining market share (e.g. Acciona S.A.) and large companies are entering the market. Most of the new companies that have entered the market have their core business in the construction sector (e.g. ACS S.A., Sacyr S.A. or Avintia S.L.)
- The period 2005–2008 (see Table 2) stands out for being highly dynamic (see data on gross entry rates and rotation rate). As of 2010, negative values have been observed in the net entry rate, which shows the loss of appeal of the sector. The evolution of the net entry rate reflects the sensitivity of the sector to change. The passing of RD 1003/2010 (Spanish Ministry of Industry, Tourism and Commerce, 2010a) and RD-L 14/2010 (Spanish Head of State, 2010) has led to a drastic reduction in the entry of companies (See Table 2).

Table 2
Evolution of the stability indicators of the Spanish solar photovoltaic sector, 2004–2018.

	Number of entries	Number of outlets	Instability and volatility index	Gross entry rate	Gross exit rate	Net entry rate	Market rotation rate
2004	74	11	0.192	164.44%	24.444%	140.00%	71.4%
2005	462	37	0.213	388.24%	31.092%	357.14%	91.7%
2006	1428	16	0.274	262.50%	2.941%	259.56%	73.8%
2007	1670	16	0.141	85.38%	0.818%	84.56%	46.7%
2008	1333	147	0.249	36.93%	4.072%	32.85%	30.9%
2009	163	111	0.111	3.40%	2.314%	1.08%	5.7%
2010	117	123	0.149	2.41%	2.537%	−0.12%	5.0%
2011	24	68	0.177	0.50%	1.404%	−0.91%	1.9%
2012	24	184	0.057	0.50%	3.835%	−3.33%	4.5%
2013	4	63	0.046	0.09%	1.358%	−1.27%	1.5%
2014	4	219	0.050	0.09%	4.783%	−4.70%	5.1%
2015	3	86	0.036	0.07%	1.971%	−1.90%	2.1%
2016	2	336	0.072	0.05%	7.849%	−7.80%	8.6%
2017	0	218	0.092	0.00%	5.523%	−5.52%	5.8%
2018	0	59	0.112	0.00%	1.582%	−1.58%	1.6%
2019	7	74		0.19%	2.02%	−1.83%	2.2%

5. Conclusions and policy recommendations

Given the high dependence of the Spanish economy on fossil energy and the pressure from Europe to move towards a more sustainable production model, Spanish policy makers built an incentive policy to improve the appeal of renewable energies, with special attention to photovoltaic energy. In Spain, an incentive policy for renewable energies, especially photovoltaic energy, was built due to the high dependence of the Spanish economy on fossil energy and the pressure from Europe for a more sustainable productive model.

In the global context, the role of the Spanish State as a regulatory agent is fundamental to promoting renewable energies. For this reason, in the period 2004–2007 there was a legislative change that ended with the passing of RD 661/2007 (Spanish Ministry of Industry, Tourism and Commerce, 2007). The institutional framework of the 2004–2007 period led to large investments. During that period, the sector's year-on-year growth rates reached over 300%. The empirical study carried out in this paper shows that during the “boom” of the photovoltaic sector the level of concentration decreased, reaching levels of perfect competition. The results of the production rates and net entry rates show the excessive growth of this industry. In the period 2006–2008, more than 4400 companies entered the sector. Most of the companies that entered the sector were small firms. This is due to three causes: the Spanish government's policy of bonuses, the reduction in technological costs and the project finance for small investors created by the Spanish financial sector (Mir-Artigues, 2013).

The high indebtedness of the Spanish economy caused a change in the premium policy from 2008 onwards. In the period 2004–2007 the Spanish government invested more than 6 billion euros in support of photovoltaic energy production. In a scenario of economic crisis, it was not possible to carry on with the incentive policy. Therefore, in 2012, RD-L 1/2012 (Spanish Head of State, 2012) was passed and the feed-in tariffs system was eliminated (Álvarez-Díaz et al., 2017). This caused the number of market entries to decrease, while the number of exits increased. The lower profitability led to the exit of small companies. Although the total number of companies decreased, there was no decrease in competition. In fact, since 2006 the degree of concentration in the sector has not been high.

The values of the rotation index and the instability and volatility index showed stagnation of the sector during the period 2012–2017. However, from 2017 onwards, the market share of the first 10 firms increased, as did the value of the remaining

concentration indices. Evidence of this is that the value of the HHI index more than doubled, as did the C1, C2 or DI indexes. This increase in the values of the indices shows the beginning of a new “boom” in Spanish photovoltaic production. There is no dominant entity in the PV power generation sector in Spain, and the leading entity in terms of market share is changing during the period analyzed. The number of institutions has stabilized since 2008, due to the lack of economic stimulus. The degree of concentration is nowadays very low according to the indicators analyzed, corresponding to a deconcentrated and competitive sector. This situation of low concentration is the result of the introduction of incentive policies in 2007. While the first photovoltaic boom was led by small companies, this second boom is linked to larger companies. The large companies in the market have increased their production. The new institutional framework is more beneficial for large companies. The elimination of the “sun tax”, the passing of RD-L 15/2018 (Spanish Head of State, 2018) and the international context where a more ecological economic paradigm is being sought, have led to the reactivation of photovoltaic energy in Spain.

The process of institutional change in our case study corresponds to an institutional change marked by the political action of the government and the legislative action of the parliament, so we refer to a “top-down”, centralized institutional change that is marked by collective action determined in laws and royal decrees (Álvarez-Díaz et al., 2017). The change of incentive policies to a sector reduces the return on investments in that sector, and as these investments once made cannot have any other purpose than the generation of PV power, a hold-up problem analogous to the one defined for the transactional economic theory of the firm is detected (Fernández-González et al., 2020). This case study serves as an example for decision-makers on how to assess possible future scenarios in the legislative design process of a sector. With the repeal of bonus schemes by the highest legislative authority in the country, a hold-up problem is created. In this way, due to legal uncertainty, a bad precedent for attracting investment is created.

It is important to realize that the so-called “green economy” is the new economic model for the European Union, of which Spain is a member. This growth strategy, already promoted previously by this supranational organization through the 20/20/20 Plan, has become increasingly important in Europe. Spain, with the background to its energy policy and the cancellation of the feed-in tariffs system, may find itself at a comparative disadvantage, even with its suitable biophysical conditions, compared to other member states.

Table A.1
Concentration rates.

Index	Formula	Description
Inverse number of entities (R)	$R = \frac{1}{N}$ N: number of companies in the sector	This index will be equal to 1 in the case of a monopoly, and will tend to 0 as the number of companies increases. This indicator does not provide information on the relative or absolute size of firms in the market; however, when studied over a time series it indicates the entry or exit of firms in the market.
Weight of the largest “k” entities (Ck)	$Ck = \sum_{i=1}^k S_i$ k: number of the main market entities S _i : market share of the ith company (in order of highest to lowest)	This index allows to understand the market share of the main k companies in the market. The number k is selected by the researcher, there is no rule for his choice. The index weighs equal to the largest k companies, but does not take into account the remaining (n – k) companies.
Herfindahl–Hirschman Index (HHI)	$HHI = \sum_{i=1}^N S_i^2$ N: number of companies in the sector S _i : market share of the ith company (in order of highest to lowest)	The HHI gives more weight to the larger companies. The maximum value of the HHI is 10,000, monopoly case. According to the US Department of Justice and The Federal Trade Commission, the market concentration varies based on the following levels: <ul style="list-style-type: none"> – HHI < 100: Very competitive market. – 100 ≤ HHI < 1500: Deconcentrated market – 1500 ≤ HHI < 2500: Concentrated market. – HHI ≥ 2500: Highly concentrated market
Herfindahl–Hirschman standardized index (HHI-S)	$HHI-S = \frac{HHI - \frac{1}{N}}{1 - \frac{1}{N}}$ N: number of companies in the sector HHI: Herfindahl–Hirschman Index	The value of HHI-S is 0 when the concentration is minimum (very large number of companies in the sector) and 1 when the concentration is maximum (monopoly case).
Rosenbluth, Hall & Tideman Index (RHT)	$RHT = \frac{1}{(2 \sum_{i=1}^N i S_i) - 1}$ N: number of companies in the sector S _i : market share of the ith company (in order of highest to lowest) i: rank of the i-one entity in the industry.	This index includes all the companies in the sector and takes into account the relative size of each one when ordering them from highest to lowest. However, unlike the HHI, the RHT index assigns greater importance to small businesses in the sector. The minimum value this index is 1/n (close to 0) when the number of entities in the industry is very high and the concentration is very low. The maximum value of index 1 (monopoly).
Dominance Index (DI)	$DI = \sum_{i=1}^N \frac{S_i^2}{HHI_i}$ N: number of companies in the sector S _i : market share of the ith company (in order of highest to lowest) HHI: Herfindahl–Hirschman Index	The DI measures the market concentration from the contribution of each entity to the HHI index. The value of the DI varies between 0 and 1. Values close to 0 are indicative of atomized sector. The DI reaches a higher value the smaller the non-dominant firms, indicating a greater ability of the dominant firm to exercise dominance over the remaining firms.
Kwoka dominance index (K)	$K = \sum_{i=1}^{N-1} (S_i - S_{i+1})^2$ N: number of companies in the sector S _i : market share of the ith company (in order of highest to lowest) S _{i+1} : market share of the entity immediately following in size	For the calculation of this index, the market shares must be ordered from highest to lowest. The Kwoka index analyzes the uniformity or dispersion of the companies’ size. When the inequality between the size of companies is high, the dominance of the main companies increases and the value of the index rises. The value of K shall be between 0 and 1, where 1 is the value corresponding to a monopoly.

However, the results show that the sector has achieved some degree of stability on the supply side. In this framework, the policymakers could implement demand-side incentives such as increased subsidies to improve energy efficiency and renewable energy in the envelope of buildings, heating, air conditioning, ventilation and sanitary hot water facilities, lighting facilities, and electric vehicle charging facilities. These incentives would be a great support in the return on investment needed. And all this would allow for faster reaching the greenhouse gas reduction targets set by the EU in the Agenda 2030 for Sustainable Development and against climate change.

CRedit authorship contribution statement

Raquel Fernández-González: Conceptualization, Methodology, Writing - original draft. **Elena Arce:** Data analysis, Methodology, Writing - original draft. **Dolores Garza-Gil:** Conceptualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Annex. Concentration and stability rates

See [Tables A.1](#) and [A.2](#).

Table A.2
Concentration rates.

Index	Formula	Description
Instability and volatility index	$I = \frac{1}{2} \sum_{i=1}^N S_{i2} - S_{i1} $ <p>N: number of companies in the sector S_{i1} and S_{i2}: market share of the ith entity in periods 1 and 2 respectively</p>	Range of values between 0 and 1. If $I = 0$ all companies kept their competitive position constant and therefore the level of competition is very low. If $I = 1$ the level of instability is maximum and the degree of competition is very high.
Gross entry rate	$GEntryR_t = \frac{NE_t}{N_{t-1}}$ <p>NE_t: number of companies entering the sector in the period t N_{t-1}: number of companies in the sector in the period prior to t</p>	<p>The index has the following interpretation (linked to the stage of the life cycle of the sector)</p> <ul style="list-style-type: none"> – $GEntryR = 0$: No companies have entered the sector. – $GEntryR$ close to 0: The entry of new companies to the sector is reduced – $GEntryR$ close to 1: The number of new companies is similar to the total number of existing companies in the previous period. – $GEntryR > 1$: The number of companies entering the sector is higher than the number of companies established in the sector in the previous period. Very dynamic sector with high volatility. <p>This indicator does not consider the number of companies that could have been destroyed in the period t</p>
Gross exit rate	$GExitR_t = \frac{NL_t}{N_{t-1}}$ <p>NL_t: Number of companies leaving the sector in the period t N_{t-1}: number of companies in the sector in the period prior to t</p>	<p>Similar interpretation to that of the previous index (closely linked to the stage of the life cycle of the sector):</p> <ul style="list-style-type: none"> – $GExitR = 0$: No companies left in period t. – $GExitR$ close to 0: The exit of companies is reduced – $GExitR$ close to 1: The number of companies leaving the sector is similar to the total number of companies in the previous period. – $GExitR > 1$: The number of companies leaving the sector is higher than the number of companies established in the sector in the previous period. Very dynamic sector with high volatility.
Net entry rate	$NEntryR_t = (GEntryR_t - GExitR_t) \times 100$	<p>The indicator is interpreted as a percentage:</p> <ul style="list-style-type: none"> – $NEntryR = 0$: There has been no change in the number of companies in the sector. The number of entries is equal to the number of exits. – $NEntryR > 0$: $GEntryR$ is greater than $GExitR$. Indicative of a dynamic sector that attracts new competitors – $NEntryR < 0$: $GEntryR$ is less than $GExitR$. Unattractive sector <p>The higher the value of the indicator (in absolute terms) the greater the instability of the sector</p>
Market rotation rate	$RM_t = \frac{NE_t + NL_t}{N_t}$ <p>NE_t: number of companies entering the sector in the period t NL_t: number of companies leaving the sector in the period t N_t: number of companies in the sector in the period t</p>	<p>If RM tends to 0 the sector's turnover is low. If RM tends to 1 the sector's turnover is high, which would imply a higher level of instability.</p>

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