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Influence of Operation and Maintenance expenditures in the feasibility of photovoltaic projects: The case of a tracking pv plant in Spain

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ABSTRACT

Operation and Maintenance (O&M) tasks are becoming increasingly important in the asset management of photovoltaic projects. However, there is insufficient evidence to analyse in depth its influence on the energy and economic performance of such systems. The wide range of O&M annual expenditures (OPEX) and the lack of standardization further complicate the proliferation of specialized studies. This paper analyses the influence of OPEX on the performance and viability of a utility-scale photovoltaic tracking plant based on real data. After a description of the O&M costs incurred to maximise photovoltaic performance, a first result shows that a percentage decrease in annual OPEX does not necessarily imply the same trend in energy losses. Although this electricity decrease may jeopardise the viability of the project, the economic outlook of this study shows that high quality O&M not always improves the Levelised Cost of Electricity or the annual liquid asset of such investment. Finally, it shows real evidence of the influence of promotion policies on the viability of photovoltaic projects, taking Spain as an example, where it is more profitable to abandon the preventive maintenance of a photovoltaic plant than to invest in O&M and only undertake corrective O&M in limit situations

1. Introduction

At present, the PV industry is experiencing exponential growth with unprecedented installation rates and a promising future in the coming years, where the estimate of cumulative solar electricity capacity could reach 1000 GW by 2030 (International Energy Agency (IEA), 2016a, 2016b; Jaeger-Waldau, 2016).

In order to increase its competitiveness in the energy sector, not only among traditional energy sources but also in the renewable energy market, it is necessary to further reduce the price of electricity generated. The decrease in manufacturing costs that this technology is experiencing in recent years, as a consequence of the slope of its learning curve, is helping to achieve this goal (Fraunhofer ISE, 2015; International Energy Agency (IEA), 2016a)

In addition to the manufacturing process, new tasks have recently emerged in relation to the photovoltaic industry, which are becoming increasingly important in improving the reliability and viability of these systems and also help to increase their energy efficiency, and are therefore also playing a significant role in boosting the profitability of photovoltaic investments and reducing unit prices for electricity generation. In order to increase the energy and economic revenues of a photovoltaic system, second-tier activities such as Operation and Maintenance (O&M) are becoming critical and also signifying an expanding market with a high potential for business future within the PV industry (Brehaut, 2014; Cedric Brehaut, 2016; Patel, 2016; Siemer, 2016; SolarPower Europe, 2016). A high quality O&M protocol can apparently improve the Electric Power Purchase Agreements (PPAs) by encouraging plant energy efficiency, which has an influence on reducing the Levelised Cost of Electricity, and can additionally mitigate plant risks and increase return on investment. (SolarPower Europe, 2016). By high quality O&M protocol, we understand that it is the one that contemplates a greater frequency for the execution of preventive maintenance tasks, as well as that it covers more aspects to be checked within the PV plant and uses first quality replacement components. Also it refers to a shorter response time to any corrective maintenance task.

Additionally, an appropriate O&M protocol can also have a positive

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impact on reducing insurance costs (Keating et al., 2015) as it may prevent from or reduce accidents caused by a lack of or insufficient O&M such as fires (Cancelliere, 2016; Cancelliere and Liciotti, 2016)

In the life cycle of a photovoltaic project, only traditional EPC (Engineering, Procurement and Construction) type contracts have been taken into account. However, the current trend in project management theory also considers the inclusion of the maintenance stage as part of a turn-key project (Bakker, 2015). In addition, some authors also propose to include the dismantling or repowering of a photovoltaic plant in the life cycle of a project (Keating et al., 2015; SolarPower Europe, 2016).

The generalised mantra of the lack of O&M requirements for operating a photovoltaic plant has recently been overcome (Siemer, 2016; SolarPower Europe, 2016), and today an increasing number of countries even claim to include this stage in public tenders for photovoltaic projects (Siemer, 2016).

Although the Operation and Maintenance protocol is becoming increasingly important in the asset management of a photovoltaic plant, after an exhaustive review, there is clearly a knowledge and technical gap in the analysis of this issue. Typically, O&M expenses are considered merely as a second level issue or even a random variable number in Levelised Cost of Electricity studies, but it has not been widely demonstrated nor analysed in depth their energy or economic influence on the LCOE calculation (Talavera et al., 2016, 2011).

Among the sources consulted, there is missing information regarding which tasks should be included in an O&M protocol and the corresponding annual operation expenditures that should be considered. Moreover, in many reports there is also a difference in the way they allocate the annual OPEX. There are reports that give annual OPEX figures depending on the initial cost of the system, others that fix it depending on the installed power, while some O&M contracts stipulate it according to a percentage of the plant's energy production.

There are reports that allocate 0.8–1.2% per annum of the initial cost of the PV project (Shimura et al., 2016), while some experts recommend to devote to O&M activities around 1% of the initial system cost per year for small systems (Powertech, 2012; PV O&M Working Group. NREL/Sandia/Sunspec Alliance SuNLaMP, 2016). Even some reports consider up to 5% of installation cost per year (Electric Power Research Institute, 2010). However, it is advisable not to consider OPEX as a percentage of the installation cost, since there are evident differences in the investment required for a PV system in 2007 when compared to 2017, whereas OPEX might resemble a similar annual disbursement for the same PV plant but installed in different years. Therefore, it is more appropriate to reflect this cost in €/kWp or in a percentage of the energy generated.

In the latest available data, fixed O&M for 2016 is set at 19 $/kWp with a standard deviation of ± 18 $/kWp (NREL, 2016). Meanwhile, also for recent PV plants, the International Energy Agency considers 30 $/kWp (International Energy Agency (IEA), 2016a) or some experts claim that they offer O&M services for 9–16 $/kWp (Siemer, 2016).

However, if previous trends are analysed, maximum OPEX values of 110 $/kWp are found (United States Department of Energy, 2017). It can be deduced that the standard deviation is too large and most data is based on face-to-face interviews with experts.

In the case of Spain, during 2007–2012, it was relatively common to sign maintenance contracts for photovoltaic plants dependent on the energy production. The most widespread practice was to fix approximately 10% of the annual photovoltaic generation of a fixed PV plant, but only considering preventive maintenance, although there was not as much standardization in the tasks involved in an O&M procedure as there is today.

In any case, operating and maintenance expenses have decreased significantly in recent years and an additional 15% decrease is expected by 2030 (Vartiainen et al., 2015).

In addition to the wide range of annual expenditure, the other major source of uncertainty comes from the lack of consensus and consistency in the content of an appropriate O&M contract, further complicating the proliferation of similar studies and the definition of an annual OPEX that could be used as a reference. This lack of standardization begins with the items to be considered in an O&M contract and is also influenced by the proliferation of different sub-concepts related to operation and maintenance (Bazilian et al., 2013; Brehaut, 2016, 2014; Cedric Brehaut, 2016; Haney, Josh, 2013; Siemer, 2016; SolarPower Europe, 2016; Vartiainen et al., 2015).

As a result of this scientific absence specifically related to O&M and OPEX in the photovoltaic industry, we have carried out the research shown in this paper, which analyses the influence of operating and maintenance costs on the feasibility of a photovoltaic plant, specializing in the viability study of a utility-scale solar PV tracker system. Instead of reviewing scientific literature and reports, or simply software simulations, the performance of a real photovoltaic system is analysed from both an energy and an economic point of view. Therefore, the availability of real energy and economic performance data from a photovoltaic plant and its annual OPEX is an added value for the photovoltaic community.

After a description of the energy performance of the selected photovoltaic plant, and a classification of the operation and maintenance tasks and their corresponding expenses committed to maximise the energy yield, a first approach addressed in this document is to analyse whether a percentage decrease in annual operating expenses necessarily implies the same trend in energy losses. The results obtained can be very valuable for PV asset management companies in order to optimise their photovoltaic O&M products and the revenues of themselves and their customers.

The second perspective discussed in the document focuses on the economic performance of a photovoltaic plant, where a reduction in O&M's tasks is likely to lead to a drop in energy and, consequently, a decrease in revenues that threaten the feasibility of the plant. However, the results discussed in the document show that a high quality of O&M does not always improve the LCOE or Return on Investment (ROI) of a photovoltaic investment, although some reports claim the opposite (SolarPower Europe, 2016).

Finally, the results of the manuscript show real evidence of the influence of policies on the viability of photovoltaic plants, taking as an example the case of Spain, where it is more profitable to abandon the preventive maintenance of a photovoltaic plant than to invest in O&M tasks. A sensitivity analysis will show the impact of O&M tasks in the OPEX, energy drop and revenues of this PV project.

The representativeness of this study is twofold. On the one hand, most PV plants in Spain have the same power configuration (100 kW) as a result of the remuneration scheme RD661/2007 (de La Hoz et al., 2010; Mir-Artigues et al., 2018), so if most preventive and corrective O&M tasks are very similar and independent of the size of the PV plant (the time spent on these tasks are the ones dependent on the size of the plant), the OPEX should be comparable among most PV plants in Spain, and hence, the PV installation analysed in this paper could be treated as a representative case as it has the same nominal power.

Additionally, one of the findings of this introduction section is that there is no consensus regarding O&M values and the tasks and concepts which should be included in any O&M contract. Despites most of the OPEX values references used in this paper are normally taken as representative data for other studies, they lack clarity as to what concepts they include and may be incomplete. Therefore, one of the side results of this paper which can make a great contribution is try to collect all the different information provided in the references used and built a more compact document.

2. Original performance of the tested photovoltaic installation

The photovoltaic plant selected for the O&M analysis (see Fig. 1 and Table 1) is located in southern Spain (Latitude: 37.287, Longitude: −3.055), where an annual horizontal global irradiation of 1880 kW h/m^2 and an average daytime temperature of 13.3 °C exists according to

Fig. 1. PV plant under analysis.

Table 1
Technical description of the PV plant.

Configuration		Characteristics of the Plant	
Strings	32	Short-circuit current - Isc (A)	257.60
Modules per string	18	Open-Circuit Voltage - Voc (V)	574.15
Number of one-axis trackers	48	Current at the maximum power point - Im (A)	236.48
Modules per tracker	12	Voltage at the maximum power point - Vm (V)	462.78
Surface of the PV plant (m^2)	4500	Maximum Power - Pm (W)	109,440
Distance between trackers (m × m)	8.30 × 11.60	Nominal Power (Inverter) - Pinv (W)	100,000

the PVGIS © database (Huld et al., 2012; Šúri et al., 2007). Based on these data, predictable high energy yield is expected (Huld et al., 2008). In the case under study, this energy production was improved as a result of the installation of the photovoltaic modules on a tilted one-axis polar-based tracker as was the case at the time in many similar installations in Spain (Bahrami et al., 2016; Eldin et al., 2016; Huld et al., 2010; Sumathi et al., 2017). Based on the owner's calculations and forecasts, the PV plant was designed to achieve prospectively an average annual energy yield of about 1885 kW h/kWp, that is, to generate approximately 206,294 kW h per year (Lomas et al., 2018).

In accordance with the legislative framework under which the plant was subscribed, the year in which the photovoltaic installation was commissioned coincided with the maximum remuneration of FiT ever existing in Spain, provided that the plant did not exceed 100 kW nominal power. In this scenario, any photovoltaic plant that adhered to the legal framework of RD661/2007, such as this study, was remunerated at 0.440381 €/kW h for the first 25 years and 0.352305 €/kW h the following ones (Ministry of Industry Energy and Trade. Government of Spain, 2007). This situation led to a de facto standardization in the design and implementation of such systems in fractions of 100 kW.

As a consequence of this power limitation and in order to be eligible for the maximum remuneration, prospective owners were looking to maximise revenues, so the only existing mechanism to cope with the restriction of the power limit was by installing trackers to increase energy captures, thereby increasing the profitability of their investments (Almonacid et al., 2011; de Simón-Martín et al., 2013). The technical characteristics of the plant analysed in this document show this trend (see Table 1), and it can therefore be concluded that most photovoltaic plants were conceived to receive maximum remuneration, so that to a certain extent, photovoltaic plants were treated in some way as an investment product (de La Hoz et al., 2010; del Río González, 2008; Gellings and Rutschmann, 2008). The goal was to achieve maximum revenues, rather than energy incomes.

Since the date of commissioning of the PV plant some adjustments were made, so the first months of operation must be rejected from any study. It could therefore be said that the plant was fully operational at the beginning of 2008. Although the aforementioned standardization in the design of photovoltaic plants in Spain and a presumed lack of commitment to design optimization, power generation was reasonably sound, even surpassing the owner's initial energy prediction, which could be explained in part by the inherent high quality of the technology (Lomas et al., 2018). This good energy scenario is illustrated in Fig. 2 for the analysed plant, showing that the annual energy yield is within the expected results of similar photovoltaic installations (Huld et al., 2010; Koussa et al., 2011). It is important to mention that this figure only shows the performance of the plant in a period in which it was maintained perfectly. From 2013 onwards, the energy yield decreases as a result of a change in the plant's legal framework, as will be discussed elsewhere.

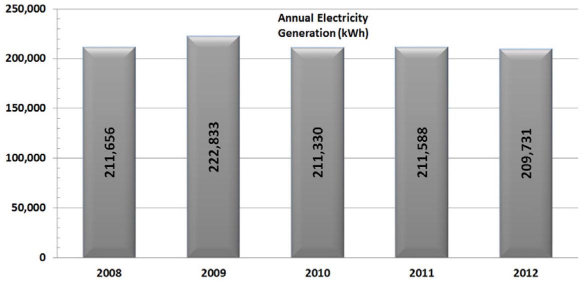

Fig. 2. Annual Energy Production of the plant (2008–2012).

Table 2 shows a summary of two key performance indicators (KPIs) widely used in the PV sector which measure whether the PV plant is operating within the target of generation set. The annual yield, also known as specific performance, measures the energy generated divided by the plant rated power and availability refers to the percentage of time during a year in which the system is operating (PV O&M Working Group. NREL/Sandia/Sunspec Alliance SuNLaMP, 2016).

As Table 2 shows, except for the year 2012, where there were some issues regarding the tracking mechanism due to original manufacturing problems (solved during the warranty period) which resulted in a low availability of the plant, these results highlight the validity of this technology, even though in a situation where its energy design was not a priority. Also interesting is the decoupling of annual yield and plant availability.

Table 2
KPI of the plant (2008–2012): Energy yield and Availability.

Year	Annual yield (kWh/kWp)	Availability (%)
2008	1933.99	98.12
2009	2036.11	99.73
2010	1931.10	99.19
2011	1933.37	99.90
2012	1916.41	91.94
Average	1950.18	97.78

It can therefore be deduced that the PV system was reaching large numbers in terms of economic incomes and profitability expectations according to the energy figures shown.

Although the performance ratio (PR) is a common KPI normally included in any photovoltaic performance report, it has not been considered as a result of the lack of measured radiation data within the site of the plant. Therefore, we would obtain estimated PR values that could mislead the results of the work

2.1. O&M protocol and OPEX

The photovoltaic plant under analysis was commissioned at a time when FiT in Spain was at its peak (del Río González, 2008; Dusonchet and Telaretti, 2015; Jenner et al., 2013; Talavera et al., 2016), which means that there was a wide margin of profit to invest in annual operation expenditures (Vartiainen et al., 2015). Although this existing margin, the importance of O&M was widely underestimated at the time, which resulted in a lack of risk perception in the absence of such operating and maintenance protocols (SolarPower Europe, 2016). This reality encouraged the negative preconceived idea that O&M is not an important task in this industry or even that it is a low-level technical field that can be carried out by self-employed workers (Siemer, 2016).

Although at present there is a growing division between the tasks of operation and maintenance of photovoltaic plants, which in most cases are carried out by different companies (Brehaut, 2016), in the photovoltaic installation under analysis both activities were considered under the same term and were carried out by a technician specifically hired for these purposes. Table 3 provides a brief summary of the concepts and their corresponding cost grouped under Operation (O), Maintenance (M) or both (O&M) in order to comply with current reports. The O&M tasks implemented by the technician are similar to those described in the expert studies (Puche et al., 2016). It is important to highlight that this technician carried out preventive and corrective maintenance tasks, which it is an important differentiation from standard O&M contracts, which only consider preventive maintenance.

The unit cost of the plant amounted to 6.68 €/W so, considering the previously identified operating expenses, they represent an annual amount of 2.29% with respect to the initial investment. However, as indicated in the previous section, it is more representative to express this amount in terms of power unit, so that, for the plant under analysis, the OPEX rises to 153.19 €/kWp. If expressed in energy terms, this annual OPEX represent around 15% of the average annual production. It is important to emphasize that the aforementioned values include preventive and corrective maintenance and other aspects normally not considered in published OPEX reports, such as spare parts, taxes, insurances, ancillary services, etc.

Although in the percentage representation, OPEX can be found to be within the range of some reports, as identified in this document, when the unit cost per unit of power is expressed, it can be clearly seen that this figure is above the range of all the cases analysed, which reinforce the idea that for small plants, O&M may not be profitable, or has to be reduced to the minimum, for the companies that offer such services (Siemer, 2016), at least to the extent of the concepts gathered for a complete O&M service as requested by the owner of the plant studied.

This high OPEX can be explained in a first approximation as a result of the remote location of the plant, its tracking system and its small size, thus, it is clearly influenced by the economy of scale of the system (Vartiainen et al., 2015) which forced to dedicate a technician to the task of supervision and also for preventive and corrective maintenance (Puche et al., 2016). In addition, the spare parts stock, which reduces response time and is very useful for remote locations such as the one analysed, means an increase in OPEX costs which it is also going to be dependent on the size of the plant and its layout (e.g. central inverter vs. string inverter). These spare parts may also require additional maintenance (International Finance Corporation, 2015).

In addition, most reports that take into account or analyse O&M only consider technical operating costs, whereas it is more appropriate to also include financial operating costs such as insurance, security, accounting and reporting (Ito et al., 2016). Moreover, some reports mention that corporate taxes, lease land or network tariffs should also be added to the cost of operation (Jones-Albertus et al., 2016; Kurokawa et al., 2006; Vartiainen et al., 2015). The above mentioned criteria justify the inclusion of such items in our analysis.

Table 3
Annual OPEX (2008–2012).

Concept	Cost	
Technician (O&M)		12,000 €
Preventive technical inspection of the main inspection hatches (4 units) and electrical wiring	220 €	
Preventive technical inspection of secondary inspection hatches (20 units) and electrical wiring	1156 €	
Preventive technical inspection of the AC electrical output panel (inverter side)	54 €	
Preventive technical inspection of the main AC electrical output panel and energy meter	54 €	
Preventive technical inspection of the DC electrical panel	54 €	
Preventive technical inspection of the string connection electrical panels (8 units)	138 €	
Preventive technical inspection of the ancillary services electrical panel	81 €	
Preventive technical inspection of trackers (48 units)	3303 €	
Preventive technical inspection of the inverter and its housing	414 €	
Insulation and ground measurements	81 €	
Voltage drop and operating current measurements	413 €	
Peak power output measurement	68 €	
Visual Inspection of the PV modules (576 units)	1017 €	
Thermal images of the PV modules and electrical connection boxes	136 €	
Supervise the inverters' morning start up	142 €	
Cleaning of the modules	1302 €	
Field clearing	217 €	
Taking energy meter and inverter readings	403 €	
Perimeter fence check	428 €	
Daily and monthly reports	1017 €	
Corrective maintenance	1302 €	
Stock of electrical and mechanical material (M)		1000 €
Deposit for inverter replacement	600 €	
Wires, Screws and bolts (electrical and mechanical small material)	400 €	
Alarms and surveillance (O&M)		420 €
Insurances (O)		1396 €
Taxes (O)		250 €
Auxiliary services (O&M)		900 €
Renting of machinery and equipment (M)		800 €
TOTAL		**16766 €**

3. Influence of the annual OPEX decrease on the electricity generated

The owner of the plant under analysis dedicated an annual OPEX in order to maximise energy production, thereby expanding the revenues of the applicable FiT. However, some important cost-containment mechanisms were introduced in Spain between 2007 and 2013. Numerous papers have analysed the evolution of national legislation on renewable energies, with special attention to those affecting plants already in operation (de la Hoz et al., 2016, 2014; Lomas et al., 2018; Mir-Artigues et al., 2015)

Under this context, many investors face liquidity problems (Daley, 2014; de la Hoz et al., 2016; Lomas et al., 2018; Nielsen, 2015) so that there is a progressive delay in the regularity of O&M's tasks or even a total abandonment of the plant in order to reverse the negative cash flow and be able to repay its investment loans.

Since the entry into force of these retroactive laws, the owner of the plant under analysis has drastically reduced the annual budget for the operation and maintenance protocol, as shown in Table 4. The annual

Table 4
Annual O&M cost (2013-onwards): values and comparison.

Concept	Cost (our case)	Contract 1	Contract 2	Contract 3	Contract 4	Contract 5
Online monitoring, energy measurement and daily automatic reports (O)	365 €			217.8 €		
Stock of electrical and mechanical material (M)	400 €					
Alarms and surveillance (O&M)	420 €					
Insurance (O)	1396 €					
Taxes (O)	250 €					
Auxiliary services (O&M)	900 €					
Renting of machinery and equipment (M) *(Corrective Maintenance)*	235 €					
TOTAL	**3966 €**					
Preventive O&M (1 cleaning, visual inspection, annual report) (Not included: travel and subsistence allowances for technical staff)		2541 €	2237.79€ no cleaning		363 € no cleaning	
Thermal analysis (modules, inverter)			742.94 €			
IV analysis			1130.14 €			
Preventive O&M (very similar to the original one of this paper)						7369 €
FULL TOTAL* It has been added the concepts not considered from 2013 O&M protocol	–	***6507 €***	***8076.87 €***	***3818.8 €***	***4329 €***	***11,335 €***

OPEX is reduced to 36.2 €/kWp or 0.5% of the initial investment. These annual values are now better adjusted to the average price mentioned in the introduction section, with the difference that in this case the concepts included under the O&M cost are mainly due to insurance and taxes, minimising as much as possible the specific tasks related to preventive maintenance and undertaking corrective tasks only when strictly necessary. The removal of the maintenance technician has meant that most preventive and corrective tasks carried out in the PV plant have been eliminated, which may resemble the plant being almost abandoned. It is also interesting to compare the current OPEX of the plant with the cost of different O&M contracts offered in Spain (see Table 4), where the lack of preventive maintenance of our plant is highlighted and that a high-quality O&M requires much more money.

This reduction in O&M's tasks has had a progressive impact on the performance of the plant. The drop in the electrical output can be seen in the results shown in Fig. 3, the KPIs in Table 5 and the differences in electricity from Table 6. Although the energy generated in 2013 is similar to that produced in previous years, a downward trend is beginning to be glimpse, mainly caused by a progressive breakdown of all trackers, increased dust accumulation and broken string connections that were not detected in time. Additionally, the appearance of hot spots have also had some impact in the reduction of the energy generated (c.a. 1–3%). There is a special remark in 2015, when the availability and performance of the plant was dramatically lower. The main reason for that decrease is the breakdown of the inverter during the summer months. For its reparation, part of the available deposit from the period 2008–2012 reserved for the inverter replacement (see Table 3) was used, so technically, corrective maintenance costs cannot be allocated to the OPEX from 2013-onwards as he did not have to devote any new money to the inverter corrective maintenance. Moreover, there is still a portion of this deposit available in case any new breakdown of the inverter happens in the future.

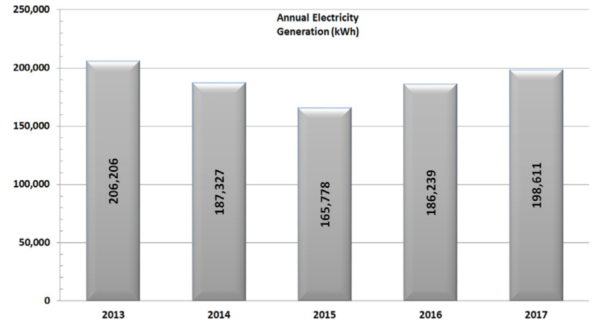

Fig. 3. Annual Energy Production of the plant with minimum O&M tasks (2013-onwards).

Table 5
KPI of the plant (2013-onwards): Yield and Availability.

Year	Annual Yield (kWh/kWp)	Availability (%)
2013	1884.20	97.04
2014	1711.69	97.44
2015	1514.78	94.08
2016	1701.75	99.44
2017	1814.79	99.52
Average 2013–2017	1725.44	97.50

Table 6
Annual OPEX variation vs PV electricity differences.

Annual OPEX		Difference
2008–2012	16,766 €	–
2013-onwards	3966 €	− 76.34%
Electricity Production		**Difference**
Maximum Electricity (2009)	222,833 kW h	–
Average Electricity 2008–2012	213,427 kW h	–
Electricity 2013	206,206 kW h	− 3.38% (average) − 7.46% (max)
Electricity 2014	187,327 kW h	− 12.22% (average) − 15.93% (max)
Electricity 2015	165,778 kW h	− 22.33% (average) − 25.60% (max)
Electricity 2016	186,239 kW h	− 12.74% (average) − 16.42% (max)
Electricity 2017	198,611 kW h	− 6.94% (average) − 10.87% (max)

It could be argued that the lack of O&M leads to a bottomless decrease in the energy generated in the plant, since the initial trend of the years 2013–2015 could be glimpsed (see Fig. 3). However, energy production in 2016 and 2017 show a stabilisation in energy losses, with power generation similar to that of 2014. With the exception of 2015, the electricity injected into the grid in the last years coincides with the average yield of an optimally inclined and oriented fixed PV system that could be installed in the same location, so it is expected that similar energy figures will be generated in the coming years.

Moreover, this stabilisation is a sign that there is no need to devote so much of the annual budget to these O&M tasks, with the exception of the share dedicated to trackers, as they are the main source of energy losses. Therefore, it is interesting to analyse the percentage influence of OPEX decrease in generated energy.

Although the 76% reduction in O&M spending, the fall in energy production does not follow the same downward trend shown in Table 6. A comparison between the average output of the period in which O&M, which corresponds to the years 2008–2012, did not decrease and the subsequent years of abandonment, shows the decoupling of the annual OPEX and the energy generated. The greatest difference occurred in 2015, when the energy drop reached a minimum of − 22% with respect to the average production of the period 2008–2012. In the most unfavourable case, when comparing the energy differences of the best and worst years of production (2009 and 2015), the percentage rises to almost 26%, which remains a large gap compared to the annual OPEX differences of 76%.

If the 2008–2012 average yield is compared to the results from 2013 to 2017, the 76% of OPEX reduction has meant an average 11% decrease in the energy yield.

Therefore, the first notable result, according to the characteristics of this tracking plant, is that the percentage of decrease in energy generated is much less than the difference in annual operating and maintenance costs, so current owners may wonder if it is interesting to maintain the level of annual operating and maintenance costs in their PV plants and be able to repay their loans.

In any case, this reduction in maintenance protocol costs has undoubtedly led to a decrease in the electricity generated by the system. Consequently, although the owner's original intention to save some money, the income received from the energy injected into the grid also decreases, so profitability presumably will. In order to evaluate the appropriateness or not of the maintenance tasks, it is essential to analyse which scenario is most significant for the viability of the photovoltaic plant: the reduction in OPEX or the reduction in electricity sales revenue as a result of a lack of O&M.

4. OPEX influence in the financial performance: results and discussion

4.1. LCOE performance and sensitivity analysis

One of the indicators typically used to assess the financial performance of a given renewable energy project is the Levelised Cost of Electricity (LCOE) concept. Although the literature has shown that the reduction in annual expenditure on O&M tasks has a positive effect on the profitability of a photovoltaic investment, precisely in the LCOE (Muñoz-Cerón, 2014; Shimura et al., 2016; Talavera et al., 2016), it is appropriate to carry out such an analysis in this study in order to assess the financial results of this investment.

The LCOE of a certain technology is the unitary cost of electricity generated (€ kWh^{-1}) (Short et al., 1995). For this calculation, the time period considered is the operating life of the system (N) and is the result of the life-cycle costs (LCC) of the investment divided by the estimated energy produced (E_{PV}). For a proper analysis, the LCOE refers to the moment in which the photovoltaic investment is committed, so that the cash outflows and the energy generated over the next 25 years of operating life of the installation must be levelled during the period considered and referred to the year 2007, which was the starting point of the business model for this investment.

The simplest equation defining the LCOE can be seen in Eq. (1)

$$LCOE_{year} = \frac{LCC}{\sum_{n=1}^{N} \frac{E_{PV}\cdot(1-r_d)^n}{(1+d)^n}} \tag{1}$$

The cash outflows (see Eq. (2)) faced by the owner, i. e. the LCC of the PV system, depend mainly on the initial investment (PV_{IN}), which is the initial front-end cost, and on OPEX (PV_{OPEX}), which is an annual operating expense (Fraunhofer ISE, 2015; Vartiainen et al., 2015). Both terms should be translated to the original investment date, therefore their present worth (PW) must be calculated.

$$LCC = PW\,[PV_{IN}] + PW\,[PV_{OPEX}(N)] \tag{2}$$

Obviously, such photovoltaic systems require a high initial investment, therefore, the PV_{IN} is normally backed by external capital (PV_{EX}) and private capital (PV_{EQ}). The external investment facility is financed with an annual loan interest (il) during the duration of the loan (N_l), while the equity participation is expected to yield a return in the form of dividends (di) over the operating life of the photovoltaic plant and private capital is expected to amortize at the end of the system's life cycle

$$\begin{aligned} PW\,[PV_{IN}] &= \left((PV_{EX})\cdot i_l\cdot\frac{(1+i_l)^{N_l}}{(1+i_l)^{N_l}-1}\cdot\frac{q\cdot(1-q^{N_l})}{1-q}\right) \\ &\quad + \left((d_i\cdot PV_{EQ})\cdot\frac{q\cdot(1-q^{N})}{1-q} + PV_{EQ}\cdot q^N\right) \\ \mathrm{q} &= 1/(1+\mathrm{d}) \end{aligned} \tag{3}$$

Concerning the OPEX, an annual amount has been considered for O &M (PV_{OPEX}). In this preliminary analysis, the original OPEX amount has been selected (PV_{OPEX} = 16766 €)

$$\begin{aligned} PW\,[PV_{OPEX}] &= PV_{OPEX}\cdot\frac{q\cdot(1-q^N)}{1-q} \\ q &= 1/(1+d) \end{aligned} \tag{4}$$

The discount rate (d) used in the LCOE equation coincides with the weighted average cost of capital (WACC) to reflect the cost that the PV system's owner must bear in order to use the aforementioned financial resources. In other words, the WACC will depend on the share of private equity with the required profitability and external capital at the applicable interest rate. It will vary according to the proportion of financial resources chosen.

Finally, it has been considered that the annual energy generated by the photovoltaic system (E_{PV}) remains constant throughout its life cycle with an annual degradation rate of the generated power (rd = 0.8%) (Jordan et al., 2016)

Once a value has been assigned to the variables involved in the above equation based on the real economic information provided by the owner of the PV installation (see Table 7), the result obtained that establishes the unit cost of the electricity generated from the system analysed is $LCOE_{2007}$ = 0.3491 €/kW h, which is within the data already published in theoretical studies for the case of Spain in that year (Talavera et al., 2016). Comparing this $LCOE_{2007}$, which is going to be constant during the operation of the plant, with the existing FiT from 2007 of 0.44081 €/kW h, which represents the unit income from the sale of energy, a profitable scenario can be seen.

According to the LCOE definition equation (see Eq. (1)), a variation in annual expenditure on O&M tasks influences the unitary price of the PV electricity generated (Talavera et al., 2014, 2011). Some studies

Table 7
Variables considered for the LCOE analysis.

$LCOE_{2007}$ = 0.3491 €/kWh							
Energy factors		**Economic factors**					
E_{PV} (kWh/year)	r_d (% annual)	PV_{IN} (€/Wp)	External Capital PV_{EX} (90% PV_{IN})		Private Equity PV_{EQ} (10% PV_{IN})	d (%)	PV_{OPEX} (€/year)
206,294	0.80	6.68	i_l (%)	N_l (years)	di (%)	4.58	16766
			4.64	12	4		

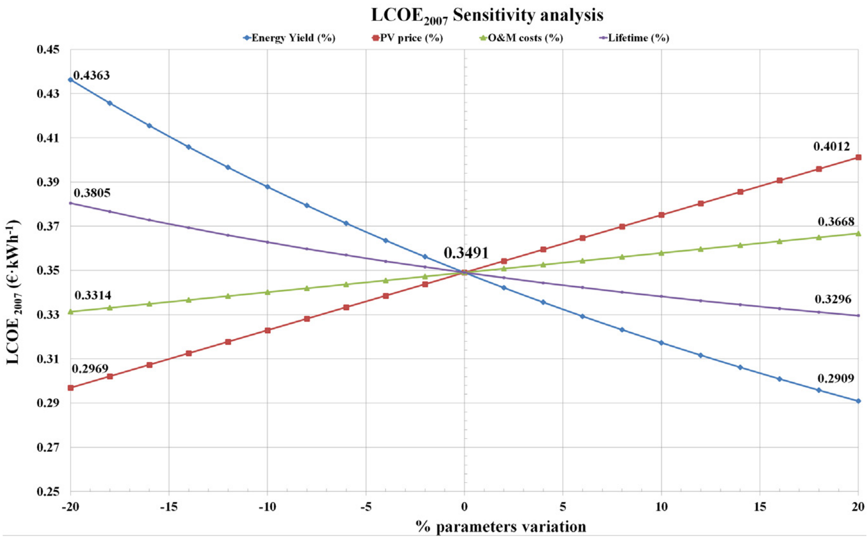

Fig. 4. $LCOE_{2007}$ Sensitivity analysis results.

Table 8
LCOE sensitivity analysis differences.

$LCOE_{2007}$ = 0.3491 €/kWh			
Variables variation			**LCOE values (€/kWh) and differences (%)**
E_{PV} (kWh/year)	± 20%	165,035–247,553	0.4363–0.2909 (+25% −16.67%)
PV_{IN} (€/Wp)		5.34–8.01	0.2969–0.4012 (± 14.93%)
OPEX (€/year)		13,413–20,119	0.3314–0.3668 (± 5.07%)
Lifetime (years)		20–30	0.3805–0.3296 (+9% −5.58%)

have attempted a sensitivity analysis to assess the influence of OPEX on LCOE (Muñoz-Cerón, 2014). In this regard, some authors argue that an increase of 0.1% in OPEX may have an impact of 1.67% on the LCOE (Shimura et al., 2016).

In addition to the influence of OPEX, we have also included in this research the impact that other parameters may have on the LCOE calculation. Fig. 4 and Table 8 show the results how a ± 20% variation in energy yield, PV price, OPEX and PV plant lifetime may have influenced the $LCOE_{2007}$ value.

According to the previous results, the energy yield is the most influential parameter, where a 20% decrease represents a 25% increase in the $LCOE_{2007}$, with a value close to that of the eligible FiT, so this reduction in the energy generated will result in an almost unprofitable scenario. This situation could be one of the cases envisaged in Section 3, where a minimization of OPEX has meant a drastic decrease in the energy generated, especially in 2015.

The above results come after an individual variation of the variables, but it could be more illustrative to show the combined effect that two variables can have on the $LCOE_{2007}$ value. Although the initial investment cost is the second most influential parameter, according to the results in Table 8, it is a variable that cannot be changed once the investment has been committed. Therefore, depending on the scope of the document, along with the most influential parameter, it is interesting to consider the influence of OPEX when both parameters vary by ± 20%.

The results from Fig. 5 and Table 9 show a wide range of possible $LCOE_{2007}$ values depending on the percentage of the combined variations of the selected parameters. In the worst-case scenario, when energy is at its minimum, possible unprofitable scenarios are presented, when the calculated resultant $LCOE_{2007}$ is 0.4584 €/kW h and 0.4142 €/kW h respectively.

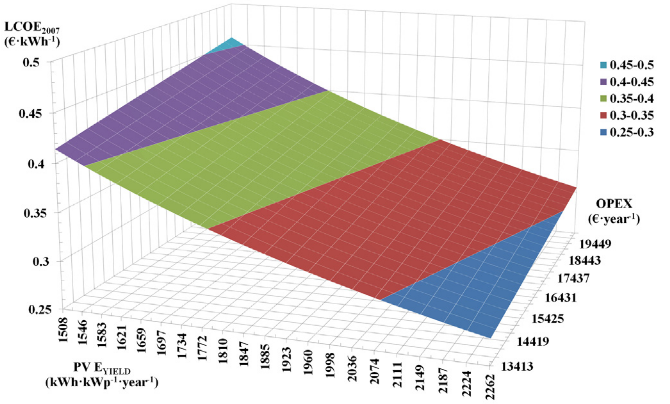

Fig. 5. $LCOE_{2007}$ Sensitivity analysis: most influencing parameters.

Table 9
LCOE differences when analysing the most influencing parameters.

$LCOE_{2007}$ = 0.3491 €/kWh		
Variables variation		**LCOE**
E_{PV} (+ 20%): 2262 kW h/year	OPEX (+ 20%): 20,119 €/year	0.3056 €/kWh (− 12.45%)
E_{PV} (+ 20%): 2262 kW h/year	OPEX (− 20%): 13,413 €/year	0.2762 €/kWh (− 20.89%)
E_{PV} (− 20%): 1508 kWh/year	OPEX (+ 20%): 20,119 €/year	0.4584 €/kWh (+ 31.32%)
E_{PV} (− 20%): 1508 kWh/year	OPEX (− 20%): 13,413 €/year	0.4142 €/kWh (+ 18.66%)

However, although the above findings are very useful in analysing the dependence of the LCOE on certain parameters, their discussion may be incomplete because the effect of OPEX and energy efficiency has been considered independently. As a consequence of not taking into account the effect that the OPEX variation could have on energy efficiency, which in turn also influences the LCOE, a more in-depth analysis should be carried out.

For an appropriate discussion, the actual performance scenarios studied in the previous section (see Table 6) are considered for a more in-depth analysis of their influence on the LCOE, the results of which are summarized in Table 10.

If the planned energy production and the original real OPEX result

Table 10
$LCOE_{2007}$ scenarios based on the real performance of the PV plant.

SCENARIOS		$LCOE_{2007}$ (€ kW h^{-1})
$LCOE_{original}$	Original Scenario $E_{forecast}$ = 206,294 kW h; OPEX = 16766 €	**0.3491**
$LCOE_{BEST}$	Best Generation Year: 2009 E_{2009} = 222,833 kWh; OPEX = 16766 €	**0.3232**
$LCOE_{AVERAGE\ 08–12}$	Average Energy Generation 2008–2012 $E_{average08–12}$ = 213,427 kWh; OPEX = 16766 €	0.3374
$LCOE_{WORST\ 15}$	Worst Generation Year: 2015 E_{2015} = 165,778 kWh; OPEX = 3966 €	0.3504
$LCOE_{year\ 2016}$	Energy Generation Year: 2016 E_{2016} = 186,239 kW h; OPEX = 3966 €	*0.3119*
$LCOE_{year\ 2017}$	Energy Generation Year: 2017 E_{2017} = 198,611 kW h; OPEX = 3966 €	*0.2924*
$LCOE_{AVERAGE\ 13–17}$	Average Energy Generation 2013–2017 $E_{average13–17}$ = 188,832 kWh; OPEX = 3966 €	*0.3076*
$LCOE_{FIXPV\ 15}$	Energy Generation Worst 2015. *Fixed system* E_{2015} = 165,775 kW h; OPEX = 3966 € PV_{IN} = 6058.67 €/kWp	*0.3204*
$LCOE_{FIXPV\ 16}$	Energy Generation 2016. *Fixed system* E_{2016} = 186,239 kW h; OPEX = 3966 € PV_{IN} = 6058.67 €/kWp	*0.2852*
$LCOE_{FIXPV\ 17}$	Energy Generation 2017. *Fixed system* E_{2017} = 198,611 kW h; OPEX = 3966 € PV_{IN} = 6058.67 €/kWp	*0.2674*
$LCOE_{FIXPV\ AVG13–17}$	Average Generation 2013–17. *Fixed system* $E_{average13–17}$ = 188,832 kW h; OPEX = 3966 € PV_{IN} = 6058.67 €/kWp	*0.2813*

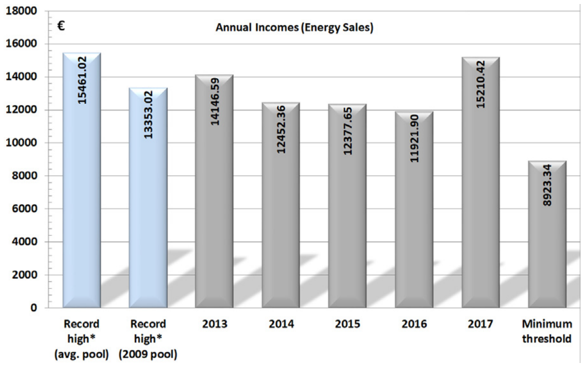

Fig. 6. Energy related annual Incomes comparison.

in a $LCOE_{2007}$ of 0.3491 €/kW h, which has been used as an indicator in this document, compared to the real energy context that occurred in 2009, when the best energy data were generated, as a consequence of really good weather conditions, there is a reduction of 7.4% in the LCOE, thus improving profitability. In addition, average electricity production in the period 2008–2012 also improves the LCOE prediction used in this work as a reference.

After the application of retroactive legal frameworks in Spain, the owner of the plant decided to drastically cut the expenses dedicated to the task of O&M, so this reduction affected the energy produced and its respective incomes, as shown in Figs. 3 and 6. Although in previous lines, according to the results of the LCOE sensitivity analysis, unprofitable scenarios could have been identified, surprisingly if all energy scenarios and their reduced OPEX are applied to the original financial conditions of 2007, we find a better LCOE, except for the year 2015, where the breakdown and reparation of the inverter meant a diminishing of the energy generated. Even in the worst-case scenario, the LCOE value (0.3504 €/kW h) is very similar to the original forecast of 0.3491 €/kW h.

In addition, if the energy data that the photovoltaic plant has produced in recent years, as a result of the OPEX reduction, are similar to those generated by a fixed system on the same site, it could be assumed that the initial investment would be lower since the tracking system and the complex foundations would not be necessary. Taking into account the amount dedicated to the tracking mechanism, the initial investment would be reduced to 6.06 €/Wp, so if the LCOE is recalculated, you will obtain an even more profitable scenario than in those years of optimum performance and perfect conservation of the photovoltaic plant.

4.2. OPEX influence in the annual liquid asset

In the previous section, different profitability scenarios have been presented based on the LCOE indicator, which inherently only takes into account cash outlets and the energy generated. However, from the owner's point of view, it is also interesting to analyse the effect that a reduction in OPEX can have on their income.

Once again, for the case under study, the legal framework of all the photovoltaic plants put into operation in 2007 was modified and they began to be regulated by Royal Decree 413/2014, which introduced some retroactive measures on photovoltaic installations already in operation. The previously approved feed-in tariff mechanism was cancelled and a new compensation system was proposed, consisting of a fixed term based on installed power and several variable terms depending on the electricity produced but subject to an annual limitation of operating hours.

Energy-related cash flow income has been defined by a first variable based on photovoltaic electricity generated in the wholesale market (Pool) (OMIE, 2018) and no annual time limit applied. The second term, called Operation Remuneration Operation (OP_{rem}), whose value was arbitrarily set by the Government, was assigned to electricity generated within a threshold operating hours (de la Hoz et al., 2016; Ministry of Industry Energy and Trade. Government of Spain, 2014).

$$INCOME_{ENERGY}\,(€) = (Pool + OP_{rem})\cdot E_{PV} \tag{5}$$

The maximum limit of the hour threshold is set at 2102 h beyond which the owner will not receive any more income related to the energy generated with the right to the OP_{rem}. At the lower limit (1261 h), the owner would only receive a proportional amount if the electricity generated is less than this value. For the calculation of the annual operating hours, the energy is divided by the nominal power of the plant (Pinv = 100 kW)

Limiting the maximum threshold may lead to a situation where it is more feasible to decrease OPEX at the expense of reducing electricity generated, while maintaining the profitability of the photovoltaic investment. Although preventive maintenance has been eliminated, and there is no corrective maintenance on an annual basis, as it was considered in the 2008–2012 period, certain corrective maintenance tasks are considered exceptionally only for cases where the productivity of the plant could jeopardise the remuneration received (minimum threshold), as it happened in 2015 with the breakdown of the inverters.

If this new compensation mechanism is applied to the energy scenario resulting from the abandonment of operation and maintenance tasks, in a first overview it is expected that the cash inflows applicable to the energy term will decrease as the electricity generated decreases, as appears to be the case in Fig. 6. Consequently, the more energy, the better for financing the investment. For example, if this new compensation mechanism is transposed to the energy performance of 2009 where record performance data was obtained as a result of very favourable weather conditions, energy-related economic revenues are higher, thus apparently reinforcing the idea that to increase the plant profitability, an improved O&M protocol should be applied to maximise the energy produced.

However, in order to achieve energy efficiency from that record year onwards, instead of an annual OPEX of 3966 €, the original amount of 16766 € should be spent. In this case, if the results in Fig. 6 are balanced, subtracting the energy-related income and the corresponding annual operating expenses (OPEX_{2009} = 3966 € and $\text{OPEX}_{2013\text{-onwards}}$ = 16,766 €), a net amount is obtained. The annual results can be seen in Fig. 7.

It is surprising that although the good energy yield context from 2009, in which the plant is perfectly maintained and therefore theoretically the best year in terms of potential energy-related revenues, the upper limit of operating hours and OPEX_{2009} turn this presumably more profitable scenario in an adverse annual liquidity situation with a negative balance. If the average pool prices from the period 2008–2017 are considered for the year 2009 (see Table 11), there is a negative balance of 1305 €, whereas if real pool values from 2009 are taken into account for the energy related incomes, the results are even worse, as the low pool electricity prices from 2009 makes we have a negative balance of 3413 €. In both cases, these values are below those obtained in the presumably worst cases from 2013 onwards. A detailed summary of the results of applying Eq. (5) can be found in Table 12.

In addition, if the energetic-economic analysis is deepened, the 2009 results are the best possible, so it is more than likely that the photovoltaic plant will generate electricity according to the results of any of the other years within the “good” period 2008–2012. In all these energy scenarios, and assuming the current legal framework but the original OPEX, the results worsen as energy sales are lower. Considering an average pool price and the original pool values from each year, in all cases there is a negative balance in the energy related term as Figs. 8 and 9 shows. There is only one exception in the year 2008 with its original pool value, but the balance is even lower than the case where the minimum threshold is analysed (see Fig. 7). It is worth mentioning that in any of the 2008–2012 scenarios, the effect of the upper limit of operating hours is almost insignificant.

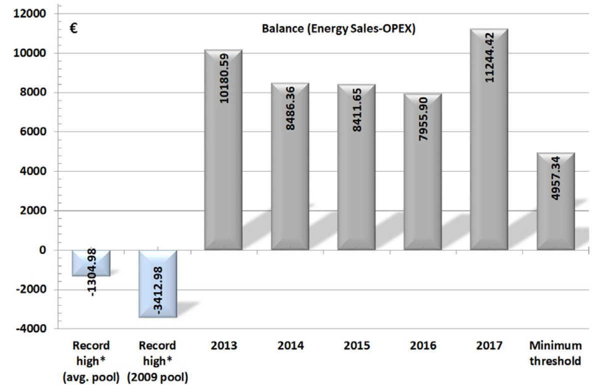

Fig. 7. Annual Net Energy Incomes balance.

Table 11
Energy incomes concepts applicable to the analysed PV plant according to IET/1045/2014.

Energy related economic incomes		
OP_{rem} (€/MWh)	24.34	
Pool (€/MWh)	2008	64.43
	2009	36.96
	2010	37.01
	2011	49.94
	2012	47.23
	2013	44.26
	2014	42.13
	2015	50.32
	2016	39.37
	2017	52.24
$\text{H}_{\text{threshold}}$ (h)	1261–2102	

Although corrective maintenance tasks will be considered in the exceptional case any breakdown could mean that the minimum threshold production could not be reached, It is important to highlight that although investing some money on a punctual basis the future, even in the minimum threshold scenario, the energy sales-opex balance (€) is much more favourable (Fig. 7) that in the scenarios glimpsed for the years of the “good period” (Figs. 8 and 9). Therefore we have a large margin of money to devote to exceptional corrective maintenance and still being more profitable than optimally maintaining the PV plant. In the worst scenario possible of Figs. 8 and 9 there would be between 3000€ and 6200€ available to specific corrective maintenance tasks of one year.

4.3. O&M sensitivity analysis

In order to complement the sensitivity analysis from Section 4.1 and although the performance, OPEX and energy remuneration values used in the paper come from real data provided by the owner of the plant under analysis, it is interesting to undertake a sensitivity analysis which include some range of uncertainty in the performance and OPEX values which may affect the energy remuneration estimates.

In Fig. 10, an analysis of the energy performance and its effect in the incomes can be observed. It has been simulated a ± 25% variation in the electricity generated from the PV plant and how it affects, under the current national legal framework, the remuneration received by the owner, only accounting for the energy related incomes. In this simulation the median energy values from the period 2008–2012 (full OPEX) and 2013–2017 (current OPEX) have been used as reference data respectively. It is easily observable the relation between energy and incomes variations in each graph, but what it is interesting is the apparent worse revenues scenario under the current OPEX situation, where the O&M tasks have been dramatically reduced. However, it is notorious that + 25% variation in the electricity generated only represents 16% in incomes for the 2008–2012 scenario compared to 21% for the apparently less favourable one (2013–2017). This is a direct consequence of the upper generation limit imposed by the national legislation which discourages optimal plant production.

In light of the above results, it is interesting to analyse how a range of variability in operating and maintenance costs may affect plant performance and, by extension, energy sales revenues.

Analysing the O&M tasks of the original maintenance protocol and the energy drops produced after the suspension of almost all preventive activities, there is no global harmony in the impact of O&M tasks with the OPEX and its consequent energy decrease. In this sense a classification of the O&M tasks depending on their impact in the energy drop

Table 12
Energy incomes comparison scenarios.

Energy Economic Incomes vs OPEX

	2009 (Record) 222,833 kWh	**2013** 206,206 kWh	**2014** 187,327 kWh	**2015** 165,778 kWh	**2016** 186,239 kWh	**2017** 198,611 kWh	**Lower Threshold** 126,100 kWh
Operational hours (h)	<u>2102</u> (limit)	2062	1873	1658	1862	1986	1261
OP$_{rem}$ (€)	5117.11	5019.89	4560.28	4035.70	4533.80	4834.99	3069.8
Pool (€)*2008–2017 average data*	10,343.91*	9126.70	7892.08	8341.95	7388.10	10,375.44	5853.56*
OPEX (€)	16766	3966	3966	3966	3966	3966	3966
Balance (€)	− **1304.98**	10,180.59	8486.36	8411.65	7955.90	11,244.42	4957.34

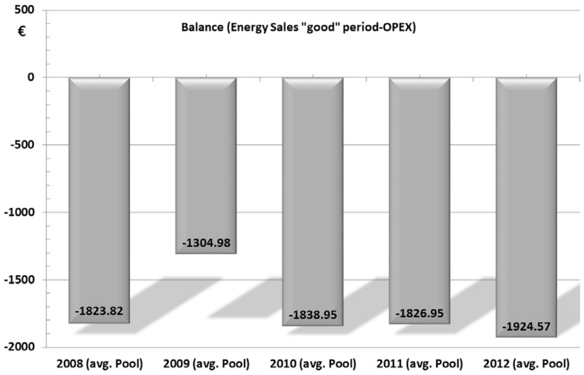

Fig. 8. Annual Net Energy Incomes balance for the "good" performance period.

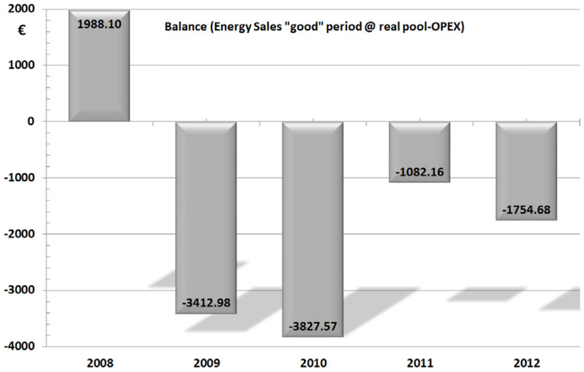

Fig. 9. Performance and O&M impact influence.

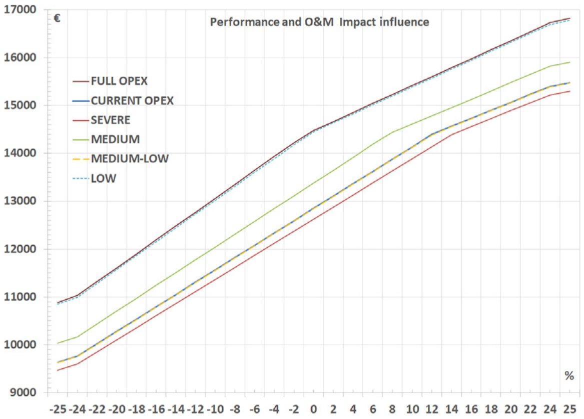

Fig. 10. performance and O&M impact influence.

for the plant under analysis is proposed (see Table 13). In order to normalise these losses, two additional columns have been included specifying how a 1% reduction in the OPEX may affect energy losses.

Table 13
Impact classification of O&M tasks.

Impact of O&M tasks	**OPEX**	**Energy drop**	**OPEX**	**Energy drop**
Severe	3.3%	13%	1%	4%
Medium	8.3%	7.8%		1%
Medium – Low	20.2%	11.5%		0.6%
Low	3.5%	0.3%		0.1%

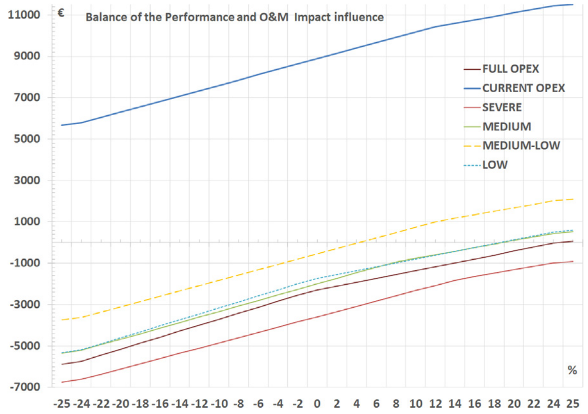

Fig. 11. Balance of the performance and O&M impact influence.

We have graphed these variabilities in the aforementioned Fig. 10 taking as reference the values of the 2008–2012 period. In all the O&M cases, there is a negative impact in the revenues, but if these results are compared with the current OPEX scenario, they apparently glimpse a more profitable situation, with the exception of the severe one.

Despite these results, and in accordance to the main discussion line of this manuscript, it is more appropriate to include in the sensitivity analysis not only the influence of O&M on the revenues, but also its corresponding cost variations.

Fig. 11 shows the net balance of the revenues and the OPEX decrease (column 2 from Table 13) taking as reference the optimum O&M protocol. Although OPEX decreases ranging from c.a. 3% to 20% mean energy losses from c.a. 0.3% to 12%, and a subsequent decrease in revenues, as pictured in Fig. 10, the less profitable scenario situation has flipped. In all the cases, the current OPEX situation of the PV plant provides more favourable data for the profitability of this project.

Therefore, it is expected that if the normalized OPEX data (only 1% decrease) are graphed (see Fig. 12), they would show an even less profitable situation when compared to the current status of the PV plant.

The above results reinforce the idea that proper promotion policies should be focused on optimizing the energy production of a system.

5. Conclusions and policy implications

Currently, the Operation and Maintenance protocol is becoming

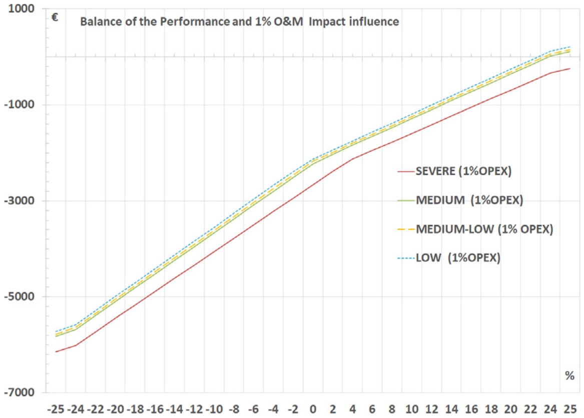

Fig. 12. Balance of the Performance and 1% O&M impact influence.

increasingly important in the asset management of a photovoltaic plant. However, there are hardly any reports and papers that analyse in depth their role in the energy and economic performance of such systems. Furthermore, the lack of consensus on the content of an appropriate O&M contract further complicates the proliferation of such studies, and if this study is intended to be applied in PV projects from 2008, the identification of annual OPEX is even more complicated.

In light of O&M's influence on the energy results shown in this work, which has been characterised by a specific photovoltaic tracking facility located in Spain, a reduction in O&M's tasks decreases the energy that this photovoltaic system can generate. However, a preliminary analysis reveals that a percentage decrease in annual operating expenses does not necessarily imply the same trend in energy losses. In the case analysed, a reduction of about 76% in the annual OPEX only meant a 26% reduction in energy in the worst-case scenario. These results could be understood as an over-dimensioning of the O&M protocol, but they should also be further analysed to assess which O&M tasks could be avoided or delayed. The standardization, still in progress, of such activities can avoid these situations.

An interesting conclusion it that O&M's activities may not be profitable for the companies that offer such services if the size of the plant is small-medium (< 100 kW) and the installation is not located within the surroundings of the company's headquarters, as the case analysed in this manuscript. The affordable alternative is monitoring the installation by a dedicated software and a relative fast response time in the case of corrective maintenance, but in any case, a high quality O&M protocol, as requested by the owner of the plant analysed, cannot be undertaken.

Therefore, the results obtained could be very valuable for PV asset management companies and plant operators to optimise their photovoltaic O&M products and maximise the revenues of themselves and their customers.

Additionally, without taking into account any legal framework under which a photovoltaic plant is subscribed, it could be estimated that although a reduction in the OPEX undoubtedly implies a decrease in the energy generated, and therefore a reduction in the energy related economic incomes, it does not necessarily imply a reduction in the profitability of the photovoltaic investment. In the case analysed, with its design, construction and location characteristics, it could even result in a more profitable scenario than the original one. In this study, the lack of O&M activities and the resulting energy losses in the 2013–2017 period, yield results of an LCOE = 0.3076 €/kW h, which is an improvement of 12% over the original business plan of LCOE = 0.3491 €/kW h. As indicated in this document, not all cases where a high quality O&M protocol is proposed for a particular PV plant result in a more cost-effective scenario or improved LCOE (SolarPower Europe, 2016).

In addition to the direct energy influence of OPEX and, therefore, its impact on LCOE estimates, the economic perspective of the annual liquid assets of the investment must be taken into account, whose results, specific to the national legal framework, show a bleak picture. Despite the fall in energy as a consequence of minimising operating and maintenance activities, from the liquidity point of view it is more feasible to reduce the annual OPEX at the expense of reducing the electricity produced, while maintaining the plant's profitability in line with the operational hourly limitations of the national legislation.

The results show a national context in which if the energy and OPEX of the "best years" period is shifted to the current date, the owner will lose money annually, therefore, this lack of liquidity is having more influence on the performance of the plant than the investment in improving the energy efficiency of the system. A significant conclusion of this report shows that, under national legal restrictions, instead of maintaining the original operating and maintenance costs, it is more profitable to remove all preventive maintenance of the photovoltaic plant and only undertake corrective O&M in those borderline situations where less energy is generated than required by law to receive remuneration.

The policy implications are also an important conclusion, as although the almost abandonment of maintenance tasks may imply an increase of the risks, the owner has no other alternative. As a result of poor policy planning, under the current national legal framework, in the case he decides to optimally maintain its plant, thus maximizing the energy production, he not only loses money in regards to the “good performance years”, but what it is more important, he has to deal with annual liquidity problems, which may jeopardise the investment. Therefore he prefers to face the risks and generate less energy than to go bankruptcy (Lomas et al., 2018)

Therefore, the results discussed in the document demonstrate that high quality O&M does not always improve the Levelised Cost of Electricity or the annual liquid asset of a photovoltaic investment.

The implication of policies not only may affects the economic feasibility of PV investments, but also the electricity generated with renewable energies as seen in this study, which indirectly may affect the national energy generation mix and the achievement of renewable generation targets.

In this paper, certain policies have had an implication in increasing the financial risk of small investors, reducing the profitability of investments already made and decreasing the productivity of photovoltaic plants, therefore, it is important to analyse whether future promotion policies will focus only on economic variables or they will pay special emphasis on maximizing the performance of a certain technology, moreover when the fall in PV installation prices is a result of economies of scale, not on improvements in its performance (Economist Special Report, 2018).

Additionally, it should be noted that this work focuses on the effect of O&M on the viability of utility-scale solar PV trackers, based on a representative case subordinated to the characteristics of Spain and its legislation. On the opposite side, as mentioned in the introduction, an increasing number of countries are claiming to include O&M requirements in public tenders for photovoltaic projects. Consequently, O&M tasks seem to be gaining importance in the policy making of photovoltaic promotion plans.

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Glossary

d: Discount rate (%)
d_i: Dividends (%)
EPC: Engineering, Procurements and Construction
E_{PV}: Annual Energy produced by a PV system (kWh/year)
FIT: Feed-in Tariff
$H_{threshold}$: Threshold of annual operational hours (h)
i_l: Annual loan interest (%)
KPI: Key Performance Indicators
LCC: Life-Cycle Costs of a PV system (€)
LCOE: Levelised Cost Of Electricity
N: Operational lifetime of a PV system (years)
N_l: loan term (years)
O&M: Operation and Maintenance
OPEX: Operation Expenditures
OP_{rem}: Operation Remuneration (€/kWh)
Pinv: Nominal power of the plant (kW)
Pool: Wholesale electricity market (€/kWh)
PPA: Power Purchase Agreements
PV: Photovoltaic
PV_{EQ}: Private Equity capital (€)
PV_{EX}: External Capital (€)
PV_{IN}: Initial Investment (€/Wp)
PV_{OPEX}: Annual Operation Expenditures of a PV system (€/year)
PW: Present Worth
RD: Royal Decree
r_d: Yearly degradation rate of the power generated (%)
ROI: Return of Investment (%)
WACC: Weighted Average Cost of Capital (%)