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Sale of profitable but unaffordable PV plants in Spain: Analysis of a real case

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ABSTRACT

The Spanish photovoltaic industry was stunningly successful during 2007–2010, fostered by a favourable feed-in tariff system. Nevertheless, the cost overrun of this promotion policy led to government legislation against existing PV plants. Although these investments will be profitable when the subsidy ends, according to the last law enacted in Spain (IRR = 7.4%), either a massive sale to vulture funds or the abandonment of PV plants is being planned. Owners are unable to cover the loans through which they were originally financed. In this scenario, investors find it more profitable to cancel all operational expenditures and allocate this working capital to cover their loans, although this measure implies a 22% energy reduction.

This study analyses a representative Spanish PV plant based on real energy and economic data. The analysis shows the turn from an attractive IRR = 10.14% to a situation with limitations where the owner injects money annually to overcome potential bankruptcy of the investment. This paper reflects the influence of promotion policies in the profitability of PV plants. Additionally, the adverse legal framework in Spain identifies a profitable but unaffordable scenario, highlighting the differences between the economic and financial performance of a PV investment.

1. Introduction

The photovoltaic (PV) industry is currently leading in installation rates in the renewable energy sector and its accumulative power is increasing exponentially (International Energy Agency, 2016a; Jaeger-Waldau, 2016). In some countries, PV technology is playing a major role in its penetration of the electricity generation mix and the future forecast is even more optimistic as this trend is expected to rise (International Energy Agency, 2016b; Fraunhofer ISE, 2015).

This promising scenario exists worldwide, but special attention should be given to the USA, South America, and MENA countries because they play a role as a driving force in the PV sector (International Energy Agency, 2016a). Moreover, in these countries, PV plants are beating records in terms of electricity generation prices; that is, the unitary electricity price generated with PV systems has dramatically decreased in recent years compared to that from similar existing PV plants. For example, in Spain, the levelized cost of electricity (LCOE) for PV systems installed in 2007 was in the range of 240 – 420 €/MWh (discount rate, d = 3.8%) (Talavera et al., 2016) and in the USA, LCOE2007 was around 270 $/MWh (d = 7%) (United States Department of Energy, 2017). Meanwhile, in the last international auction tenders from 2015 and 2016, the generation price has been around 35€/MWh in Mexico, 29.9€/MWh in the United Arab Emirates, and even 29.1 $/MWh in Chile (Dezem, 2016; Hirtenstein, 2016a; Photon.info, 2016), which confirms the maturity of this technology.

These records have been so meaningful that this industry is switching from grid-parity, where the cost to generate a PV electricity unit can be compared to the retail electricity tariff that the user pays the utility company, to a situation of generation-parity, where the cost of generating a PV electricity unit is similar and can compete with production prices of other sources of energy, including those from non-renewable origins. For example, if previous PV electricity cost figures are compared with those of non-renewable energy sources, the difference is over a third for coal plants in Dubai, where it is expected to generated electricity at around 4.5 c$/kWh (Hirtenstein, 2016a), or a half price reduction in Chile (Dezem, 2016).

Some reports identify LCOE for PV in the range of 46.5 $/MWh to 110.5$/MWh for 2016 in the USA, whilst the solar thermal minimum range is 134.6 $/MWh or for wind-offshore is between 125.1 $/MWh and 201.4$/MWh. Regarding non-renewable sources, advanced nuclear

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lies within a range of 95.9 – 104.3 $/MWh, and conventional combined cycle is around 52.4–83.2$/MWh (US EIA, 2017). Other reports assign a PV LCOE of 35–180 $/MWh for 2015, 29–114 $/MWh for wind onshore, or 53–168 $/MWh for gas (VGB PowerTech E.V.V, 2015). Of course, these LCOE values depend on the location of the energy source (Joseph Salvatore, 2013)

The most remarkable achievement was reaching this electricity generation unitary price with no direct subsidies or retribution schemes, though it could seem contrary to past trends (Bolinger et al., 2015).

Despite this favourable context, European countries, and specially Spain, have shifted from a prevailing position to a marginal one in terms of PV installation rates and accumulated capacity (International Energy Agency, 2016a). Therefore, it is interesting to analyse the reasons for this slowdown in the Spanish PV industry from a realistic approach based on measured data from real PV owners. This study analyses and describes a representative sample from a Spanish investor's perspective.

The current astonishing worldwide penetration rates of PV technology and its corresponding low generation prices have been possible as a consequence of the maturity of the technology, which has produced a dramatic decrease in manufacturing expenditures, and therefore in the installation investment cost, which has a direct influence in the electricity generation price. Nevertheless, this level of maturity has been fostered by promotion policies that have accelerated the reduction in PV energy cost (International Renewable Energy Agency, 2014a). These supporting policies, which are mostly defined at the national level, mainly materialised through different subsidy schemes that supported either the installation investment cost or, most commonly, the energy generated (International Renewable Energy, 2012; International Renewable Energy Agency, 2014b). The ultimate objective of these policies was to stimulate manufacturing and to optimise installation procedures, with the purpose of reducing costs through a large-scale deployment. Therefore, the development of PV technology could be considered a policy-driven market (Lacchini and Rüther, 2015; Winkler et al., 2016).

Notwithstanding the current situation, European countries in general, and Spain in particular, were pioneers in defining subsidy systems (European Photovoltaic Industry Association, 2014; Dusonchet and Telaretti, 2015). Among all the possible supporting schemes, the feed-in tariff (FiT) (Jenner et al., 2013) is the most widespread in Europe, which meant a real boost for the penetration rates of this technology, placing countries such as Spain at the forefront of the technological development of the photovoltaic industry.

Nevertheless, a massive promotion of such supporting policies implied a cost overrun for national administrations in many cases (Ciarreta et al., 2014; López Polo and Haas, 2014), obligating governments to legislate to contain these expenditures (Del Río and Linares, 2014). Principally, subsidies for future installations have already been cancelled, with the aggravating circumstance that in some countries, this regulation to restrain cost overruns has been applied retrospectively (Fouquet and Viktoria Nysten, 2015; Pyrgou et al., 2016).

One of the countries where these retroactive measures have had a major impact is Spain, and hence, it is interesting to thoroughly analyse its extent based on real data. Determining the effect and consequence that these retroactive measures have caused to thousands of Spanish investors (ANPIER, 2015; Cala, 2013) is paramount for developing improvements in current regulations or in definitions of prospective regulations in other countries which take Spain as a model.

This study provides a brief description of the Spanish PV framework evolution, and analyses a real case of the effects of retroactive measures on a representative photovoltaic investment from 2007. For this analysis, Spain is a suitable scenario due to its widely known frequent, controversial, and changing regulatory framework for the PV industry (Talavera et al., 2016; Urbina, 2014). This study undertakes a detailed analysis of the energy and economic performance of a PV plant as an example for most PV plants in Spain. It could be observed that a profitable PV installation, in terms of energy production and Internal Rate of Return (IRR), could result in a situation where the owner of the plant is forced to either sell it to external investors or refinance the existing debt.

This study complements, with real energy and economic data, other research that proposes different scenarios analysing the effect of retroactive measures based on simulated or theoretical assumptions. It can also serve as a proven record of the differences between the economic and financial performance of an investment (de la Hoz et al., 2014). The economic dimension of an investment is the result of an analysis of the profitability parameters such as the net present value (NPV) or the IRR. On the other hand, the financial feasibility of a project deals with its annual liquid assets, where expenses should be subtracted from incomes to identify possible deficits in the annual accounting. When the economic variables show a positive value, i.e. the NPV is positive and the IRR is higher than the weighted average cost of capital (WACC), it may induce investors to make a certain investment, but if the financial dimension of the project identifies a negative cumulative annual liquidity scenario, the project, although economically viable, is financially unfeasible.

Similar to other studies in which policy implications and risk management are an important issue to consider or in other studies examining the implications of a FIT on solar deployment (Chapman et al., 2016; Sommerfeld et al., 2017; Zhang et al., 2017), the results of this paper could be very valuable to potential investors, as a changing regulatory framework can turn a profitable scenario into a non-feasible one. Therefore, this study could contribute to future policy recommendations as an example of lessons learnt (Gatzert and Vogl, 2016; López Polo and Haas, 2014) similarly to other studies carried out in Spain (Ciarreta et al., 2011; Del Río and Mir-Artigues, 2012; Talavera et al., 2016),

2. Spanish context

From 2007 to 2010, and supported by a favourable legislative framework (del Río González, 2008), renewable energies in Spain reached unprecedented success, placing the country's PV industry as a worldwide model of technological development and installation rates (International Energy Agency, 2010; EurObserv'ER, 2013; Montoya et al., 2014).

Since 2007, most of the investments made in Spain concerning electrical power supply system installations focused on renewable energy sources (Girard et al., 2016), where the power of these sorts of systems multiplied and their contribution to the total power installed in the country shifted from a 25% to a 37% share (Eurostat, 2017; REE, 2017). Likewise, the evolution of PV systems led to its representation of around 3% of the energy produced in the Spanish electricity generation mix, with peaks up to 4.5% during the summer months (REE, 2017). In the case of PV technology, the endorsement in May 2007 of Royal Decree (RD) 661/2007, which regulated the production of electricity with renewable energy sources and created a specific economic subsidy payment mechanism through a FiT scheme (Ministry of Industry Energy and Trade. Government of Spain, 2007), was a wake-up call for investors. Under this RD, around 75% of the current PV power existing in Spain was installed as the decree established a very favourable and profitable scenario for this technology (de la Hoz et al., 2016).

During the time under analysis in this study (2007–2015), Spain had no other promotion policies for PV grid-connected systems than the FiT. Previously, there were some tax deductions or subsidies to decrease the upfront investment for PV plant (Asociación de la industria fotovoltaica, 2008). Subsequently, during mid – 2017, there have been two tender auctions for the promotion of renewables plants in general (Bellini, 2017; Díaz-López, 2017; Reuters, 2017a, 2017b)

In order to obtain the maximum remuneration considered in RD 661/2007, most PV plants followed a similar arrangement; that is, a grid-connected PV system located on the ground with a central inverter and a nominal installed power of 100 kW. Most were turn-key plants and were considered as a mere investment product, and thus the design, implementation, and investment in these sorts of systems was somehow standardized, as is the case for the plant under analysis (De La Hoz et al., 2010).

The Spanish economic crisis from 2008 onwards, the electricity tariff deficit between the government and electricity companies, and the unexpected and uncontrolled installation rate of PV plants that the RD661/2007 produced, forced the government to legislate in order to solve problems mainly related to cost overruns in the system (de la Hoz et al., 2014; López Polo and Haas, 2014). Since 2007, an average of two RDs were approved in Spain annually with the purpose of preventing future PV installation from the same policy mistakes made in the past. Some authors already published a thorough review of the Spanish PV regulatory framework (Mir-Artigues et al., 2015; Talavera et al., 2016).

The drawback of these measures is that some cost-containment instruments implied retroactivity to already operating PV investments with the aim of limiting their profitability and consequently reducing the cost overruns of the 2007 policy. Recently, RD-Law 9/2013 defined several emergency measures in order to guarantee the financial stability of the electricity system and cancelled all previous legal decrees applicable to renewable energy plants. At the same time, it promoted new remuneration schemes which offered, according to the Government concept, *a reasonable level of profitability* for these sort of systems (Ministry of Industry Energy and Trade. Government of Spain, 2013). Following the previous RD, in June 2014, RD 413/2014 and the Ministerial Order IET/1045/2014 were published, revoking all existing remuneration mechanism and defining completely different new ones. These laws are the latest to regulate the production of electrical energy from renewable energy sources, cogeneration, and waste. In the case of PV plants, a new grouping of PV power ranges was established and the FiT payment mechanism was substituted for a more complex system. Additionally, an annual limitation of operational hours was set, and this RD included a revision to the payment parameters after a 6 years period (de la Hoz et al., 2016; Ministry of Industry Energy and Tourism. Government of Spain, 2014; Ministry of Industry Energy and Trade. Government of Spain, 2014), which is a source of uncertainty.

The immediate effect of these retroactive measures in Spain is that the country has been sued by several investors, as they claim the government has reneged on the original contract under which the investment was made, specifically, the legal framework under RD 661/2007 (Pentland, 2014; Rucinski and Rodríguez, 2013).

Nevertheless, the most severe consequence of the last RD is the lack of liquid assets and that many investors are facing unpredictably, which is analysed in this study (Daley, 2014). Around 60,000 small investors, like the one in this study, could be affected by the last Spanish law (ANPIER, 2015; Cala, 2013; Miralda, 2013; Nielsen, 2015; Rodríguez, 2013). The aggravating factor is that the government already knew that many investors would not be able to cover their loans, which explains why banks were notified to be prepared to refinance some PV investments in the country (Clark and Johnson, 2013). This is a problem for banks. Due to the changing regulatory framework some solar companies are suing banks recently as a consequence of presumably unfair loans (Kenning, 2016).

In this bankruptcy scenario, private equity or vulture funds are discovering market opportunities (Hirtenstein, 2016b; Wigglesworth and Johnson, 2012), either by acquiring PV-related enterprises or buying large PV plants (Gray and Clark, 2014a; Photon.info, 2017, 2015). In this scenario, even insurance companies are looking for new market niches (Gray and Clark, 2014b).

Therefore, under this unfavourable, unpredictable, and unstable regulatory framework, it is interesting to undertake a profitability and feasibility analysis of a real representative PV plant in order to check the extent to which these laws have influenced in the business model of already operating PV systems. Prior to the profitability and financial scenarios changes, this study conducts an exhaustive comparison of the estimations in energy versus the real production measurements in order to confirm the good original design and optimum operational state of the plant, thus verifying the reliability of the simplified calculation model used at the design stage.

Finally, this study analyses the evolution in the profitability parameters of the plant depending on the different legislative scenarios. Starting from the original business model at which the plant was planned, and comparing the profitability forecast with the real annual liquid assets, the consequences of the changes due to the Spanish PV legislation can be analysed. In order to complement other papers that mention a lack of studies of these retroactive measures (de la Hoz et al., 2016), this study intends to reveal the dramatic situation produced by a wrong rectification to a promotion policy. The analysis is based on real energy and economic data from one representative example of the 60,000 investors aforementioned, which is not so frequent in the policy literature. The added value of this study is that the owner of the plant is one of the co-authors of the paper; therefore, it creates a valuable link between research and the real operating PV industry. The results and conclusions could be very valuable for the design of future legal frameworks or for modifications of existing ones (López Polo and Haas, 2014).

3. Electricity production: original forecast vs real generation after 8 years of operation

3.1. Description of the PV plant with one-axis trackers

The PV plant under analysis is located in the south of Spain, precisely in the province of Granada (UTM coordinates X: 495.134; Y: 4.127.026; time zone: 30). The high values of solar radiation in the area, combined with cold wind flows from the nearby Sierra Nevada, make this location suitable for the production of large amounts of solar electricity, thus resulting in high energy yield rates.

The grid-connected PV plant is composed of 576 monocrystalline modules manufactured by Solara with an individual power of 190 W. Therefore, the system has an overall peak power of 109.44 kW. With the goal of accessing the maximum FiT payment available in Spain in 2007, the PV generator was connected to a three-phase inverter with a nominal power of 100 kW, manufactured by Xantrex (model GT100E).

Although there were no restrictions in the nominal power to be installed, the 100 kW cap that allowed the maximum remuneration could, at first glance, limit the energy generated. However, there were mechanisms in place to increment the electricity produced by each kW installed, thus obtaining higher energy yield rates and better profitability data (de Simón-Martín et al., 2013; Jones-Albertus et al., 2016). For this purpose, PV modules were mounted on tilted one-axis trackers, polar based, whose model corresponds to the Etatrack 1500 manufactured by Lorentz. Each tracker is composed of 12 modules, so the plant has 48 trackers. For the string configuration, 18 modules were connected in series. Therefore, a 1.5 tracker creates a string, of which the plant has 32.

Figs. 1–3 provide a wide overview of the PV plant and its electrical configuration, whereas in Table 1 describes the main characteristics of the plan.

3.2. PV electricity production estimation

During 2007–2008, most grid-connected PV systems in Spain were conceived merely as an investment product. Therefore the designs were somehow standardized in order to minimise installation cost. This standardisation to a nominal power of 100 kW, was indirectly imposed by the RD 661/2007 classification so investors could receive the maximum FiT for the energy produced.

Likewise, the result of this standardisation was that the estimates of the electricity produced was a second-level issue for many other

Fig. 1. Aerial photograph of the grid-connected PV plant (Adapted from Google Maps™).

projects at that time. Potential investors usually calculated the energy the PV plant could generate by round numbers according to the possible installed power, availability of space, and performance of PV plants in the surrounding areas. In this sense, this study intends to reproduce the simplified methodology used by the grid-connected PV plant promoter, which it is very illustrative of the trend existing in Spain at that time.

Once the location was chosen, the investor next studied solar radiation data for the area to predict electricity production, mainly for economic reasons rather than the availability of the solar resource. Among the radiation resources available on the internet, the plant used the data sources shown in Table 2 to obtain the annual horizontal global radiation values near the location of the PV plant (Huld et al., 2012; Joint Research Center. European Union, 2016; Ministry of Agriculture Food and Environment. Government of Spain, 2015; Satel-Light, 2015; Šúri et al., 2007).

The reasons for using these radiation data sources were twofold. First, their use was the most extended in the aforementioned standardisation of the PV designs and there is a small deviation among their radiation values. Sometimes, the differences between the measurement devices and the equations used to calculate the radiation variables, make the available data offer a large scattering when they are compared. According to certain studies, the differences may be up to 14% (Lorenzo, 2006; Perpiñán et al., 2007).

The data used for the energy estimations were the average among the radiation sources to reduce the divergence, so the daily average horizontal global irradiation (the H(0)) used in this study is 5.04 $\text{kWh}\,\text{m}^{-2}\,\text{day}^{-1}$.

After selecting the radiation data source, the simplified procedure for the AC energy generated by the PV system considered the influence of the inherent sources of losses that any such system has. Table 3 summarizes the losses considered for this system according to its characteristics and the performance of similar PV plants in the surrounding area. Moreover, the literature contains definitions of these performance losses, which corroborate the estimations made by the developer of the PV plant (Drift et al., 2007; Pérez-Higueras et al., 2010).

According to the losses considered, the theoretical performance ratio (PR) of the plant's system is 69.71%, which lies within the experimental range of PR values measured in Southern Spain.

To estimate the annual electricity production of any grid-connected PV system, it is necessary to know the radiation available on the plane of the arrangement (H(α,β)), the performance ratio, and the power of the system rated at Standard Test Conditions (P_{GPV}). There is a wide variety of methods for estimating the energy generated by any PV system (Fuentes et al., 2007), but for the scope of this work, this study considers a simplified one that uses the following equation (Abella and Chenlo, 2006; Commission, 1998):

$$E_{AC} = \frac{P_{PV}}{G_{STC}} \cdot H(\alpha, \beta) \cdot PR \cdot 365 \tag{1}$$

The divergence in the energy results, which depends on the calculation methodology used, are within the percentage of uncertainty that should be assumed in any PV prediction model (Herrmann et al., 1997; Müller et al., 2015).

The daily average horizontal global radiation value selected previously is referred to as a horizontal surface, but in the case of the plant in this study, the modules are mounted on one-axis trackers, so the energy collection is enhanced. According to the literature, the typology of the tracking mechanism and the solar resource in the location chosen, the solar radiation falling on the plane of the arrangement could be assumed to increment by around 47% with respect to the horizontal data; thus, in the Eq. (1), H(α,β) can be easily estimated as (de Simón-Martín et al., 2013; Narvarte and Lorenzo, 2008):

$$H(\alpha, \beta) = 1.47 \cdot H(0) \tag{2}$$

Under this calculation procedure and the installed power (109.44 kWp), the average annual forecast of energy production and its corresponding yield is summarized in Table 4.

The calculation of the electricity generated under this simple methodology has been validated with the results obtained from PV design tools such as those offered by the PVGIS© of the Joint Research Center (Joint Research Center. European Union, 2016) and the PVWatts® Calculator of the NREL (NREL, 2018). The performance data from Table 4 are well aligned with the results derived from these tools, provided a certain level of uncertainty, as in any case, as the meteorological data used for these simulations are not located in the immediate surroundings of the PV plant.

For the purposes of this study's analysis, the forecasted results are

Fig. 2. Detail of the PV plant and the tilted one-axis tracker.

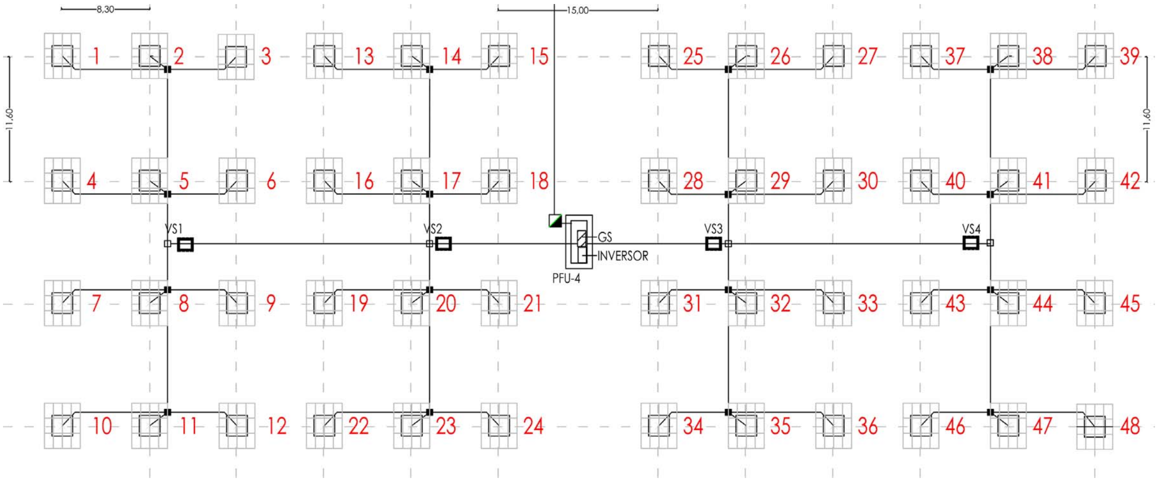


Fig. 3. Configuration scheme of the plant.

Table 1
Main electrical characteristics of the PV system.

PV generator configuration	
Series-connected modules per string	18
Strings in parallel	32
PV plant short-circuit current (A)	257.6
Open-circuit Voltage (V)	574.2
Current at the maximum power point (A)	236.48
Voltage at the maximum power point (V)	462.6
Maximum Power (kW)	109,440
Nominal Power (kW) (Inverter's)	100
Number of trackers	48
Modules per tracker	12

Table 2
Radiation data comparison of a nearby location of the PV plant.

Radiation data source	**Annual horizontal global Irradiation (kWh m^{-2})**	**Percentage difference from the average value (%)**
PVGIS©	1880	2,04
SATEL-LIGHT	1847	0,25
SIAR	1800	− 2,29
Average	*1842*	

Table 3
Performance losses assumed in the design.

Performance losses	
Mismatch	1.2%
Soiling	2.0%
Angular	1.7%
Spectral	1.5%
Low Irradiance	1.0%
DC wiring	0.3%
AC wiring	0.9%
Thermal	11.0%
Inverter	4.1%
Inverter MPPT	1.0%
Shadowing	5.6%
TOTAL	**30.3%**

valid enough, as the following section demonstrates.

3.3. Analysis of electricity generation through the grid-connected PV plant since its commissioning

The PV plant started operations in October 2007, but the first months should be rejected from any analysis because there were many stops due to adjustments issues. Therefore, this study's energy analysis starts from January 2008 onwards.

Table 4
Annual energy production estimations and energy yield.

Estimated performance	
E_{AC} (kWh year^{-1})	206,306
Annual final system yield (kWh kWp^{-1}year^{-1})	1885

The results shown hereafter refer to the electricity measured at the output of the energy meter; that is, just before its injection to the grid. Thus, it includes all potential losses estimated in Table 3.

Looking at the energy generated by the system during the first operational years (see Fig. 4), the simplified method used by the plant's promoter, where a round energy number was determined, confirms that the estimations are reasonably acceptable. Additionally, the generation-estimation balance lies within the uncertainty defined by some authors (Müller et al., 2015), which also explains why the reports generated by the PVGIS © tool show some differences. The underestimation that these authors mention is especially evident in the plant's performance in 2009.

It is important to highlight that since 2013, a progressive reduction in the energy generated by the system is observed, which became especially dramatic in 2015. This energy drop was caused by the breakdown of several motors in the trackers, which were not repaired due to the lack of liquid assets for maintaining the scheduled operation and maintenance (O&M) protocol. Presently, the solar trackers are south-fixed at the optimum position for this latitude awaiting a more favourable regulatory framework that at least does not affect the annual liquid asset. This issue will be covered in the following section as an example of how Spain's regulation is influencing PV plants to abandon O&M tasks.

To emphasise the adequacy of the generation-prediction comparison, in Fig. 5, the energy generation is disaggregated on a monthly basis. It can also be observed that the monthly predicted energy closely matches the real production data measured each month. For this analysis, the best and worst performance years of the plant were selected.

Delving into the discussion of the plant's good design in energy terms, although it is a general standardisation, the annual results are compared with two similar PV plants (same maximum power) that were promoted, designed, and implemented by different actors. These systems, which can be observed in Fig. 1 above our PV plant, use the same tracker but different PV module manufacturers.

The annual results in Fig. 6 confirm that the PV plant selected is

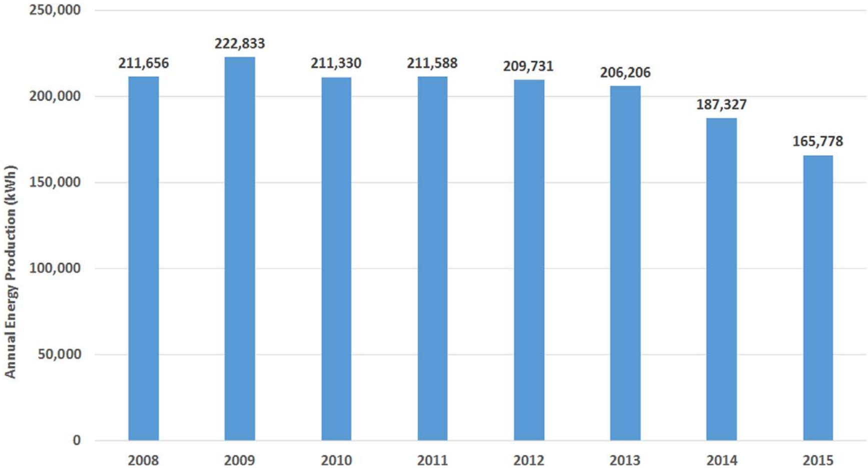


Fig. 4. Annual AC energy production of the PV plant.

optimally designed and the performance is within expectations. Moreover, these figures also reinforce the standardisation in the implementation of PV plants existing in Spain during 2007–2008.

Based on the data monitored, the performance ratio and the annual yield of the system can be deduced. Tables 5, 6 show the consistency of the theoretical data calculated and the real measurements according to the aforementioned underestimations. Table 5 also includes the worst period in order to analyse the effects that the lack of maintenance has on the plant's performance and to show that these O&M tasks are necessary, at least in energy terms. In further sections, the study will analyse whether O&M tasks are justifiable from an economic point of view. Regarding the PR values, it should be noted that they do not fully correspond with real data, as the radiation values could not be measured on-site. However, although these PR values may slightly differ from the real ones, they may be valid enough to show a trend.

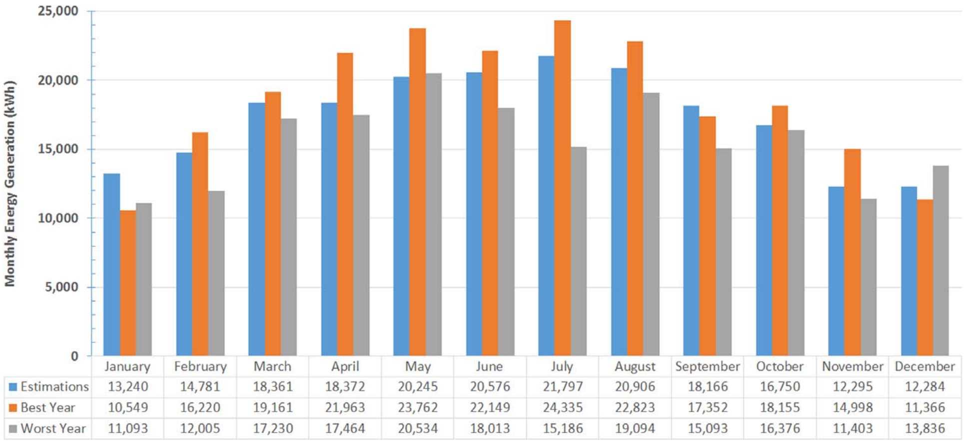
In summary, although the standardisation in the design and implementation stages of PV plants was a trend during 2007–2008, the analysis of the plant's energy production shows that, in this case, the energy generation figures overcame initial expectations, with the exception of the last two years due to a decrease in the O&M tasks. According to the regulatory framework existing in 2007, these good energy yield data should translate into a very profitable scenario as it was derived from a favourable FIT, to which the installation in this case study was subscribed. Indeed, the frequent changes in the regulatory framework in Spain brought the installation analysed in this study to a risky situation regarding its profitability and feasibility.

4. Influence of the changing regulatory framework in the profitability and feasibility of an operating PV investment

4.1. Business plan and profitability prospects

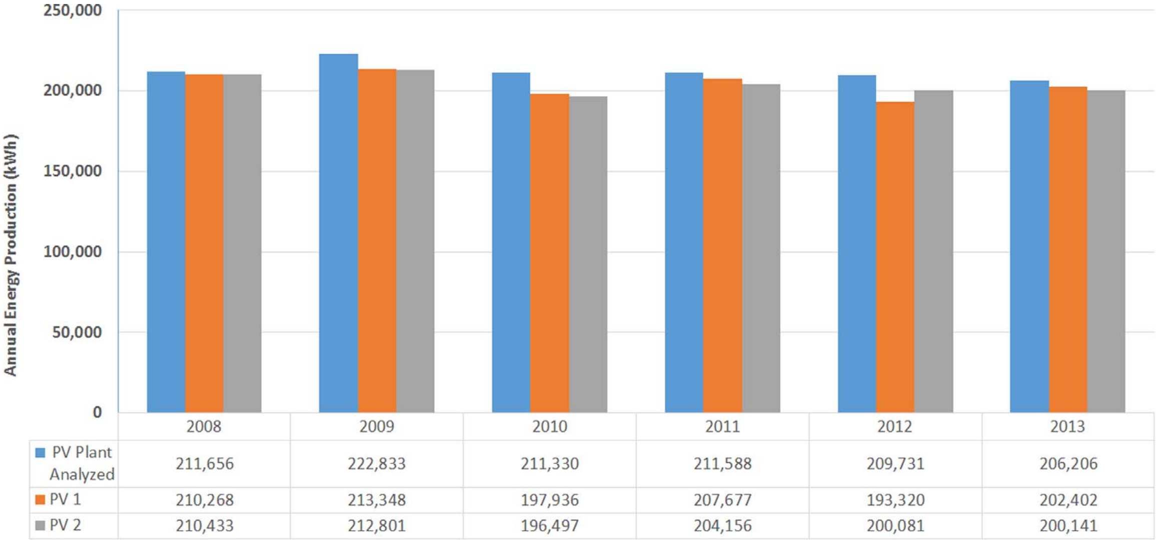
The case PV plant was commissioned in late 2007. At that time, the PV unit cost of a turn-key plant was surprisingly high ((IEA) International Energy Agency, 2008). The main explanation is that the industry was still not technologically prepared for an exponential deployment and a broad market penetration, in addition to a lack of stock, which mainly influenced the increase of the prices related to the PV modules (Rogol and Song, 2008). Nevertheless, the excess stock of subsequent years, the maturity of the manufacturing process, and the boost in the Chinese industry caused installation prices to drop, especially the unit cost of PV modules, which have dramatically decreased in the last years in terms of the balance of the system (Fraunhofer ISE, 2015).

According to the invoices of the PV plant under analysis, the cost of the whole intervention, fully installed, was up to 630,000 €. Therefore, considering the plant's peak power (109.44 kWp), the PV unit price amounted to 5.76 €·kWp^{-1}. In addition to the installation cost, the owner also acquired the land occupied by the PV system, so the total investment was up to 730,000€ (6.67 €·kWp^{-1}). Nowadays, with the current state of the art of the technology, this unit price could seem surprisingly high; however, in 2007, it was within the range of values considered in some PV reports ((IEA) International Energy Agency, 2008; Unión Fotovoltaica Española (UNEF), 2008). Fig. 7 provides a cost breakdown of the plant according to the constituent parts of the



	January	February	March	April	May	June	July	August	September	October	November	December
🟦 Estimations	13,240	14,781	18,361	18,372	20,245	20,576	21,797	20,906	18,166	16,750	12,295	12,284
🟧 Best Year	10,549	16,220	19,161	21,963	23,762	22,149	24,335	22,823	17,352	18,155	14,998	11,366
⬜ Worst Year	11,093	12,005	17,230	17,464	20,534	18,013	15,186	19,094	15,093	16,376	11,403	13,836

Fig. 5. Monthly energy estimations vs. electricity generated in the best and worst operational years.



	2008	2009	2010	2011	2012	2013
■ PV Plant Analyzed	211,656	222,833	211,330	211,588	209,731	206,206
■ PV 1	210,268	213,348	197,936	207,677	193,320	202,402
■ PV 2	210,433	212,801	196,497	204,156	200,081	200,141

Fig. 6. Electricity generation comparison of similar PV plants.

system, which corroborates the great influence of the PV module prices in the overall system's cost.

During the high deployment of PV systems in Spain during 2007–2008 promoted by the favourable legal framework, installations were conceived of as more like an investment product rather than an environmental awareness-raising and commitment issue (Gellings and Rutschmann, 2008). Even banks included such systems in their product portfolios offered to their clients.

According to this reality, the design of PV systems was greatly standardised and plant investors care about energy production only up to a certain point. The concern was more focused on how large the return on investment will be and to shorten its payback time, rather than reducing the electricity demand from fossil fuels. As an example, Fig. 8 provides a sketch of the initial business plan between the PV system promoter analysed in this study and the bank that financed it, where it is noticeable that there is no data regarding the potential amount of electricity to be produced.

Although the PV system analysed was originally planned under RD 436/2004, which really meant the starting point for the promotion of such systems, its full implementation and commissioning was undertaken once RD 661/2007 came into force in May 2007. As stated before, this legal framework was the real driving force for the deployment of renewable energies in Spain. Thousands of small and medium sized enterprises (SMEs) and particular investors started to plan their investment in this financial product, which shifted the country to a leading position in the annual rate of PV power installed. Table 7 summarises the main characteristics of this supporting legislation based of FiT (Ministry of Industry Energy and Trade. Government of Spain, 2007).

In 2007, the existing PV business scenario in Spain shows that most profitability studies were rather automated and standardized, and similar profitability values were expected from similar PV systems. However, in order to clarify the investment made by the owner of the plant under analysis, this study follows a similar procedure as in other theoretical studies in which the main parameters to assess the feasibility of a PV investment are the NPV and the IRR (Oiroli and Di Gangi, 2014; Talavera et al., 2016, 2014, 2011).

The NPV (see Eq. (3)) reflects the balance of the cash inflows (incomes) and expenses (outflow) at the end of the lifecycle of the PV investment (N). Normally, those annual quantities refer to the year of the investment.

$$NPV = \mathrm{PW}[\mathrm{Inc}(N)] - LCC \tag{3}$$

On the other hand, the *IRR* of the investment is defined as the value of the discount rate (d) that leads to $NPV = 0$. If IRR is above the WACC, which refers to the cost of financing the project, the investment is feasible from an economic standpoint.

In the analysis shown in this paper, the IRR is expressed in nominal terms, that is, it considers the effect of the inflation.

Analysing Eq. (3), the present value of the cash incomes may be formulated as follows:

$$\mathrm{PW}[\mathrm{Inc}(N)] = p_u \times E_{PV} \times \frac{K_{PU}(1 - K_{PU}^{N})}{1 - K_{PU}} \tag{4}$$

In the previous equation, p_u is the unitary price per kWh for the PV electricity injected to the grid, which, in this paper, is equal to the eligible FiT. E_{PV} is the annual energy generated by the PV system, as described in the previous section, and N is the operational lifecycle of the PV plant. In order to simplify the previous equation, we use the parameter K_{PU}, which considers the nominal discount rate (d), and the annual rate of increase in the FiT ($\varepsilon_{\mathrm{pu}}$) (see Eq. (5)). This study considers the annual rate of increase related to RD 661/2007 (see Table 7).

$$K_{PU} = (1 + \varepsilon_{pu})/(1 + d) \tag{5}$$

In Eq. (3), LCC stands for the Life Cycle Cost of the PV system, which is referred to as the annual expenditures. This variable depends on the initial investment ($\mathrm{PV_{IN}}$) and the present value of the annual O&M cost ($\mathrm{PW[PV_{OPEX}\ (N)]}$). According to the previous terms, LCC can be expressed as follows:

$$LCC = PW\,[PV_{IN}] + PW\,[PV_{OPEX}(N)] \tag{6}$$

Table 5
Measured average annual PR and yield of the system.

	Complete 2008–2015	Best period 2008–2012	Worst period 2013–2015	Original estimations
Average Annual PR (%)	68.61	72.02	62.91	69.71
Average yield (kWh kWp^{-1} year^{-1})	1857.7	1950.18	1703.56	1885

Table 6
PR and yield yearly disaggregated values.

	2008	2009	2010	2011	2012	2013	2014	2015
Average Annual PR (%)	71.42	75.2	71.31	71.4	70.78	69.59	63.21	55.94
Average yield (kWh kWp^{-1} year^{-1})	1933.99	2036.12	1931.01	1933.37	1916.41	1884.2	1711.69	1514.78

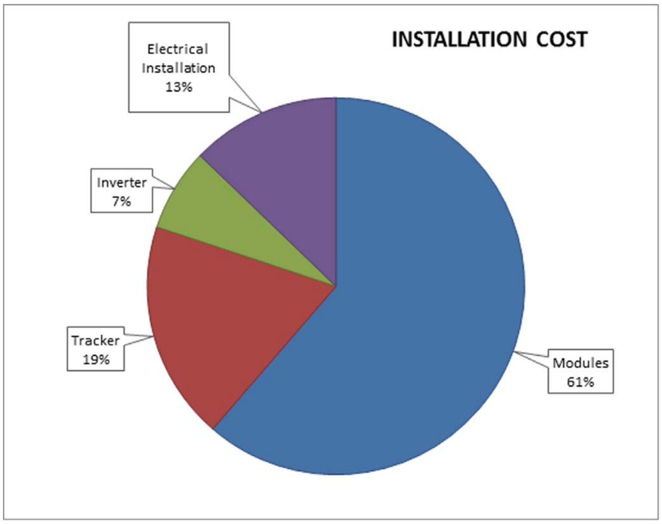


Fig. 7. Distribution of unit costs of the plant in 2007.

The business plan for this investment was completed through Real Estate Leasing, where the promoter financed 90% of the total cost with external capital (PV_{CAPEX}) through a long-term loan, and the remaining balance (10%) was private equity (PV_{EQ}). The loan term has an annual loan interest i_l and loan term N_l (years), while the private equity share has an annual retribution in form of dividends (d_i) and is amortized at the end of the lifecycle of the system.

Table 7
FIT terms of the RD 661/2007.

Power	Timing	Feed-in tariff (€/kWh)	Annual FIT updating mechanism	
P ≤ 100 kW	1–25 years	0.440	Until 2012	Inflation – 25 basic point
	From 25 years onwards	0.352	2012 onwards	Inflation – 50 basic point

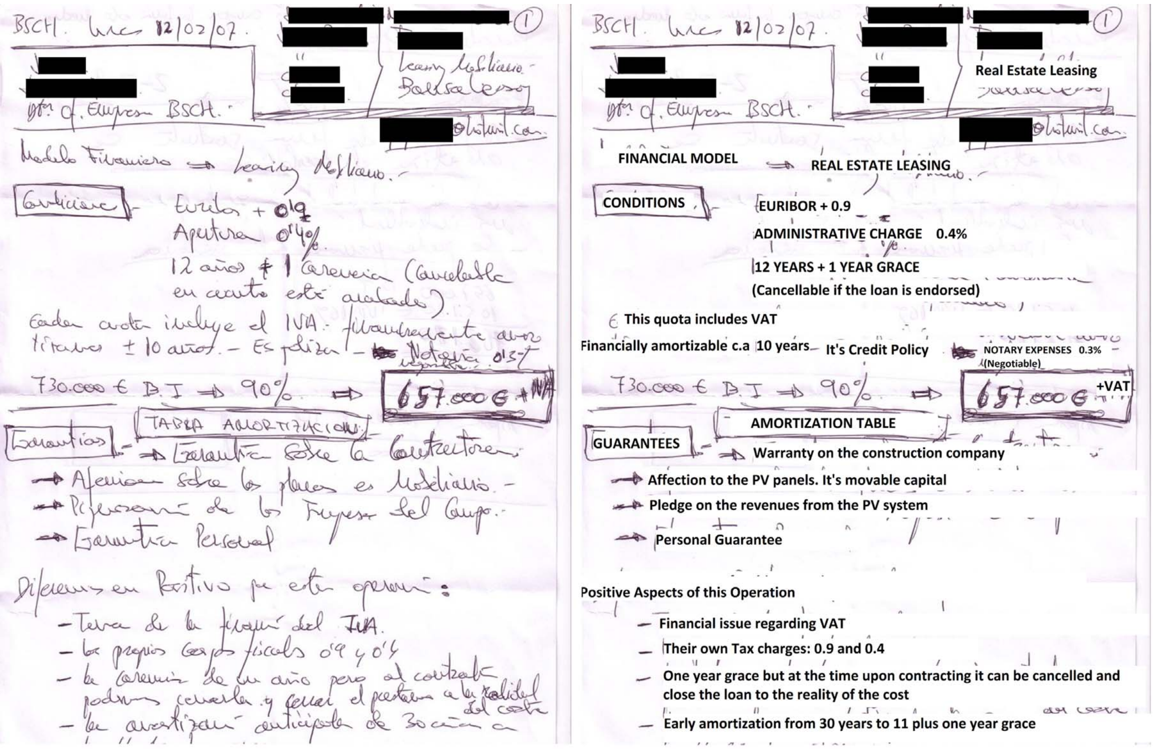
If PV_{EQ} (€) is the portion of the initial investment financed with private equity, the present value of the initial investment PW[PV_{IN}] can be formulated as:

$$PW[PV_{IN}] = \left((PV_{CAPEX}) \times i_l \times \frac{(1+i_l)^{N_l}}{(1+i_l)^{N_l}-1} \times \frac{q(1-q^N)}{1-q} \right) + \left((d_i \times PV_{EQ}) \times \frac{q(1-q^N)}{1-q} + PV_{EQ} \cdot q^N \right) \tag{7}$$

The factor q is related to the discount rate:

$$q = 1/(1+d) \tag{8}$$

The present value of the O&M cost PW[PV_{OPEX}] is calculated using Eq. (9), where PV_{OPEX} is the annual O&M cost of the plant, which is normally referred to as a percentage of the initial investment. Similarly, in Eq. (5), the parameter K_{OPEX} is used to simplify the equation considering the annual escalation rate of the system's O&M costs (ε_{OPEX})



BSCH. Lunes 12/02/07. [redacted] ①
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[redacted]
Dtor. of. Empresa BSCH.
Leasing Inmobiliario - Bolsa Leasing
[redacted]
[redacted]@hotmail.com

Modelo Financiero → Leasing Inmobiliario.

Condiciones - Euribor + 0'9
Apertura 0'4%
12 años + 1 carencia (Cancelable en cuanto esté acabado)

Cada cuota incluye el IVA. Financieramente amortizable ± 10 años. - Es política - Notaría 0'3% negociable

730.000 € B.I → 90% → 657.000 € + IVA

TABLA AMORTIZACIÓN.

Garantías - → Garantía sobre la Constructora.
→ Afección sobre las placas es Mobiliario. -
→ Pignoración de los Ingresos del Grupo.
→ Garantía Personal

Diferencias en Positivo para esta operación:
- Tema de la financiación del IVA.
- Los propios Gastos fiscales 0'9 y 0'4
- La carencia de un año pero al contratar podemos cancelarla y ajustar el préstamo a la realidad del coste
- La amortización anticipada de 30 años a

BSCH. Lunes 12/02/07. [redacted] ①
[redacted]
[redacted]
Dtor. of. Empresa BSCH.
Real Estate Leasing
[redacted]
[redacted]@hotmail.com

FINANCIAL MODEL → REAL ESTATE LEASING

CONDITIONS - EURIBOR + 0.9
ADMINISTRATIVE CHARGE 0.4%
12 YEARS + 1 YEAR GRACE
(Cancellable if the loan is endorsed)

This quota includes VAT
Financially amortizable c.a 10 years - It's Credit Policy → NOTARY EXPENSES 0.3% (Negotiable)

730.000 € B.I → 90% → 657.000 € +VAT

AMORTIZATION TABLE

GUARANTEES - → Warranty on the construction company
→ Affection to the PV panels. It's movable capital
→ Pledge on the revenues from the PV system
→ Personal Guarantee

Positive Aspects of this Operation
- Financial issue regarding VAT
- Their own Tax charges: 0.9 and 0.4
- One year grace but at the time upon contracting it can be cancelled and close the loan to the reality of the cost
- Early amortization from 30 years to 11 plus one year grace

Fig. 8. Sketch of the business plan and financial mechanism for the PV plant's funding.

Table 8
Factors considered for the PV Business Plan.

Factors		Units	Value
Annual Yield	Y_{PV}	kWh/kWp/year	1885
Initial investment cost of the plant	PV_{IN}	€/ kWp	6670.32
External capital Loan	PV_{CAPEX}	% PV_{IN}	90%
Private Equity capital	PV_{EQ}	% PV_{IN}	10%
PV electricity unitary price received (FiT) (before VAT taxes)	p_u	€/ kWh	0.440381
VAT 2007–2010		%	16
VAT 2010–2012		%	18
VAT 2012 -onwards		%	21
Annual increase rate of the electricity price injected to the grid (FiT increase)	ε_{pu}	%	2
Annual Operation and Maintenance Cost (Annual percentage referred to PV_{IN})	PV_{OPEX}	%	2.5
Annual increase rate of the operation and maintenance cost of a PV system	ε_{OPEX}	%	2
Annual degradation rate of the PV power	r_d	%	0.8
Nominal discount rate (= WACC)	d	%	4.58
Annual loan rate	i_l	%	Variable (APR + 0.9%)
Loan duration	N_l	years	12(+ 1 year grace)
Dividends rate	d_i	%	4
Life cycle of the PV plant	N	years	25

$$PW[PV_{OPEX}] = \left(PV_{OPEX} \times \frac{K_{OPEX}(1 - K_{OPEX}^{N})}{1 - K_{OPEX}}\right) \quad (9)$$

$$K_{OPEX} = (1 + \varepsilon_{OPEX})/(1 + d) \quad (10)$$

Reviewing the business plan sketch from Fig. 8 and according to the equations described above, Table 8 summarises the values of all the parameters considered. In this scenario, with the original RD 661/2007, Table 9 shows the forecasted profitability indices for the investment.

With the eligible FiT and the energy produced in 2008, the monetary incomes during the first operational year were up to 97 779€, which was far above the outcomes resulting from the loan, equity bond, and O&M terms. Therefore, assuming a similar energy generation scenario and accounting for the updating mechanism considered in this RD, the expected incomes for future years could be around 98 490€, as was forecasted for 2013 (see Table 10). In this context, no liquid assets problems seem to appear. Therefore, it could be stated that this PV investment is profitable and feasible.

4.2. Real profitability of the 100 kWp system: parallel between its involution and the regulatory framework retroactivity

Despite the aforementioned PV design standardisation, it is obvious that the larger the electrical production is, the greater the revenues resulting from the FiT remuneration, so the original profitability indices could be improved. According to the results of the previous energy analysis, the operational yield of the selected PV plant was above the calculations, and subsequently, the revenues could be expected to be slightly higher than the ones predicted. However, Fig. 9 shows that some differences between the PV electricity generated and the energy remunerated.

During 2008, 2009, and 2010 all the electricity billed was subject to the FiT, but the amount remunerated was less than that generated originally, mainly for two reasons. The first was due to the plant's own consumption, which lies within a reasonable rate, but the additional difference in the energy billed was controversially justified by a fee that the electrical company imposed in terms of a so-called ‘loss rate’. This rate was established in 2.35% of the net electricity produced by the plant; that is, the AC injected minus the internal consumption.

Table 9
Profitability estimations in 2007.

	Estimation in 2007
IRR	10.14%
NPV	482,204€

Table 10
First year incomes and forecast for 2013.

	Incomes
2008	97779 €
2013 (forecasted)	98490 €

The differences between the variables PV billed and PV billed (FiT), which is noticeable from 2011 onwards, is whether all of the electricity eligible for remuneration was at FiT conditions or at a different price. The cases where FiT was not applicable to all of the energy generated was billed according to the wholesale electricity market conditions.

According to the energy values in Fig. 9, from 2011 to 2013, there is a huge gap between the energy generated and the PV electricity billed at FiT conditions. The main reason is that in October 2010, the government introduced the first retroactive measure, when the number of operational hours subject to FIT remuneration was limited until December 31st, 2013. For one-axis tracking plants in the southern Spain, this maximum was 1644 h, from which the energy generated was paid at the wholesale electricity market price instead of the original FiT.

Throughout 2011–2013, this energy limitation was approximately achieved in September, so there was an average of 19% of the annual production that was paid at around 0.05 €/kWh instead of approximately 0.48 €/kWh (FiT + VAT). Obviously, this retroactive measure had an undesirable effect on the owner's planned profitability scenarios, as it directly affected the cash inflows of the economic balance.

In 2014, the legal remunerative scenario was completely modified, not only for prospective installations, but for existing ones as well. The justification was the Spanish economic crisis and presumably an alleged imbalance between the electricity systems cost and the incomes that the Government obtained through regulated electricity tariffs. This imbalance was additionally exacerbated by the overpaid FiT to renewables according to some social agents. RD 413/2014 and the Ministerial Order IET/1045/2014 abolished all previous subsidy payment mechanisms and established a ‘*reasonable return on investment*’ of around 7.4% for existing plants and just 5.4% for future plants. Table 11 provides a brief explanation of the new and complex remuneration scheme (Ministry of Industry Energy and Tourism. Government of Spain, 2014), which was further detailed in other works (de la Hoz et al., 2016).

In this Ministerial Order, the existing PV plants were regrouped under 578 different PV installations, each entitled to a different value of the concepts detailed in Table 11. Additionally, the values assigned are subject to a partial revision every 3 years and they could be completely modified every 6 years. In the first revision, the estimations correspond to the incomes resulting from the sale of electricity to the wholesale

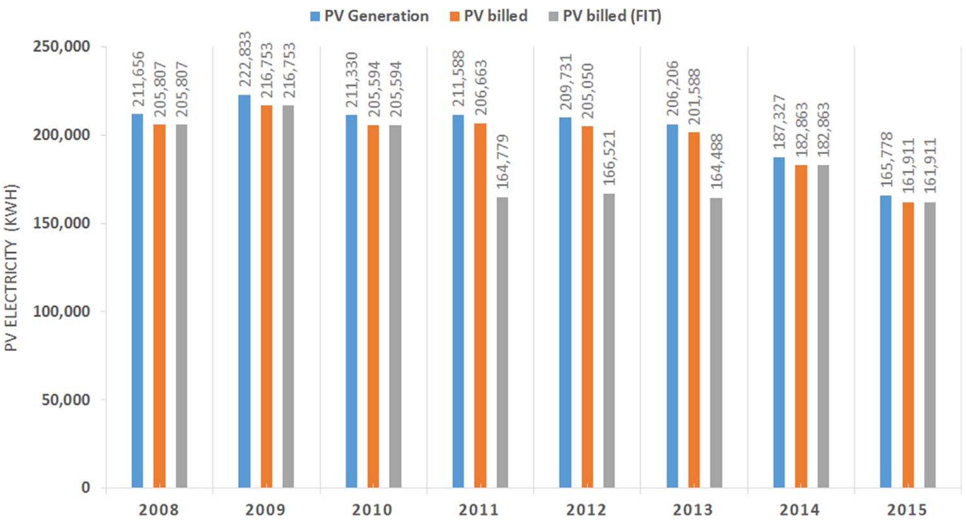

Fig. 9. Energy generated versus energy billed.

market could be reviewed, while the complete revision could affect all terms so as to redefine or adjust this '*reasonable return on investment*'. In light of these facts, these revisions add an extra uncertainty level to the already damaged investments in this technology.

According to the year of commissioning, the sort of PV plant built, and its nominal power, the concepts corresponding to the system analysed in this study are summarized in Table 12 (Ministry of Industry Energy and Tourism. Government of Spain, 2014).

Therefore, the first question that may arise is whether the original PV investment maintains its expectation for the IRR. If the IRR data from Table 9 (10.14%) is compared with the 'forced' IRR established in the last RD, it is clear that the expectations will be lower. Nevertheless, the novelty of this study comes from a deep analysis of the cash flows, uncovering other hidden risks for the PV investors.

Fig. 10 provides a graph of the annual evolution of the incomes received by the plant's owner. This figure shows two sets of values. The calendar year values correspond to the incomes received during the year under consideration, but there is a decoupling between the real energy generated and the incomes, as there is a liquidity gap sometimes. In order to overcome this issue, the same graph plots balanced year values, where the incomes, although received in a deferred time, have been coupled to the month of energy production. Therefore, the balanced year values perfectly match the incomes generated with their corresponding energy months.

In Fig. 10, the income reduction during 2011–2013 is clearly significant due to the cap imposed by the limitation of hours. In this period, much less energy was billed at the FiT compared with the original generation value. On the other hand, the effect of the last Ministerial Order applicable since 2014, which introduced a completely new remuneration scheme, can be observed. The deep reduction suffered in the calendar value in 2014 is remarkable, and is due to a default in a government payment. Therefore, although the plant's owner finally received the corresponding payment, at certain periods, this default caused an undesired and unexpected reduction in income, obliging the owner to add more working capital, thus reducing the profitability of the plant.

One may argue that the decrease in income is proportionally related to the reduction in the electricity generated due to the plant failing to follow an O&M protocol. First, the decrease during 2011–2013 was independent of the electricity generated, as the government established a cap for the number of operating hours. Therefore, although the energy produced in this period is within the average value from the previous years, the income is significantly lower. On the other hand, the percentage reduction in the electricity generated is less pronounced than

Table 12
Concepts applied to the PV plant according to IET/1045/2014.

Concept	
Ro (€/kWh)	0.024344 €/kWh
Rinv (€/kW)	637435 €/MW (53.12 €/kW/month)
Pool (€/kWh)	Variable (Depends on the market) (around 0.052 €/kWh in 2015)
Nmax (h)	2102 h
Nh (h)	1261 h
Uf (h)	736 h

Table 11
Main concepts defined in the new regulatory framework in Spain.

Concept		Definition
Ro (€/kWh)	**Operation Remuneration**	Remuneration depending on the energy injected to the grid which cannot be compensated through the sale of the electricity to the wholesale market
Rinv (€/kW)	**Investment Remuneration**	Remuneration depending on the installed power[a] in order to compensate for the investment cost which have not be recovered through the Net Present Value formulae and will not be recovered by the exploitation incomes in the lifetime service of the plant
Pool (€/kWh)	**Electricity Wholesale market**	Electricity produced injected to the grid and sold like all the generating energy plants existing in Spain at the wholesale market
Nmax (h)	**Maximum Operating hours**	Maximum hours which correspond to the quantity of energy injected to the grid entitled to receive remuneration from Ro and Rinv terms. The electricity sold at pool is excluded from this limitation
Nh (h)	**Minimum Operating hours**	Minimum hours entitled to receive 100% of Ro and Rinv terms. The electricity sold at pool is excluded from this limitation
Uf (h)	**Operation Threshold**	Minimum number of hours to receive any remuneration at all. The electricity sold at pool is excluded from this limitation.

[a] Instead of using Peak power, this term is referred to the nominal power, therefore there is a reduction in this compensation according the original investment.

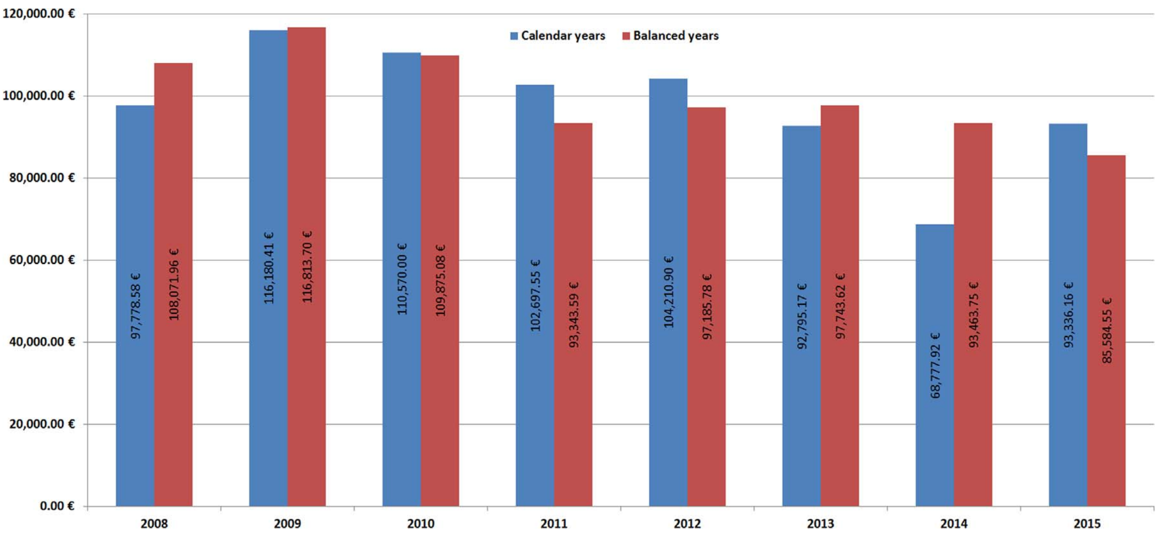

Fig. 10. Annual evolution of income.

the income decrease.

To support the argument that this income reduction is independent of the energy drop presumably caused by the absence of a proper O&M protocol, the revenues from 2015 are compared with the possible revenues from the energy generated in the best year under the remuneration concepts of the last Ministerial Order. In this analysis, the average electricity produced considering the best years, that is, 2008–2012, will be also taken into account. Table 13 reports the results.

Because the VAT tax has changed several times in the period analysed, to avoid distortions, we exclude this while comparing the incomes. Therefore, the taxable incomes from 2015 (balanced value), that is, eliminating the 21% VAT, is 70 731.03€. If this quantity is compared with the results in Table 13 (translated incomes concept), it can be observed that the revenues only differ around 11%, whereas the differences in energy increase to 26% and 22% compared to amount generated in 2015, with the best and average years, respectively. Therefore, the energy losses are not directly proportional to the decrease in incomes.

Finally, the expected income that the owner foresaw for 2013 in the original business plan was 84 905.17€, excluding 16% of the VAT (see Table 10). This value clearly differs from the real values that year, when the plant received only 80 779.85€.

Therefore, it is proven that the changing regulatory framework has negatively influenced not only the profitability of already operating PV investments, but in its feasibility too, producing an involution in parallel with the retroactive measures of the laws in Spain.

Table 13
Comparison of the best and average annual incomes translated to the 2014 legal framework.

Concept	Best year (2009 → 222833 kWh)	Average "good" years (2008–2012 → 213000 kWh)
Ro (€/kWh)	5112.24 € (limit of 210000 kWh)	5112.24 € (limit of 210000 kWh)
Rinv (€/kW)	63743.5 €	63743.5 €
Pool (€/kWh)	11587.32 €	11076 €
Extra fees and self-consumption	− 1252.41 €	− 1189.96 €
Original Incomes (no taxes considered)	100701.47 €	95865.55 € (2008–2010 average incomes)
Translated Incomes (no taxes considered)	79190.65€	78741.78 €

4.3. Side effects

Although the reduction in the expected profitability index could be reasonable to a certain point, and the owner could somehow withstand this loss, the first immediate side effect was the legal uncertainty that these constant changing laws produced for current owners. Would the Ministerial Order from 2014 be the last one, or would there will be a downward revision of the subsidy payment variables after the 6-year period? It is important to mention that the next revision will be in 2020, when most of the PV owners are at the end of their loan terms. Therefore, it could mean an opportunity to further reduce the profitability of these plants.

Nevertheless, besides the legal instability for current and prospective ones, a critical side effect is detected if the outcomes are also analysed in combination with the incomes studied in the previous section. Figs. 11 and 12 show the annual cash flow of the PV plant considering both calendar and balanced years.

The results follow a similar trend until 2013, as the reduction in profit is evident, albeit this tendency reversed in 2014 and 2015, where there is lack of annual liquid assets, specially remarkable in 2014 (calendar year) as a consequence of a default in Government's payment.

On examining in detail the cash flows since 2013 (Tables 14–16), although it may seem that there is a positive annual liquid asset depending on whether the calendar or balanced years are analysed, actually, the owner has a negative balance several times each year. Therefore, the investor requires more working capital, which has to be anticipated in order to avoid bank overdrafts and debt default. In other words, the owner is indirectly refinancing the plant by regular cash injections as the Ministry does not pay in time. The main problem is that many investors do not have sufficient economic power or bank support to apply for more loans to refinance their photovoltaic plants in order to obtain this working capital.

If no further changes are made in the Spanish legislation, and accounting for this increase in the working capital, the IRR has shifted down to 6.98%, which it is even below the "reasonable" rate of 7.4% imposed by the Government. However, although this decrease, it is still above the WACC.

A second-level side effect that the current legislation is causing in Spain is the progressive abandonment of PV plant maintenance protocols in order to avoid or minimise the lack of liquid assets. This

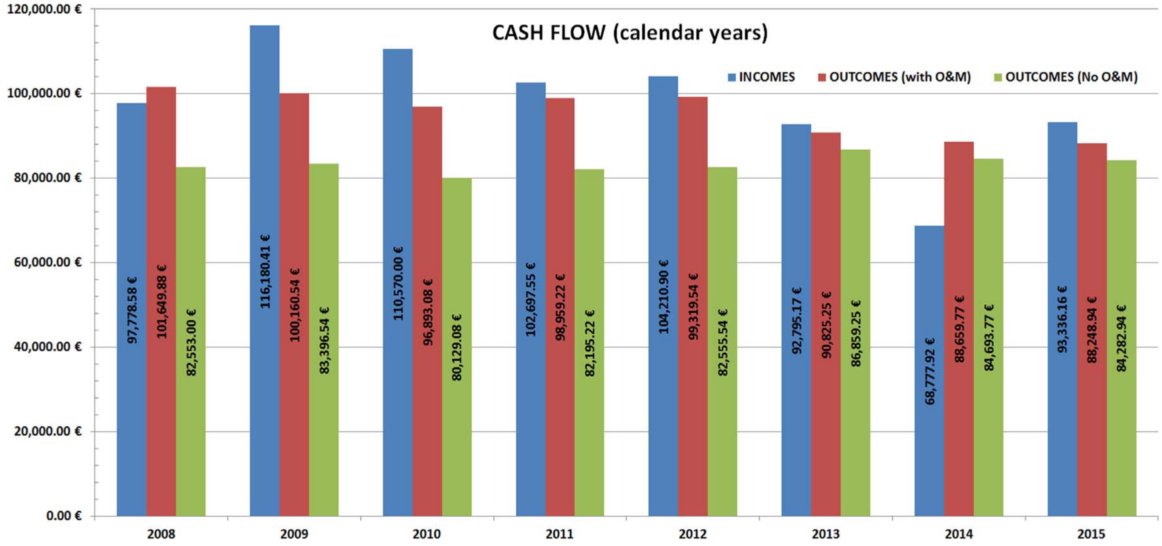

Fig. 11. Cash flow (calendar years).

information can be deduced from Figs. 11 and 12 when comparing 2008–2012 ($OPEX_{08–12}$) and 2013 onwards ($OPEX_{13–15}$). As an extreme situation, the negative liquid assets in 2015could be avoided by cancelling the O&M costs.

Although the OPEX decrease means an energy reduction, the maximum threshold of operational hours for the variable remuneration (R_O) and the low unit cost assigned to non-subsidized production (Pool) of the last applicable legislation can lead to a situation where, from an economic point of view, it is more feasible to decrease the annual OPEX at the expense of reducing the electricity produced, but maintaining positive revenues (minimally). This situation makes any improvement in the plant with the aim of optimizing its performance meaningless. For example, analysing the energy generated from 2010 and 2013 (Fig. 10), for example, there is a difference of 5124 kWh/year, which correspond to a non-subsidized production income of around 260€. According to the annual production cap, the owner will receive not much more income from the subsidized production; therefore, comparing the savings in $OPEX_{08–12}$ and $OPEX_{13–15}$ (c.a 12,000€) with the incomes, the ‘advantage’ of abandoning the plant is somehow evident.

Table 14
Cash flow summary for 2013.

Outcomes			Incomes	
Date		Leasing + vat	Settlement period	Billing + vat
January	2013	7313.85 €	nov-12	440.56 €
February	2013	7313.85 €	dec-12	613.60 €
March	2013	7088.59 €	jan-13	8387.6 €
April	2013	7088.59 €	feb-13	8374.47 €
May	2013	7088.59 €	mar-13-settel. 2011	3840.29 €
June	2013	7088.59 €	apr-13	10732.97 €
July	2013	7088.59 €	may-13	11420.80 €
August	2013	7088.59 €	jun-13	12273.85 €
September	2013	7088.59 €	jul-13	11599.18 €
October	2013	7088.59 €	aug-13	10881.31 €
November	2013	12400.24 €	sep-13	9829.13 €
December	2013	7088.59 €	oct-13	4401.41 €

5. Conclusions

This study analyses an operating PV plant commissioned in Spain in 2007 from an energy and economic point of view in order to assess the

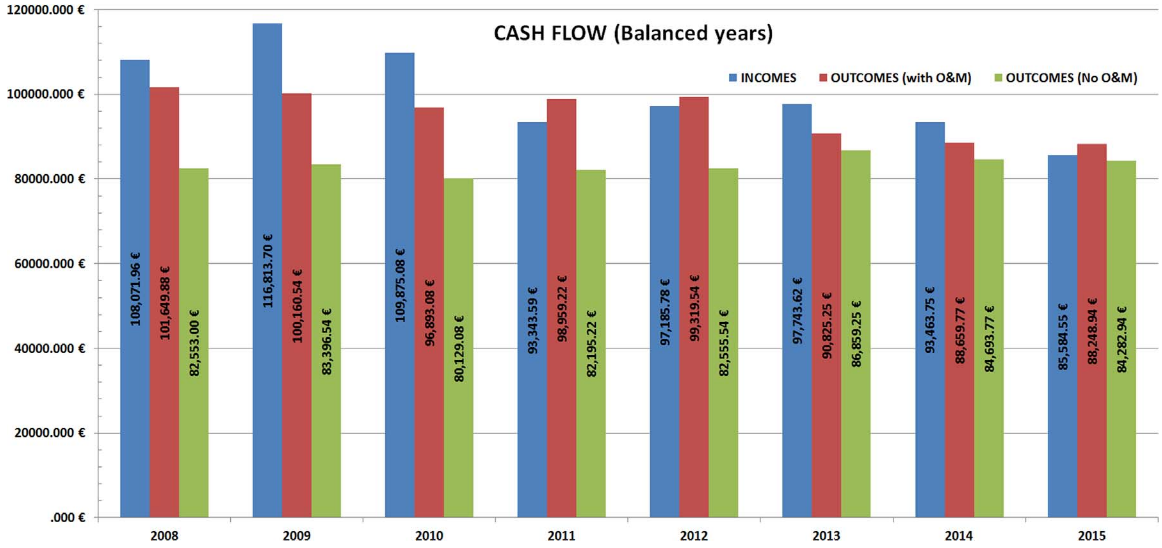

Fig. 12. Cash flow (balanced years).

Table 15
Cash flow summary for 2014.

Outcomes			Incomes	
Date		**Leasing + vat**	**Settlement period**	**Billing + vat**
January	2014	7088.59 €	nov-13	604.60 €
February	2014	7088.59 €	dec-13	922.03 €
March	2014	7088.60 €	jan-14	1826.11 €
April	2014	7088.60 €	feb-14	4215.69 €
May	2014	7088.60 €	mar-14	6944.25 €
June	2014	7088.60 €	apr-14	6165.78 €
July	2014	7088.60 €	may-14	6268.55 €
August	2014	7088.60 €	jun-14	6240.18 €
September	2014	7088.60 €	jul-14	9449.13 €
October	2014	7088.60 €	aug-14	7358.96 €
November	2014	10,685.14 €	sep-14	7772.11 €
December	2014	7088.65 €	oct-14	11010.53 €

Table 16
Cash flow summary for 2015.

Outcomes			Incomes	
Date		**Leasing + vat**	**Settlement period**	**Billing + vat**
January	2015	7088.60 €	nov-14	7079.22 €
February	2015	7088.60 €	dec-14	10353.39 €
March	2015	7047.52 €	jan-15	2858.48 €
April	2015	7047.52 €	Settl. 2014	6343.55 €
May	2015	10644.06 €	feb-15	13415.21 €
June	2015	7047.52 €	mar-15	7700.61 €
July	2015	7047.52 €	apr-15	6196.91 €
August	2015	7047.52 €	may-15	8998.26 €
September	2015	7047.52 €	jun-15	6647.03 €
October	2015	7047.52 €	aug-14	8252.02 €
November	2015	7047.52 €	sep-14	8501.23 €
December	2015	7047.52 €	oct-14	6990.25

influence of the promotion policies on the profitability of this investment and in the energy generation figures due to of the abandonment of maintenance tasks.

Related to the energy analysis, although the design and implementation of such systems were rather standardised in Spain, the annual measures demonstrate that the real results even improve the initial energy expectations. Consequently, this is a sign that during the Spanish boom and the experience gained, the PV industry reached a remarkable maturity, making the country a leader within the PV market.

Nevertheless, the retroactive legal measures affecting RD 661/2007 PV plants implied energy losses of around 19% for 2011–2013 due to the annual operation limit imposed, which shifted expectations downward to 2% from 2014 onwards due to the maximum operating hours (Nmax) defined in the last RD 413/2014 and in Ministerial Order IET/1045/2014.

Additionally, the most detrimental effect of these laws was that many small investors are being indirectly forced to abandon their plans; in other words, to cancel the annual expenditures on O&M tasks, so they can divert this OPEX to their loan duties and overcome possible bankruptcy scenarios. In the case of the plant analysed in this study, although this abandonment could mean energy losses of up to 22%, it avoids total bankruptcy in its PV business.

In an international scenario, where promoting renewable electricity is the mainstream policy, the indirect encouragement of energy losses from renewable sources like PV fostered by the Spanish government is somehow remarkable.

The economic perspective shows a dismal outlook. After the induced modifications in the subsequent regulatory frameworks in Spain, PV economic investments have changed from an attractive initial profitable scenario to a limited situation in terms of the original business plans for the installations. With the last governmental actions, the chances of covering the loans by which the PV plants were financed under the framework of Spanish RD 661/2007 are in the borderline and sometimes below, as this study shows, which explains why thousands of small investors in Spain are selling their plants to international vulture funds.

In the case analysed in this study, it could be concluded that although the PV plant will be profitable at the end of its lifetime (IRR = 6.98%), provided that the Government makes no further changes, the investment is no longer feasible because the owner has to invest extra working capital to overcome the shortage of annual liquid assets that this law introduces. In most cases, these investors are selling their profitable but unaffordable PV plants.

Moreover, the new legal framework imposes a maximum and minimum threshold of operational hours. Although this situation, especially in regards to the minimum threshold, could have represented an opportunity to force the owner to maintain their plants at their optimum status and therefore generate as much electricity as possible; paradoxically, RD 413/2014 set the minimum number of hours below 50% of the average operational hours of a standard PV system in Spain, so the question that arises is whether it is worth keeping the annual investment in O&M protocols to obtain high energy yields provided that the minimum threshold is reached, as the economic effort to optimally maintain the plant does not overcome the maximum hours cap and its corresponding incomes.

Moreover, this lack of liquid assets is additionally damaged by the slow pace of the government's subsidy payments.

This study confirms that the bankruptcy scenario that the owner of this PV plant in particular, and around 60,000 small investors in Spain, are facing was mainly caused by the changes in the regulatory framework promoted by the Spanish government, whose retroactive effects are incompatible with the original business scenario, at least from a financial perspective, as the economic parameters are still positive, although much less profitable than the initial expectations. Therefore, the results prove the influence of changing promotion policies in the profitability of such investments.

Changes in policies are not bad by themselves, if they are properly planned in advance. Although it may discourage future investors at some point, they may still may a margin of benefit depending on the financial strength of the promoter.

In this study, when mentioning the financial risk that discourages investors, it focused on policies made with retroactivity, not on changes affecting future PV investment. Supposedly, there are no better guarantee for an investment than one offered by any government, but if once the investment is made, the rules of the game change, an atmosphere of mistrust arises for future investors, who may be suspicious of legal guarantees offered by the government regarding their investment. If these prospective investors are large capital firms, they have the capacity to fight back, as recent reports show. However, in the case of these 60,000 SME owners, the helplessness is stifling.

However, an important conclusion is that these policies changes increase risks (regulatory risks), as they create an environment of uncertainty for future investor. The consequence of such risk increases is that investors will require a higher return on their capital (equity) which will result in a higher WACC.

In this discouraging scenario for prospective investors, vulture funds are surprisingly finding an opportunity to capture a new market niche. Thus, there may be a certain degree of government complicity with some powerful equity funds or energy companies, which are also acquiring many of the bankrupted PV investments.

Paradoxically, a distributed energy system like PV should represent accessibility to the general public, but is being advocated to large enterprises, setting SME investors aside.

Finally, this sort of profitability study that considers a retrospective scenario could offer some useful lessons learned for the implementation of prospective promotion policies for solar PV in emerging countries where this technology is becoming a reality in their energy generation mix.

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Appendix A: Terminology

α	Azimuth angle
β	Tilt angle
APR	Annual charge rate (%)
d	Discount rate (%)
d_i	Dividend rate or annual retribution rate for private equity (%)
$\varepsilon_{\mathrm{pu}}$	Annual increase in the FiT (%)
ε_{OPEX}	Annual increase in the operation and maintenance cost of a PV system (%)
E_{AC}	Alternating energy injected to the grid (kWh)
E_{PV}	Annual energy generated by the PV system (kWh)
FiT	Feed-in Tariff (€)
H(0)	Daily average horizontal global irradiation
H(α,β)	Daily average global irradiation on the surface of the module
i_l	Annual loan interest (%)
IRR	Internal rate of return (%)
LCC	Life cycle costs of the PV plant (€)
LCOE	Levelised cost of electricity (€/kWh)
MPPT	Maximum power-point tracking mechanism
N	Useful life of the PV plant (years)
Nh	Minimum operating hours (h)
N_l	Time duration of the loan (years)
Nmax	Maximum operating hours (h)
NPV	Net present value (€)
O&M	Operation and maintenance
OPEX	Operation expenditures
$\mathrm{P_{GPV}}$	Power of the PV system rated at standard test conditions (W)
Pool	Electricity wholesale market (€/kWh)
PR	Performance ratio
p_u	Unit price per kWh for the PV electricity injected to the grid (€ $\mathrm{kWh^{-1}}$)
PV	Photovoltaic
PV_{CAPEX}	Capital expenditure (external financing of the PV investment) (€)
PV_{IN}	Initial investment of a PV plant (€)
PV_{EQ}	Initial investment of the plant financed with private equity (€)
PV_{OPEX}	Annual operation and maintenance costs (€)
$PW[Inc(N)]$	Present value of the cash inflows of a PV investment (€)
PW[PV_{IN}]	Present value of the initial investment (€)
PW[$\mathrm{PV_{OPEX}}$ (N)]	Present value of the operation and maintenance costs (€)
RD	Royal decree
Rinv	Investment remuneration (€ $\mathrm{kW^{-1}}$)
Ro	Operations remuneration (€ $\mathrm{kWh^{-1}}$)
SME	Small and medium sized enterprises
Uf	Operation threshold (h)
UTM	Universal Transverse Mercator
VAT	Value-added tax
WACC	Weighted average cost of capital
Y_{PV}	Annual yield of the plant (kWh $\mathrm{kWp^{-1}}$ $\mathrm{year^{-1}}$)

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