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Evolution of the cost and economic profitability of grid-connected PV investments in Spain: Long-term review according to the different regulatory frameworks approved

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ABSTRACT

Spain has shifted from a predominant position in the worldwide market according to the accumulated PV power installed, to an irrelevant level where it is even no longer present at the PV market survey; but not always this has been the situation.

The Spanish Government have promoted renewable energy policies which have turned very rapidly from a promising scenario, especially in the 2004–2008 period, into an unstable situation not only for future investors in this technology, but also for current owners that have been witnesses of a decrease in their profitability expectations. Furthermore, although the retroactive measures that have been applied to the owners of these PV plants could be, paraphrasing the Government words, "reasonable profitable", the problem arises when they may be unable to afford the annual liquid assets of the funding mechanism chosen for their PV investments.

Therefore, in a scenario where in the last decade more than 12 laws and Royal Decrees have been promulgated in Spain, it is interesting to review the effects in the profitability and cost parameters that this legislation has had on the PV market, on the owners and also on prospective investors.

In this paper a complete economic profitability and cost analysis based on the NPV, IRR and LCOE has been undertaken for the case of Spain since 1998, correlating it to the evolution of the legislative framework applicable to the photovoltaic technology.

Contents

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1. Introduction

In 2009, the worldwide PV capacity was around 24 GW, meanwhile in 2010 and 2011 it reached 40 GW and 71 GW respectively. The following years also experienced an incremental trend, when in 2012 and 2013 an additional power of 102 GW and 139 GW was installed respectively. The PV technology is increasing not only its cumulated capacity, but its annual installation rate is also raising [1].

Historically, European countries have been the leaders in annual installation rate, but although Europe is still the region where there is more PV power installed with around 82 GW, China and other Asian- Pacific countries are rapidly surpassing the European annual increase rate in PV capacity [1]. During these European boosting years, Germany was the first market for PV systems. This country installed 7.5 GW in the period 2010–2012, summing up 32 GW of PV power capacity at the end of 2012. Regarding the regulatory framework, this country has phased out feed-in tariff supporting schemes, encouraging at the same time other supporting mechanisms like the self-consumption, in addition to the establishment of new incentives which facilitate the implementation of distributed generation systems [2].

In the 2007–2012 period, throughout Europe existed some sort of uncontrolled expansion of these systems, which turned into a rationalization of new PV power installations through the promulgation of several policy measures to restrain their development. Some of these actions have been retroactively applied, producing a certain degree of instability in the sector and also a potential danger for the viability of existing plants [3].

In the case of Spain, it could be assessed that this country was the first boom and boost country in the European region. During 2007 and 2008, PV installations soared in the country when the annual power installed reached 512 MW and 2700 MW respectively. In those years Spain achieved a prevailing position in the market, becoming the world leader in annual installation rate with a total PV power capacity over 3.5 GW.

The boom of the Spanish PV industry was fostered by several favorable renewable energy policies [4], but although the great solar potential of Spain, the reality is that, on the basis on the previous installation data, this country yielded its predominant position in the worldwide PV market long time ago according to the accumulated PV power installed and the annual installation rate. As a consequence of this uncontrolled expansion, the Government started to promulgate different Royal Decrees in order to rationalize the unexpected increase of the PV installed power, due to a favorable Feed-in Tariff (FIT) regime in the 2004–2008 period. The subsequent new frameworks implied a substantial reduction of the previous FIT for new installations, but since late 2010, some of these measures have been applied with retroactivity. Nowadays there are almost no new PV plants and the existing ones have been continuously affected by a changing regulatory framework. The annual PV power installed in 2011 reached 423 MW, in 2012 it lowered down to 273 MW and there were only 6 MW in 2014 [5].

From the PV promoter's standpoint, the apparently promising policies that the Spanish Government legislated in the 2004–2008 period with the aim of fostering this technology have turned very rapidly into an unstable situation. The excessively favorable measures of these policies, as some social agents denominated the Spanish FIT, could represent a thread for the Government in terms of the great amount of money subsidized. This instability was perceived not only by future investors in this technology, but also by current owners which have been witnesses of a decrease in their profitability expectations, due to the retroactivity of these laws. Furthermore, although these PV plants could still be, paraphrasing the Government words, “reasonable profitable”, the problem arises when they may not be able to afford the annual liquid assets of the funding mechanism chosen for their PV investments.

In this paper a complete profitability and cost analysis of the photovoltaic grid-connected systems (PVGCS) in Spain has been carried out in order to ascertain the influence of this continuously changing and confusing regulatory framework has had on the investments in this technology. Additionally, the retroactive measures will also be addressed.

The criteria for the economic analysis used in this paper follows similar studies found in the literature, that is, the Net Present Value (NPV) and the net Internal Rate of Return (IRR). The PV electricity cost production has been estimated through the widespread concept of Levelised Cost Of Electricity (LCOE) in order to compare the PV generation cost with other sources of electricity and the retail electricity tariffs, with the aim of assessing the feasibility of these systems, proving that, in this study, the grid parity paradigm has been demonstrated to be possible and profitable.

2. Review of the Spanish photovoltaic regulatory framework

In Spain, the National Energy Plan 1991–2000 was the first step for the promotion of renewable energies. One of its main targets was the promotion of the increase share of these energy sources to the national electricity mix [6]. Nevertheless the first real supporting mechanism was through the publication of the Royal Decree 2818/1998 in December 1998, which established the incentives for the electricity generated with photovoltaic systems and fed into the grid [7,8]. The financial support was by means of an advantageous FIT regime for every kWh generated with PVGCS, differentiating this support according to their power size. For systems smaller than 5 kW a FIT of 0.36 €/kWh was established, meanwhile it decreased to 0.18 €/kWh for larger ones, in which case a maximum installed power of 50 MW was allowed (see Table 1). In this law the FIT mechanism could be revisable every four years and the complete duration of the FIT subsidy was not established. Although this RD apparently sets a good scenario for the promotion of these renewable energy systems, the unitary prices for their installation were still too high, so the installed PV power did not increased much at all. In Table 2 there is a compilation of the annual installed PV power which has been referenced to the Royal Decree applicable in Spain at that time.

In 1999, after the faint results obtained, the government approved a new Energy Plan for the development of renewable energies for a 10 years period (2000–2010). This Plan encouraged the introduction of financial incentives, such us the application of subsidies of 30–35% of the initial investment cost, in addition to a tax deduction for these systems, including grid-connected and off-grid PV installations. This plan also fixed the expected target for the installed PV power in 2010, rising up to 135 MWp [9].

In order to support the new Energy Plan, the Government approved the Royal Decree 1663/2000 [10] which established the technical conditions for the grid connection of the photovoltaic systems to the low voltage grid. Although it was not until 2004 when a new legislation came into effect, the RD 436/2004, which represented the real driving supporting mechanism and produced

Table 1
Feed-in Tariff for PV systems under RD 2818/1998 [7,8].

Power	Feed-in tariff (€/kWh) Period from 1998 to 2004[a]
P < 5 kW	0.36
P > 5 kW	0.18

[a] Only until first quarter of the year 2004.

Table 2
Parallelism of the evolution of the installed PV capacity in Spain and the regulatory framework development in the period 1998–2014 [5].

Year	Regulatory Framework		Supporting mechanism and remarkable events	Annual Power	Accumulated Power
1998	RD 2818/1998		Feed-in tariff	1	1
1999				1	1
2000		RD 1663/2000	Initial investment subsidy	1	2
2001				2	2
2002			Technical conditions for the PV connection to the low voltage grid	3	5
2003				6	11
2004	RD 436/2004		Feed-in tariff	10	21
2005				*22*	43
2006				82	125
2007	RD 661/2007		Feed-in tariff	512	637
2008		RD 1578/2008	Feed-in tariff (quarterly modified for the new installations)	2716	3353
2009			Annual cap	46	3399
2010			Feed-in tariff		
	RD 1565/2010		Annual cap	440	3839
	RDL 14/2010		Operational hours limitation		
2011			PV Self-consumption systems. Initial consideration (< 100 kW)	420	4259
		RD 1669/2011	Reduction of approval procedure for PV < 10 kW		
2012	RD-L 1/2012		Removal of FiT for new installations	300	4559
	Law 15/2012		7% income tax on all electricity sales generated		
2013	RD-L 2/2013		Updating revision of the retribution mechanism modified	107	4666
	RD-L 9/2013				
2014[a]	RD 413/2014		Reclassification of existing PV plants	6	4672
	OM IET/1045/2014		New retribution mechanism (Investment and O&M costs fix tariff plus electricity sales to market prices)		

[a] In the year 2104, data are collected until November.

a significant boost to the renewable energy industry in general and the PV technology in particular. The RD 436/2004 established a different supporting tariff depending on if the PVGCS were larger or smaller than 100 kWp, referred to the nominal power of the inverters [11,12].

PV plants up to 100 kW could sell all the electricity generated during the first 25 years after its commissioning at a fixed tariff of 575% of the average electricity tariff applicable in Spain and in the following years, the percentage was reduced down to 460%. The average electricity tariff is a data that was annually published by the Spanish Government. For larger PVGCS (> 100 kW) the tariff was calculated as a 300% of the average electricity tariff during the first 25 years, lowering it to 240% afterwards. In this Royal Decree a fee for reactive power compensation was also included. These percentages could be updated each four years and an annual FIT update was also considered.

This RD also included a second option for the retribution of these systems. It consisted on the sale of the electricity fed to the grid directly to the electrical market, thus a different price was applied instead of assigning the average electricity one. In this option, a premium of the 250% of the average electricity tariff during the first 25 years and 200% in the following ones was paid. Additionally, an incentive of the 10% of the average electricity tariff was also included plus a fee for the reactive power compensation. In this study this second option for the retribution of the energy generated is not considered. Table 3 shows the FIT assigned to these systems until the approval of the next Royal Decree.

Later on, in 2005, the Government approved a revision of the existing Renewable Energy Plan for the period 2005–2010. This plan fixed that by 2010, Spain should meet its primary energy consumption and the total electricity consumption needs with renewable energy sources in a percentage of 12% and 29.4% respectively. Moreover, a target of 400 MW for PV installed systems was also set [13].

The first legislation after the publication of this plan modification was the Technical Building Code (TBC), which came into force under the Royal Decree 314/2006. Although it is not specifically dedicated to Renewable Energy sources, in its HE5 section, the "Minimum contribution of photovoltaic electricity" was considered, so this Code can be considered one of the first regulations of solar PV energy in buildings [14].

The inflection moment in the supporting mechanisms for the deployment of the PV technology in Spain was the Royal Decree 661/2007 which repealed the former one from 2004. This Decree regulated the electricity production activity in the so-called "special regime", that is, systems based on renewable energy sources and cogeneration. The photovoltaic installations, classified under the nomenclature b.1.1, were assigned the FITs shown in Table 4, differentiating their first 25 years of operation from the subsequent ones. An annual tariff revision was also included, which

Table 3
Feed-in tariff assigned to PVGCS during the first 25 years of operation under RD 436/2004 [11,12].

Power	Feed-in tariff (€/kWh)			
	2004[a]	2005	2006	2007[c]
P ≤ 100 kW	0.41	0.43	0.44	0.44
P > 100 kW	0.21	0.22	0.23	0.23

[b]Included first and second quarter of 2007 (until the approval of RD 661/2007).
[a] Excluded the first quarter of the year 2004.

Table 4
Photovoltaic's FIT according to RD 611/2007 [15,16].

Power	Duration of the Support	Feed-in tariff (€/kWh) 2007[a] – 2008[b]
P ≤ 100 kW	1–25 years	0.440381
	From 25 years onwards	0.352305
100 kW < P ≤ 10 MW	1–25 years	0.4175
	From 25 years onwards	0.3340
10 < P ≤ 50 MW	First 25 years	0.2297
	From 25 years on	0.1838

[a] Only third and fourth quarter the year 2007 (since the approval of the RD).
[b] Excluded the fourth quarter of the year 2008 (RD1578/2008 came into force).

was updated depending on the inflation rate minus a 25 basic point until the year 2012 and 50 basic point afterwards [15,16]. Whilst the previous Decree clearly tried to promote installations smaller than 100 kW, differentiating around 50% the tariffs in regards to larger plants, in the RD 661/2007 the promotion limitation is now set in 10 MW as Table 4 shows.

Although this Decree was enforced in May 2007, the forecast PV power target of 371 MW of photovoltaic power installed was achieved only 5 months later. In order to highlight the success of this framework, the objectives set by the Spanish Government's Renewable Energy Plan for the period 2005–2010 (400 MW) were easily surpassed, because at the end of the year the annual PV power installed was 512 MW. This unexpected fast achievement and exceedance of the power target for the electricity production with the photovoltaic technology caused that in the 2008–2013 period, the legislative framework in Spain was repeatedly reviewed and modified.

The first attempt to restrain the speed of the installation rate in Spain was in September 2008, when the Government published the Royal Decree 1578/2008. This document provided a new regulatory framework for the development of the photovoltaic systems in Spain. Among the measures approved, a reduction of the FIT of around 30% was entailed including further progressive cuts proportional to the achievement of quarterly targets of installed capacity. In addition to that, an annual cap of 500 MW for the period 2009–2011was established.

The photovoltaic installations were again regrouped under a different classification, with the aim of promoting building integrated PV plants. Therefore, the new classification was: Type I.1: building-integrated and roof-top systems up to 20 kWp; type I.2: building-integrated and roof-top systems ranging from 20 kWp up to 2 MW and type II: ground-mounted systems up to a maximum size of 10 MW [17–20].

This RD 1578/2008 was applied until the first quarter of 2011, when some modifications were introduced in the legislation. A review of the FITs approved for each quarterly call depending on the type of PV system is shown in the following Table 5.

At the end of the year 2010, two important changes that affected the Spanish photovoltaic market were introduced. In November 2010 an additional reduction in FITs for new PV installations was included. The RD 1565/2010 meant a decrease of the retribution of 5% for type I.1 systems, 25% for type I.2% and 45% for type II, as Table 6 shows. This new RD intended to emphasize more intensively than the previous RD the promotion of PV systems integrated in buildings, either on façades or on top of roofs, at the expense of the ground-mounted ones [21–23]. Concerning the PV systems already in operation which were registered before September 30th, 2008, the FIT remuneration after the 25 years period was removed, so it was one of the first retroactive measures applied.

The second change produced in 2010 was through the Royal Decree Law 14/2010, which established some urgent measures for the adjustment of the electrical market's tariff deficit. Within these measures, the annual operational equivalent hours were limited; therefore, no FIT retribution would be paid to the energy generated once they have reached that limit. The definition of equivalent hours is the coefficient between the annual net energy production (kWh) and the nominal power of the installation (kW). This number of hours limitation (see Table 7) depended on the type of installation (fixed, one-axis or two-axis tracking) and the climatic zone established by the Spanish Building Technical Code law [15,23].

In a first approximation, the limitation established could seem reasonable because a well-designed PV plant which has been optimally installed and properly maintained, it is unlikely to reach this limitation. However, this RDL 14/2010 imposed an additional temporary cap (scheduled until December 2013) on the total number of hours per year for which existing solar PV systems are eligible to receive FITs (see Table 8). In this new scenario, most PV systems easily reached the limit, so this new law was a negative retroactive measure which really affected the profitability of the investment that PV owners planned under the legal guarantee offered by the Government.

At the same time the economic supporting mechanism was modified, some technical aspects were also reviewed. In December 2011, the Royal Decree 1699/2011 regulated the network connection of small power electricity production systems of less than 100 kW and the possibility of self-consumption (total or partial) of the electricity generated by these systems was also considered [24]. It also intended to reduce the approval procedure and bureaucracy for systems smaller than 10 kW.

One month later, a moratorium for the installation of new PV systems was introduced. The Royal Decree-Law 1/2012, published in January 2012, suspended the pre-assignment procedure for the remuneration of renewable systems and it also removed the FIT incentives for the new electricity installations which either use combined heat and power, renewable energy sources or waste, among which there were the photovoltaic ones [25].

One year after the controversial retroactive action of limiting the operational hours, in December 2012 the new Law 15/2012 was published by the Spanish Government, where an extra tax to guarantee the energetic sustainability was included. In the case of renewable energy sources, it implied the introduction of a 7% tax on all electricity sales, with the excuse of covering the electricity deficit [26].

Presumably justified by the Spanish economic crisis, in 2013 another Royal Decree Law was approved (RDL 2/2013) introducing additional measures to reduce the imbalance between the electrical systems costs and the incomes obtained through the regulated electricity tariffs, which have presumably produced an electricity deficit in Spain between the Government and the Electrical companies. The first action consisted on the modification of the updating mechanism of the regulated activities of the electrical system, in other words, the updating of the tariffs applicable to the FIT of renewable energy sources. Instead of using the Consumer Price Index, a new one was created, with no historical series, based on basic inflation where the energy and unprocessed food were excluded. The immediate result was that the

Table 5
Evolution of the FIT for those PV plants subscribed under RD 1578/2008 [11,15,20].

Power	Duration of the support	Feed-in tariff (€/kWh)									
		2008[a]	1st/2009	2nd/2009	3rd/2009	4th/2009	1st/2010	2nd/2010	3rd/2010	4th /2010	1st/2011
Type I.1 (BIPV $\leq$ 20 kWp)	25 years	0.3400	0.3400				0.3400	0.3346	0.3305	0.3219	0.3135
Type I.2 (20 kWp < BIPV $\leq$ 2 MWp)		0.3200	0.3200				0.3116	0.3030	0.2952	0.2868	0.2788
Type II Ground $\leq$ 10 MWp		0.3200	0.3071	0.3071	0.2991	0.2908	0.2810	0.2731	0.2655	0.2586	0.2517

[a] Starting at the fourth quarter of the year 2008 (RD1578/2008 was published).

Table 6
Different FIT applied with the RD 1565/2010 [11,15].

Power	Duration of the support	Feed-in tariff (€/kWh)						
		2nd/2011	3rd/2011	4th/2011	1st/2012	2nd /2012	3rd /2012	4th /2012–2013[a]
Type I.1 (BIPV ≤ 20 kWp)	25 years	0.2888	0.2812	0.2738	0.2662	0.2605	0.2540	0.2476
Type I.2 (20 kWp < BIPV ≤ 2 MWp)		0.2037	0.1983	0.1931	0.1931	0.1837	0.1791	0.1747
Type II Ground ≤ 10 MWp		0.1345	0.1303	0.1249	0.1217	0.1214	0.1183	0.1154

[a] In the year 2103 the Feed-in tariff is until July 14th, 2013.

Table 7
Limitation of the Annual Operational hours eligible for the FIT support established in the RDL 14/2010.

PV installation type	Operational hours per year				
	Area I	Area II	Area III	Area IV	Area V
Fixed installation (no tracker)	1232	1362	1492	1632	1753
1-axis tracking system	1602	1770	1940	2122	2279
2-axes tracking system	1664	1838	2015	2204	2367

Table 8
Additional Temporary Restriction (until December 2013) of the operational hours eligible for the FIT established in the RDL 14/2010.

PV installation type	Operational hours per year
Fixed installation (no tracker)	1250
1-axis tracking system	1644
2-axes tracking system	1707

retribution to the PV systems should have raised around 3% but it really was reduced to −0.03% [27]. As a result, the profitability of existing photovoltaic systems was again decreased.

Under the scenario of a profound energy reform, in July 2013 an additional the Royal Decree-Law 9/2013 defined the urgent measures to be taken in order to guarantee the financial stability of the electrical system [28]. It also set out the principles of a new legal and economic framework for production technologies of electricity from renewable energy sources, cogeneration and waste, which entered into force on July 14th, 2013. This RDL repealed all the previous regulations on economic incentives applicable to special regime installations, including the PVGCS. In return, according to the Government's words, the RDL 9/2013 ensured a "reasonable" IRR based on the 10-year Treasury obligations plus 300 basis points. This is the equivalent to an IRR of around 7.5%. These principles were collected afterwards in the new Electricity Sector Law from December 2013 (Law 24/2013) [29] and they have been detailed in the Royal Decree 413/2014 [30] and the Ministerial Order IET/1045/2014. This Ministerial Order is presumably the largest one published in Spain regarding its volume and longitude, as it has a total of 1,761 pages.

As provided in these rules, the Ministerial Order IET/1045/2014 (June 16th, 2014) completes the regulatory development of the new legal and financial regime applicable to the electricity generator facilities using renewable energy sources, cogeneration and waste [31]. This Order collects the remuneration regime applicable to all facilities that were entitled to perceive economic incentives economic, like the PVGCS.

Regarding PV systems, there is a new classification in terms of the tracking technology, power, year of commissioning and the RD originally subscribed to. These facilities will receive remuneration based on the sales of the electricity generated, valued at market price, with an additional compensation for investment and operating costs not covered by these market prices. The profitability before taxes for these existing installations will rotate on the secondary market yield on medium term, ranging the ten years prior to July 14th, 2013 of the State obligations to ten years afterwards increased by 300 basis points (7.4%). Some reviewing periods are also set to some parameters: the first regulatory half period (three years) ranges from the July 14th, 2013 to December 31st, 2016, meanwhile the first full regulatory period (six years) is set from of July 14th, 2013 to December 31st, 2019. Therefore, besides the reduction in the profitability of their systems, an additional uncertainty is added to current owners.

As a summary, Table 2 gathers the correlation of the different regulatory frameworks approved in Spain with the evolution of the annual power installed. At the beginning, the effect of a favorable legislation is clearly seen together with the slowdown of the market produced by the latter retroactive measures. It is worth mentioning that in 2008 the Spanish PV market was the largest one worldwide because that year there was 2.7 GW of new capacity installed, summing an accumulated power of more than 3.3 GW. The effect of latest Royal Decrees in the descending trend is evident because in 2013 only 107 MW were installed, while in 2014 there was an annual increment of 6 MW. Actually, many of these 2014 figures correspond to systems authorized in 2012 before the moratorium but they were installed afterwards, so it can be concluded that in 2014 there was practically a standstill of the Photovoltaic sector.

This negative evolution has been produced as a consequence of the successive reforms approved by the Government, combined with the legal uncertainty created after the constant legislative changes and, what it is more important, the retroactive character of some measures, which in addition could be checkable each three years, so these sorts of actions have blocked the development and feasibility of the Spanish PV sector. It is important to mention that there is an International litigation against the Spanish Government as a consequence of these measures [32,33].

3. Economic and cost overview of installed pv plants: temporal evolution

After reviewing the vast number of different policy regulations approved in Spain since 1998, it is interesting to undertake a temporal analysis of the evolution regarding the economic profitability of PVGCS depending on the time when they were commissioned and the legislation applicable at that right moment. However, the profitability index of PVGCS should be updated with the retroactive effect that the last law from 2014 introduces in the already installed PV plants.

At the same time that the economic profitability is analyzed, an overview of the evolution of the PV electricity generation cost is very clarifying. This analysis is through the concept: Levelised Cost Of Electricity (LCOE). In order to compare these costs with the ones produced by other generation technologies, the PV electricity unitary price during the life-cycle of the system should be estimated. In this long-term review analysis proposed in this paper, these unitary costs will depend on the point of time when the PV installations were connected.

3.1. Economic analysis methodology

The economic analysis is based on the Net Present Value (NPV, in €) and the Internal Rate of Return (IRR, in %). Likewise previous works, a similar methodology has been followed [34,35], but in order to cover more realistic scenarios, some improvements and variables have been considered in the formulation, such as the income tax rate and the tax depreciation.

3.1.1. Net present value

This first parameter used for the economic analysis stands for the balance of the annual cash inflows and outflows during the operational lifetime of the investment (N, in years) [36]. This summation is translated to the year at which the investment is done; therefore, the *NPV* is the difference of the present worth of the cash inflows and the life-cycle expenditures. The following expression reflects it:

$$NPV = \mathrm{PW}\ [\mathrm{CIF}\ (N)] - LCC \tag{1}$$

Depending on the moment of time when the plant was commissioned and the applicable laws, different values of NPV should be obtained, thus these values could be used for a comparison of the different scenarios that have existed in Spain throughout the period analyzed in this document.

Regarding the cash outflows, that is, the life-cycle cost of the PV system (LCC), it will mainly depend on the initial investment (PV_{IN}), the present worth of the operation and maintenance cost (PW[PVOM (N)]) and also the present worth of the tax depreciation (PW[$DEP\ (N_d)$]), where N_d is the period of time over which an investment is amortized for tax purposes. Finally, as a novelty regarding similar studies, the tax rate (T) applicable to this sort of projects is also considered, which could mean a saving in the annual cash outflow. According to the previous terms, LCC can be expressed as follows:

$$LCC = PV_{IN} + PW\,[PV_{OM}(N)] - PW\,[DEP\ (N_d)]\cdot T \tag{2}$$

In this life-cycle cost equation, the initial investment of the PV system (PV_{IN}, in €), is financed either through long-term debt or equity capital. In renewable energy projects, debt financing may be chosen because the cost of debt is usually lower than the issue of stocks from the equity capital [37]. The debt financing has also some fiscal advantages aside from beneficing of a lower interest rate. In those cases where PV_{IN} is financed solely through long-term debt, which will be composed of loan (PV_l) and bonds (PV_b) terms, so that $PV_{IN}=PV_l+PV_b$. Therefore, the initial investment may be expressed as:

$$PV_{IN} = \left(PV_l\cdot\frac{i_l(1-T)}{1-(1+i_l(1-T))^{-N_l}}\cdot PVIF\,(N_l)\right) + \left((i_b\cdot PV_b)\ (1-T)\cdot PVIF\,(N_b) + PV_b\cdot q^{N_b}\right) \tag{3}$$

The term related to the loan (PV_l) is an amount of the initial investment that is borrowed at an annual interest (i_l) to be repaid in N_l years, where the possible tax rate (T) influence is also included. In this equation, PVIF is the Present Value Interest Factor over the period considered, in this case it corresponds to the number of years of the loan (N_l). This factor is related to the nominal discount rate (d) according to the following equations:

$$PVIF\,(N_l) = q\cdot(1-q^{N_l})/(1-q) \tag{4}$$

$$q = 1/(1+d) \tag{5}$$

The second term of the initial investment sum depicts bonds (PV_b). The payment of interest on bonds takes place on an annual basis at an annual interest rate (i_b). PV_b must be completely paid at the end of the stated life of the bonds (N_b, in years). It is worth mentioning that the left-hand side of Eq. (3) only equals its right-hand side if the selected value of *d* is equal to the weighted average cost of capital (*WACC*) of the investment, that is, how much does it cost the financing chosen.

Some of the first renewable energy policies applied in Spain considered a subsidy for the initial investment. Although this supporting mechanism was soon overruled, we should include it in our analysis methodology to collect all the possible scenarios that have existed in Spain. In those cases where an initial investment subsidy (PV_{IS}, in €) is applicable, the amount to be financed through long-term debt would be: $PV_{IN}-PV_{IS}=PV_b+PV_l$. Therefore, Eq. (3) must be rewritten as:

$$PV_{IN} = \left(PV_l\cdot\frac{i_l(1-T)}{1-(1+i_l(1-T))^{-N_l}}\cdot PVIF\ (N_l)\right) + \left((i_b\cdot PV_b)\ (1-T)\cdot PVIF\,(N_b) + PV_b\cdot q^{Nb}\right) + \left(\frac{PV_{IS}}{N_{IS}}\cdot T\cdot PVIF\ (N_{IS})\right) \tag{6}$$

It should be noted that PV_{IS} was also taxable in a given period of time over which the investment subsidy was amortized (N_{IS}, years) and that the amount of the investment subsidized is non-repayable.

Additionally to long term debt, through loans and/or bonds, there are other mechanisms for financing the initial investment. The equity capital is another mechanism frequently used in PV financing. In this new scenario where any possible investment subsidy is considered, the amount to be financed including the equity capital is: $PV_{IN}-PV_{IS}=PV_b+PV_l+PV_{ec}$. If the initial investment cost of the PV system is financed with both mechanisms, Eq. (6) can be rewritten just by adding a corresponding equity capital term, with an annual payback in the form of dividends (d_{ec}), that is, the return on equity, and it must be paid in full at the end of the life cycle of the system (N, years).

$$PV_{IN} = \left(PV_l\cdot\frac{i_l(1-T)}{1-(1+i_l(1-T))^{-N_l}}\cdot PVIF\ \ (N_l)\right) + \left((i_b\cdot PV_b)\ (1-T)\cdot PVIF\ \ (N_b) + PV_b\cdot q^{Nb}\right) + \left(\frac{PV_{IS}}{N_{IS}}\cdot T\cdot PVIF\ \ (N_{IS})\right) + \left((d_{ec}\cdot PV_{ec})\cdot PVIF\ \ (N) + PV_{ec}\cdot q^{N}\right) \tag{7}$$

Resuming the life-cycle cost (LCC) of a PV system (Eq. 2), the owner of the installation has to take into account the expenditures related to the operation and maintenance cost PV_{OM} of the devices. This parameter is assumed constant over the useful life of the PVGCS (N, years) and it should be translated to the present worth of the analysis years chosen.

Therefore, the present worth of the operation and maintenance cost of the life cycle system, (PW[$PV_{OM}\ (N)$], in €) can be written as:

$$\mathrm{PW}\,[PV_{OM}(N)] = \left(PV_{AOM}\ \ (1-T)\cdot\frac{K_{PV}\cdot(1-K_{PV}^{N})}{1-K_{PV}}\right) \tag{8}$$

In the previous equation, (PV_{AOM} , €) is the annual operation and maintenance cost, K_{PV} is a factor which clusters the annual escalation rate of the operation and maintenance cost of the system (ε_{PVOM}) and the nominal discount rate (d), so $K_{PV}=(1+\varepsilon_{PVOM})/(1+d)$.

Likewise previous similar studies, the tax influence has been considered for the life-cycle cost of the PV system (LCC). In this case, the tax depreciation is assumed lineal over the period time (N_d) at which a PV investment is amortized for tax purposes, bearing in mind that it represents a saving in the cash outflow. Therefore, the last term of the LCC summation, which stands for

Table 9
PV electricity yields at different Spanish locations and climate areas.

Location	Climate area	E_{PV} (kWh/kWp)	Latitude	Longitude	H_d (kWh/m^2/day) (Radiation database)	
		Meteonorm data			PVGIS	Meteonorm
Santander	I	1067	43.46°	3.81°W	4.13	3.90
Burgos	II	1298	42.28°	3.64°W	4.88	4.74
Salamanca	III	1388	40.89°	5.62°W	5.39	5.07
Madrid	IV	1418	40.42°	3.70°W	5.64	5.18
Seville	V	1508	37.42°	5.90°W	5.94	5.51

the present worth of tax depreciation for the PV system (see Eq. 2), is expressed as follows,

$$PW[DEP] = DEP \cdot PVIF(N_d) \quad (9)$$

Where *DEP* is the annual tax depreciation for the PV system and $PVIF(N_d)$ is the Present Value of the Interest Factor which, similarly to the previous ones, is set equal to:

$$PVIF\ (N_d) = q\ (1 - q^{N_d})/(1 - q) \quad (10)$$

Once cash outflows have been defined, for the proper calculation of the NPV, the present worth of the cash inflows should be analyzed. The amount of money that the owner receives will mainly depend on the PV electricity produced by the system (E_{PV}, in kWh) and the unitary price applicable to each unit of kWh generated fed into the grid (p_u, in €/kWh). This last variable matches the FIT of the corresponding legislation applied. Nowadays, it should be recalled that there is no longer any retribution to new PV systems. According to the previous factors, the annual cash inflows may be calculated as follows:

$$PW\ [CIF(N)] = p_u\ E_{PV}(1 - T) \times \frac{K_{PU}(1 - K_{PU}^N)}{1 - K_{PU}} \quad (11)$$

Notice that the tax influence (T) is also considered and the factor K_{PU} considers the annual degradation rate of the PV modules efficiency (r_d), the annual increase rate of the PV electricity unitary price paid to the owner (ε_{pu}) and the discount rate (d). This factor can be estimated as follows:

$$K_{PU} = (1 + \varepsilon_{Pu}) \cdot (1 - r_d)/(1 + d) \quad (12)$$

From an economic perspective, this NPV of an investment on PVGCS could be eligible for its implementation provided that its value is greater than 0, although this is not the unique criterion that should be studied.

3.1.2. Internal rate of return

Another criterion traditionally used for the economic analysis is referred to the Internal Rate of Return (*IRR*) of an investment. It is defined as the value of the discount rate *d* that leads to *NPV*=0, so modifying Eq. (1), the following expression is obtained:

$$0 = PW\ [CIF\ (N)] - LCC \quad (13)$$

At this point it is important to differentiate between nominal and real IRR. If the parameters involved in the estimation of the IRR are expressed in current currency which considers the effect of the inflation, the equation above yields the nominal IRR. On the other hand, if the parameters have been expressed in constant currency, which means that the effect of the inflation is not taken into account, Eq. (13) yields the real *IRR*, but this is not the case of the analysis of our paper.

From an economic standpoint, if the IRR is over the Weight Average Cost of Capital (*WACC*), the implementation of the investment on PVGCS is feasible. Although the minimum profitability may be achieved, the final decision is also dependent whether this criterion also exceeds a profitability threshold arbitrarily fixed by the future investor or owner.

3.2. Estimation of the factors involved in the economic analysis

Prior to the analysis of the influence of each Royal Decree in the IRR and NPV results, a review of the values for the parameters involved in their estimation will be carried out in this section. It should be noted that figures presented here referred to costs, incentives and electricity yields, are all normalized per unit of power (kWp). The symbols used for these factors are the same for those not normalized, except that they are shown in brackets with the subscript 'kWp'.

Previously to the analysis of the purely economic related factors, a parameter needed for the calculation of the economic criteria is the annual PV electricity yield (E_{PV}, in kWh/kWp). In this paper, an average value has been estimated for five representative cities matching different climate areas existing in Spain, which are classified according to the Spanish Building Technical Code [14]. The purpose of extending the study to several cities is to widen the sensitivity of the analysis and consider good and bad energy yield scenarios.

The annual electricity generated in each zone has been estimated assuming a flat-plane silicon PV fixed system of 1 kW, which it is optimally tilted and oriented and whose performance ratio (PR) have been assumed equal to 0.75. For the radiation data, the daily average annual radiation available on two distinguished and well extended databases has been used [38–40]. The electricity yield results are summarized in Table 9. In order to be relatively conservative in this studio, the worst scenario has been chosen related to the amount of average daily radiation.

The energy generated by any PV system is not only affected by the stochastic behavior of the radiation available at a certain location but it is also under the influence of the intrinsic degradation that modules suffer throughout its lifetime, therefore the PV electricity yield generated by the system is assumed to decrease every year. In this study an annual degradation rate in the efficiency of the PV panels of 0.5% is considered [41,42]. Finally, the lifetime of the systems will be assumed to be N=25 years, although nowadays, flat PV systems have a life cycle that can go beyond this figure. The horizon of this economic analysis is then established in 25 years.

The combination of the energy yield and the PV electricity unitary price has a direct influence on the annual cash inflows of our investment. According to the focus of this study, historically in Spain the PV electricity unitary price per kWh (p_u, in €/kWh) has been fixed by different regulatory frameworks (Royal Decrees) through a FIT supporting mechanism. The already described Tables 1–6 from Section 2 gather all the possible FIT scenarios that PV investors have encountered in Spain depending on the moment these installations were connected to the grid and the Royal Decree applicable. Therefore, the PV electricity unitary price paid to the user (p_u) comes from assigning the FIT which correspond to the power and type of the installation and the commissioning year.

Nevertheless, this tariff was not constant over the specific supporting period as an annual increase rate of the PV electricity unitary price (ε_{pu}) was considered. In this sense, the Royal Decree 661/2007 defined this increment according to the following rule: until 2012, ε_{pu} is equal to the inflation rate (g) minus 0.25% and beyond 2012 it would match the inflation minus 0.5%. As it was mentioned in previous section, those installations under the RD 1578/2008 and 1565/2010 have the same updating mechanism. However, in all the cases it changed since the enforcement of the decree published in 2013.

In order to define these increments, a historical review of the inflation rate in Spain has been done averaging the data obtained for the complete period considered [43,44]. A value for the inflation rate of g=3.3% can be assumed for the economic analysis in the period 1998–2006, meanwhile there was a decrement in this variable in the period 2007–2013 as a consequence of the Spanish crisis, so in this last period g=2.2% will be considered [45]. According to these inflation values, the annual increase rate proposed is ε_{pu}=1.95% for the period 2007–2012 and ε_{pu}=1.7% onwards. The reality is that beyond 2013 the different Royal Decrees Laws approved in that year modified the methodology for the calculation of this increment and in practice ε_{pu}=0% since 2013.

Additionally to the energy yield and the remuneration of each unit of PV energy generated, the next most influencing parameter in the cash flow of a particular system is the PV unitary price per kilowatt installed (€/kWp) [46], or in other words, the initial investments cost (PV_{IN}) of a system. It is important to mention that for this study, a salvage value of the system at the end of their lifecycle (S_V) equal to zero has been considered.

This installation unitary price is very variable depending on the country, the module stocks existing and also it is influenced by some business strategies that certain countries, like China, are taking in order to have a dominant position in the market [47–56]. Regardless any business and market strategy, the maturity of the technology has helped to reduce the manufacturing costs as Table 10 shows, where the evolution of the PV price in Spain is analyzed. The maximum reached in 2007 is remarkable, when the Spanish Government approved the most favorable legislative framework that this technology has had in the country. In this period, the lack of modules stock forced the prices to surge. In the subsequent years, the Chinese industry boosted, the manufacturing technique was highly improved and some European countries also reduced the speed of PV implantation so the large stock available needed to be released. All these factors induced a dramatic decrease in the photovoltaic unitary prices [49].

Regarding the definition of the parameters involved in the financing tools considered, it was stated above that the initial investment cost may be financed by means of debt or equity capital. Due to the cost of debt is usually lower than the issue of stocks, long-term loan (PV_l) has been chosen, where it has been assumed that 80% of this amount is borrowed at an annual loan interest (i_l) that will vary depending of the period of time considered (1998–2006: i_l=5%; 2007–2013: i_l=6%) [57]. The loan term (N_l) will always be 20 years in this paper.

The remaining investment amount, 20%, will be the issues of stock, that is, equity capital. In all the periods analyzed in this paper, the annual payment of dividend (d_i), that is, the return on equity, will be assumed equal to 6% and they will be payable completely at the end of the life time of the system (N).

At the beginning of the PV sector regularization, initial investment subsidies (PV_{IS}) were considered because several Spanish Autonomous Regions developed specific programs to support photovoltaic solar energy. These programs subsidized PV installations, both off-grid and grid connected. These subsidies ranged around 30–35% of the initial investment [58], but they are no longer available since mid-2000. Nowadays some regions consider economic support for those PV systems under the self-consumption and net-balance category, but since it is a recent financial mechanism and the regulatory framework of these installations is not clear, it will not be in the scope of this paper. In those initial cases where PV_{IS} exists, the fragmentation of the financing is as follows: 60% loan, 10% issues of stock and 30% subsidies.

The influence of a tax rate (T) for the organization or taxpayer is also considered and it changes depending on each country regulations. For the case of Spain, the value assumed equals to 30% until the year 2013, when the Government introduced an additional tax (7%) for the incomes obtained in the electricity generation sales with renewable energies [26]. The tax depreciation has been considered using a maximum linear coefficient of 5%, with a tax life for depreciation of 20 years [59–61].

Another parameter used for the economic analysis is the nominal discount rate (d), which in this study will be assumed equal to the weighted average capital of cost (WACC) in order to estimate the profitability of the system [37]. This cost of capital has not been constant in the period analyzed as it will vary depending on the capital resources chosen to finance the initial investment. In the period 1998–2003, as a result of the subsidies available (30% of PV_{IN}), the discount rate after taxes is 1.6%. In the following period (2004–2006) it raises up to 4.3%, meanwhile d=3.8% for the years 2007–2012. Since 2013, the WACC is assumed to be 3.6%.

Lastly, the operation and maintenance costs have to be considered. According to the bibliography existing on this issue, an estimation of 1% of the initial investment dedicated for these operation and maintenance cost is normally considered annually [62]. Additionally, these costs will also be influence by an escalation rate (ε_{PVOM}). In this paper, this increment is going to be assumed equal to the value of the annual inflation rate, so ε_{PVOM}=3.3% and 2.2%, for the periods 1998–2006 and 2006-onwards, respectively. A summary of the aforementioned assumptions together with the values assigned to each factor is gathered in Table 11.

For our analysis purposes of the already installed PV systems, the previous values could have been assumed to remain constant, considering the annual variations proposed, throughout the operational time of the plant. Nevertheless, since the Royal Decree 9/2013 and the formulas defined in the subsequent ones, which modified retroactively the economic scenario of these systems, the unitary price received for the energy generated has been divided in several terms to accomplish the "reasonable" internal rate of return of a PV plant defined by the Government. According to this modification, the previous values defined should be adapted to

Table 10
Average evolution in PVGCS unitary prices in Spain (completely installed) [2,18,22,48–56].

Power	PV_{IN} (current currency for each year) (€/kWp)															
Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
P < 10 kW	9.5	9.2	9.2	8.8	8.8	8.0	7.0	7.0	7.2	8	7	3.9	2.8	2.9	2.5	2.4
P > 10 kW	9.0	8.8	8.8	8.5	8.5	7.5	6.5	6.5	5.9	6.3	5.8	3.6	2.6	2.6	2	1.4

Table 11
Values assumed for the financing factors in PV systems for the periods among 1998 and 2013.

Factors	Units	1998–2003	2004–2006	2007–2012	2013/07/14[a]
$[E_{FV}]_{kWp}$	kWh/kWp/year	(see Table 9)			
$[PV_{IN}]_{kWp}$	€/kWp	(see Table 10)			
p_u	€/kWh	(see Tables 1–5)			
ε_{pu}	%	Not applicable		1.95	0
PV_{OM}	%	1			
r_d	%	0.5			
ε_{PVOM}	%	3.3		2.2	
T	%	30		37	
g	%	3.3		2.2	
$[PV_{IS}]_{kWp}$	€/kWp	30% of PV_{IN}	Not applicable		
d	%	1.6	4.3	3.8	3.6
i_l	%	5		4	
N_l	years	20			
d_i	%	6			
N	years	25			

[a] In the year 2103, the date is until July 14th, 2013.

Table 12
Financing factors in PV systems starting the 14th of July of 2013.

Factors	Units	2013/07/14 - onwards[a]
$[E_{FV}]_{kWp}$	kWh/kWp/year	(see Table 9)
$[PV_{IN}]_{kWp}$	€/kWp	(see Table 10)
Incomes	€	(see RD 413/2014 and IET/1045/2014)
PV_{OM}	%	1
r_d	%	0.5
ε_{PVOM}	%	2.2
T_i (income)	%	30
T_g (generation)	%	7
g	%	2.2
$[PV_{IS}]_{kWp}$	€/kWp	Not applicable
d	%	3.6
i_l	%	4
N_l	years	20
d_i	%	6
N	years	30

take into account the later variations. In Table 12 there is a brief summary.

With the values defined previously for each period identified and the equations proposed in the economic methodology used, the figures for the IRRN and the NPV results will be obtained for each location chosen in this study.

3.3. Economic analysis and results

Once the diverse scenarios resulting from the changing regulatory frameworks existing in Spain have been defined, it is interesting to review the different profitability results that a certain investor may have encountered in Spain depending on the type of PV plant, its location, the unitary price per kWp, and the most important fact, the commissioning year, which it is translated into the retribution received according to the Royal Decree applicable.

The results shown in this section do not represent the trend that a particular PV investment on a precise moment has experienced in time, as it was supposed that the aforementioned legal frameworks guaranteed the unitary price per electricity generated over a long period of time (mostly 25 years). On the contrary, these results show that depending on the year the system was commissioned, and thus, subscribed to a specific Royal Decree, the profitability result from one owner to another may have differed, even in a period of time of months. Therefore, this section is a review of the different profitability scenarios that have merged in Spain influenced by the unitary cost per kWp evolution, and the retribution applicable to each unit of photovoltaic electricity generated and fed into the grid.

This analysis has been extended to different locations using the same economic scenario in order to assess that the availability of the solar resource has a great influence in the profitability results. This analysis reinforce the idea of equimarginality that some authors claim, as they assert that the installation of PV plants, among other renewable energy technologies, should be optimized with the best renewable energy resource available in a location [63].

According to the economic analysis, in the following results the prices used for the calculation are expressed in current or nominal terms, that is, they are actual prices paid in the stated year, so the effect of the inflation is already considered. On the other hand, the constant or real prices shown in the figures are adjusted for an inflation indexed to the year 2013 ($€_{2013}$), when the average value of the inflation rate is assumed equal to 2.8%.

The first economic indicator used in this analysis to assess the profitability of a certain PV plant investment is the Internal Rate of Return. In a first approximation, if this value is greater than 0%, it may indicate that the investment could be profitable. However, only in the case where IRR is greater than the WACC used for financing the investment, the PV plant will be viable.

Figs. 1–3 show the IRR results for three arbitrary locations in Spain, which have been selected because their differences in the availability of Sun are significant.

From these figures and under the assumptions made in this study, the first result is that all PV systems larger than 5 kW installed under the first Royal Decree (1998-Q1, 2004) are not profitable in any location, as the IRR is negative. On the contrary, although the IRR is not too high in the locations III and V, for any year of this period, and PV plants smaller than 5 kW these plants are profitable enough because IRR is higher than the Weighted Average Cost of Capital. Regarding the Northerner sites, only the systems in the last period of this RD 2818/1998 could be considered feasible. The main reason of this small or, in some cases, none profitability of these PVGCS installed under the RD 2818/1998 is caused by the large installation prices in those days.

As mentioned in previous sections, the beginning of the real supporting mechanisms for the deployment of the PV technology in Spain started in 2004 with the enforcement of the RD 436/2004. However, there is a clear distinction in the FIT applicable between systems greater or smaller than 100 kW. In the first case (> 100 kW), IRR figures show that none of the locations are profitable as they are either negative or below the WACC, which was much higher than in the previous period considered. This fact

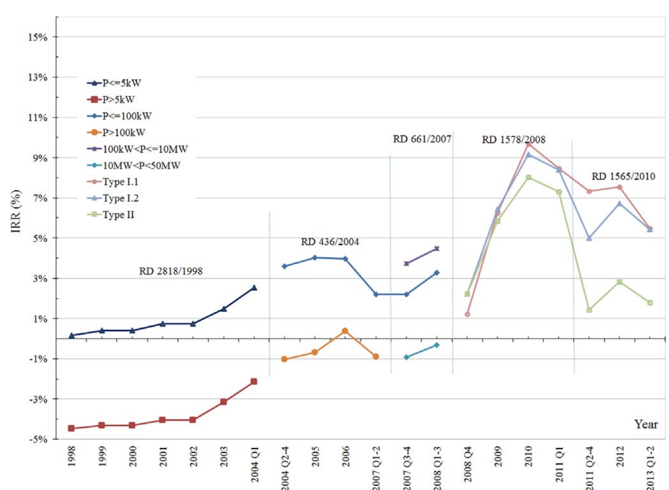

Fig. 1. IRR for a PV system located in the North of Spain (Santander, Area I).

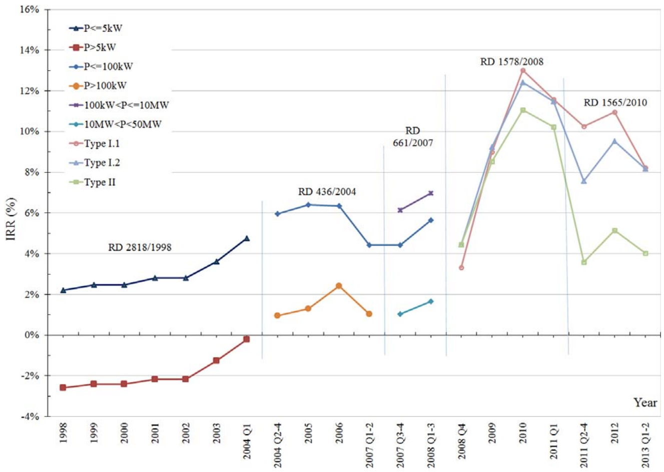

Fig. 2. IRR for a PV system located in the Middle of Spain (Salamanca, Area III).

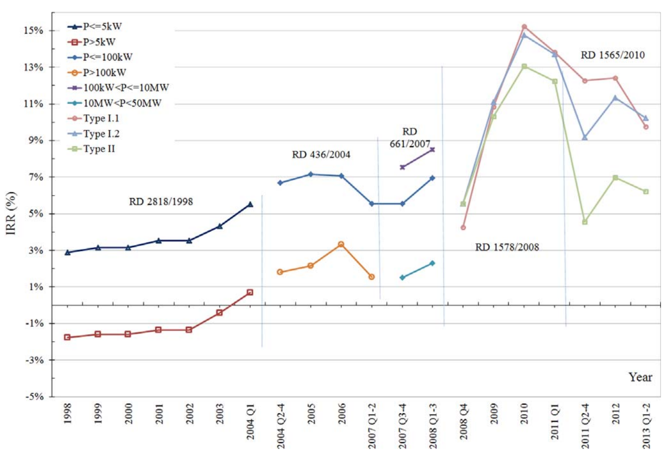

Fig. 3. IRR for a PV system located in the sunny South of Spain (Seville, Area V).

could explain the reason why many owners decided to split their systems into 100 kW ones in order to have a higher retribution. During this period (Q1,2004–Q2,2007), PVGCS < 100 kW are always profitable in Areas III and V, with the exception of Area I, where only at certain years these systems could be feasibly installed. It can be considered that the 100 kW limit imposed by this RD was the starting point for the standardization of the Balance of System (BoS) elements according to this size of power.

Although the RD 4336/2004 meant a progression in the promotion of these systems, the latter one, RD 661/2007, was the real boosting legislation for the PV technology in Spain, when all the expectations for power installed were soon surpassed. In the period comprised between Q3,2007–Q3, 2008, only large systems ranging from 10 MW up to 50 MW are not profitable in any region, while the rest of systems and locations show feasible figures with some exception for small ones (< 100 kW) at the North of Spain. Nevertheless, it is outstanding that although systems larger that 10 MW were supposed to be non-profitable in Spain, the reality is that several of these systems were installed. Once more, the main explanation is that these large plants were artificially divided into 100 kWp systems, where the higher FIT was assigned.

In the years thereafter 2008, there was certain controversy related with the enforcement of RD 1578/2008 and the latter RD 1565/2010, as they reduced substantially the retribution tariff, especially for ground-mounted PV plants as well as an annual power cap was also introduced. However, it was the period of time when these systems generated higher IRR figures. The excess of stock generated in the highly demand period should be released and the deployment and highly automation of the manufacturing process, boosted mainly by China, contributed, in the following years starting in the late 2008, to a dramatic collapse in prices. In spite of the FIT reduction, the favorable unitary price scenario contributed to the most profitable period of time for the installation of these systems in Spain.

Additionally to the comparison of the profitability of several PV systems depending on the specific moment of time they were installed, an interesting analysis for any owner of a PV system subscribed under one of the previous Royal Decrees, is focused on whether their investments have suffered a substantial change in profitability terms with the retroactive measures adopted in the ruling legislation approved in July 2014. In order to cover this issue, some general PV examples, subscribed to each of the last RD, analyzed and the economic parameters from Table 12, have been chosen in this document. According to the sort of systems planned, each PV plant corresponds to a specific identification code in the last Ministerial Order, where there is a fixed assignation of incomes and also new unitary prices for the electricity generated is also defined (see Table 13).

After the recalculation of the Internal Rate of Return of the already installed PV plants, with the new legislation applied, the results are revealing as Table 14 shows. The dramatic reduction of the IRR value in all types of PV plants in each Royal Decree scenario possible is outstanding. Although these investments are still economically feasible, under the so-called "reasonable profitability" defined by the Government, because their values are higher than the WACC used in the cases analyzed in this paper, the inflexion point is whether the owners could face the annual liquid assets under this new financial scenario. Despite the economic analysis could result positive at the end of the lifetime of the investment, if the financial feasibility is not accomplished, the owners will be forced to sell their PV properties notwithstanding they could afford the annual liquid assets under the Royal Decrees they were subscribed to. This reality is already happening in Spain to a vast number of small/medium PV investors [64].

Likewise the results shown for the IRR, NPV figures, under the assumptions and circumstances considered in this document, show the same expected trend (see Figs. 4–6). The previous effect of the last framework approved in Spain over the IRR prediction of the owners is expected to be repeated. A temporal analysis of the

Table 13
Main characteristics of a representative PV installation (Climatic Area V) translated to RD 413/2014 and IET 1045/2014.

	Original RD subscription								
	RD 661/2007			RD 1578/2008			RD 1565/2010		
Group size or type of system	100 kW < P ≤ 10 MW	10 MW < P ≤ 50 MW	≤ 100 kW	Type I.1	Type I.2	Type II	Type I.1	Type I.2	Type II
Inscription call				Q1st 2009	Q1st 2009	Q1st 2009	Q4th 2011	Q4th 2011	Q4th 2011
Nominal power of the system	1 MW (Fixed)	10 MW	90 kW	15 kW	100 kW	1 MW	15 kW	100 kW	1 MW
Operational year authorization	2008	2008	2008	2009	2009	2009	2011	2011	2011
NEW ID code of the plant IET1045/2014	IT-78	IT-90	IT-30	IT-100	IT-239	IT-424	IT-228	IT-366	IT-487

Table 14
IRR values (%) before and after the enforcement of the RD 413/2014 and IET 1045/2014.

Type	RD 661/2007		RD 1578/2008		RD 1565/2010	
	Before	After	Before	After	Before	After
≤ 100 kW	7.0	5.1				
100 kW < P ≤ 10 MW	8.5	7.1				
10 MW < P ≤ 50 MW	2.3	4.7				
Type I.1			10.9	7.0	12.3	9.0
Type I.2			11.1	6.8	9.2	6.0
Type II			10.3	6.7	4.6	2.8

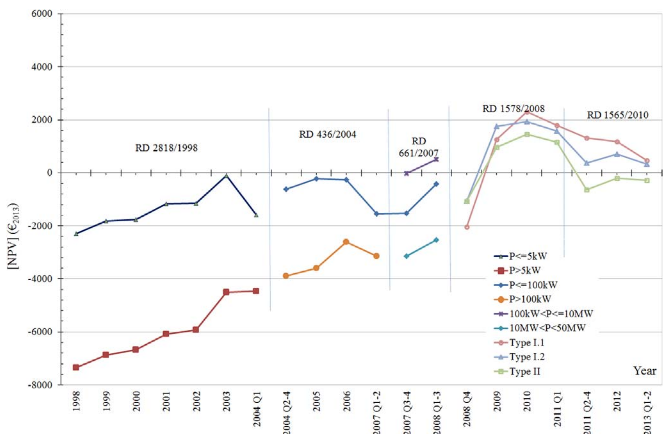

Fig. 4. NPV results for a PV system located in the North of Spain (Santander, Area I).

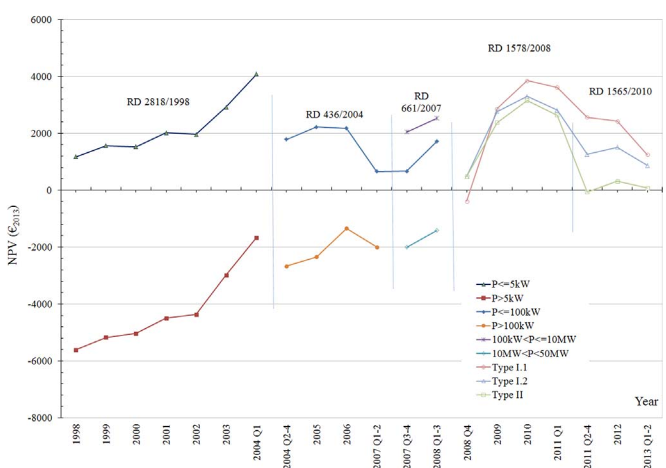

Fig. 5. NPV results for a PV system located in the Middle of Spain (Salamanca, Area III).

NPV will also provide evidence of the decrease as Table 15 shows for the systems defined in Table 13.

3.4. Levelised cost of electricity analysis and results

Nowadays it is quite often to discuss whether the prices of the electricity generated with PV technology can compete with the electricity retail tariffs, whose concept in the photovoltaic argot is known as grid parity. Therefore grid parity is defined as the moment when photovoltaic grid-connected system's unitary price equals the retail electricity price. In this direction, complementary to the economic analysis from previous sections, an overview of the evolution of the PV electricity generation costs is very clarifying.

In this paper, likewise similar studies [65], the analysis is based

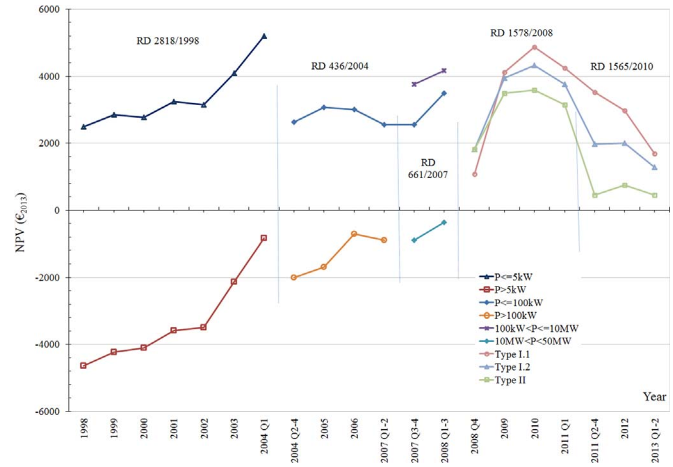

Fig. 6. NPV results for a PV system located in the sunny South of Spain (Seville, Area V).

Table 15
Net Present Value (€$_{2013}$) effect after the enforcement of the RD 413/2014 and IET 1045/2014.

Type	RD 661/2007		RD 1578/2008		RD 1565/2010	
	Before	After	Before	After	Before	After
≤ 100 kW	3493	930				
100 kW < P ≤ 10 MW	4165	2395				
10 MW < P ≤ 50 MW	−336	517				
Type I.1			4115	1565	3526	1860
Type I.2			3943	1300	1968	687
Type II			3497	1307	447	−275

on the estimation of the cost of producing PV electricity through the concept levelised cost of electricity (*LCOE*), which could be defined as the constant and theoretical cost of PV electricity production over its entire lifecycle. If the annual PV electricity generated (E_{PV}) is assumed to remain constant over the system's lifecycle, LCOE may be calculated as:

$$\mathrm{LCOE} = \frac{LCC}{E_{PV} \bullet \sum_{n=1}^{N} \frac{(1-r_d)^n}{(1+d)^n}} \tag{14}$$

The previous equation could also be expressed as:

$$\mathrm{LCOE} = \frac{LCC}{E_{PV}\frac{K_{pl}(1-K_{pl}^{N})}{1-K_{pl}}} \tag{15}$$

where K_{pl} equals to $(1-r_d)/(1+d)$.

Assuming the same values for the parameters proposed in the economic section (see Tables 11,12), Figs. 7–9 show the evolution of the LCOE depending on the moment of time when these PV installations were commissioned. It is important to mention that the LCOE calculations have been referred to the year 2013 (€$_{2013}$).

In the period of the first RD, 1998–2004, PV plants larger than 5 kWp have LCOE values comprised between 0.27 €/kWh up to 0.64 €/kWh according the location, meanwhile those installations smaller than 5 kW, their LCOE is between the range 0.3–0.67 €/kWh. Obviously, those costs cannot compete with the retail electricity tariffs. At that moment, the concept of grid parity was still unknown.

From the second quarter of the year 2004 until the enforcement of the RD 661/2007 (Q2–2007), LCOE values in Spain ranges

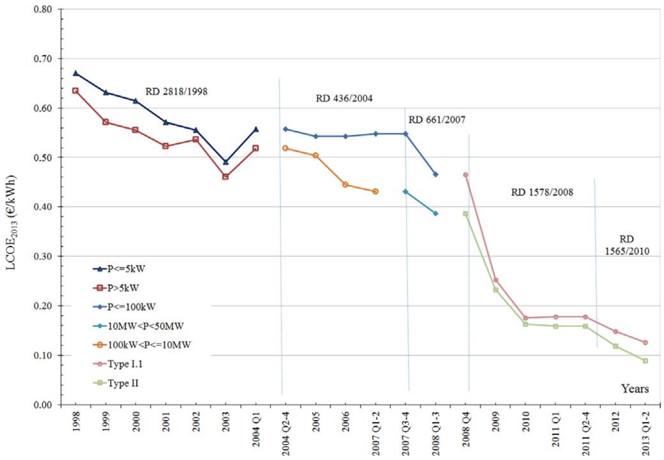

Fig. 7. LCOE evolution for a PV system located in the North of Spain depending on the commissioning year.

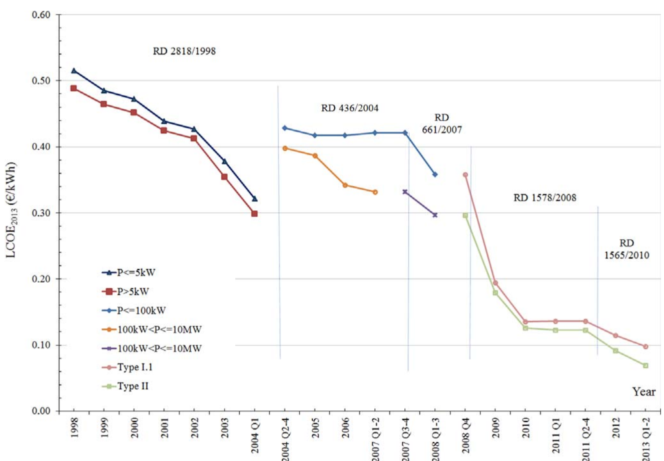

Fig. 8. LCOE results dependent on the commissioning year for a PV system located in the middle of Spain (Salamanca, Area III).

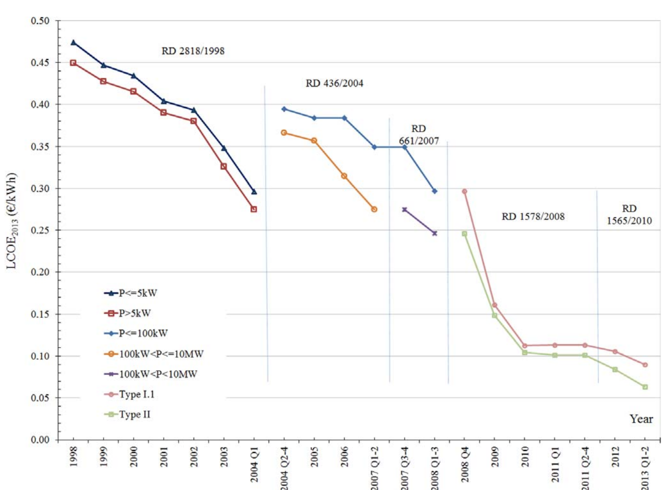

Fig. 9. LCOE evolution dependent on the commissioning year for a PV system located in the South of Spain.

from 0.35 to 0.56 €/kWh and 0.27–0.52 €/kWh depending on the location and whether the systems were smaller or larger than 100 kW respectively. In the period of the favorable RD 661/2007, PV systems greater than 100 kW show the best LCOE results. Regarding the location, LCOE changes from 0.42 €/kWh down to 0.24 €/kWh.

Since 2008, when the unitary prices of PV systems experienced a great decrement, the LCOE has been continuously decreasing. In the most unfavorable location in this study, the North of Spain, LCOE results to change from 0.38 to 0.48 €/kWh in 2008 to 0.08 €/kWh in the best case in 2013. Better results are obtained in the South of Spain where, at the end of the period of this analysis, LCOE values of 0.07 €/kWh have been obtained.

Resuming the discussion regarding the grid parity in Spain, Table 16 shows the average retail electricity prices in the commercial/industrial sector in some EU countries in the period from 2010 to 2013 [66,67]. In light of the LCOE figures obtained in Spain in the last years, grid-parity is a reality since 2013, at least in the commercial/industrial sector and for most of the types of PV systems studied in this paper.

Table 16
Average retail electricity prices (€/kWh) in the commercial/industrial sectors for some selected EU countries between 2010 and 2013. Taxation is not included [66,67].

Country	*Year*			
	2010	*2011*	*2012*	*2013*
Germany	0.092	0.09	0.082	0.091
Italy	0.092	0.117	0.112	0.112
Spain	0.108	0.108	0.114	0.114
France	0.066	0.072	0.068	0.066
United Kingdom	0.095	0.094	0.091	0.116
Portugal	0.088	0.09	0.101	0.101
Greece	0.087	0.094	0.098	0.102

4. Conclusions

The analysis presented in this paper highlights the economic profitability and the generation electricity cost of different investments in PVGCS in Spain, comprising the period ranging from 1998, when the promotion policies began, to 2014, when there have been applied some regulatory frameworks that affect not only new PV installations, but the existing ones too.

One main conclusion is that supporting measures to the photovoltaic sector in Spain, through laws and Royal Decrees, lacked of long-term vision. In this direction, continuous legislative changes were introduced periodically, which turned to produce instability to the owners of these installations in the last years in relation to the economic profitability of their investment. Furthermore, a legal uncertainty was created to prospective investors.

The economic analysis based on the NPV and IRR shows that the profitability of a certain PV plant is location-dependent, as it was expected, because the radiation levels decrease with the latitude. Variations in the IRR up to 6% are found in this study when a general case PV system located in Seville (South) is compared with another one from the North of Spain. This location dependency comes to reinforce the idea of some policy makers, who affirm that the installation of PV plants (among other renewable energy technologies) should be optimized with the best renewable energy resource available in a location. The term used to define this suitability is equimarginality [63].

Additionally to the influence of the solar resource of the representative locations chosen, the figures of this study clearly show the way an investment of a certain PV system (the general case considered in this study) changes depending of the moment of time it was installed and commissioned. One may think that the economic situation can have a main influence, as the financing of the investment affects the cash flows. Nevertheless, this paper shows that the different policies are the critical influencers in the profitability of a PV system.

In a first approximation, the development of the several Royal Decrees should not have any effect in the LCOE, as it is only influenced by the LCC of the system, whereas the legislative framework only affects the cash inflows. The only exception is related to the taxes imposed by the government. However, a favorable promoting regulatory framework can favor the technological maturity of a certain industry, and in consequence, it is immediately translated into a reduction of the unitary cost, therefore, the initial investment.

The promotion policies in Spain in the years 2004–2008, although they have not reduced the LCOE of the systems installed during this period, they have had a tremendous effect on the maturity of the photovoltaic technology which afterwards it was reflected in the dramatic reduction in the unitary prices of installed PVGCS in Spain. In this sense, it is revealing that the great surge in the IRR and NPV has occurred in the period 2009–2013, as a consequence of a great decrease in the unitary PV prices. This reduction has been greatly caused by the promoting regulatory frameworks of 2004–2008, whose policies implied many investments in R&D focused on the improvement and lowering the cost of the PV manufacturing process.

Nowadays, when the technology is mature enough and the grid-parity has been reach, as this technology can compete with other energy sources regarding the retail electricity tariffs, alternatives such as the self-consumption or net–metering represent an excellent opportunity to develop a cost-effective and sustainable PV market. The question is whether the Government will legislate to promote this sort of distributed energy solutions.

This document also tends to shed light regarding how the profitability of photovoltaic systems has been affected according to the last regulatory framework changes in 2014 (RD 413/2014 and Ministerial Order IET 1045/2014). The indirect effect these laws produce, the ones with retroactive character, is whether the lack of feasibility to support the annual liquid assets due to the change of the "reasonable profitability" could mean the renegotiation of the initial investment financing or just the sale of the PV plant to foreign investment groups.

Additionally, this study can also be used for consulting purposes by institutions or governmental organisms in order to possibly plan any further legislative framework regarding this technology in those countries where there is an Institutional support to this sort of renewable energy source.

Appendix Terminology

d	Nominal discount rate (%).
DEP	Tax depreciation.
d_r	Real discount rate (%).
E_{PV}	Annual PV yield injected into to the grid by user (kWh).
$[E_{PV}]_{\mathrm{kWp}}$	Normalized per-kWp annual PV electricity yield (kWh/(kWp•year)).
g	Annual inflation rate (%).
i_l	Annual loan interest.
i_b	Annual bonds interest.
IRR	Internal rate of return.
IRR_n	Net internal rate of return.
LCC	Life - cycle cost of the PVGCS (€).
$LCOE$	Levelised cost of electricity (€/kWh)
N	Useful life of the PVGCS, equal to analysis period (years).
N_b	Time duration of bonds (years).
N_d	Period of time over which an investment is amortized (years).
N_{IS}	Period of time over which an initial investment subsidy is amortized (years).
N_l	Time duration of loan (years).
p_u	PV-electricity unitary price into to the grid by the user (€/kWh).
PV_{AOM}	Annual operation and maintenance cost of the PVGCS (€).
PV_{IN}	Initial investment cost on the PVGCS (€).
$[PV_{IN}]_{\mathrm{kWp}}$	Normalized per-kWp initial investment cost (€/kWp).
PV_{IS}	Initial investment subsidy (€).
$[PV_{IS}]_{\mathrm{kWp}}$	Normalized per-kWp initial investment subsidy (€/kWp).
PV_l	Amount equal to the portion of the initial investment financed with loan (€).
PV_b	Amount equal to the portion of the initial investment financed with bonds (€).
$PVIF$	Present value interest factor
$\mathrm{PW}[\mathrm{CIF}(N)]$	Present worth of the cash inflows from a PVGCS system through its useful life (€).
$\mathrm{PW}[PV_{OM}\ (\mathrm{N})]$	Present worth of the PVGCS system operation and maintenance cost (€).
r_d	Annual degradation rate of the PV modules efficiency (%).
T	Income tax rate (%).
S_V	Salvage value of the system at the end of their life-cycle (€).
$WACC$	Weighted Average Cost of Capital (%).
ε_{PVOM}	Annual escalation rate of the operation and maintenance cost of the CPV system (%).
ε_{pu}	Annual increase rate of the electricity price into to the grid by user (%).

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