Profitability expectations and uncertainty in the photovoltaic diffusion process in Germany and Spain, 2004-2013.

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Abstract.

Photovoltaic (PV) technology shows the greatest potential towards the decarbonization of electricity generation. Regulation, by setting incentives, has shaped the expected profitability of PV installations, which has therefore triggered the diffusion of the technology. This paper studies the diffusion process of PV in Germany and Spain during the last decade by looking at the link between regulation, expected profitability (reflected in the Internal Rate of Return) and diffusion (installed capacity) in 3 different segments: residential, commercial-industrial and utility. We find that not only the expected profitability level matters, but also its relative evolution to the profit rate of the economy, which reflects the evolution of the opportunity cost of capital. Whereas both expected profitability and diffusion evolved smoothly in Germany, showing a clear correlation, Spain experienced a diffusion and profitability bubble. However, the profitability bubble was not the cause of the diffusion bubble, as it is generally though, but in some extend its consequence. Although the correlation between expected profitability and diffusion cannot be seen in Spain, our conceptual model is able to explain the evolution of PV diffusion by integrating the “Net Profitability Index” concept, as well as the role of uncertainty and capital mobility. Finally, the sensitivity analysis shows that for achieving a 5% return on investment without any subsidy, in Spain and Germany respectively: the PV system price should drop by 35% and 65% relative to 2013 levels, electricity price should be 3.5 and 3 times higher, or its annual escalation rate 6% and 11%.

Keywords: Internal rate of return, solar orchads, profitability, diffusion.
1. Introduction

Expectations and uncertainty play a key role in the diffusion of novel technologies (Rosenberg, 1976; Ireland and Stoneman, 1986; Alkemade and Suurs, 2012). Photovoltaic (PV) technology shows the greatest potential towards the decarbonization of electricity generation, not only for its technological developments, but also for the dramatic cost decline experienced during the last decades and forecasted for the next years (EPIA & GP, 2011; IEA, 2014; MIT, 2015; NREL, 2016).

Within those technological expectations, profitability has a major relevance in determining the diffusion of the technology, since investment decisions are mainly based on expected profitability forecasts. However, expected profitability is difficult to estimate for PV investments. Although the main cost is the initial investment and there are no fuel costs, the uncertainty comes mainly from the variability of PV generation on the one hand, and the uncertain evolution of electricity prices during the lifetime of the investment (25-30 years) on the other hand. That is why regulation has played a significant role incentivizing this technology, not only for the economic direct effect of the financial incentives, but also for the certainty provided to investors by guaranteeing that all the electricity generated would be purchased during the lifetime of the system at a given price, which ensures a certain income flow (Klessman et al, 2011; Grau, 2014).

Knowing the income flow during the lifetime of the investment, and given the certainty of the initial investment, which is the largest cost of the system (Operation and Maintenance —O&M hereafter— account for around an annual 1% of the total system price), the estimation of the Internal Rate of Return (IRR) of the investment becomes accurately estimable.

In this paper we will study the diffusion process of the PV technology in Germany and Spain between 2004 and 2013. Germany is the leading country in terms of PV installed capacity, both per capita and in absolute terms, with more than 34 GW installed capacity in 2014 (REN21, 2015). Spain, which was the leading country in 2008, accounting for 45% of the global PV market (ASIF, 2009 and 2011), lies now in the sixth position with a virtually paralyzed PV
market, after having experienced a boom and bust cycle in both the diffusion of the technology and the profitability of the installations. (Del Rio and Mir-Artigues 2012 and 2014; Mir-Artigues, 2013; Prieto and Hall 2013).

Our hypothesis is that regulation, by setting financial incentives (Mainly Feed-in Tariffs — FiTs—, but also investment subsidies and soft loans), has shaped the expected profitability of PV installations, and likewise the expected profitability has largely determined the diffusion of the technology.

We will estimate the expected Internal Rate of Return (IRR) for three different types of installations/segments: small scale (residential segment), medium scale (commercial and industrial), and large scale (utility), and then study and compare its evolution in both countries and how it is related to the diffusion of the technology. Finally, we will carry out a sensitivity analysis, which will allow us to assess how far PV technology is from achieving competitiveness at current market prices.

Several papers have already studied the profitability of PV installations from different perspectives. Spertino et al. (2013) calculate the Net Present Value and the IRR for several case studies in Germany and Italy over the period 2005-2013, focusing on rooftop installations. The results obtained by Spertino et al. for Italy show a similar evolution to that experienced in Spain, and the results for Germany are consistent with our estimations for the Residential and Commercial-Industrial segments. Talavera et al. (2010) carries out a comprehensive sensitivity analysis on the determinants of PV profitability for the Euro Area, Japan and the USA. Their results are interesting as long as they show how different factors affect the profitability of PV depending on different market and regulatory circumstances. In the three cases, they find that the initial investment and the PV yield-electricity price (these both have the same quantitative effect on the IRR) are the most important factors determining the profitability of PV investments. Other analyses focus on the profitability of PV for self-consumption applications, such as Colmenar Santos et al (2012), Chiaroni et al. (2014) and Talavera et al. (2014). We follow
and develop the methodology used in this previous literature, and try to not only quantify profitability, but link it to the regulations which shaped it and the diffusion that it triggered.

This paper is organized as follows: section 2 reviews the IRR methodology and the data and assumptions used for its calculation, focusing on the difference between static and dynamic determinants of profitability; being the latter those who determine its fluctuations over the period studied. Section 3 presents the main results, focusing on the link between regulation, expected profitability and diffusion, stressing the role of the solar orchards owning structure on the formation of the Spanish PV bubble, and presenting a conceptual framework to explain how these elements affect diffusion. Section 4 studies the sensitivity of profitability to the main market factors (system price and electricity price levels and evolution), and shows the economic circumstances under which Utility PV would reach competitiveness. Finally, section 5 concludes.

2. **Methodology and data**

2.1. **Methodology**

2.1.1. **The Internal Rate of return**

There are many ways to evaluate the profitability of a PV investment. Nofuentes et al. (2002) review how different profitability indicators can be applied to Grid-Connected Photovoltaic Systems (GCPVS). The most useful indicators are Net Present Value (NPV), Profitability Index (PI), Pay-Back Time (PBT), and Internal Rate of Return (IRR).

The NPV is simply the sum of all the cash flows of the investment lifetime (revenues less expenditures), discounted to the present. The investment is profitable when NPV>0. However, this indicator forces us to make an assumption about the discount rate, and it might not be suitable for comparison of investments with different initial costs and lifetimes, because it is an absolute value instead of a relative measure (as the IRR), and because the assumption about the discount rate implies an arbitrary discrimination based on the lifetime of the investment.
The profitability index (PI) is the ratio between the net present value and the life cycle cost of the investment. It shows the same information than the NPV but relative to the cost of the investment.

The Payback Time (PBT) shows the time required to recover the money invested. It is a useful indicator but it dismisses the cash inflows received after that moment and it is not very useful for comparisons because it only provides information about the time to recover the investment, but not about profitability itself.

Finally, the IRR shows the discount rate at which the net present value equals zero. It is the most useful indicator for several reasons: it does not force us to make any assumption about the discount rate; it provides a relative result easily comparable among different types of investment, and it is indeed the most popular indicator amongst investors.

The calculation of the IRR derives from the NPV equation (1). As we have already mentioned, it is sum of the present worth of the cash inflows during the lifetime of the investment \(PW[CIF(N)]\) minus the Life Cycle Cost of the investment from the user standpoint\(^1\) (\(LCC_{usp}\))

\[
NPV = PW[CIF(N)] - LCC_{usp} \tag{1}
\]

The present worth of the cash inflows has two main components: the electricity price \((Pu [€/kWh])\), and the annual electricity yield of the system \((Epv [kWh/kWpy])\).

Besides these two main elements we will include the grid-access charge \((\gamma)\) and the generation tax \((\lambda)\) for the case of Spain. The last element of eq. 2 depicts the effect of the annual escalation rate of energy prices \((\varepsilon_{PU} [%])\), the annual degradation rate of the system \((d_g [%])\) and the discount rate \((d [%]):\)

\[
PW[CIF(N)] = (Pu - \gamma) * (1 - \lambda) * Epv * \frac{K_{PU} \left(1 - K_{PU}^d\right)}{1 - K_{PU}} \tag{2}
\]

\(^1\) The LCC can be considered either from the point of view of the system (excluding investment subsidies, soft loans or any other incentive), or from the point of view of the user including all available incentives (Nofuentes et al. 2002: 556). As we are interested in the investor’s perspective we will analyze the LCC from the user standpoint.
Being $N$ the lifetime of the investment and $K_{PU}$:

$$K_{PU} = \frac{(1+\varepsilon_{PU})^{(1-d)q}}{1+d}$$ (3)

On the other hand, the $LCCusp$ comprises the present worth of the initial investment of the PV system ($PW[PV_{IN}]$ [€/kWp]) and the present worth of the annual operation and maintenance (O&M) costs ($PW[PV_{OM}]$ [€/kWpy]):

$$LCCusp = PW[PV_{IN}] + PW[PV_{OM}]$$ (4)

The main parameters regarding the initial investment are the system cost itself ($PV_{IN}$ [€/Wp]), the investment subsidy ($PV_{IS}$ [€/Wp]) and the financial conditions: percentage financed ($\alpha$), interest rate ($i$), and the maturity of the loan ($Nl$):

$$PW[PV_{IN}] = (1 - \alpha) \cdot (PV_{IN} - PV_{IS}) + \alpha \cdot (PV_{IN} - PV_{IS}) \cdot i \cdot \frac{(1+i)^{Nl}}{(1+i)^{Nl-1}} \cdot \frac{1-q^{Nl}}{1-q}$$ (5)

$q$ being:

$$q = \frac{1}{1+d}$$ (6)

Finally, the present worth of the O&M costs is simply:

$$PW[PV_{OM}] = PV_{OM} \cdot K_{PV} \cdot \frac{K_{PV}^{(1-K_{PV})}}{1-K_{PV}}$$ (7)

$\varepsilon_{OM}$ being the escalation rate of O&M costs and $K_{PV}$:

$$K_{PV} = \frac{(1+\varepsilon_{OM})}{1+d}$$ (8)

In conclusion, we must calculate the discount rate ($d$) of eq. 9 when $NPV=0$:

$$NPV = (Pu - \gamma) \cdot (1 - \lambda) \cdot E_{pv} \cdot \frac{K_{PU}^{(1-K_{PU})}}{1-K_{PU}}$$

$$-(1 - \alpha) \cdot (PV_{IN} - PV_{IS}) + \alpha \cdot (PV_{IN} - PV_{IS}) \cdot i \cdot \frac{(1+i)^{Nl}}{(1+i)^{Nl-1}} \cdot \frac{1-q^{Nl}}{1-q}$$
\[-PV_{OM} \frac{K_{PV} (1-K_{PV})}{1-K_{PV}} = 0 \]  \hspace{1cm} (9)

This methodology follows the developments and terminology of previous literature (Nofuentes et al., 2002; Talavera and Nofuentes, 2010; Talavera et al., 2014), and includes the effects of the recent generation and grid-access charges for the case of Spain.

In the case of Germany, FiTs are provided for 20 years. Since the lifetime of the system is 25 years we have to add those last five years to the present worth of the cash inflows. For the sake of simplicity we get rid of the taxes and call \( A \) to the last element of equation (2), the discount factor. We call \( A' \) to the same discount factor but for the last 5 years (n=5 instead of 20). Then we have

\[ PW [CIF(N)] = Pu \times Epv \times A + Pu' \times Epv \times A' \]  \hspace{1cm} (10)

Where the first addend represents the cash inflows of the first 20 years and the second represents the cash inflows of the remaining 5 years. \( Pu' \) represents the wholesale electricity price (at which the electricity must be sold once FiTs expire) in the year 20, that is:

\[ Pu' = Pu \times (1 + \varepsilon_{pu})^{n'} \]  \hspace{1cm} (11)

Note that \( Pu \) here refers to the current wholesale price of electricity, not to the Feed-in Tariff.

2.1.2. Installation categories

The main obstacle we face in the present work is the temporal and spatial inconsistency of the installation categories: Residential or small scale (R), Commercial-Industrial or medium scale (C-I) and Utility or large scale (U). That is, on the one hand, due to the many regulation changes happened in Spain, which changed the criteria for FiT categories not only in terms of installed capacity, but also in qualitative terms (rooftop vs. ground-mounted), as summarized in Table 1. On the other hand, due to the different categorization criteria applied in Germany and Spain in the data, which make the diffusion data only comparable in general terms. The diffusion data is structured as follows:
Table 1. Installation categories for the diffusion data:

<table>
<thead>
<tr>
<th></th>
<th>Residential or small scale</th>
<th>Commercial-Industrial or medium scale</th>
<th>Utility or large scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>&lt;10kW</td>
<td>10-500kW</td>
<td>&gt;500kW</td>
</tr>
<tr>
<td>Spain</td>
<td>&lt;5kW</td>
<td>5kW-1MW</td>
<td>&gt;1MW</td>
</tr>
</tbody>
</table>

Figure 1. Installation categories established by each regulation in Spain for the application to Feed-in Tariffs (RD: Royal Decree; L: Law).

To overcome this limitation we apply the following criteria for the definition of the three different segments for the calculation of the IRR:

(i) Residential or small scale (R): They face the highest installation and financing costs, and receive the highest FiTs. As the system is usually rooftop we assume horizontal tilt.

(ii) Commercial industrial (C-I): they face intermediate installation and financing costs, and receive the medium FiT levels. As the system is usually rooftop we assume horizontal tilt.
Utility or large scale (U): They face the lowest installation costs and receive the lowest FiTs. As the system is usually ground-mounted we assume optimal tilt of the panels and therefore optimal irradiation.

These criteria allow us to build, although not perfectly consistent categories, coherent and comparable groups. The data assumed for each category are summarized in the next section.

2.2. Data: determinants of profitability

2.2.1. Static determinants

2.2.1.1. Irradiation

The amount of solar resource is one of the main determinants of profitability. Although variable along the day and the year, the solar irradiance is constant in the long term. The electricity yield of the PV system depends mainly on climate conditions (solar irradiation), technological development (cell efficiency, performance ratio and degradation rate) and mounting conditions (vertical, horizontal or optimal tilt). Since roofs are not usually designed for PV systems, we assume horizontal tilt and the country average irradiation for R and C-I segments. Ground-mounted systems however, can be designed to optimize the irradiation caught by the panels, and large investors have more flexibility to locate the system in optimal conditions. Consequently we assume for the U segment optimal tilt and sunniest location (Andalucía in Spain and Bayern in Germany), which entails between 21 and 23% higher PV yield than the other two segments. This segment is therefore not directly comparable with the other two, and represents the profitability of PV in the countries' best conditions.

The data regarding the PV electricity yield of the systems is taken from the PVGIS project developed by the European Commission. It refers to the potential solar electricity [kWh/kWp] generated by a 1 kWp system per year with photovoltaic modules mounted at optimal or horizontal tilt and assuming system performance ratio 0.75. The data represent the average of Murcia is slightly sunnier than Andalucía, but we chose the latter because is more representative of the location where most of the utility installations are located.
the period 1998-2011 (Šůri M., et al., 2007; Huld T. et al., 2012). Likewise, the efficiency of the system degrades at an annual rate of 0.8% (Dirk et al., 2012). The comparison between the solar irradiation and PV yield in both countries can be seen in figure 2:

Figure 2. Global irradiation and solar electricity potential in Spain and Germany.

![Global irradiation and solar electricity potential in Spain and Germany.](source: PV GIS)

### 2.2.1.2. Financing cost

The financing conditions have a significant impact in the profitability of any investment. Previous literature has paid little attention to this factor, assuming either own capital investments or hundred per cent financed. According to the information provided by the Spanish PV Industry association (UNEF), which is consistent with previous literature (Prieto and Hall, 2013), we assume that 80% of the investment is financed at 10 years maturity. The most critical parameter regarding financing conditions is, however, the interest rate. Although the interest rate is in principle a dynamic determinant of profitability, as it changes nearly every day, provided that this is a long term investment the investors discount the future evolution of interest rates during the maturity of the loan. Therefore, instead of just taking the current interest rate in each moment of time, we apply the average interest rates for the period 2004-2015. This is exactly the same duration than the maturity of the loan: 10 years.
Likewise, we differentiate amongst the three segments, taking the average interest rate for household purchase for R segment, the average for loans below 1M€ for C-I segment, and the average for loans above 1M€ for U segment, according to the ECB. We observe that whilst the range amongst segments is wide in Spain (3.8-7.2%), interest rates are more homogeneous amongst segments in Germany (4.2-4.3%).

During the years 2004 and 2005 soft loans have been provided by ICO and IDAE\textsuperscript{3} with an interest rate equal to the euribor-6months plus a maximum premium for intermediary financial institutions of 1,025 percentage points. Since the Euribor of the period has been around 2%, we assume the soft loans to have an interest rate of 3%.

2.2.1.3. Other static determinants

There is consensus in the literature in the assumption of operation and maintenance cost (O&M) as 1% of the initial investment (Sick & Erge, 1996; Konen et.al., 2000; Talavera et al., 2010; Talavera et al., 2014). Likewise, and according to Talavera et al. (2010) we assume an annual escalation rate of O&M costs of 1%.

2.2.2. Dynamic determinants

2.2.2.1. Electricity price/Feed-in Tariffs

The first dynamic determinant, in the sense that they determine the fluctuations over the studied period, is the electricity price at which the electricity generated by the system is sold to the grid. This price is determined by the Feed-in Tariffs (FiTs) established by the governments. The FiTs consist in preferential electricity prices paid to PV generators. There are usually different FiT levels for different types of installations (larger installations enjoy lower costs and therefore receive lower FiTs). In Spain no FiTs were available anymore since 2012 for new installations, so the electricity price paid to new installations became that of the wholesale electricity market (pool price). Likewise, we assume an average escalation rate of electricity

\textsuperscript{3} ICO: Instituto de Crédito Oficial; IDAE: Instituto para la Diversificación y el Ahorro de la Energía.
prices of 2% for both countries, in accordance with Talavera et.al. (2010) and EPIA (2011). We will carry out a sensitivity analysis of both electricity price and its escalation rate in section 4.

Figure 3 shows a simplified evolution of the FiTs for the case of Germany and Spain.\(^4\) Whilst the FiT system was stable in Germany, with a degression rate to adjust to the declining costs of PV, the FiT system was changing and unpredictable. There were three different schemes over this period: (i) constant FiTs until September 2008; (i) FiTs with a degression and installations quotas factor between October 2008 and December 2011; and (iii) no FiTs at all (the so-called "Moratorium") since 2012 up to now. We will see these three systems with more detail in section 3.1.

Figure 3. Simplified Feed-in Tariffs (€/kWh) for the Residential (R), Commercial-Industrial (C-I) and Utility (U) segments, 2004-2013.

A) Germany

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3a.png}
\caption{A) Germany}
\end{figure}

b) Spain

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3b.png}
\caption{b) Spain}
\end{figure}

Note: years 2007 and 2008 are divided into two sections in Spain due to the regulation changes, which will be studied with more detail in section 3.1.

2.2.2.2. System price

The system price comprises the cost of modules, the balance of systems and the taxes (VAT). The data about system prices are provided by the International Energy Agency in their annual

\(^4\) See figure 1 in the appendix for the more detailed description.
PV trends reports. These reports provide rough numbers, and only since 2011 they started differentiating between three categories (before there were only installations below and above 10kW).

There are no data about Spain for the years 2004 and 2005, so we estimate it from the values of the years 2003 and 2006 assuming a constant evolution. There are no data about Germany for the year 2004. For the years 2006-2010 there are two ranks of prices: one for installations below 10KW and the other for those above that level. As we have three categories, we assume the lowest price per Watt for the large-scale (U), the highest for the small-scale (R), and the mean for the medium-scale (C-I).

The data is expressed in €/W (nominal power), whilst the PV yield in our equation is expressed in kWh/kWp (peak power), so we must convert nominal into peak power. The ratio between the peak and nominal power is neither fixed nor standardized; it varies across installations. According to a research carried out by the Spanish PV industry association, the peak/nominal ratio is 1.1 in the north of Spain and 1.15 in the south (ASIF, 2011:67). We therefore assume a ratio of 1.13 for Spain as a whole, and a 1.1 ratio for Germany.

We must also include the Value Added Tax. In Spain, VAT has been modified twice during this decade: from 16 to 18% in July 2010, and from 18 to 21% in September 2012. We add the VAT for each year and assume 17% and 20% for 2010 and 2012 respectively. The VAT in Germany was 16% until 2006 and 19% since 2007.

Initial investment subsidies were in place mainly in 2004 and 2005 in Spain, and amounted up to 40% of the installation cost. According to Bernal-Agustin and Dufo-López (2006:1111), in the year 2004 IDAE subsidized as an average, 27% of the cost of the installation for power

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5 Peak power vs. Nominal power: peak power is the quantity of kW installed in the solar panels, whilst nominal power refers to the power of the inverter (the device that transforms the energy generated by the panels into energy suitable for consumption). Peak power is usually higher than nominal power, as the inverter determines the bottleneck of energy fed into the grid. In other words, having a higher peak power than nominal power allows using the inverter at a 100% capacity longer than if both values were the same (ASIF, 2011).
ratings of less than 100kW, and 11% for installations greater than 100kW”. However, there is not any official statistical database about financial incentives (neither soft loans nor investment subsidies). Thus, for each segment we will calculate an upper bound with all possible incentives (40% subsidy and 3% soft loan), and a lower bound for installations with neither subsidies nor soft loans.

Figure 4. System prices (investment cost) for the Residential (R), Commercial-Industrial (C-I) and Utility (U) segments, 2005-2013.

![Graph of system prices](image)

Source: IEA and own calculations.

Again, we can see that the downward trend in Germany has been more stable during the studied period. In Spain however, prices kept high until 2008 due to the silicon scarcity (international factor) and peak demand (national factor) during 2007-2008, and then plummeted in 2009.

Finally, all the data and assumptions, as well as their sources are summarized in table 2.
Table 2. Data summary

<table>
<thead>
<tr>
<th>Country</th>
<th>Figure</th>
<th>LCC&lt;sub&gt;OSP&lt;/sub&gt;</th>
<th>PV&lt;sub&gt;IN&lt;/sub&gt; (€/kWp)</th>
<th>PV&lt;sub&gt;IS&lt;/sub&gt; (€/kWp)</th>
<th>i (%)</th>
<th>NI (years)</th>
<th>PV&lt;sub&gt;OM&lt;/sub&gt; (€/y)</th>
<th>ε&lt;sub&gt;PVOM&lt;/sub&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Figure 3.A</td>
<td>R: 4.2</td>
<td>-</td>
<td>C-I: 4.3</td>
<td>U: 4.2</td>
<td>10</td>
<td>1% of PV&lt;sub&gt;IN&lt;/sub&gt;</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 40%</td>
<td>(2004-2005)</td>
<td>C-I: 5.3</td>
<td>U: 3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>Figure 3.B</td>
<td>R: 7.2</td>
<td>-</td>
<td>C-I: 5.3</td>
<td>U: 3.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: IEA, MINETUR, IDAE, ECB, IDAE, UNEF, Talavera et al. (2010), Konnen et al. (2000)

<table>
<thead>
<tr>
<th>Country</th>
<th>Figure</th>
<th>PW CIF(N)</th>
<th>Charges/taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Figure 4.A</td>
<td>R, C-I: 762</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>U: 935</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R, C-I: 0.8%</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>U: 1,406</td>
<td>(since 2011)</td>
</tr>
<tr>
<td>Spain</td>
<td>Figure 4.B</td>
<td>1,165</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>U: 1,406</td>
<td>(since 2013)</td>
</tr>
</tbody>
</table>


Charges/taxes: 
- Grid-access charge (€/MWh)
- Generation tax (%)
3. Results and discussion

3.1. Regulation

The main financial incentive provided to PV generators was the Feed-in Tariff. As aforementioned, the FiTs consist in preferential electricity prices paid to PV generators, which are higher the smaller installation, as it can be seen in figure 3. In Germany, FiTs were provided for 20 years. The FiTs levels diminished over time for new installations to adapt to the decreasing costs of the PV technology at a certain rate (degression rate). The installation categories for receiving FiTs were slightly changed in 2012, and the degression rate was increased in the last years. A closer look at the German FiT system can be found in Grau (2012 and 2014) and Hoppman et al. (2014).

In Spain, we can differentiate three different regulation schemes during this period (see figures 1 and 3.B or figure A2 in the appendix):

(i) **FiTs**: Between 2004\(^6\) and September 2008 there were constant Feed-in Tariffs provided to PV generators for 25 years. In June 2007, the FiTs for installations between 100kW-10MW almost doubled (from 23 to 42 €/kWh).

(ii) **Quota + degression**: In October 2008 the system changed due to the diffusion bubble created during the previous year. FiT levels decreased, the categories were changed (from (a) ≤100kW, (b) 100kW-10MW and (c) 10-50MW; to (a’) roofs≤20kW, (b’) roof 20kW-2MW, and (c’) ground≤10MW); and both degression rates and installation quotas for each category were established. Besides, FiTs levels were further decreased and a grid access charge (0.5€/MWh) established in the year 2011.

(iii) **Moratorium**: FiTs were finally removed in January 2012, so new installations would have to sell the electricity generated at pool price. A 7% generation tax was also established in January 2013.

\(^6\) FiTs were in place already since 1998.

In conclusion, we can see that the regulation was stable and predictable in Germany, whilst it was very unstable and erratic in Spain. In addition to the mentioned changes for new installations, the government also made retroactive cutbacks for installations already functioning; so that the number of hours remunerated was limited, harming therefore the actual profitability of existing installations. According to Mir-Artigues et al. those retroactive cutbacks caused a fall in profitability of around 2 percentage points, remaining always above 7%. According to UNEF (2013a, 2013b, 2015) these retroactive changes broke the legal certainty of investors, destroying therefore the profitability expectations created by FiTs, and causing an unquantifiable damage to the link between expected profitability and diffusion.

3.2. Expected profitability

Expected profitability of PV installations in Germany has ranged between 5 and 12%, being consistently higher the larger installation. Until 2011 the cost decline was faster than the degression rate of the Feed-in Tariffs (See figures 3.A and 4.A), leading to an upward trend of the expected profitability until that year. Since 2011, however, the decline of the FiTs has been faster than the cost drop, causing the decrease of the profitability, which was in 2013 the lowest of the period studied.

In Spain, FiTs were not high enough to make PV investment profitable in 2004-2005, so only installations that could access to investment subsidies (up to 40%) and/or soft loans (3%) could get positive returns. Between June 2007, and October 2008, when the diffusion bubble happened (around half of the cumulative installed capacity in 2013 had been deployed in that period
according to the National Commission for Market and Competence: CNMC), “intended” expected profitability was lower than 5% for all segments. Paradoxically, it was in 2009-2011, when the incentives were lowered and the degression rate established, when profitability rocketed, because the costs (system prices) fell faster than the FiTs (see figures 3.B and 4.B). Consequently, we find that the profitability bubble (2009-2011) was not the cause of the diffusion bubble (June 2007 - September 2008). On the opposite, PV system prices peaked in 2007-2008 due to both international (silicon scarcity) and national (demand tensions) factors, and plummeted in 2009-2010 when the demand fell, so the causality seems to be the opposite: the diffusion bubble was in some extent the cause of the subsequent profitability bubble.

Figure 5. Profitability (Internal Rate of Return, left axis, lines) and diffusion (annual installed capacity, right axis, bars). Note that the left axes (profitability) are in the same scale, so both figures are visually comparable, whereas the right axes (diffusion) are in different scales.

A) Germany, 2005-2013
B) Spain, 2004-2013

Note: In Spain there were regulation changes in June 2007 and September 2008. The profitability values for those two years reflect the situation after the reform. Therefore, the

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As we will see later, actual expected profitability was higher due to the solar orchads owning structure. But these levels were the ones intended by the regulation without considering the effect of solar orchads.
profitability levels associated with the diffusion bubble of June 2007-September 2008 are those of 2007. Sources: Profitability: own calculations. Diffusion: Fraunhofer, PSE AG and CNMC.

3.3. Diffusion

In Germany, where the regulation was stable and the profitability easily predictable, there seems to be a link between expected profitability and diffusion, which is stronger the larger installation. However, not only the level of profitability matters, but also its relative evolution to the profit rate of the economy. This is reasonable, since a higher profit rate entails a higher opportunity cost of capital, and the existence of attractive investment opportunities in other sectors. Therefore, we compute the Net Profitability Index as the ratio between the PV expected profitability index (2005=100), and the general profit rate of the economy provided by Eurostat (net returns on net capital stock, 2005=100). We can see then that diffusion accelerates when the expected profitability increases higher than the profit rate of the economy, and slows down in the opposite situation. Likewise, the sensitivity of diffusion to the evolution of the Net Profitability Index seems to be higher the larger installation, which could be explained by the higher capital mobility amongst sectors of the large investors than that of households and medium/small firms, for whom investment alternatives are usually more limited.

Figure 6: Correlation between the Net Profitability Index (defined as the ratio between the expected profitability index of PV and the profit rate index of the economy as a whole), and the diffusion rate (annual installed capacity) between 2005-2013 for the segments:

a) Residential  

\[ R^2 = 0.322 \]

\[ \text{Net Profitability Index} \]

\[ \text{Diffusion Index} \]

B) Commercial-Industrial  

\[ R^2 = 0.5394 \]

\[ \text{Net Profitability Index} \]

\[ \text{Diffusion Index} \]

C) Utility  

\[ R^2 = 0.6835 \]

\[ \text{Net Profitability Index} \]

\[ \text{Diffusion Index} \]
In Spain, however, the link between expected profitability and diffusion cannot be drawn. This might be due to three factors:

(i) **The continuous regulation changes**: the qualitative change of categories (from installed capacity to type of installation: rooftop/ground mounted) makes it impossible to follow the evolution of the different segments along time. Besides, the retroactive changes broke the legal certainty harming therefore the link between expected profitability and diffusion, as regulatory risk increased. Finally, the installation quotas entail a cap on installed capacity, limiting therefore the diffusion of the technology independently of the expected profitability.

(ii) **The external shock caused by the economic and financial crises**: the real estate bubble bust and the subsequent economic crisis caused a capital flight from the construction and real estate to the PV sector (Del Rio and Mir-Artigas 2012, 2014), due to the similarities between both sectors, and the innovative “solar orchads” owning structure, and the financialization of the PV sector (Prieto and Hall 2013:34-35). This explanation is consistent with our previous finding that not only the static level of profitability matters, but its relative evolution to the profit rate of the economy. Thus, although expected profitability were low, its increasing trend relative to the general profit rate of the economy, (which fell by 10.5% in 2008, and by a cumulative 18% between 2007-2009, the sharpest fall since oil crises in the seventies according to AMECO database) caused a surge in deployment. Besides, it was regarded as a safe investment, since it was guaranteed by the government (retroactive cutbacks were carried out later), in a time of high economic uncertainty, which stresses the relevance of certainty for the diffusion of novel technologies in particular, and for investment decisions in general.

(iii) **The distortionary effect of the “solar orchads” owning structure**: this innovative owning structure allowed investors to obtain higher profitability levels than those
intended by regulators (see fig 4.B). Due to the relevance of this factor in the Spanish PV bubble we will study it closely in the following section.

3.4. The solar orchads owning structure.

A "solar orchad" is an innovative owning structure for PV installations through which small investors come together to build a large (and therefore low cost) installation, formed by many small ones so that they can receive the highest Feed-in Tariffs. Solar orchads are usually ground-mounted, so they enjoy lower costs than small scale rooftop installations, and they are able to install optimally inclined solar panels, being therefore able to minimize costs and maximize revenues; both for the optimal exploitation of solar irradiance, and for the application of small-scale high FiTs.

We can therefore analyse the impact of solar orchads, both in terms of the profitability increase for investors, and in terms of the extra-policy cost caused. We define "extra-policy cost" as the difference between the FiT actually paid to solar orchads, and the FiT they would receive in the case that the solar orchad were considered as one installation. Profitability soars to a range between 11.8-13% depending on the FiT finally received: medium or high. We can identify 4 different cases depending on the FiT they actually receive (medium or high), and the one they should receive according to their actual total size (low or medium FiTs for large or medium scale installations respectively).

As shown in table 2, the medium scale (C-I) solar orchads receiving medium FiTs do not entail any extra policy cost, since its higher profitability comes from cost minimization and system optimization. The other cases, however, entail an extra policy cost, since the FiT these installations receive is higher than the one they would get if the installation were considered as one. The paradigmatic case is the large installation (10-50MW) receiving the high FiT for small installations (≤100kW), increasing expected profitability by 11.3 percentage points and causing an extra-policy cost of 210.62€ per Mega Watt hour generated.

Table 3: classification and impact of solar orchads:
<table>
<thead>
<tr>
<th>Actual scale</th>
<th>Actual FiT</th>
<th>Profitability</th>
<th>Extra policy cost (£/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-I</td>
<td>Medium</td>
<td>Intended (%)</td>
<td>Achieved (%)</td>
</tr>
<tr>
<td>1</td>
<td>Medium</td>
<td>4.2</td>
<td>11.8</td>
</tr>
<tr>
<td>2</td>
<td>High</td>
<td>13</td>
<td>8.8</td>
</tr>
<tr>
<td>U</td>
<td>Medium</td>
<td>1.7</td>
<td>11.8</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>13</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Solar orchards have played a determinant role in the Spanish PV diffusion bubble. Although the profitability provided by the FiTs was designed to lie below 5% for all installation types in average conditions, this owning structure allowed investors to minimize costs (through lower installation, O&M and financing costs) and maximize revenues (through system optimization and FiTs rent-seeking), achieving expected average profitability levels of between 11.8-13% in a time of plummeting profit rate, and causing a high extra-policy cost that would lead to the cutbacks between 2008-2011 and to the total collapse of the FiT system in 2012.

3.5. A simple conceptual model

With all the insights obtained during the previous analysis, we can build a simple conceptual model to explain the diffusion process of PV technology. The fact that the economic and regulatory conditions in Germany and Spain, as well as the diffusion process, were so different between each other, confirms the suitability of this model to explain the diffusion process of novel technologies.

The expected profitability ($\pi_{PV}^e$) is the main variable determining the diffusion process of the PV technology. The expected profitability, likewise, is determined by the costs (system prices), and the revenues (electricity prices). Solar irradiation, whilst obviously affecting the profitability level of the technology, does not dynamically affect its evolution over time. Since renewable energies have preferential access to electricity markets we do not have to care about demand issues here. Regulation plays a key role on ensuring revenues through FiTs and removing
uncertainties associated to demand factors by establishing that all electricity generated by the PV installation will be purchased by the electricity system. However, not only the level of profitability matters, but its dynamic evolution to the profit rate of the economy (net surplus on net capital stock: \( \pi \)), since it represents the opportunity cost of capital and the existence of better economic alternative in other sectors of the economy.

We can construct then, the Net Profitability Index as the factor between the expected profitability index and the index of the profit rate of the economy. By doing so, we can see the dynamic evolution of these two factors. If the capital mobility between sectors is high we can expect that the difference between the PV expected profitability and the profit rate of the economy and therefore the fluctuations of the NPI will be low, since capital will quickly switch to the more profitable sectors. Likewise, the segments with higher capital mobility (\( \beta \)) will show a stronger relationship between the NPI and the diffusion rate, since relative profitability changes will quickly translate into higher investment. Thus, the NPI will increase when the profitability of PV grows faster than the general profit rate of the economy (causing a higher diffusion rate), and will decrease otherwise.

The last relevant factor is uncertainty (\( \delta \)). The link between the NPI and the diffusion rate will be significant as far as the expected profitability is a reasonably certain condition. That is, even if the expected profitability is high and increasing, it will not entail diffusion if it is uncertain. Figure 7 show graphically this simple conceptual model and equation 12 presents its analytical formalization. In the rest of this section we will briefly explain the diffusion process in Germany and Spain according to this framework.
Figure 7. Conceptual model Regulation-Profitability-Diffusion.

\[ D = \frac{\pi_{PV}}{\pi} (1 - \delta) \beta \]  \hspace{1cm} (12)

In Germany, expected PV profitability grew faster than the profit rate of the economy between 2005 and 2011 leading to an increasing NPI and therefore diffusion rate. Between 2011-2013 the diffusion rate was still positive but declining due to the lower NPI caused likewise by the faster drop of the PV expected profitability than the fall of the profit rate. Since both the regulation and the market dynamics were stable and predictable in Germany, uncertainty was low and therefore the link between the NPI and the diffusion rate relatively strong. The larger investing segment (with higher capital mobility) showed indeed a stronger correlation between the NPI and the diffusion rate.

In Spain, on the contrary, the link between NPI and diffusion cannot be seen, due to the factors mentioned in section 3.3 and to the legal uncertainty caused by the retroactive cutbacks which broke the legal certainty provided by the previous regulations. The diffusion bubble of 2007-2008 happened because the PV profitability soared (from values below 5% and even negative to up to 13% considering solar orchads) in a moment of historical fall of the profit rate of the economy. NPI therefore rocketed in a moment of legal certainty (retroactive cutbacks were made afterwards), when the link between NPI and diffusion was strong, making consequently the diffusion rate to go through the roof. Quota establishment in 2008 broke any
further link between profitability and diffusion by establishing a limit on the amount of installed capacity able to receive FiTs.

4. Competitiveness assessment/sensitivity analysis

Finally, we carry out a sensitivity analysis which can be interpreted as a competitiveness assessment. We do so by estimating how a change in the main market parameters would affect profitability. The base case corresponds to the Utility segment (large scale) in 2013, selling the electricity at wholesale price (i.e. no FiTs). We can see then how far from being profitable is the technology at current market prices. As we assume 80% of the investment is externally financed at market interest rates, this calculations include the cost of debt, but not the remaining cost of equity (or opportunity cost of the own capital). Consequently, the zero threshold would be the point where all costs are covered at zero profit for the investor. Competitiveness, therefore, would be achieved when profitability covers the opportunity cost of capital (return on equity (ROE) demanded by investors). The ROE demanded by investors is the risk free interest rate plus a risk premium, which is different amongst countries and sectors, and likely to vary over time. Where to set the competitiveness threshold is, thus, a matter of discussion.

Previous literature has shed some light regarding the cost of capital of renewable investments in Europe. Table 4 summarizes the most representative estimations of the Weighted Average Cost of Capital (WACC) and Return On Equity (ROE) for Germany and Spain, for PV (EPIA, 2011) and onshore wind (Noothout et al. 2016). The conclusion we can draw for these numbers is that the cost of capital for renewable investments is structurally higher in Spain than in Germany, according to Noothout et al. (2016: 141), driven mainly by the additional risk posed by policy design and sudden regulatory change, which supports our previous analysis and stresses the significant role of regulations on providing certainty and the disastrous consequences of legal uncertainty.

Table 4. Weighted Average Cost of Capital (WACC) and return On Equity (ROE) estimated for Photovoltaics (PV) and Onshore Wind (OW)
<table>
<thead>
<tr>
<th></th>
<th>WACC</th>
<th>ROE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>3.4-4.5% (OW)</td>
<td>6-9% (OW)</td>
</tr>
<tr>
<td></td>
<td>4.4-6.5% (PV)</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>10% (OW)</td>
<td>13-15% (OW)</td>
</tr>
<tr>
<td></td>
<td>6.1-8.2% (PV)</td>
<td></td>
</tr>
</tbody>
</table>

*Sources: EPIA 2011 for PV and Noothout et al. 2016 for OW.*

Figure 8 shows the IRR as a function of the main market determinants: system price, current electricity price and its annual escalation rate, departing from the base case of the utility segment in the year 2013 (see table 5). We find, on the one hand, that the IRR responds exponentially to PV cost declines and linearly to both the current electricity price and its escalation rate, which is consistent with the results of Talavera et al. (2010). On the other hand, we find that the sensitivity of IRR is higher to the current electricity price than to its escalation rate in Germany, and the opposite in Spain.

If we simplify the competitiveness-cost of capital discussion mentioned above and set a threshold at 5% IRR, Spain would need either a 35% cost drop, a 3.5 times higher electricity price or a 6% annual increase of electricity prices to achieve competitiveness. Germany would achieve a zero net position when costs decline by 50%, electricity prices double or its escalation rate reaches an annual 7%; and competitiveness when the system price falls by 65%, electricity price triples or its escalation rate reaches 11%.

We should take these results with caution, not only for the competitiveness-cost of capital discussion already mentioned, but also for the discussions regarding the real market value of PV electricity, and its downwards evolution as penetration increases due to the cannibalization effect caused by the merit order effect (Sensfuß et al., 2008; Hirt et al. 2013; Ueckerdt, 2013).
Table 5. Base case parameters

<table>
<thead>
<tr>
<th></th>
<th>PV&lt;sub&gt;in&lt;/sub&gt; (€/kWp)</th>
<th>P&lt;sub&gt;u&lt;/sub&gt; (€/kWh)</th>
<th>ε&lt;sub&gt;pu&lt;/sub&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment (System price)</td>
<td>PV electricity price/FiTs</td>
<td>Escalation rate of PV electricity price</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>1,515</td>
<td>0.03778</td>
<td>2%</td>
</tr>
<tr>
<td>Spain</td>
<td>1,285</td>
<td>0.04426</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8. Sensitivity analysis: profitability (IRR) as a function of the initial investment (system price, PV<sub>in</sub>), electricity price (P<sub>u</sub>) and escalation rate of electricity price (ε<sub>pu</sub>)

Conclusions

We have drawn a conceptual model to explain the diffusion process of PV technology in Germany and Spain as a function of the expected profitability and regulation design. We have found that not only the expected profitability level matters, but its dynamic comparison with the profit rate of the economy, which represents the opportunity cost of capital and the existence of investment opportunities in other sectors. This model is able to explain the PV diffusion process in Spain and Germany over the period 2004-2013, and is likely to be extensible to the diffusion process of other technologies. More research is needed to empirically test this model. Although uncertainty is not an observable parameter, it could be considered as constant and test for
structural breaks (e.g., when retroactive cutbacks are carried out). Likewise, capital mobility is not directly observable, but we can assume that large investors have higher capital mobility than small ones.

In Germany, we have observed a clear correlation between profitability and diffusion, which is stronger the larger installation types or investing segments. In Spain, however, the correlation between profitability and diffusion cannot be seen due to the external shock derived from the financial and economic crises, the continuous regulation changes and quota establishment, and the distortionary effect of the “solar orchards” owning structure. This owning structure allowed investors to obtain average profitability levels up to 13%, just in 2008 when the profit rate of the economy was experiencing its sharpest drop since the seventies, and even though the intended average profitability provided by FiTs was supposed to lie below 5%.

Consequently, the profitability bubble in Spain was not the cause of the diffusion bubble, but in some extent the consequence, as it kept system prices high due to demand pressures until the bust in 2008. Then system prices fell much faster than FiTs, causing a profitability bubble just when the government was decreasing the incentives. This profitability bubble did not translate into another diffusion bubble due to the establishment of installations quotas. The cause of the diffusion bubble was, therefore, the sharp increase of the net profitability index (expected profitability of PV over the profit rate of the economy), due to the solar orchards owning structure, which allowed investors to increase profitability up to 13%, and the shrink of the profit rate of the economy due to financial and economic crisis (it fell by 10.5% in 2008, and by a cumulative 18% between 2007-2009).

In order to achieve a 5% return on investment without any incentives for large installations optimally located, the system price should drop by 35% relative to 2013 levels in Spain, wholesale electricity price should be 3.5 times higher or its annual escalation 6%. In Germany, the same result would be obtained when either the system price falls by 65%, electricity price triples or its escalation rate reaches an annual 11%.
In conclusion, we have found that the diffusion process of PV depends mainly on the joint evolution of the expected profitability of PV and the profit rate of the economy (what we have called Net Profitability Index), link which is stronger the higher capital mobility of the investing segment. The regulation plays a major role not only by allowing positive profitability levels, but also by providing certainty about the future realization of current profitability expectations.

Further research is needed to empirically test our simple conceptual model with richer statistical data, and extend its application to the analysis of the diffusion process of other novel technologies. Likewise, in order to accurately assess the competitiveness of PV, more research is needed on market value of non-dispatchable electricity, the cannibalization effect caused by higher PV penetration levels.
References

Alkemade, F; Suurs, Roald A.A. (2012): “Patterns of expectations for emerging sustainable technologies”. In: Technological Forecasting and Social Change 79 (3), S. 448–456

ASIF - Asociación de la industria fotovoltaica


Del Rio and Mir-Artigues


EPIA – European Photovoltaic Industry Association


Grau T.


UNEF – Unión Española de Fotovoltaica


E-references

Appendix

Figure A1: Feed-in Tariffs structure in Germany (/€/cesnts/kWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>On building</th>
<th>Open space</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004-2012</td>
<td>&lt;30kWp</td>
<td>100kWp-1MWp</td>
</tr>
<tr>
<td>2012-2013</td>
<td>&lt;10kWp</td>
<td>1-10MWp</td>
</tr>
</tbody>
</table>

Figure A2. FiTs structure, regulation schemes and Pool electricity price in Spain (/€/kWh).