

Renewable energy – technology, production costs and profitability

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Abstract

The advancements in solar PV and wind energy, together with cost reductions have increased the competitiveness of these technologies in the power sector. The cost of generating electricity with these systems has decreased considerably in the last decades and it is becoming very attractive to invest in this area. Taking this into consideration the aim of this paper is to provide a financial and economic model to assess the profitability of solar PV and wind projects. This model is applied to two residential PV installations located in Portugal and Spain and a wind farm located in Argentina. Although all the projects are profitable under the conditions of the base case scenario, there are several differences between the factors considered and the methodology followed for each case, which result in the largest profitability for the Portuguese case, followed by the Spanish and finally the Argentinian. The influence of the different factors over the profitability parameters is analyzed through a sensitivity analysis, which concludes that the installation cost, electricity output and electricity price strongly affect the parameters. Consequently, it is evidenced the importance of technology improvements and cost reductions, together with a favorable and reliable regulatory framework, in order to achieve larger profitability on PV projects.

Keywords: Electricity production cost; wind energy, solar PV energy; energy projects assessment.

1. Introduction

Renewable energy technologies are in the spotlight of the power sector; yearly it is set a new record of capacity installed worldwide. The growing implementation of renewables in the electricity generation mix is a consequence of the innovation and development of the renewable energy industry, which is leading to a reduction in the cost of generating electricity with renewables. The technology improvement and cost evolution of the two most employed non-convectional renewable energy sources worldwide, solar photovoltaic and wind energy, are presented within this work.

In the photovoltaic (PV) industry huge advancements have been achieved in the last decades. In the

technology side, continuous improvements in materials and manufacturing process are boosting the performance of PV installations. Whilst crystal silicon still being the most used technology, new materials are under research for future implementation. Additionally, the cost of PV has plummeted since the early 1980s and it is achieving grid parity in some locations. In the last two years the price of the PV modules has been drastically reduced to values forecasted to 2025. Whereas in 2015 the average price of PV modules for utility-scale projects, according to the International Renewable Energy Agency (IRENA, 2016), ranged between 0,52 \$/W in India to 0,72 \$/W in Japan, current prices for utility scale projects are as low as 0,32 \$/W in some locations.

The technology improvements in the wind sector have been focused in scaling up the size of wind turbines, which have resulted in the current multi-megawatt wind turbines. In line with this increase, other improvements have been implemented like controlling systems, better materials, etc. Although the wind industry has experienced great reductions since early 1980s, the cost of wind energy has been increased during some periods, mainly caused by market constraints and unfavorable financial support.

The main purpose of this work is to analyze those economic and technological trends of the sector and present a financial and economic model that allows to assess the profitability of renewable energy projects. The model will be applied to three recent projects: two residential PV installations in Spain and Portugal and a wind farm in Argentina. Each project includes the most accurate information regarding installation and operating costs, capacity factor, useful life, capital cost and subsidies in order to perform the viability study. Moreover, it is performed a sensitivity analysis for each case. This analysis evaluates the uncertainty with the most relevant factors, which are installation cost, electricity output, electricity prize, operating expenses and discount rate.

2. Evolution of renewables energies

2.1 Solar photovoltaic

Crystalline silicon and thin film technologies have hoarded the PV market. At the beginning mono-Si was the technology dominating the market due to its better conversion efficiency of light into electricity. This trend has

periodically changed to a domain of multi-Si, which controls the PV market (69% of the production of PV modules in 2015) (Fraunhofer ISE, 2016). The switch from monocrystalline to polycrystalline was due to advancements in the PV industry focused in reducing cost and increasing the rate of production. Therefore efficiency of the solar cell as well as its cost played an important role in determining the share of each technology in the market. Other factors like useful life and carbon footprint also influence the market.

The efficiency of the different technologies has varied considerably. Monocrystalline silicon experienced an early increase in cell efficiency that led it to domain the market. This technology has improved its efficiency more than 80% in 40 years, from 13,8% to 25,3%. A smaller increase of 46% has been achieved in multicrystalline, which current efficiency is 21,9%. Thin film technologies have also improved their efficiencies considerably, positioning their efficiencies right above multicrystalline levels, with an exception of amorphous silicon technology whose best efficiency result is 14%. Regarding third generation technologies a wider range of results is presented, from 11,5% (organic cells) to 46% (III-IV multi-junction solar cells)

The degradation rate of the solar cells is also an important factor because it determines the losses in electricity production and useful life of the module (i.e. typically a 20% decline is considered failure of the PV module). Although most manufacturer's warrant period is 20-25 years, it has been demonstrated that the useful life of old technologies is above 25 years, and new ones are expecting 30 years life time or even more (Realini, 2003; Harrabin, 2009). Table 1 summarizes the degradation rates of the different technologies in the market. This table also includes the footprint of such technologies by presenting the metrics most used to assess the environmental impact, global warming (CO₂-eq. per kWh produced) and energy payback period (EPBP). Notwithstanding c-Si solar technologies are the most pollutant and required more energy to be produced, still hoarding the PV market.

<i>Technology</i>	<i>Degradation rate</i>	<i>CO₂-eq/kWh</i>	<i>EPBP</i>
<i>Monocrystalline</i>	<i>0,4% – 0,7%</i>	<i>50</i>	<i>3,3</i>
<i>Multicrystalline</i>	<i>0,5% – 1%</i>	<i>50</i>	<i>2,1</i>
<i>CdTe</i>	<i>0,75% – 1,5%</i>	<i>23</i>	<i>1,2</i>
<i>a-Si</i>	<i>0,1% – 1,25%</i>	<i>42</i>	<i>2,4</i>
<i>CIGS</i>	<i>0,6% – 2%</i>	<i>-</i>	<i>1,75</i>

Table 1 Degradation rate and environmental footprint of the main PV technologies in the market

The installation cost of a PV system is divided into PV module and balance of system (BOS) costs. The most important components in the overall cost of the PV installation are modules and inverter. The module price has significantly decreased since 1980s, from 90 €/Wp to below 1 €/Wp. This reduction in cost is the result of technological innovation, manufacturing automation and economies of scale. Introducing bigger manufacturing plants has allowed

decreasing substantially the price of per module produced. Likewise, improvement in the machinery has enhanced the overall efficiency of the plant and reduced the breakage of cells during the fabrication process. Similar levels of cost reduction have been achieved with inverter technology, which cost has dropped in the last decades to almost 0,10 €/Wp from 1 €/Wp. The main reasons behind this reduction are the improvement of efficiencies and power density, which drivers were new circuit topologies and better power semiconductors. Whereas the reduction in module cost in the last decades has been the leading factor for reducing the overall installation cost, it is forecasted that reduction in BOS will represent the next leading factor in reducing the plant cost.

LCOE (Levelized Cost Of Energy) has been considerably reduced due to the reduction in installation cost. The improvements in efficiency and management of the plant (i.e. performance of the PV panels) have also helped to reduce considerably the LCOE. In fact, last year (2016) in Abu Dhabi was set the lowest bidding price in solar PV (29,9 \$/MWh), which is half the average electricity spot market price in Europe (Magyary, 2017). It is important for PV systems to have an LCOE similar to the traditional technologies that allows the competition in the market. Accordingly, PV systems use the technology that has the lowest LCOE, which is achieved by multicrystalline PV modules. The future technology used in the PV sector and its cost is unpredictable due to the dynamisms of PV industry seen in the last years.

2.1 Wind

The evolution of the wind energy sector is a combination of engineering and scientific skills and entrepreneurial spirit. In the recent history of wind power it has been several improvements in the technology of wind turbines, being the scaling up factor of the turbines the most relevant one. In this sense, the average power capacity has increased from 0.05 MW in 1985 to 2,20 MW in 2014 (IEA-ETSAP and IRENA, 2016). Likewise, other developments in alternative materials, power control system, electric systems, foundations and drive train mechanisms have been also relevant in other to achieve the current multi-megawatt power generations machines. For instance in September 2016 the Vestas' V164-8.0 MW, largest turbine in the world, was installed at the Burbo Bank Extension offshore wind farm, standing at 195 meters.

The rotor size has been scaled up in order to increase the capture and conversion of wind velocity into rotational energy. Technology material and aerodynamics have played a key role. The evolution to the use of polyester resin and glass fiber from wood epoxy allowed increasing the dimensions of the blades. Furthermore, taller towers have been built in order to access to higher and more constant wind velocities. Traditionally, cylindrical steel towers have been the most used solution, currently hybrid towers (steel and concrete) are emerging because allows to access greater heights avoiding transportation problems and volatility of steel (DOE, 2016; Lacalet *et al.*, 2014).

Wind turbines have also experience a development of the drive train and control systems. The former has

evolved to equipment that maximizes the efficiency of the wind turbines under variable wind speeds and interact with the grid. The latter allows operating the turbine in its maximum power coefficient, which increases the electricity output. Along the recent history of the wind industry other advancements in technology has improved the overall performance of wind turbines. For instance the turbine's electronic controller, which monitors and controls the turbine and collects useful data (e.g. rotational speed, temperature of hydraulics, blade pitch, nacelle yaw angles to wind speed, etc.), is facing new developments that will allow forecasting the upcoming winds, thus, increasing considerably the performance of wind turbines (Kaldellis *et al.*, 2011).

The cost of onshore wind energy has experienced a remarkable decreased since first wind turbines were launched into the market. These reductions are consequence of the technology improvements, economies of scale and learning of the industry. Nevertheless, the cost of onshore wind has not always experienced a downward trend. In fact, between 2004 and 2009 the cost of wind energy increased considerably. Fluctuations in the turbine cost have affected the price of the installation cost in wind projects. In the history of wind turbines, it is possible to distinguish three different periods. First period embraces the years before 2004, where turbine prices were decreasing at a fast rate, 10% reduction with double cumulative power installed. The main factor guiding this trend was the scaling up of wind turbines, technological improvements allowed great increases in the output power of the turbines with slight increases on prices. During the second period, 2004 to 2009, a pattern of increasing turbine prices was dominating the market. This phenomenon is easily explained by the great increase in wind turbines demand along with constrains in the supply side. The turbine manufactures were not prepared for such an increase, neither were the sub-suppliers of turbine components (Gardner *et al.*, 2009). Moreover, the increase on commodity prices, in particular steel and copper, contributed to the increase in costs during this period that peaked in 2009. Since then prices have declined considerably, showing a reversal on the upward trend. In addition, economies of scale plus the increased competition has helped to return to decreasing costs.

Since the early 1980s, LCOE of onshore wind has experimented different trends. From the 1980s until 2004, the LCOE of wind energy experienced great reductions due to increases in performance (i.e. greater energy outputs), reductions in CAPEX and in capital cost. LCOE of onshore wind installations declined by a factor of five, from 0,25 \$/kWh to 0,05 \$/kWh (Wiser and Bolinger, 2011). Between 2004 and 2008 the LCOE increased up to 0,075 \$/kWh due to the aforementioned increased in CAPEX and hence cost of capital. However, this increased did not have a proportional effect on LCOE due to increases in capacity factor. Since then, this upward trend was reversed due to reductions in capital cost and CAPEX and technological improvements. Thus, current LCOE values are around 0,055 \$/kWh.

Regarding offshore projects, great reductions in the following years after the construction of the first offshore wind farm (coast of Vindeby in Denmark, 1991) were achieved. However, the LCOE was drove up to 0,19 €/kWh by 2010 due to mishaps in the construction (increase in turbine prices) and operation, together with the hesitant of

governments to support this form of renewable energy, which increased the financing cost. Investors were reluctant to invest in such projects without clear support from governments. This trend was reversed thanks to initiatives like the Offshore Wind Accelerator in the UK and the Far-and Large Offshore Wind program in the Netherlands. In fact, the first tender under the new support regime in the Netherlands for two wind farms (Borssele I and Borssele II) presented a winning bid of 87 €/MWh, which is a 54% decreased from 2010 values.

3. Financial and economic model

The advancements in solar PV and wind technologies, together with cost reductions have increased the competitiveness of such installations in the power sector, making important to assess the profitability of those projects. If we examine the parameters calculated in the financial and economic assessments performed by different researchers, we find that the most widely used are the net present value (NPV) and internal rate of return (IRR) (Hammond *et al.*, 2011; Bakos, 2008; Talavera *et al.*, 2010; Swift, 2013). Additionally, the discounted pay back period (DPBP) is also a widely used parameter in financial studies to assess risk (Rehman *et al.*, 2005; Chandel *et al.*, 2013). Finally, another extensively used parameter is LCOE (El-Shimy, 2009; Branker *et al.*, 2011; Talavera *et al.*, 2011; Girard *et al.*, 2015), which is commonly used as a benchmarking tool to compare the cost of generating electricity with different technologies or to evaluate if a certain technology has achieved grid parity. The analysis of PV and wind projects may also include the positive externalities of these energy sources

In our model, the calculation entails the evaluation of the future inflows and outflows evaluated in constant euros (i.e. excluding the effect of inflation). Thus the real discount rate is used to discount the future cash flows.

$$r_r = \frac{(1 + WACC)}{(1 + i)} - 1 \quad (1)$$

Where r_r is the real discount rate, WACC is the weighted average cost of capital and i is the inflation

The WACC represents the minimum return that an investor can expect taking into account the sources of financing. It is calculated by applying Equation 2, which weights the percentage of equity and debt in a project and calculates the cost of each source

$$WACC = \%E \times r_e + \%D \times r_d \times (1 - \tau) \quad (2)$$

Where $\%E$ is the percentage of the project financed by equity, r_e is the cost of equity, $\%D$ is the percentage of financing that is debt, r_d is the cost of debt and τ is the corporate tax rate

The cost of debt is generally the interest rate of the money borrowed from a financial institution. The methodology to calculate the cost of equity varies according to the perspective. Thus, individual investors calculate it by adding up to terms known as risk free interest rate and subjective risk premium. Companies not listed in on a stock exchange market follow similar methodology. Finally, listed companies may use the capital asset pricing model (CAPM) (Soares *et al.*, 2006).

Thereafter, the followings items are evaluated: capital investments (ICF_t), revenues, operating expenses, depreciation & amortization, tax liabilities and net cash flows. Revenues of PV and wind projects come from saving or/and selling electricity, which are calculated by applying the following expression.

$$R_t = Q_{saved,t} \times P_c + Q_{sell,t} \times P_s \quad (3)$$

Where $Q_{saved,t}$ is the annual electricity savings; P_c is the price of each kWh consumed; $Q_{sell,t}$ is the annual electricity sell to the grid; P_s is the price of the electricity sold.

The annual electricity savings term ($Q_{saved,t}$) is only considered in the self-consumption models. This value is calculated using Equation 4, which includes the percentage of the electricity produced that is absorbed by the load (i.e. residential building, factory, commercial building, etc.) and the degradation rate (for annual reductions in electricity generation). Thus, the revenues obtained from saving electricity are calculated by multiplying this term times the price of the electricity consumed (P_c)

$$Q_{saved,t} = \%Q_{saved} \times Q_{gen,n} \times (1 - r_d)^{t-n} \quad (4)$$

Where $\%Q_{saved}$ is the share of the total production that it is absorbed by the load, r_d is the annual degradation rate, t is the evaluated year and n is the year in which the plant starts operating.

On the contrary, $Q_{sell,t}$ account for the electricity feed into the grid (Equation 5). In self-consumption models, this term accounts for the excess of electricity feed into the grid. Regarding power plants, all the revenues come from this term of the equation.

$$Q_{sell,t} = \%Q_{sell} \times Q_{gen,n} \times (1 - r_d)^{t-n} \quad (5)$$

Where $\%Q_{sell}$ is the share of the total production that it is sold to the grid, r_d is the annual degradation rate, t is the evaluated year and n is the year in which the plant starts operating.

The operating expenses are all the expenses that occur during the serviceable life of the generating facility. Such cost are presented by different means according to project and countries. Therefore, in order to harmonize the different costs considered in the renewable energy projects, it has been considered the following items: (1) fixed O&M cost [€/kW], which considers all the fixed cost that need to be assumed; (2) variable O&M cost [€/kWh], which accounts for the costs associated with the electricity generation of the plant; (3) additional fixed costs [€/kW] that considers extra charges related with the capacity installed; and (4) additional variable costs [€/kWh] that includes fees or charges to electricity generation. These four items add together account for the annual operating expenses of the installation ($Opex_t$).

Furthermore, the cost of a renewable energy project is allocated over its useful life by using depreciation and amortization. In this model a linear depreciation methodology over a specific period is employed. Depreciation of the assets is only applied to companies, not to individual owners. The value depreciated each year (D_t) is the sum of the depreciation of the different assets, which is subtracted from the EBITDA to reduce the amount of taxes paid.

Tax liabilities are the product of the operating income times the corporate income tax rate.

$$T_t = \tau \times (R_t - Opex_t - D_t) \quad (6)$$

Where τ is the corporate income tax rate

Finally, annual net cash flows (CF_t) are calculated. It is the sum of the investment (ICF_t) and operating cash flows (OCF_t).

$$CF_t = OCF_t - ICF_t \quad (7)$$

Moreover, the LCOE including and excluding externalities is calculated with the following expressions.

$$LCOE = \frac{\sum_{t=0}^T (Opex_t + ICF_t) / (1 + r_r)^t}{\sum_{t=0}^T E_t / (1 + r_r)^t} \quad (8)$$

$$LCOE_e = \frac{\sum_{t=0}^T (Opex_t + ICF_t - Ex_t) / (1 + r_r)^t}{\sum_{t=0}^T E_t / (1 + r_r)^t} \quad (9)$$

The LCOE including externalities has been calculated by considering the social cost of avoiding CO₂ emissions to the atmosphere. In order to proceed with such calculation it has been considered a factor of electricity generation - CO₂ emission intensity (kgCO₂/kWh), which measures the emissions of CO₂ associated with the generation of 1kWh of electricity produced in a certain country. Moreover, it has been considered a cost for each unit of CO₂ emitted to the atmosphere (€/kgCO₂). This cost is considered equal to the price on GHG emissions imposed by governments and organizations.

4. Cases studies

The model is applied to three real cases in order to present updated information regarding solar PV and wind energy projects: two residential solar PV cases and an onshore wind project, in order to show the differences between both technologies and the approach followed when a project is addressed from the company perspective. Furthermore, it has been performed a sensitivity analysis for each case.

4.1 PV system in Santarém

This is a residential PV installation sized to cover the base household electricity consumption. The household will consume most of the electricity generated by the installation. The surplus of electricity will be given away for free to the grid system. The inputs used in the base case scenario (BCS) of this PV system can be found in Table 2.

Factor	Data
Installation cost [€/W]	1,53
Electricity output [kWh/kWp year]	1756,4
Operating expenses [€/kWp]	15,27
Electricity price [€/kWh]	0,2018
Project lifetime [years]	25
Real discount rate [%]	1,97
CO ₂ emission intensity [kgCO ₂ /kWh]	0,7
Price GHG emissions [€/kgCO ₂]	0,007

Table 2 Input data for the PV system in Santarém

Results: The cumulative cash flows of the project (Figure 1) shows that the money invested will be recovered during the sixth year of operation of the PV system. Moreover, the project has a NPV equal to 5.812,61 € and a nominal IRR of 20,24%. Consequently, the project is profitable under the base line considerations. Such positive results explain the great difference between the LCOE (0,067 €/kWh) and the electricity price (0,2018 €/kWh).

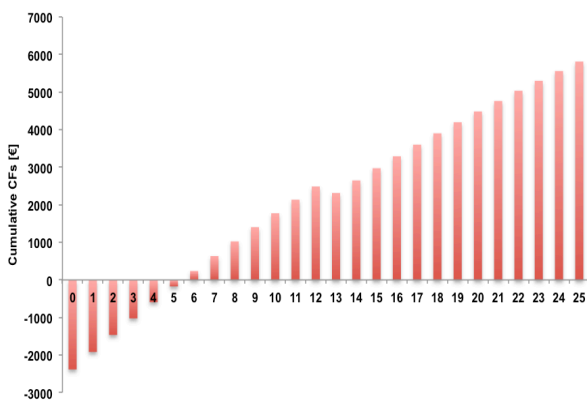


Figure 1 Cumulative cash flows of the PV system in Santarém

Regarding the sensitivity analysis, the following factors have been considered: percentage of financing that is debt, installation cost, electricity price, electricity production and O&M cost. Although the installation cost and financing of the project is defined because the installation is already constructed, it has been considered important to see how the project would have been affected by these factors. The rest of variables considered in the sensitivity analysis have been selected because its unpredictable nature (i.e. these values might change due to variations in weather, regulation, technology performance, etc.). The weight of each factor on the financial results varies widely. The following Figures 3, 4 and 5 presents the variations of the NPV, IRR and LCOE with the relative percentage variations of the main factors from the base case scenario. The electricity price it is not presented within the graphs because entails the same influence as the electricity output over the NPV and IRR.

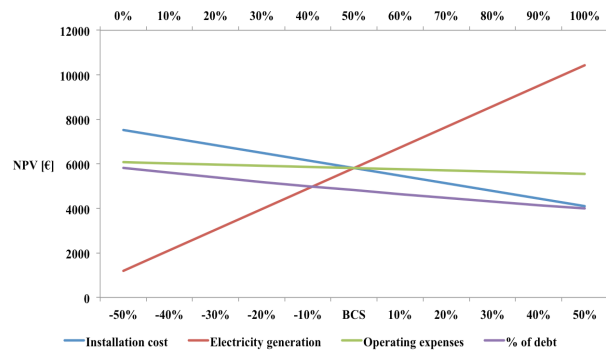


Figure 2 NPV of the PV system in Santarém as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS and the percentage of financing that is debt

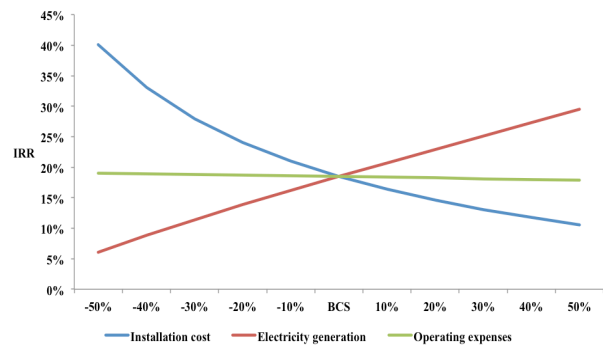


Figure 3 IRR of the PV system in Santarém as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS

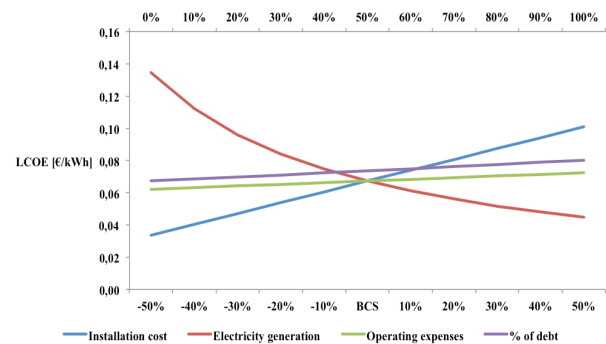


Figure 4 LCOE of the PV system in Santarém as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS and the percentage of financing that is debt

It can be concluded that installation cost, electricity output and electricity price have the greatest influence over the profitability and cost indexes. The NPV is more affected by variations in the electricity price and electricity output, resulting in relative percentage variations up to 79%. Meanwhile, the IRR is more influenced by the installation cost, which entails relative percentage variation up to 117%. Regarding LCOE variations, electricity output entails the strongest influence with relative changes up to 100%.

4.1 PV system in Valencia

The PV installation is designed to cover over half of the current electricity consumption, thus an installation of 6,72 kWp is needed. The system is going to be located in a household in Valencia, Spain. Due to unfavorable regulatory framework (none compensation is received from the electricity feed into the grid), a storage system will be acquired in order to store the surplus of electricity during peak sun hours. The values used in the BCS of this PV system are presented in Table 3.

Factor	Data
Installation cost [€/W]	2,17
Electricity output [kWh/kWp year]	1300,6
Operating expenses [€/kWp]	30,73
Electricity price [€/kWh]	0,193
Project lifetime [years]	30
Real discount rate [%]	2,69
CO ₂ emission intensity [kgCO ₂ /kWh]	0,34
Price GHG emissions [€/kgCO ₂]	0,005

Table 3 Input data for the PV system in Valencia

Results: Figure 5 shows the cumulative cash flows of the project during the serviceable life of the installation. The investment is recovered during the 19th year of operation. The project generates a NPV of 6.884,8 € with a nominal IRR of 7,92%. In this case study, the difference between the LCOE (0,146 €/kWh) and the electricity price is considerably smaller, thus the project is less profitable.

As a consequence of the results obtained, it is necessary to elaborate a sensitivity analysis over the most likely values to suffer variations: installation cost, percentage of financing that is debt, electricity production, operating expenses and electricity price. Figures 8, 9 and 10 present the variations in the NPV, IRR and LCOE when this parameters change.

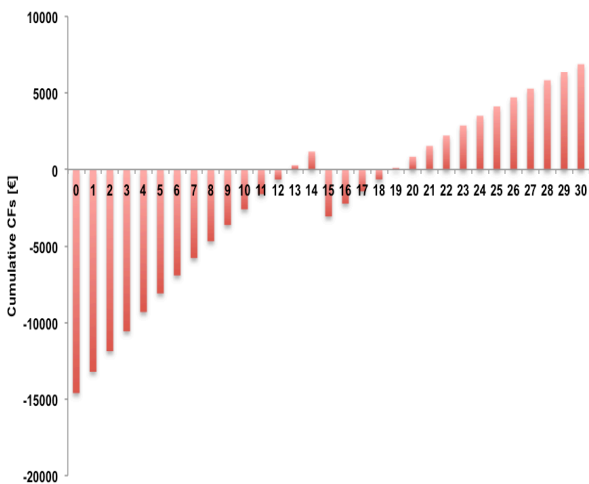


Figure 5 Cumulative cash flows of the PV installation in Valencia

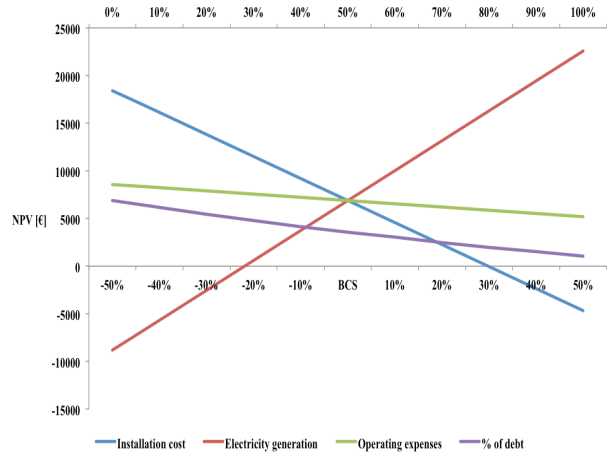


Figure 6 NPV of the system in Valencia as a function of the relative percentage variations of the installation cost, electricity generated and operating expenses from the BCS and the percentage of financing that is debt

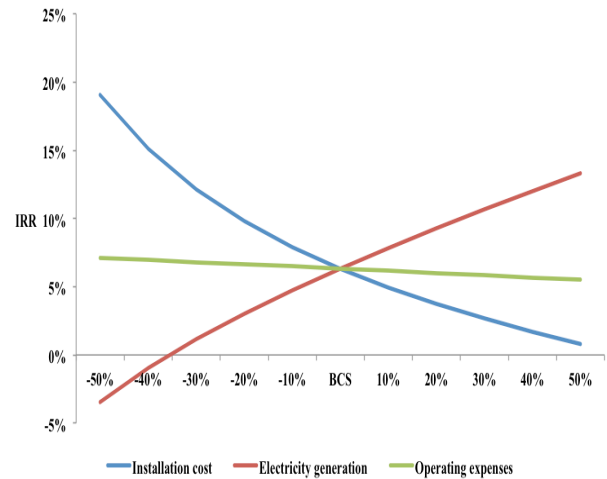


Figure 7 IRR of the PV system in Valencia as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS

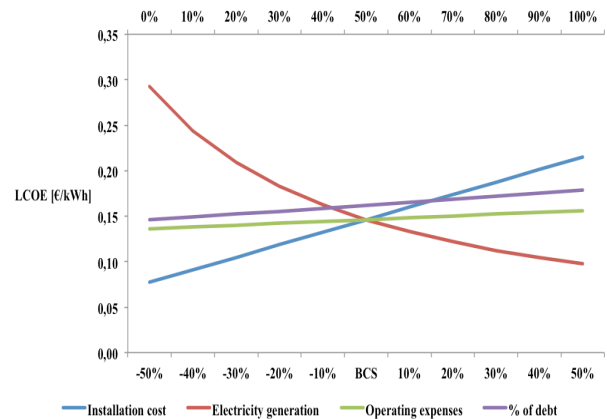


Figure 8 LCOE of the PV system in Valencia as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS and the percentage of financing that is debt

In normal circumstances, it is unlikely that the profitability of the PV installation of Valencia will be affected. However, 30% variations of the electricity output, electricity price or installation cost will result in negative values of NPV and a nominal IRR below the opportunity cost of capital. Variations in the operating expenses and percentage of debt entail smaller influence over the financial parameters. There are clear evidences from the sensitivity analysis that the electricity output and electricity price have the strongest influence over the NPV. Meanwhile, the IRR is more influenced by the installation cost with relative percentage variations up to 201%. LCOE values experience relative percentage variations up to 100% when the electricity output varies.

4.1 Wind farm in Argentina

The wind farm known as La Castellana will add 99 MW of wind energy to the Argentinean generation mix. The wind farm will be located south of the province of Buenos Aires, 36 km northwest of the city of Bahia Blanca. It has signed a power purchase agreement (PPA) for 20 years with the wholesale electric market administrator (CAMMESA), which will paid a bidding price of 61.50 \$/MWh for the electricity injected into the national interconnection system. The input data used for the BCS is summarized in Table 4

Factor	Data
Installation cost [€/W]	1,23
Electricity output [kWh/kWp year]	4439,4
Operating expenses [€/kWp]	44
Electricity price [€/kWh]	0,05606
Project lifetime [years]	20
Real discount rate [%]	8,04

Table 4 Input data for the wind farm in Argentina

Results: Figure 9 shows the cumulative cash flows of the project during the 20 years. The return of the money invested occurs at the end of the project life, during the 18th year of operation. The NPV is equal to 10.297.211,88 € and a real IRR is 9,22%, slightly above the cost of capital (8,04%).

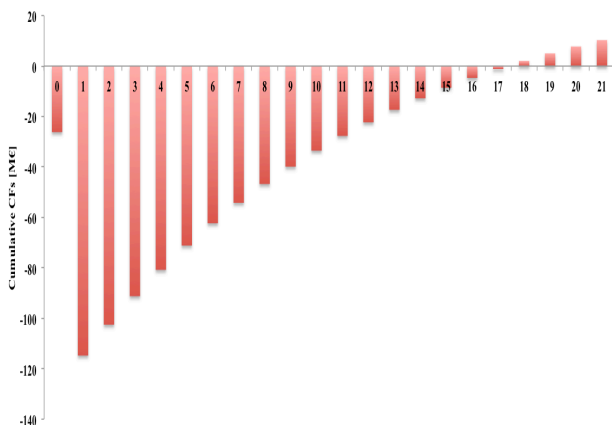


Figure 9 Cumulative cash flows of the wind farm in Argentina

A sensitivity analysis has been performed over the variables that are subject to some uncertainty like electricity production, installation cost operating expenses and the rate of return used for discounting future cash flows. In this case, the price received for the electricity produced will remain constant because is the bidding price agreed in the tender.

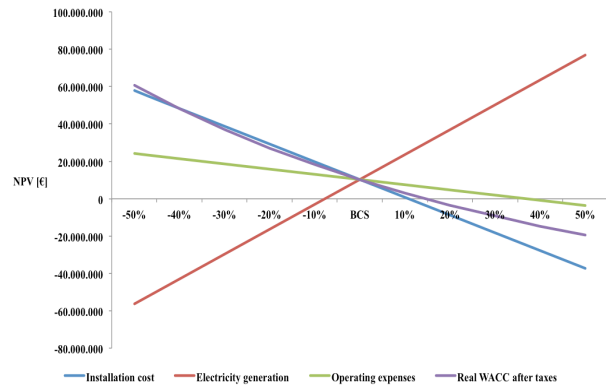


Figure 10 NPV of the wind farm in Argentina as a function of the relative percentage variations of the installation cost, electricity output, operating expenses and discount rate from the BCS

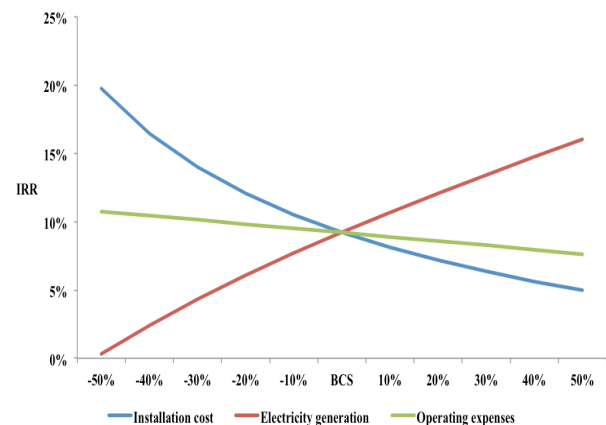


Figure 11 IRR of the wind farm in Argentina as a function of the relative percentage variations of the installation cost, electricity output and operating expenses from the BCS

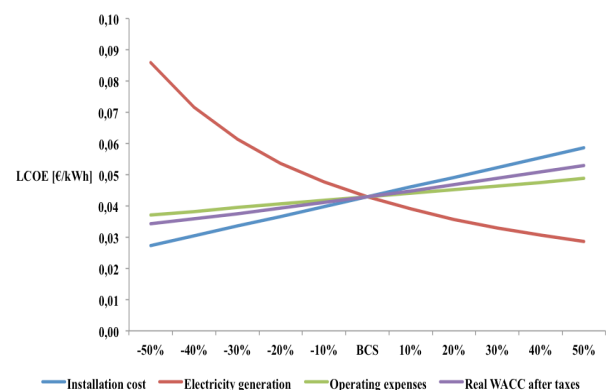


Figure 12 LCOE of the wind farm in Argentina as a function of the relative percentage variations of the installation cost, electricity output, operating expenses and discount rate from the BCS

In this third case, the electricity generation entails the largest influence over all the parameters calculated. Installation cost and discount rate have similar influence over the NPV and LCOE, although installation cost has slightly more influence over these parameters. Finally, operating expenses has the weakest influence over the financial criteria. Furthermore, the project will be unprofitable if there is a decrease in the electricity output below 7,7% from the BCS. Increases of 10,8%, 14,63% and 37% in the installation cost, discount rate and operating expenses, respectively, from the BCS will result in unprofitable financial outcomes for the project.

5. Comparison between the case studies

Both wind and PV cases have been presented in order to show the differences between the technology regarding the data and methodology employed. As shown in the input data tables above, significant differences exist regarding installation cost, electricity output and operating expenses. These factors combined together result in a generally lower LCOE for the wind projects compared to PV systems. In the cases analyzed, the LCOE values are 0,067, 0,146 and 0,043 €/kWh for the PV installations in Santarém and Valencia and the wind farm in Argentina, respectively.

The differences in the methodology used for investments in projects under the private owner and the company perspective are also clear. The latter includes within the calculation of the net cash flows tax liabilities and depreciation, which are not considered within the private owner case. Furthermore, there are differences regarding the calculation of the WACC according to the perspective, which results in different discount rates applied in the calculation. The wind farm discount rate (8,04%) is significantly larger than in the Portuguese (1,97%) and Spanish (2,69%) PV projects. This directly affects the results of the NPV and LCOE. The demand of a larger rate of return is a consequence of the riskiness of an investment. In the Argentinian case, the high inflation and the political turbulence of the country, which may affect the project outputs, motivate such rate of return. In the PV cases there is not such uncertainty. Furthermore, there is a great difference between the price of the electricity in the wind and PV cases. Whilst the PV cases present a mean electricity price of 0,197 €/kWh, the value used in the wind case is considerably lower (0,056 €/kWh). Therefore, the results for each case, are a consequence of the differences between their different inputs.

It can be concluded that the highest sensitivity of the NPV for all the cases is caused by the electricity production. Regarding IRR, it is more influenced by the installation cost in the PV cases, whereas electricity generation entails larger influence in the wind case. Relative percentage variations of the profitability with relative variation of the operating expenses entail the smallest influence among the factors presented. Moreover, the variations on the percentage of debt (in the PV cases) and discount rate (in the wind farm) have more influence than the operating expenses over the profitability of the project.

Specifications regarding the technology used and the perspective considered to analyze a project are relevant in order to define the parameters used and the methodology

followed. However, projects using the same technology and analyzed under the same perspective also present differences on the results. The comparison between the residential PV cases analyzes such differences. Albeit both systems are profitable under the conditions of the BCS, the results obtained for the Portuguese case are considerably better. Although the Spanish project requires an initial investment 6,13 times larger, the difference between the NPV is small (only 1,18 times larger). Likewise, the real IRR of the Portuguese case (18,47%) is larger than in the Spanish case (6,33%). Such difference over the IRR is a consequence of the input data employed for each case. The difference between the cases regarding the normalized installation cost is mainly due to the device used to store electricity, which price (7600 €) increases considerably the final installation cost. Whilst the Portuguese installation cost is equal to 1,53 €/Wp, the Spanish one is equal to 2,17 €/Wp. Additionally, the Spanish system presents higher normalized operating expenses (almost double) because more equipment is used and taxes paid due to the storage system. Regarding electricity production, the Portuguese installation performs more efficiently because of the lack of structural constraints (i.e. PV panels face to the south).

The immediate consequence of the differences among these factors is reflected in the cost of producing 1 kWh in each system, which is also affected by the discount rate employed in each case. The discount rate is higher in the Spanish case because the risk free interest rate (rate of return of bonds) in Spain (2,957%) is larger than in Portugal (2,23%). Accordingly, the Portuguese PV installation presents an LCOE of 0,067 €/kWh while the Spanish doubles it with 0,146 €/kWh. Such values are slightly decreased when considering the positive externality of reducing the emitted CO₂. The reduction is greater in the Portuguese scenario because both the carbon tax and factor of electricity generation –CO₂ emission intensity are larger in Portugal than in Spain. Therefore, considering that the price of the electricity consumed by the households slightly differs (below 1,0 c€/kWh), the great difference on the financial results obtained is a consequence of such disparity on the LCOE. Furthermore, the Portuguese investment is less risky because the money is recovered sooner. Whilst the Portuguese owner recovers the money in the 6th year after the initial investment, the Spanish one has to wait almost until the end of the project life (19th year).

6. Conclusions

The development of the solar PV and wind industries has been driven by technology improvements, government support and experience acquired. All these factors combined together are making these technologies competitive in the power sector by continuously decreasing their cost of generating electricity. Although these technologies have already achieved grid parity in some locations without any support, there are still many locations that need a favorable regulatory framework in order to make it profitable. This is essential in order to provide a favorable environment for investing in solar PV and wind projects. A stable government support and a reliable regulatory framework in the renewable energy sector boost investments in the industry by reducing the perception of risk (e.g. Law

27.191 supports the use of renewable energies in Argentina). Additionally, more investment results in technology advancements and diminishing costs, the right virtuous circle. On the contrary, unfavorable regulation (e.g. RD 900/2015 for self-consumption systems in Spain) negatively affects the financial indexes of a project (e.g. the PV installation in Valencia).

The results obtained from the application of the model to the three cases conclude that all the cases are profitable under the conditions of the base case scenario. Differences on the results are a consequence of the factors considered for each case. Each factor entails a different degree of influence over the profitability criteria. The sensitivity analyses performed for the three cases provide evidences that installation cost, electricity output – electricity price and operating expenses are classified from highest to lowest influence over the IRR. In the case of the NPV, the factors ordered from highest to lowest influence are electricity output – electricity price, installation cost, rate of return and operating expenses.

It is also clear that wind and PV solar projects are profitable in some locations without any governmental support thanks to the improvements in technology performance and reductions in costs achieved through the years.

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