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The Solar Photovoltaic Sector in Spain: Policy Framework Implications

Master's Thesis

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Abstract

The present Master's Thesis seeks to analyze the state of Spanish solar photovoltaic (henceforth PV) energy sector, putting a special focus on research, development and innovation (henceforth RD&I) and other policies affecting the development of the PV manufacturing industry. Historical factors are analysed in order to understand how Spain has arrived at its current situation. Policy-mixes from several top-manufacturing countries are put into perspective so it can be understood what is working internationally and which lessons can Spanish policy-makers learn. Writing an in-depth analysis of the Spanish policy framework affecting solar PV sector in general and RD&I in particular is one of the main objectives of this Master's Thesis. The main finding is that although the Spanish institutions are supporting RD&I, there are not enough market interventions for creating demand for solar PV technology. While there are very few interventions of this type in Spain, they are common in all the rest of the countries that have been analysed.

INTRODUCTION

The efficiency of solar photovoltaic systems has been growing since its discovery, although in the last two decades the sector has experienced remarkable changes. It is today the fastest growing renewable energy sector. Moreover, compared to other renewable energy sources, it is the most abundant and the largest potential energy in the world (Hermann, 2006). A large European PV industry was developed over 20 years that went from manufacturing to the service sector, in part owing to large investments in RD&I. Solar PV became a great investment opportunity, especially if taking into account the increasing energy consumption in the EU and its dependence on external energy sources that could reach 70% of the consumed energy by 2020 (Kusku, 2010).

Until 2013, Europe was the region annually installing more capacity and it is still the region with the highest total installed PV capacity, with the global 42% share. However, Europe experienced a slowdown in demand, in part, due to changes in public policy. PV used to be supported, especially at national level, with schemes such as feed-in tariffs and investment subsidies. As an example of the result of the support policy measures, Spain experienced in 2008 the highest PV capacity expansion in Europe. Other policy priorities and the entrance of cheaper products coming from China made European governments stop the PV support schemes or decrease them (i.e. Feed in tariffs were reduced by adjusting them to the forecasted price of electricity and to the estimated decreasing cost of the PV technology). In the case of Spain, the government changed the support schemes and introduced quotas, which led to almost no new installations between 2009 and 2017. It also led to a lack of confidence for investors.

In this context, Chinese module manufacturers and their production capacity experienced a big growth. Initially, it came partially as a response to the demand growth in Europe (Zhang and He, 2013). But, while Chinese PV manufacturers developed a high productive capacity the decrease of the demand in Europe led to an overproduction that globally decreased the market prices of PV products. As a result, the European Commission and the US adopted defence measures and anti-dumping tariffs to the import of Chinese panels and modules. Nonetheless, the European module manufacturers could not recover their place in the global market and the anti-dumping measures were ended in 2018.

European PV industry suffered a lot with the change in the global PV market, but it still retained some parts of the PV value chain. The RD&I investment in Europe and the development of PV technology have received continuous support from both national and EU funds, creating a strong RD&I environment that other regions do not have. Still existing capacity can be seen as an opportunity to reorient policy in order to match the changes in the market and rebuild the PV sector based on the high added-value parts of the value chain. Europe is losing ground against other regions year by year, and PV technology development is showing that RD&I efforts will remain crucial for improving the efficiency of the PV technology and for the development of new products.

In this paper, the focus will be on the Spanish policy framework. Spain is the country with the highest solar irradiation of Europe (Gaetani et al., 2014) and is one of the European places where most electricity can be generated (Šúri et al., 2007). It has even been discussed the possibility of Spain conducting solar electricity to the rest of Europe (Girard et al., 2016). The country has numerous organisations developing PV technology although the employment in the PV sector dropped from 41,700 in 2008 to 5,000 in 2014. Many authors and organisations (IEA, 2017a; de la Hoz et al., 2016; del Río and Mir-Artigues, 2012; Girard et al., 2016) recognize that the Spanish policy framework is not designed for the better development of the sector. There is also literature about the role of energy lobby in renewable energy sources' (RES) legislation, whose interests to maintain their dominance position may be the reason for the dramatic changes in Spanish legislation approach towards sustainable energy sources (Gabaldón-Estevan et al., 2018). In this paper, the aim will be to assess the existing policy framework and institutions affecting solar PV development in Spain. Here, comparison with other countries will be conducted to see where it fails and how it is conditioning the capacity of the Spanish PV sector to compete in the current global reality. In particular, analysis of the different policy approaches affecting PV technology in various leading countries will be carried out. The objective will be to extract applicable and empirical lessons regarding different policy options from them. Understanding RD&I policies will be fundamental since the current situation requires to strongly focus on them for being able to find a competitive advantage and lessons to learn from the existing competing regions.

Throughout this paper we will try to answer the following question: **Why has not the Spanish solar PV sector recovered and what role has the current policy framework played in it?**

For arriving at any conclusions, it is crucial to understand what the situation of the solar PV sector has been in the recent years, so understanding the recent history of the PV sector in Spain will be a secondary objective of this paper.

The main methodology used in this paper will be desk study/literature review. The literature review will be useful for identifying not only the existing problems but also potential solutions to them, comparing different studies and authors' opinions. It will serve to discover the existing state of the art and for explaining how the PV sector has evolved to its current situation.

Various authors and national/international organisations (i.e. UNEF and IEA) have evaluated the specific policies applied in various European countries. The use of the Productive Policies Development (PDP) framework will set in this paper a new approach to the analysis of the existing policy mixes. According to the Productive Development Policies framework, the first objective of any region should be to set the conditions to improve productivity so as to compete with better-performing countries (Crespi et al., 2014). In the case of solar PV, China has developed a strong market which covers most areas of the value chain whereas it has been damaged in Spain. Chinese manufacturers are global leaders in the production of solar modules and wafers and, partly thanks to their economy of scale, Chinese companies have presence in the whole PV value chain.

To understand how the Spanish policy mix is designed, challenges, objectives, instruments, history, actors, interactions and governance of the photovoltaic RD&I will be explored, trying to find gaps and possible improvements. The global value chain analysis framework will be used to understand the importance of the factors affecting the Spanish manufacturing. Checking the existing policy mixes in top global players will be relevant to get a comprehensive picture of the PV sector's reality, allowing to compare them with the Spanish reality and assessing the Spanish framework.

This Master's Thesis will be structured as such: First, a theoretical framework will be presented where "PV value chains and RD&I" and "policy frameworks for RD&I and development" will be introduced. Then there will be an analytical part about PV policies in successful countries in PV manufacturing and installation (China, Japan, South Korea, the US and Germany). This section will be followed by the analysis of the Spanish solar PV sector and the Spanish policy framework. Finally, a discussion about the Spanish PV policy and general conclusions about the analysed matter will be presented.

1 Theoretical framework

1.1 PV value chain and RD&I

The aim of this section is to get a better understanding of the activities in the solar PV value chain in order to comprehend where RD&I has its impact and to show how RD&I has always played a relevant role in the past, present and (maybe) future of the solar PV industry.

Value chains describe the full input-output processes and activities needed to bring a product to its end use. Typically, value chains include segments such as research and design, inputs, production, distribution and marketing, sales, and, in some cases, recycling. In a globalized context those activities happen on a global scale. There is usually a difference in the activities of different countries. For instance, developing countries usually offer low labour costs and raw materials; and developed countries, high educated workforce that is usually behind R&D (Gereffi and Fernandez-Stark, 2011).

Photovoltaic (PV) systems transform sun's radiation (light) into electricity. It is a potentially disruptive mode of electricity generation and delivery (Schleicher-Tappeser, 2012). The manufacturing of PV products consists of transforming light absorbing materials into solar cells and then assembling them into PV modules. The PV value chain can be divided into upstream manufacturing activities including silicon feedstock, wafer, cell, module and balance of system (BoS) component manufacturing, and downstream service activities, including activities such as installation, operation and maintenance and recycling.

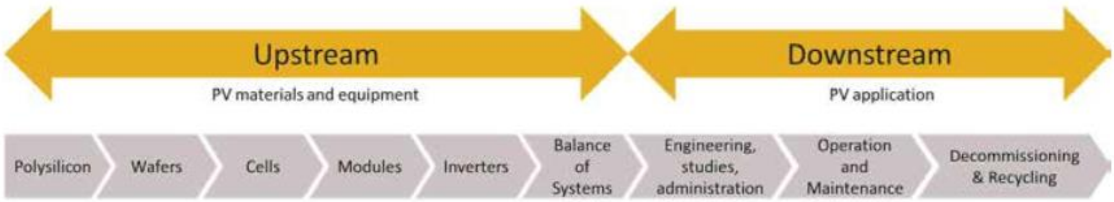

Figure 1. Solar PV value chain

Source: Solar Power Europe (SPE) and Ernst and Young (EY) (2017)

According to (Gereffi and Fernandez-Stark, 2011), the understanding of the Governance behind a value chain is essential to understand its economic, social and institutional dynamics -this is, the way a chain is controlled and coordinated-, and the power relations between certain actors in the chain. It is remarkable that global value chains not only depend on international conditions. Besides this, they highly depend on national/local conditions and, for instance, key inputs such as innovation policy can promote or hinder the growth and development of industry.

For instance, the RD&I has been an extremely important factor for the development of the solar PV in the last two decades[1]. The figure below shows how the efficiency of the modules has been continuously growing. Together with it, their price has continuously fallen. The efficiency of solar cell is considered to be one of the important factors for the stabilizing of the technology (Kumar Sahu, 2015). There are several types of cells that integrate the modules and different technologies are being researched all around the world. In the Spanish case the whole solar sector was established around the silicon (Si) with a preference for thin-film technologies.

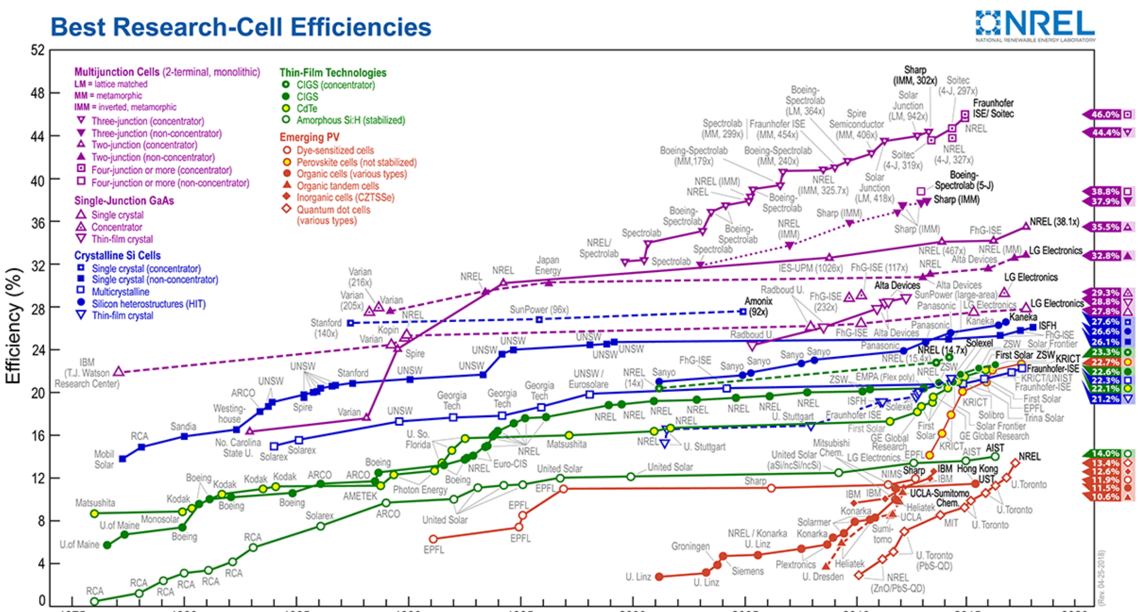

Figure 2. Best Research-Cell Efficiencies

Source: NREL (2018)

The governance of PV industry has been marked by a strong governmental implication during the whole lifetime of PV technology. On the one side, governments supported the basic research and first development of this technology. On the other side, governments have controlled the internal market, setting profitability margins for solar

1 The price of the modules and of the generated electricity is not the only factor for explaining the importance of RD&I, since the system of the solar PV value chain has various parts where the focus can be set.

PV investors (via FiT) and also being a customer themselves (i.e. via energy auctions). Being governments such a powerful actor in defining market conditions for PV, the governance of PV technology has been of a captive type. In these type of chains there is a remarkable power asymmetry between suppliers and buyers, being the last ones who set the conditions (Gereffi and Fernandez-Stark, 2011).

The historical review shows that the most successful countries have been those with integrated and geographically concentrated PV supply chain on which governments supported the development of the industry. Even so, since PV produced kWh price approaches the grid parity and some parts of the supply chains are sold in a globalised market, the governmental influence may be reduced. There is evidence that successful PV business models highly depend on consumer-related factors (Strupeit and Palm, 2016) and access to demand has become the most important priority for industry together with the efficiency improvements (efficiency not only defined as the ratio of energy output from the solar cell to input energy from the sun but also referred to manufacturing processes).

Still, manufacturing is only a small part of the whole solar PV business. The latest available data (UNEF and Deloitte, 2017) shows that in 2015 the direct contribution from solar manufacturers to the GDP (41.3 million €) was almost anecdotical by comparison with the contribution of the whole sector (including energy production, installation, operation and maintenance, etc.) which in total reached 2,551.5 million €.

1.2 Policy framework for RD&I

Assessing the main policies that can have an impact on technological development requires a comprehensive framework that a policy-mix analysis can provide. The solar PV sector has been highly influenced not only from strictly RD&I policy but also from other policy domains such as environmental and energy regulations and goals, industrial policy and competition policy. The interaction between different instruments has set the arena for the development of different technologies in different ways, and coordination and synergies highly define the threats and opportunities. It is important to understand how innovation systems affect the development of one specific sector and the challenges that a specific domain experiences in that framework. Furthermore, in order to understand future scenarios, knowing the actors interacting in the R&D and in the industrial domains is also fundamental.

The policy-mix concept can be described as "the combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors." (UNU-MERIT, 2009)

The policy mix emerged in economic policy literature in the beginning of the 60's, when Mundell (1962) noted that monetary policy becomes a powerful tool for stabilizing the economy whilst fiscal policy becomes powerless, whereas under a fixed exchange rate the opposite becomes true. The concept remained in the economic arena until it was adopted in the environmental policy during the 90's and, later, to innovation policy.

Various studies highlight that there are various factors driving eco-innovation, with the primary role played by public policies, which are used to increase the rates of introduction and diffusion of new technologies that meet sustainable development goals (Costantini et al., 2015). This is common when some specific technologies are under development and public procurement is deemed fundamental to overcome barriers (Crespi et al., 2014).

There are several global trends towards RD&I Policy based on different economic traditions such as the Productive Development Policies, the New Structural Economics approach and the Self-Discovery approach. Innovation policy has become in the last two or three decades a new item on policy-makers agendas although specific policies targeting innovation have been in place since the modern states exist (Edler and

Fagerberg 2017). As stated by the Productive Development literature (Crespi et al., 2014) various schools of thought have revisited their basics so as to redefine the role that governments are supposed to play regarding RD&I and the importance of technology. These traditions defend the use of policy mixes, although they have different approaches and consider different policies more relevant than others based on their philosophy. As a brief explanation, the New Structural Economics considers the structural characteristics the most fundamental factor for the economic development of any country, including in their definition of structure both hard infrastructures (such as power, transport, telecommunication systems) and soft infrastructures (such as financial system and regulation, education system, legal frameworks and other intangible structures). It argues that in different stages of industrial development the state should improve infrastructures in different manners to upgrade industry and to achieve a correct industrial diversification (Crespi et al., 2014). The Self-Discovery approach sets its focus on learning what one is good at producing and defends that governments should play a dual role in fostering industrial growth and transformation, encouraging entrepreneurship and investment in new activities ex ante and pushing out unproductive firms and sectors ex post (Hausmann and Rodrik, 2003). This school also recognises the importance of a coherent policy mix toward technologies in important policy areas for their economic thinking such as trade protection, export subsidies, government loans and guarantees. Finally, the Productive Development Policies (PDP) framework puts the focus of their economic thought on RD&I.

In accordance with Crespi et al. (2014) PDPs work in various dimensions depending if they are focused on specific sectors (vertical policies) or do not try to benefit particularly any industry (horizontal policies). They also differ in the form of being public inputs/goods or market interventions. The considerations that public policy should take into account are different in each of these quadrants.

Table 1: A Typology of PDP Interventions

	Horizontal policies	**Vertical policies**
Public Inputs	Higher education/training. Support to scientific research. Intellectual property rights. Research infrastructure. Human capital immigration. Labour training. Competition policy. Regulation. Technology transfer organisation.	Technological Institutes. Standardization. Thematic funding. Signalling strategies. Information diffusion policies. Technological consortiums. Contests.
Market interventions	R&D subsidies, R&D tax credits. Financial measures (guarantees for technology investments, intangibles values, etc.). Adoption subsidies.	Public procurement. General purpose technologies (ICTS, biotech, nano-tech). Strategic sectors (semiconductors, nuclear energy, electronics, etc.) Defense sector.

Source: “Rethinking Productive Development” (Crespi et al., 2014)

According to the revised literature (Crespi et al., 2014):

- Horizontal Public Inputs are associated with the cost of doing business in a country. Policies in this quadrant should be designed for achieving the desired objectives, having the desired impact and being cost-effective. Policies in this quadrant are the least controversial. When it comes to renewable energy and solar PV objectives, most of the developed countries have specific targets regarding RD&I, so although the ambition of every country may be under discussion, the fact of setting objectives is not.
- Horizontal Market Interventions should serve to address market failures and can also be used to push competitive new export activities. The policy instruments should be adjusted to be as precise as possible and take into account if the size of subsidies or exemptions are related to the size of the possible spillover. In the case of Solar PV these interventions are highly important since one of the main problems in Spain, and in Europe in general, is the difficulty to translate public investment into basic RD&I in market ready products.
- Vertical Public Inputs are those arranged to generate benefits for specific sectors. Deciding which sectors to choose is a task that the government should play carefully, taking into account things such as targeting exports in growing

sectors where the country has latent comparative advantages. The dialogue between public and private part in the sector-level should address coordination problems, removal of obstacles for becoming more productive, etc. instead of subsidies or other market interventions that would not improve productivity. Although these policies are more controversial since they involve “picking winners”, they are justified since they contribute to productivity and to the good functioning of certain markets that, factors that the private sector would not necessarily provide. In the case of Solar PV, several governments have created technological institutes and have pushed technological consortia and clusters.

- Vertical Market Interventions include those actions with the objective of developing sectors with competitive potential that would not develop without them. Still, protecting specific sectors could lead to rent-seeking behaviour. Thus, policies in this quadrant should foster the reallocation of factors of production into productive sectors and not benefit those with limited potential. In the case of Solar PV, the vertical market interventions have been fundamental in order to develop this type of technology. It will be shown that all the top global players have applied various kind of policies in this quadrant, and they are considered to be the main driver of solar PV implementation and development.

Having developed a matrix where all policies are affecting PV technological development the next objective will be to analyse if those policies are both coherent and effective. The Productive Development Policies framework provides insights about what public institutions should do to create coherent policies and shows which difficulties are usually present when governments try to push technological innovation.

2 PV Policies worldwide

2.1 The most popular solar PV policies

There are various kinds of policies that most of the developed countries share such as quotas, education and training and national/regional energy plans which set Renewable Energy Sources (RES) consumption objectives. There are also common R&D programs and other financial measures aimed at solar PV.

Nevertheless, the literature has mostly analyzed those policies pointing at the installation of solar PV systems. According to the existing studies (Dusonchet and Telaretti, 2010) (Dusonchet and Telaretti, 2015) the following policies, and the combination of them, seem to be the most effective and common for promoting the solar PV sector (and specially for increasing the PV installed capacity): Feed-in-tariffs, green tags, Renewable Portfolio Standards, Net metering and capital subsidies/grants/rebates.

- Feed-in-tariffs

Feed-in-tariffs (FiTs) are “preferential prices to renewable energy generators per kWh generated, combined with a purchase obligation by the utilities” (del Río and Mir-Artigues, 2012). In other words, they are a fixed price guaranteed by the government to producers feeding electricity into the grid. They are used to create a framework of low risk for investors, but if the design elements of the instrument are not appropriate for the system where they are put in place, they can suppose increasing and unsustainable support costs. The received payment per kWh tends to go down as the PV installation gets amortized.

There is an academical consensus on the important role that FiT have played in the solar PV development. This mechanism has been the main policy for supporting RES development in Europe and in USA (Campoccia et al., 2009).

Various publications have evaluated the impact of FiT determining that designing elements have been relevant on the effectiveness and sustainability of this type of policy. There is a trend against FiT since its operating costs are high in comparison with other policies. Still, it has been argued that when FiT are complemented by other policy instruments such as net-metering schemes they become more successful even if the tariffs are lower (Ramírez et al., 2017).

It has been discussed the possibility of translating the analysis of policy support systems to an investor language for analyzing risk and profitability for project developers. (Dinica, 2006). Following this understanding, the internal rate of return for investments in grid-connected PV systems has been calculated, finding that most of the countries have used FiT and that it has been favorable to the investors and for building a PV industry (Sarasa-Maestro et al., 2013). Sarasa-Maestro et al. also found that there is a great difficulty for forecasting market trends (and consequently, the cost of the FiT program). This has caused governments to reduce FiT programs even in a retroactive way (i.e. reducing the monetary quantity to be paid in already approved contracts). A good design of renewable energy sources for electricity (RES-E) support policies is indispensable to create investor confidence. Factors as tariff size and contract duration have positive influence on solar PV confidence although non-significantly (García-Álvarez et al., 2018). There are also factors such as irradiation levels that should be considered when support measures are stablished, since areas of the same country might be much more profitable than others. The history demonstrates that the highest possible profitability is not necessarily the best policy. A stable and consistent policy can create stability in the investor demand and thus, a steadier and more manageable growth of the market (De Boeck et al., 2016).

- Green tags:

Green certificates, also known as green tags, are a mechanism used for the certification of renewably produced energy. Every time a renewable energy producer produces a MWh of electricity, a green certificate is emitted. These green certificates can be traded or sold in the market. The certificates can also be redeemed to claim that the energy that the distributor sells comes from renewable energy sources or that certain business or individuals consume energy coming from renewable energy sources. To be effective, green tags need to be accompanied by a quota system, mostly referred in the solar PV area as quota obligations or Renewable Portfolio Standards. Certificate prices, together with electricity market prices, might be high enough to increase investment security in solar PV energy. (García-Álvarez et al., 2018)

- Renewable Portfolio Standards:

A renewable portfolio standard is a regulation which requires increased production of energy from renewable energy sources. Electricity supply companies are required to produce certain amount of the energy they supply from renewable sources. Green certificates are used to certify this production.

- Net metering:

The net metering is a billing mechanism that offers a credit to those making excess electricity with their solar systems and sending it to the grid (IRENA, 2015). Generally, the net metering legislation forces the utility companies to offer net metering contracts of certain length to their clients. Then the client, who would also be an energy producer, only must pay to the company for the "net" energy used each month (the difference between the energy produced by the solar PV system and the energy consumed by the house or the facility). If the energy produced exceeds the energy consumed the output can be different depending on the legislation: sometimes the producer gets paid for the exceed energy sent to the grid (like in a Feed-in-Tariff system) and sometimes the producer does not get paid for that energy.

- Capital subsidies, grants or rebates

This typology of policies includes different types of governmental funding and incentives. PV technology requires a high initial investment, so many countries have introduced capital aids and other policies to reduce the weight of this cost (Dusonchet and Telaretti, 2015).

These policies fall into the category of vertical market interventions. As mentioned in the previous section, these kinds of policies are used to develop sectors with competitive potential that would not develop without being helped. According to the PDP framework this type of interventions should gradually diminish whilst the technology is developed to its potential or, also, when the technology stops needing a public intervention to keep its development. The efficiency of solar PV systems has been continuously growing as shown in previous sections, and the potential of this technology is still unknown. Still, the nature of the policies that had led to the current state of the art is quickly changing.

2.2 Policy-mixes worldwide

This section presents various findings about the policy being carried in several countries leading the PV technology panorama. The objective of this section is to briefly look at the kind of policies that are being executed in various countries in order to discover lessons for Spain. Because of the limited scope of this paper, only the most common policy measures will be shown.

Every single one of the analysed countries is carrying a relevant set of policies that affect PV technological development. They have been selected because of their global market importance in PV manufacturing. Since some of the countries have higher decentralisation than others, some regions also maintain competences which influence the policy-mix of the country, although they are out of the scope of this paper. Still, it is remarkable that the effectiveness of certain policies in large countries is reduced if policies are equal among all regions (Hafeznia et al., 2017).

As a matter of fact, policy stability is present in all the analysed countries. Although some policies such as Feed-in-tariffs have changed yearly, there is still a general continuity in the overall policies and objectives, especially if taking into account the nature of these kind of interventions using the PDP interventions approach.

2.2.1 International policy

China is undoubtedly the top PV global manufacturer. Chinese companies cover the whole value chain of PV products. Their installed capacity is growing at a fast pace and China represents around half of global solar PV demand. Still, the growth of the industry was “export-oriented” (Zhang et al., 2014). According to IEA, the country prepared the supply chains for anticipated future growth (IEA/OECD, 2015a). Chinese government started its support to the development of solar PV sector mainly with unconnected policies aiming to develop PV industry. These policies were packed into the 2006 Renewable Energy Law and the 11th and 12th Five Years Plans (2006 and 2011). They mainly consisted of soft loans, refunds, subsidies, duty exemptions, tax concessions to encourage foreign investment and standardization (IEA, 2017b). The 12th Five Years Plan already included capacity targets for renewable energy sources (no specifically for PV), that were updated with the 13th Five Year Plan (2016). Feed-in-Tariff schemes were introduced in 2006 in order to develop a domestic market. The cumulative installed PV power grew from 80 MW in 2006 to 131,140 MW in 2017. The 13th Year Plan deepens in the issue of pushing the domestic demand. Nowadays, they are trying to move away from FiT because of its growing cost, substituting it for a “green certificates” system (IEA, 2017c). There is a lack of data about specific R&I Policy targets.

Regarding the Chinese PV industry, the polycrystalline silicon production of the country accounted a 54,7% of the global output in 2017. Still, there was a gap in demand/supply and China still needed to import the material. China accounted almost the 86% of silicon wafer global production capacity. It also produced the 69% of solar cell global production and the 71,1% of PV module global production in 2017. According to IEA data (IEA, 2018a), the estimated PV-related R&D labour places in 2017 was of a “few thousands”, but there is not specific data. Even so, it is estimated that nearly 3 million labour places of the country are related to PV.

Table 2: Chinese PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs	Renewable Energy Law and the 11th and 12th Five Years Plans	Standardization
Market interventions		Soft loans, refunds, subsidies, duty exemptions, tax concessions to encourage foreign investment, Feed-in-Tariffs, green certificates

Japan was until recently the third most important actor in Solar PV. Nowadays the PV demand in India has exceeded the Japanese one, although Japan is a fundamental actor regarding manufacturing of PV products. Governmental support has strongly focused on renewable energy, especially after the Fukushima nuclear plant disaster (which strongly affected electricity supply) boosted social and governmental support for renewable energy. Among the policies that the Japanese government executes there are Feed-in-Tariffs, investments funds for large-scale PV, capital subsidies, income taxes, green certifications, self-consumption incentives, and more demand-side policies (IEA, 2017d). Between 2006 and 2016 the cumulative installed PV power grew from 1708 MW in 2006 to 42,040 MW in 2016. Following the global trend, the country is also trying to move away from FiT. Japan has also capacity targets for renewable energy. There has been a strong focus on RD&I, supporting high added value and high-priced products thanks to the favourable internal market. The New Energy and Industrial Technology Development Organization (NEDO) has been one of the main actors regarding the promotion of fundamental R&D and demonstration research. The Ministry of Economy, Trade and Industry has budgets allocated for technological developments for PV power generation, field testing of new technology, grid testing of large scale PV power generations and developments of an electric PV power energy system (Kumar Sahu, 2015). The estimated labour places in PV R&D were 900 in 2015 and 800 in 2016, while the total labour places in the sector was 128900 in 2015 and 100800 in 2016. The Japanese PV industry covers the whole value chain, although in 2016 there were companies withdrawing from manufacture of polysilicon for solar cells. Also, the lower prices of Chinese cell and module manufacturers has decreased the production in Japan, which are trying to focus on high efficiency and high output products. According to IEA (2017d) the estimated value of PV business in Japan is of 1,823,723 MJPY (€4.635 billion) and public budgets for R&D, demonstration/field test programmes and market incentives in the sector between 2014 and 2016 were more than 20 BJPY (€155.8 million).

Table 3: Japanese PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs		Promotion of demonstration activities, technological developments for PV power generation, field testing of new technology, grid testing of large scale PV power generations and developments of an electric PV power energy system
Market interventions	Promotion of fundamental R&D	Capacity targets for PV, tenders, Feed-in-Tariffs, investments funds for large-scale PV, capital subsidies, income taxes, green certifications, self-consumption incentives

South Korea is one of the top global PV products manufacturers. The Country launched the Green Growth Plan in 2008 which aimed to stimulate economic recovery investing in renewable and efficiency sectors. The cumulative grid-connected installed PV power grew from 351 MW in 2008 (Yoon and Kim, 2009) to 4,524 in 2016 (IEA, 2018b). Manufacturing capability through the PV value chain was stimulated through favourable financial, fiscal and taxation policies and through preferential government loans (IEA, 2017e). Furthermore, government-led PV R&D initiatives generated numerous noticeable outcomes in breakthrough core technologies. It is estimated that the PV R&D support per year is of about 200 billion KRW (€158 million). The total value of Korean PV business is estimated to be 4,159,960,000,000 KRW (€3.296 billion) (IEA, 2018b).

The certification of PV products is a promoted praxis in South Korea in order to promote commercialization. South Korea has clear capacity targets and policies such as subsidy programmes for rooftop installations, public building obligation for installing renewable energy and soft loans. The Feed-in-Tariff (which was active during the years 2002-2011) was substituted by a Renewable Portfolio Standard (RPS). RD&I has historically been a priority for Korea, and commercial solar PV is nowadays one of their RD&I targets. In 2017, the Korea Energy Agency organized its first fixed-price solar auction (Stubbe, 2017). Another related policy is the public support for Energy Storage Systems (ESS). Korean government is actively supporting the combination of PV systems and ESS placing policies for ESS installation and reducing the electricity tariff to half of normal price when ESS is used.

Table 4: South Korean PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs	Green Growth Plan	Certification of PV products
Market interventions		Government-led PV R&D initiatives, Public building obligation for installing renewable energy and soft loans, fixed-price solar auction, Favourable financial, fiscal and taxation policies and through preferential government loans, subsidy programmes for rooftop installations, The Feed-in-Tariff (now substituted by Renewable Portfolio Standard), Energy Storage System support (promoting internal demand)

US is the second most demanding country for PV. The cumulative installed PV power capacity grew from 295 MW in 2006 to 51,638 MW in 2017. Federal and state support has focused on investment tax credits (which will gradually be reduced until 2022), Renewable Portfolio Standard, power purchase agreements, net metering instruments, low-cost loans and rebates and sales tax incentives (IEA, 2017f). Capacity targets for PV capacity are not defined in the US plans, although there are Renewable Energy Sources capacity targets. Some RD&I goals for PV are to reduce manufacturing costs and to improve efficiency and lowering levelized cost of electricity (PV Magazine, 2017a). One of the main bodies regarding RD&I is the U.S. Department of Energy with its SunShot initiative which consisted of making solar electricity cost-competitive with traditionally generated electricity by 2020 without subsidies. This plan is being used for funding R&D activities, eliminate market barriers and encourage innovation. Another policy indirectly affecting the solar PV implementation has been the Clean Power Plan, which obliges each state to have a plan for reducing emissions. Zero- and low-carbon power sources is a major block of the plan, and solar PV energy could be included here.

It is estimated that there are approximately 250,000 PV-related labour places in the US (IEA, 2018c).

Table 5: US PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs		Renewable Energy Sources capacity targets, Clean Power Plan
Market interventions		Power purchase agreements, Renewable Portfolio Standard, net metering instruments, low-cost loans and rebates, sales tax incentives and R&D funding (Sunshot Initiative).

2.2.2 European policy

European Union launched in 2007 the Strategic Energy Technology (SET) Plan, defining EU’s long-term strategy. PV global leadership was then one of the targets of the SET-plan (European Commission, 2016) and it still is. This assures financing for solar PV R&I. The public funding for R&I has come from the Framework Programmes for Research and Technological Development (FPs). The EU has also pushed several R&I networks and operates research infrastructures.

Another policy affecting the solar sector is the EU's Renewable energy directive, which set a binding target of 20% final energy consumption from renewable sources by 2020. Still, there is no specific target for solar PV energy and each EU country committed to their own target.

Continuing with the value chain, Europe is still prominent in BoS manufacturing (holding the 25% global market share of inverter manufacturers), and in the equipment and tools manufacturing (still holding a 50% of the global market share). Most of the cell and module manufacturing has almost disappeared from Europe, although some European companies are still competitive in the high-quality segment.

Table 6: EU PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs	SET-plan	Promotion of R&I networks, research infrastructures.
Market interventions	FP7 & H2020 public funding for R&I, energy consumption targets	

Germany is unarguably the main European industrial actor in solar PV. The policy measures of the country are very broad. The core of the German environmental and economic policy is the "Energiewende" strategy, which establishes renewable energy as the core of their energy system. PV is specially supported via 3 models: FiT, feed-in premiums and calls for tenders (IEA, 2017g). Particularly new ground-mounted PV installations have been supported via auctions. In 2017 The German Renewable Energy Act (EEG) was reformed with the objective of adding public tender procedures for solar projects. This reform aimed to replace FIT supported renewable energy deployment substituting it by a market orientated price finding mechanism (BMWi - Federal Ministry for Economic Affairs and Energy, 2016). The country also established PV capacity targets. The installed PV capacity in Germany grew from 2,900 MW in 2006 to 41,300 MW in 2016 and experienced a pronounced growth between the year 2009 and the year 2012. It is estimated that 31.600 people were employed in the PV sector in 2015 (IEA, 2018d). Although German manufacturers are present in the whole value chain, Balance of System (BoS) component manufacturers (including inverters, cables, connectors, tracking systems and mounting systems manufacturers) put together the largest part of the German PV industry.

Regarding RD&I, the Federal Ministry for Economic Affairs and Energy (BMWi) is supporting various technologies linked to the applied research of PV. The Federal Ministry of Education and Research (BMBF) is funding long-term R&D complementarily to BMWi funding, and both together launched the “R&D for Photovoltaics” to support R&D activities with participation of German PV industry. In 2016, the BMWi support for R&D projects on PV totalled about 57,8 million EUR and was shared by 366 projects (IEA, 2018d).

Table 7: German PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs	Energiewende strategy	
Market interventions	Funding for long-term R&D	Feed-in-Tariffs, Feed-in premiums, calls for tenders, auctions, capacity targets, public building obligation for installing renewable energy

The review of the policies mentioned in this section brings to following conclusion: most of the countries are implementing various vertical market interventions to support the development of the solar PV sector.

3 Spanish solar PV sector and policy framework

3.1 Progression and regression of the Spanish PV sector

A historical review of the solar photovoltaic sector is fundamental to understand the reasons for the decline of the European industry and for the emergence of new dominant industrial actors.

The EU PV industry was created during more than 20 years of continuous investment from private and public sector. However, in less than five years, Chinese companies overtook the global market dominance, which until that moment had belonged to Germany. Large market opportunities in Europe, encouraged by demand-side policies pushing PV technology, created an operative environment for the industry. One of the main policies for encouraging the development of the market was the introduction of the Feed-in Tariffs. These tariffs consisted of economically rewarding PV electricity producers connected to the grid, which generated a revenue stream attracting investors to build large grid-connected PV systems, both integrated in buildings or in PV parks. The PV industry emerged in order to respond to the supply needs for this kind of systems. The development of the industry supposed that European companies would dominate the global PV market.

The turning point for the EU industry occurred in 2008 because of a problem in the supply chain of (poly)silicon during the years before 2008. The silicon industry was not prepared for the enormous volume growth required by the PV industry, and its price was increased from $27/kg in 2003 to more than $450/kg in 2008) (Bazilian et al., 2013). The European industry did not invest in silicon production capacity and it was overtaken by Chinese (and other foreign) companies which had vertically integrated factories, including (poly)silicon production.

As the investment in PV in Europe stopped, the production continued, so the industry overproduced solar PV products. Consequently, the profit margin fell to 0% or even to a negative margin (PV Magazine, 2014). The EU and the US launched anti-dumping/anti-subsidy measures, but these interventions were not enough for European PV module manufacturers to recover. Many European companies went bankrupt. Others have been bought by the Chinese companies.

Spain experienced its own decay, not only because of the global situation of the PV sector, but also because of a very unsteady framework for solar PV industry. According to UNEF (Spanish Photovoltaic Union) the support to solar PV in Spain experienced different legislative phases between 1998 and 2013, with a turning point after 2007-08.

During the years 1997 and 1998 the bases for the liberalization of the Spanish electric system were set. Until then the electricity system was regulated, so the Government established fixed prices for electricity. With the changes, a specific feed-in tariff for photovoltaics was introduced. This tariff was granted until the point where Spain would meet 50MW of PV power, but this generated uncertainty since nobody knew when this would happen. This problem was tackled in 2004 (RD436/2004), when it was set a specific time for receiving the tariff. Because of this the solar PV sector started to grow.

In 2007, legislative changes were introduced again (RD661/2007), affecting the photovoltaic electricity distribution, although the government decided to maintain the "old" tariff amount in order to consolidate the sector. This legal situation allowed Spain to become the global leader in annual installed capacity and various manufacturers became relevant in the global market (Prieto and Hall, 2013). The development of a strong industrial sector in the area of PV was highly affected by the internal demand of PV products (Bazilian et al., 2013).

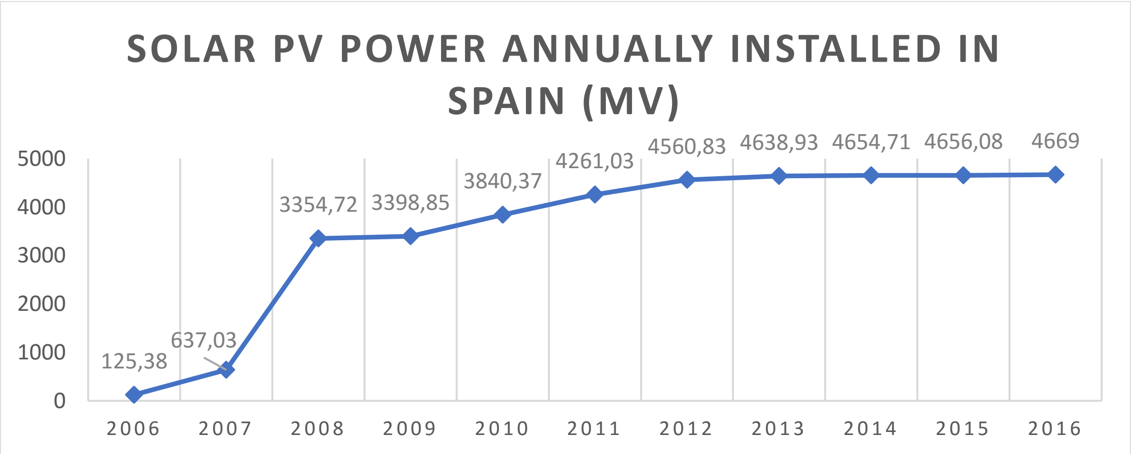

Figure 3. Solar PV power annually installed in Spain (MV)

Source: UNEF (2017)

Still, as the previous graph shows, the growth was not sustainable in time. As a matter of fact, in 2008 it was a 385% higher than expected. The demand grew so fast that by the end of the year 2008 the government declared that the growth of photovoltaics was unsustainable and decided to cut out the grants. This reform was the first of a series that drastically changed the approach of the government towards renewable energy in general and to photovoltaics in particular. In the year 2010, when the government approved the RD14/2010, 62.000 households (i·ambiente, 2015) and various international investors saw that their investment would not be amortized in the estimated time. Since 2013, the feed-in-tariffs for small producers disappeared and additional tolls were introduced both for the maintenance and development of the grid (Access toll) and for the usage of the producers' own electricity (Backup toll). These tolls became known as the "Sun tax" and changed the amortization time of a solar panel from 10 years to more than 20. Spain became the leader in international pleas because of their energy system and the country had already to pay €128 million as a fine to just one of the twenty-six plaintiff that are still waiting for the resolution of their case (PV Magazine, 2017b).

During this period the trust in the sector was undermined, and the installation of new PV panels almost stopped.

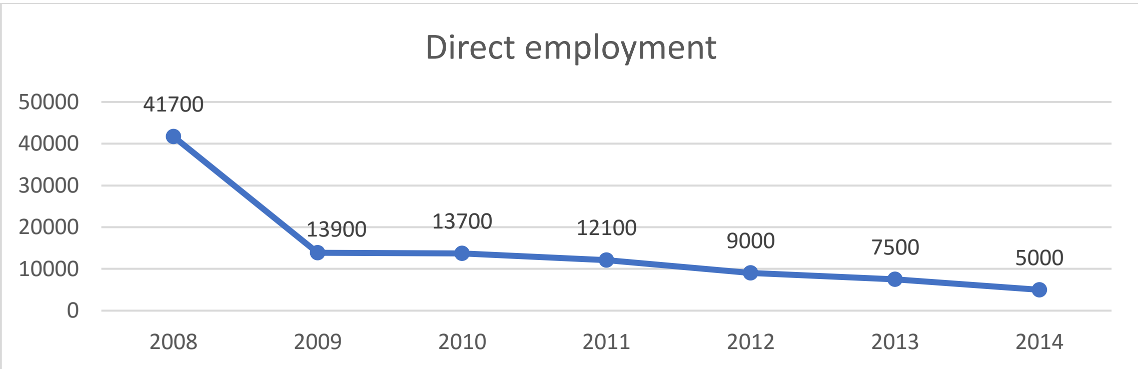

Figure 4. Direct employment generated by the solar PV sector

Source: UNEF and Deloitte (2017)

The graphic above shows that the direct jobs in the PV sector dropped from 41,700 in 2008 to 5,000 in 2014. Furthermore, indirect jobs were also lost.

3.2 Spanish PV industry and RD&I

Between the years 2007 and 2010 there were around 40-50 manufacturers of PV equipment in Spain. The whole value chain of PV technology was covered, although modules, inverters and trackers (used for BoS) were the main components produced. For instance, the modules produced in Spain in 2008 accounted for the 7% of the global production. Most of these modules were made of monocrystalline silicon, which provided the highest efficiency out of all commercial PV technologies.

Most of the production in those years was used to meet the internal demand, so the exports were low during 2008. In fact, since the national demand stopped, there was a huge growth of the percentage of the national production used for exportation after the legislative changes.

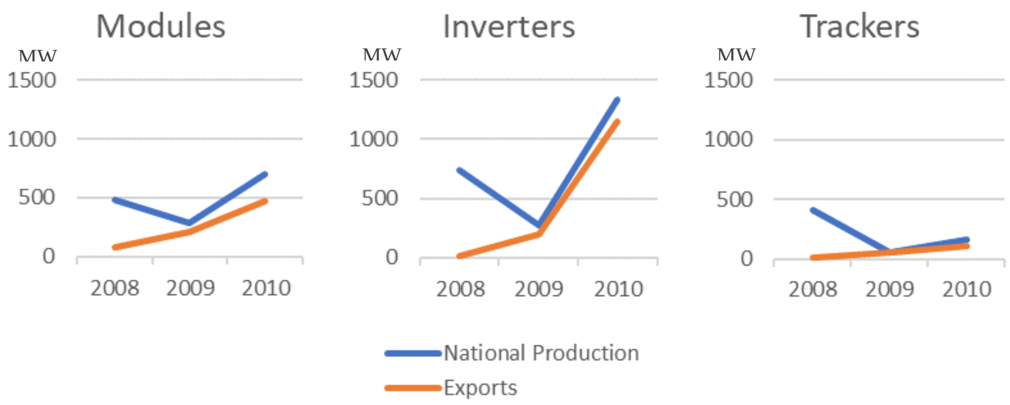

Figure 5. Spanish production and exportation of PV products

Source: ASIF, 2011, 2010, 2009

Several companies started to operate abroad in 2010 and eventually shifted their whole activity. In any case, by 2010 the relative importance of the Spanish manufacturing was already in a diminishing tendency. The global manufacturing, led by Chinese producers, experienced a boom whereas the Spanish capacity did not substantially change. Spanish modules already accounted for the 3% of the total global production (in comparison with the 7% of 2008), although the inverters were holding better with a 6% of the total. In 2014, only one module producer (Atersa) remained active (UNEF, 2015a).

Spanish RD&I in the solar PV sector was affected by the changes in the policy framework, although it did not suffer as much as the industrial sector did. First of all, the RD&I of the country in this sector existed previously to the creation of an internal market. Although some institutes summed up to conduct research related to solar PV with the boom of the market, the traditional ones have existed during various decades. As an example, in the year 2007 the main RD&I institutes where the following:

CENER, Fundación CIRCE, IES, Instituto de Tecnología Microelectrónica, ISFOC and TECNALIA. In the year 2018 all of them still exist.

In the foundation of the Spanish solar PV sector there was a strong link between RD&I institutes and manufacturer companies. Various industrial initiatives adopted the national technologies that the institutes where developing and, in several cases, researchers were recruited into the workforce of the manufacturing companies. As an example, the Spanish company Isofotón was one of the top 10 world manufacturers using technology developed by the IES. Concurrently, the activity in RD&I centers rose and Spanish research activity became competitive in their global context (UNEF, 2015b). In 2009, there was a workforce of around 350 people in RD&I related activities (ASIF, 2009).

This situation started to change in 2009 after the Spanish companies realized they could not compete against the low-cost Chinese modules. By that time, the Spanish government had changed the Feed in Tariffs, reducing the investor profitability and creating legal uncertainty. As the investment in solar PV installations went down, the national market of the Spanish manufacturers almost disappeared. This affected RD&I activity in different manners. On the one hand, and although the number of RD&I workers remained similar during the last decade, there was a "brain drain" of Spanish researchers, on the other, the RD&I research areas of the institutes started to focus on improving their commercial/organizational capacity and on the new markets related to self-supply and isolated systems such as BIPV (Building Integrated Photovoltaics). This last system has been seen as a great opportunity by various Spanish organisations and its importance has grown since BIPV is considered a radical architectural innovation (Awerbuch, 2000).

As an example of the change in the research areas, the graphic below shows how most of the RD&I projects in 2008 were those related to materials (cells, etc.), test/improving of existing components, and CPV (Concentrator photovoltaics). However, in 2010, "Other" kind of activities strongly emerge together with the previously mentioned commercial/organizational RD&I.

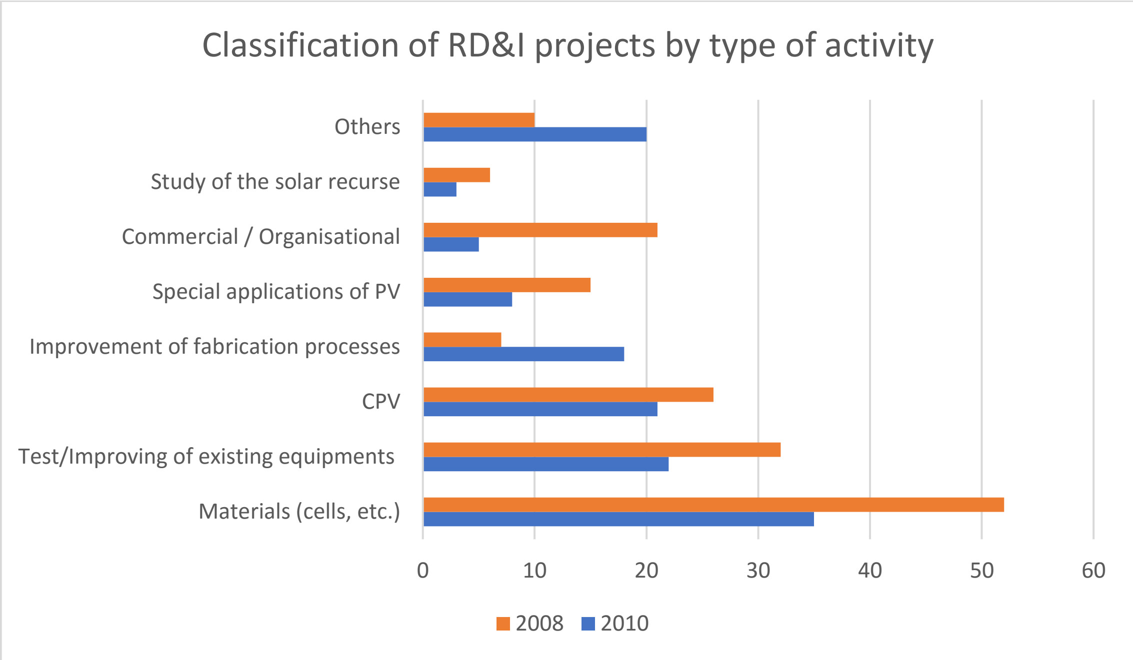

Figure 6: Classification of RD&I projects by type of activity

Source: ASIF (2009, 2011)

In 2016 the Spanish Photovoltaic Technology Platform (FOTOPLAT) created a Strategic Plan and established as Spanish PV priorities the self-consumption, large generation plants, BIPV, improvement of fabrication processes and O&M (Operations and Maintenance). This plan recognized that the industrial fabric was damaged but emphasized the RD&I capacity and expertise as the main instrument to overcome the threats that the sector experiences. It is remarkable that in 2015 the solar PV sector contribution to RD&I activities was a 3% of their total expenses (FOTOPLAT, 2016a), whereas in other sectors it was only of about a 1,2% (UNEF, 2016), which gives a glimpse of the remaining strength of RD&I even if the manufacturing activities almost stopped.

3.3 Spanish policy-mix

The Spanish policy and strategy for solar PV is formulated by several institutional bodies. Since energy is a transversal topic, some responsibilities are assigned to specific organisations while others cut across the portfolios of several of them. For instance, the implementation of the national energy R&I policy was coordinated by the Ministry of Economy and Competitiveness (MINECO), the Ministry of Industry, Energy and Tourism, and the Ministry of Public Works and Transport, the first two being the most relevant ones. The Autonomous Regions (Comunidades Autónomas) are the entities in charge of the Regional Research and Innovation Strategies for Smart Specialisation (RIS3) and are strongly involved in designing and implementing energy efficiency and renewable energy policies at regional level.

As it is shown in this section, and in the following table, there are almost no market-oriented policies nowadays.

Table 8: Spanish PDP Interventions in solar PV

	Horizontal policies	**Vertical policies**
Public Inputs	Spanish Strategy for Science, Technology and Innovation 2013-2020, Renewable Energy Plan 2011-2020 (support frameworks, finance, legislation, energy infrastructures and planning, promotion, information, training), education, technology transfer, rendering technical services, advising (CIEMAT), National Plan for Scientific Research, Development and Technological Innovation 2013-2016	Support of R&I and demonstration facilities (CIEMAT, CENER, IES, IDAE), standardisation (IDAE), creation and support of R&I collaboration and networks, renewable energy capacity targets
Market interventions		R&I public funding (including special funding for public-private collaboration, projects with potential of replication), PV auction tenders, Renewable Energy Plan 2011-2020 (reducing administrative

		barriers for R&I and demonstration projects, supporting and financing R&D of new prototypes, first demonstration projects and unique projects in commercial phase or with some market barrier)

3.3.1 FiT scheme

Various international institutions (such as the International Energy Agency) and authors considered that the main PV support policy measure has been the Feed-in-tariff system, including in the case of Spain. However, other market interventions in late 2000s such as capital subsidies for equipment or total cost, PV-specific green electricity schemes, renewable portfolio standards, income tax credits, net metering and net billing did not exist in Spain (Salas, Vicente, 2009).

In the EU most of the new PV capacity installed was in countries using FiTs. Still, their design has been different from one country to another and it is subject to changes also within single countries. For instance, when a favourable regulative framework for investors was set in Spain (under RD546/2004 and RD661/2007 laws), the sector boosted, but with the changes in 2008 (RD1578/2008), which reduced the FiT rates, the investments stopped. This regulation had a negative impact on the profitability of solar PV plants (de la Hoz et al., 2016) (Mir-Artigues et al., 2018). Additionally, since the draft of the new Royal Decree was made public, the FiT installations before the application of the 2008 decree were exceptionally high. The figure below shows the change in tariffs within different legal periods for different kind of installations. The growth periods of the sector correspond with the growth of the tariffs, which generated a tremendous demand.

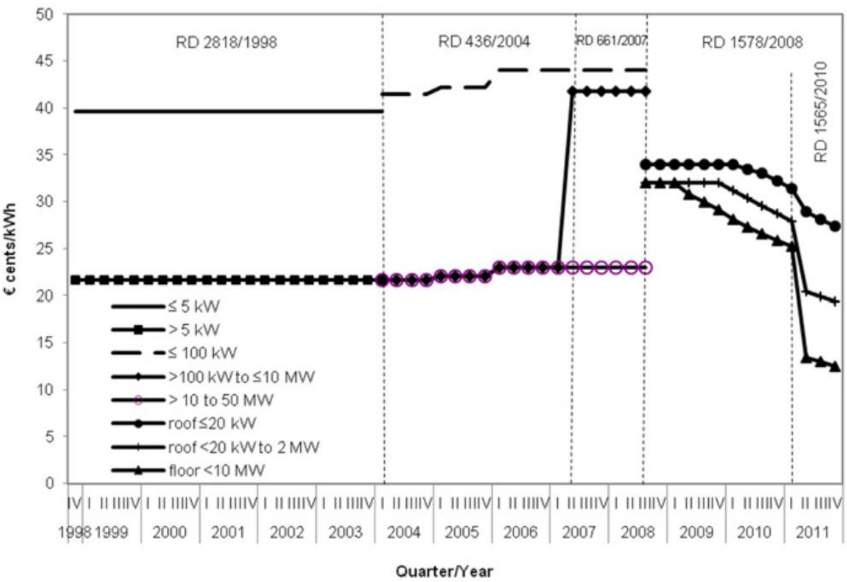

Figure 7. Regulated tariff for solar PV (€ cents/kWh)

Source: del Río and Mir-Artigues (2012)

Moving forward to 2013, the income tax credits became the only market related support measure for PV installations, since the Feed-in-Tariffs ended that year (UNEF, Universidad Carlos III de Madrid, IEA, 2013). Besides the investment part, the solar PV in the residential segment was also damaged, since the impossibility of selling the surplus electricity to the grid made the amortization impossible taking into account the existing installation costs (López Prol and Steininger, 2017).

3.3.2 Sun tax

One of the most controversial policies affecting the solar PV sector is the one known as the “sun tax” approved in 2015 (RD900/2015). This regulation was implemented by the Ministry of Industry, Tourism and Commerce, which preceded the current Ministry of Energy, Tourism and Digital Agenda. This intervention regressively affects the market. It consists of taxing the self-consumers by capacity installed and also by the electricity self-generated and self-consumed if the installation is larger than 10kW. It only applies to installations connected to the grid. Some authors defend that this retroactive vertical market intervention has risen the time of amortisation of solar PV systems investments and makes PV grid-connected systems for self-consumption unprofitable for average residential users and industry (López Prol and Steininger, 2017). The application of this regulation has been very limited, so its effect may be more related to legal insecurity than to return-related factors. They defend that the situation of policy instability and administrative hurdles that come from this law become more important than return-related factors (after surpassing a certain level of return).

3.3.3 Financial and tax incentives

In 2008 there were numerous financial and tax incentives (such as non-refundable subsidies, soft loans and their combination) for priority activities, and these incentives were coming from both national and regional governments (Salas, Vicente, 2009).

3.3.4 Auction tenders for renewable energy

In 2017, the Ministry of Energy, Tourism and the Digital Agenda launched two auction tenders for renewable energy, being the second one more attractive for solar PV producers than the former (where virtually no solar PV energy was awarded). (PV Magazine, 2017c) This kind of vertical market intervention towards renewable energy is the main market intervention existing nowadays. Still, it is not specific for solar PV, since more types of renewable sources, specially wind energy, are allowed (and in some cases prioritised (Donoso, 2017)) in the auctions.

3.3.5 Spanish Strategy for Science, Technology and Innovation 2013-2020

The Spanish Strategy for Science, Technology and Innovation 2013-2020[2] set the general objectives to be achieved during the period 2013-2020 in the promotion and development of R&I[3]. These objectives were aligned with the Europe 2020 strategy, the SET Plan, and the H2020 programme. Like the latter, it aimed at addressing societal challenges, with "Secure, Sustainable and Clean Energy" being one of them. This plan only established the objectives in broad terms, so although it had an impact on renewable energy, it was not specifically pointed at solar PV.

[2] (MINECO, 2013a)

[3] The legal basis of the strategy is the Law of Science, Technology of Innovation which came into effect the 3rd of December of 2011, substituting the previous Law of Science of 1986.

3.3.6 National Plan for Scientific Research, Development and Technological Innovation 2013-2016

The Spanish Strategy for Science, Technology and Innovation 2013-2020 is implemented through four-year plans. The National Plan for Scientific Research, Development and Technological Innovation 2013-2016[4] established overall energy-related priorities: sustainability, competitiveness, security of supply, and social and technological impulse towards lower energy consumption. The specific solar PV related priorities proposed for the period 2013 – 2016 were the following:

1. Research on and introduction of new components linked to hybridization for energy production;
2. Development and incorporation of new materials;
3. Performance, duration and production costs of solar PV energy and development of advanced manufacturing processes of components;
4. Development of energy storage systems and technologies for firms and households;
5. Renewable energy management and integration in conventional networks.

The operational implementation of the National Plan is done through the Annual Action Plans, which reflect the budgetary resources, the foreseen timetable, the conditions and the managing bodies for each of the actions that are undertaken during the specific year.

When comparing these priorities with the ones established by the Spanish Photovoltaic Technology Platform (FOTOPLAT) and the historical ones, the second priority (related to materials) and the third priority (related to manufacturing processes) are more aligned with the historical RD&I activities. The forth priority (related to households) is more related to the new BIPV tendency that FOTOPLAT's strategy is following.

Because of the low private R&D funding, the organisations conducting R&I activities are highly dependent on public support. Aware of this challenge, the National Plan for Scientific Research, Development and Technological Innovation (2013-2016) set the ground for increasing private sector investment through the development of instruments for public-private cooperation, for adopting measures encouraging access to bank

[4] (MINECO, 2013b)

financing, and for creating a favourable environment to the development of venture capital.

3.3.7 Renewables Energy Plan 2011-2020

The Renewable Energy Plan 2011-2020[5] was published by the Institute for Energy Diversification and Saving (IDEA)[i] in 2011. Regarding the needs of solar PV R&I, it refers to the SET Plan as a guide and highlights the necessity of intensifying efforts in the field of energy R&I.

The Plan proposes 87 measures (divided in action lines) covering support frameworks, finance, legislation, energy infrastructures and planning, promotion, information, training and other activities. Most of these measures fall into the horizontal public input category.

The most relevant measures for photovoltaic R&I are, on the one hand, reducing administrative barriers for R&I and demonstration projects, and on the other hand, supporting and financing R&D of new prototypes, first demonstration projects and unique projects in commercial phase or with some market barrier (such as BIPV). In this case, these interventions affect the market since they are used to support R&D projects, although their impact on creating any internal market is limited.

This plan also establishes a target of 40% of electric generation by renewable energy by 2020.

Both the Renewable Energies Plans and the National RD&I Plan have been gradually evolving since 2005, without experiencing major or unexpected changes. It is remarkable that there have been cutbacks because of the budget restrictions that Spain suffered, but the objectives and the approach of the plans have not significantly changed.

3.3.8 R&I public funding

The overall R&D budget in Spain has experienced considerable reductions since the beginning of the economic crisis. For instance, the Government spending on energy R&I was reduced from EUR 163 million in 2012 to EUR 72 million in 2013. The overall budget of CIEMAT (the main publicly funded energy research institution in

[5] (IDAE, 2011)

Spain) has also fallen by 25% since 2009 (IEA/OECD, 2015a). The Spanish PV Platform FOTOPLAT estimates that the accumulated public funding for solar PV R&I over 2009-2013 amounted to EUR 35 million (ALINNE, 2014).

The European Union is a major source of funding for Spanish photovoltaic R&I, via both EU's Framework Programmes and the European Regional Development. In 2014, out of the approximately EUR 300 million allocated to energy programmes, around EUR 46 million benefited Spanish organisations.

The Spanish institutional bodies (more specifically MINECO State Secretariat for Research, Development and Innovation and MINECO-CDTI) are involved in the preparation of calls for proposals, and in the evaluation and follow-up of granted projects, and offer several funding schemes such as direct subsidies or soft loans. Bottom-up proposals with special relevance for achieving the following objectives are eligible for public support; those objectives being the reduction of levelised cost of electricity through the whole value chain, and the improvement of industrial product quality based on high quality technological developments that potentially improve Spanish companies position in the global solar market. In 2014, CDTI financed 102 R&I projects related to energy, with public funding liabilities of almost EUR 55 million, of which EUR 10 million were allocated to solar energy R&I.[6] IDAE also financed projects of technology innovation which fulfilled the condition of having potential for replication (Herrero Rueda, 2016).

3.3.9 Support for R&I organisations and demonstration facilities

Policies related to public inputs such as generating knowledge, fostering cooperation in RD&I, etc. have been constant during the last decade. These kind policies still exist today and have been quite successful for maintaining the RD&I capacity. For instance, the Spanish solar RD&I capacity in terms of number of people dedicated to RD&I has not experienced dramatic changes since the boom (researchers dedicated to solar PV are estimated to be 350).

There are several organisations involved in solar R&I activities (CIEMAT identified over 50 centres as potential developers). Still, governmental support has been fundamental in regard of solar R&I activities since the most relevant institutes have

[6] (Ministerio de Industria, Energía y Turismo, 2015)

been directly subordinated to the Ministries in charge of Energy or Innovation. The main public centres during the last years were the Centre for Energy, Environmental and Technological Research (CIEMAT), the National Renewable Energy Centre (CENER), the Institute for Energy Diversification and Saving (IDAE) and the Institute of Solar Energy (IES).

CIEMAT, is a public research organisation working on energy and environment related topics and on the technologies related to them. It had a budget of EUR 106 million and more than 1,300 staff in 2013. Apart from R&I, among their activities there are education, technology transfer, rendering technical services, advising to the administrations, and representation of Spain in several international forums. It was the Spanish representative (and an executive member) of the European Energy Research Alliance (EERA), one of the instruments of the SET plan to increase Europe's research capacity in low-carbon energy technologies. CIEMAT is in charge of the organisation of the "Dissemination Days of EERA Activities" with the objective of promoting Spanish participation in EERA's Joint Programmes. In 2014, CIEMAT was part of 256 external committees related to energy R&I, of which 162 were international. CIEMAT has also participated in 23 energy-related technology platforms. Two territorial centres related to solar photovoltaic R&I were created under CIEMAT: the Plataforma Solar de Almería (PSA), which is the largest concentrated solar technology RD&I and test centre in Europe, and the National Centre for Renewable Energy (CEDER) which has a unit dedicated to energy efficiency in buildings and conducting research on active solar systems manufactured in Spain (including photovoltaic modules).

CENER focuses on applied research and on the development and promotion of renewable energies including solar PV. It has an annual budget of approximately EUR 23 million (of which 60% is self-financed) and it has around 200 staff. The goal of the Photovoltaic Solar Energy department of CENER is to support the industrial sector and to contribute to reducing costs of solar PV electricity (kWh). It promotes the generation, accumulation and dissemination of knowledge for the industrial sector, and drafts reports as well as technical and economic feasibility studies Compared to CIEMAT, their activities are closer to the market.

The Institute of Solar Energy (IES) of the Polytechnic University of Madrid (Universidad Politécnica de Madrid, UPM) is a publicly owned institute. Its objective is to conduct fundamental research and to develop practical applications in the field of solar PV.

The focus of these organisations R&I activities vary from one to the other:

- CIEMAT Photovoltaic Solar Energy R&I Group is particularly focused on cost reduction, increasing performance and reliability of photovoltaic modules, components and systems, as well as in developing new devices based on thin films applied to different materials and deposition processes.
- CENER R&D activities focus on aspects related to photovoltaic cells, where work is carried out on the characterisation and integration of new materials, and the development of production processes, as well as on the innovation and improvement of other photovoltaic installation components, such as trackers, inverters and photovoltaic modules for specific applications. They also offer support, test, validate and certify components.
- IES research topics are Concentrator photovoltaics, Distributed generation and smart grids, Energy storage, Novel materials and solar cell concepts, Off-grid PV and rural electrification, Photovoltaic modules and power plants, Silicon technology, and III-V Multijunction solar cells. IES also runs several research infrastructures for silicon production, epitaxial growth, cell manufacturing, cell and material characterization, CPV, PV system quality control, intermediate band materials and solar cells characterization.
- IDAE focus is more general, and its activities relate to demonstration and deployment projects for pilot PV systems, with the objective of bringing technology to the market. In addition, they also provide measures for standards, reliability and quality.

3.3.10 Support for R&I collaboration and networks

Public-private collaboration were highly encouraged by Spanish institutions. The 2014 call from MINECO, "RETOS-COLABORACIÓN" (which supports innovative, public-private cooperative, and close to the market projects) financed solar PV energy projects over 2014-2017 with more than EUR 4 million.

The MINECO programme INNFLUYE (dated 2011) aimed to promote scientific-technological research within the science-technology-enterprise system through the creation of stable public-private groups. It was determinant for creating the Spanish Technology Platform for solar PV (FOTOPLAT). The main objective of this platform is, with continuity in time, to promote R&I in the photovoltaic sector through bringing together in a same forum both companies and research centres of different technologies. In 2018. it was composed of 85 institutions including universities, research centres and companies. FOTOPLAT secretariat is held together by the Technology Centre TECNALIA and UNEF (the most representative association of the Spanish PV Sector, which brings together 250 companies and associations -more than 85% of the activity of the sector in Spain-).

Other technology platforms created via governmental aid and carrying out R&I activities on solar PV include FUTURED, for electrical transmission and distribution networks, and PTE EE, for energy efficiency. Both are also supported by MINECO.

It has been shown above that relevant RD&I institutions remain active in the solar PV sector. Their importance largely comes from the strong investments in the solar PV sector occurred in the first decade of the 2000's, and they were fundamental for the first development of the sector. They play a strong role since their activity sets the possibility of regenerating the national value chain. Although they directly accuse the government of destroying the internal market, their network is especially active in providing policy makers with information in comparison with other European networks since that is one of their objectives.

4 Discussion on Spanish PV Policy

To answer the question of why the Spanish solar PV sector has not recovered from its stagnation, it has been demonstrated that it has not been because of a lack of supporting policies in RD&I. Although the budget dedicated to PV (and the PV RD&I labour force) is lower than in the rest of the analysed countries, the effort dedicated to this technology is remarkable if taking into account the small national market. The analysis shows that there are plenty of public actors involved in the development of several horizontal and vertical public inputs and it seems that there is a public commitment towards RD&I even if that commitment is not translated in the creation of an internal market.

As presented in the previous section, there are three national strategies/roadmaps setting the objectives for solar PV RD&I: The Spanish Strategy for Science, Technology and Innovation 2013-2020, the National Plan for Scientific Research, Development and Technological Innovation 2013-2016 and the Renewable Energy Plan 2011-2020. They are well aligned not only with the challenges of the Spanish Innovation System but also with the European Plans. This shows that Spain, like the rest of the analysed countries, has a set of well stablished horizontal public goods. RD&I is an important part of the Spanish policy mix and improving the energy sector and boosting renewable energies are objectives of the existing plans.

Still, when it comes to solar PV, the objectives are too broad and not specific, covering energy production, new materials, performance, duration and production cost of solar PV energy, advanced manufacturing, new applications and households' technologies. This makes the approach of the Spanish national Strategies to solar PV extremely horizontal. In any case, there is a general consistency between the main challenges and objectives.

Most of the Spanish market interventions are horizontal and serve for supporting RD&I in a general way, such as financing for R&D new prototypes, first demonstration projects and unique projects in commercial phase or with some market barriers.

In the case of horizontal public goods, the government has funded several technological institutes dedicated to energy and also supported the creation of R&I networks (with public-private collaborations) such as FOTOPLAT.

The most popular policy instruments in the international panorama are vertical market interventions. They can be found in one way or another in every one of the countries shown in the previous section, although they slightly differ in their nature. For instance, Germany and United States have applied various measures to provide with additional revenue such as price premiums, cash grants and net metering, and Japan and China have focused on providing guaranteed prices via Feed in Tariffs.

In the case of Spain, there are very few of these types of interventions. According to this paper’s analysis, effectively, only auction tenders can be found, which are very recent (from 2017). Most of the measures that are considered a primary driver of renewables such as Feed-in-Tariffs (which were removed from the Spanish policy framework), grants or other subsidies do not exist. The rest of the support for PV comes from RD&I policies.

In order to achieve the objectives of the national strategies and give access to demand to the Spanish companies, it is fundamental that the Spanish interventions not only focus on horizontal policies and on horizontal market interventions and again focuses on vertical market interventions that are those that seem to be working for good in all the global manufacturer countries.

The main actors funded by RD&I plans are research institutes and collaboration networks. Still, knowing the problem of the Spanish research groups to bring products to the market, the RETOS-COLABORACIÓN public-private collaboration fund is useful for bringing together institutions which are at different distances from the market. The EU funding for this kind of collaboration has also had an impact on the Spanish research institutions, although most of the previous important producers seem to have disappeared from the international panorama. The main reasons for this seem to be the policy instability that undermined investors’ trust and the negative effects that the governmental legislation had on demand for PV products.

In the case of the policy instability, it can be seen that in the rest of the analysed countries, stability has been one of the greatest values and that some plans such as the US tax incentives, or the FiT schemes in Asian countries, are being gradually reduced in order not to affect negatively the trust of investors. The vertical market interventions are the instruments that have impacted more on the RD&I of solar PV, giving immediate access to demand and liquidity to manufacturers and safe profits to investors, although most of the countries have been conscious of the need to gradually reduce them.

Looking at the international panorama, solar PV technologies have scaled at an extremely high pace, especially since China packed its policies aiming to develop PV industry.

Nowadays, the Spanish strengths in the solar PV area are in advanced research. Dubiously the amount of given funding can tackle the whole PV value chain, which is being a difficult task even for countries with four times more funding such as Germany. Because of this reason, there should be a discussion on Spanish strategies and decisions. The following question ought to be well-thought-out: should Spain substitute its broad focused interventions and start focusing only on the parts of the value chain that can have an international impact? Or should the country continue with the horizontal approach that it has now? As for now, the countries that have been analysed all have had an integrated approach of the whole value chain, but as it has been seen in the analysis, China has gradually monopolised some parts of the PV industry. In this scenario, there is no easy answer and only the future development of the sector may show if Spanish industry has an opportunity to become a competitive global player.

As a transversal topic, policy stability is a factor that existed in all the analysed countries, while Spain drastically changed its approach from one year to the other. This should not be repeated as it has had clear negative effects on the industry.

5 Conclusions

In this paper it has been made an introduction on how Asian competition has damaged European PV manufacturing not only because of problems in the supply chain but also because of the support that their governments towards PV sector. Spanish industry, which in 2008 experienced a boom thanks to an investor-friendly FiT scheme, suffered the decay even more than other countries because the changes in the governmental approach towards PV consumption, that stopped a local demand which turned to be fundamental for the development of the industry. In the following years Spain continued to support solar PV RD&I but did not make any strong market intervention with the objective of regenerating the market.

The top manufacturers of the world have applied a mix of policies with different nature. All of them have strong horizontal public inputs, and market interventions, but where the biggest difference with Spain is found is in the lack of verticality of the market interventions of the last one apart from its RD&I support policies. This type of interventions seem to be working in all the analyzed countries for pushing solar PV industry, and Spain has only recently launched PV auction tenders so as to create demand.

All in all, Spanish RD&I framework has its virtues, such as well-developed strategies, objectives, RD&I infrastructures and networks. Still, it cannot be said that the existing policy framework can rebuild the solar PV sector and a relevant industry (active in the whole value chain). We can conclude that the changes in the Spanish policy approach did not aim to create an internal market for solar PV and neither does the current policy framework.

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