Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 7 (2021) 199–203
www.elsevier.com/locate/egyr

6th International Conference on Advances on Clean Energy Research, ICACER 2021 April 15–17, 2021, Barcelona, Spain

Levelized cost of electricity for the deployment of solar photovoltaic plants: The region of León (Spain) as case study

José-Ramón Rodríguez-Ossorio[a], Alberto González-Martínez[b,*], Miguel de Simón-Martín[b], Ana-María Diez-Suárez[b], Antonio Colmenar-Santos[c], Enrique Rosales-Asensio[d]

[a] *Dept. of Electrical Eng., Systems and Automation, Universidad de León, Escuela de Ingenierías Industrial, Informática y Aeroespacial, Campus de Vegazana, s/n, 24071, León, Spain*

[b] *Dept. Area of Electrical Eng., Universidad de León, School of Energy and Mining Engineers, Campus de Vegazana s/n, León, 24071, Spain*

[c] *Dept. of Electrical Eng., Electronics, Control, Telematics and Applied Chemestry, UNED, c/ Juan del Rosal, 12, Ciudad Universitaria, 28040, Madrid, Spain*

[d] *Dept. of Electrical Eng, Universidad de Las Palmas de Gran Canaria, Escuela de Ingenierías, Campus Universitario de Tafira, s/n, 35017, Las Palmas de Gran Canaria, Spain*

Received 18 May 2021; accepted 9 June 2021

Abstract

In the current context of mandatory growth of renewable energy sources for electrical supply, in order to reduce CO2 emissions in the process of electricity generation, it is worth interest to evaluate the feasibility of the deployment of new large solar photovoltaic production facilities. This study seeks to analyze the costs and benefits of this type of infrastructures, considering the region of León (Spain) as case study due to its high potential. The Levelized Cost of Energy is used in this study as main decision tool, so a sensibility study on this indicator has been carried out, including the financial interest rates, the capital and operation expenditures, the facilities performance and the expected life span of the installations. Three main locations have been selected in the region, close to the main power demand sites, in order to minimize power distribution losses between the power plants and end-users. Results show that an LCOE in the range between 0.21 and 0.26 €/kWh can be achieved. The simplified calculation presented allows a preliminary and quick assessment of the grid parity of a photovoltaic plant in locations where they are not known in detail.

Peer-review under responsibility of the scientific committee of the 6th International Conference on Advances on Clean Energy Research, ICACER 2021.

Keywords: Renewable energy; Solar photovoltaics; LCOE

* Corresponding author.
E-mail address: agonmar@unileon.es (A. González-Martínez).

https://doi.org/10.1016/j.egyr.2021.06.034

Peer-review under responsibility of the scientific committee of the 6th International Conference on Advances on Clean Energy Research, ICACER 2021.

Nomenclature

CAPEX	Capital Expenditures.
CRF	Capital Recovery Factor.
i	Discount rate.
LCOE	Levelized Cost of Electricity.
n	Number of periods (years) of the useful life span of the power plant.
O&M	Operation & Maintenance.
OPEX	Operation & Maintenance Expenditures.
η	Efficiency.

1. Introduction

In recent years, concern about climate change has been growing, as global temperatures continue to rise and sea level gradually increases, as a result of the emission of greenhouse gases into the atmosphere. This climate change is already considered irreversible, but strategic plans are being developed to mitigate its effects, as declared Shishlov et al., in 2016 [1].

To achieve these objectives, the aim is to promote the use of cleaner energy sources, free of CO_2 and other greenhouse gases in their emissions. In 2013, Tudisca et al. [2], indicated that renewable energies such as solar, wind, hydraulic, geothermal or biomass, are emerging as an alternative to traditional energy sources, mainly because of the lower impact they produce on the environment, and also because of their availability. From data published by Red Eléctrica de España, in relation to electricity generation in recent years, as shown in Fig. 1(a), the use of energies without CO_2 emissions exceeds those that do produce it. In 2009, 55% of energy sources produced CO_2 in their emissions. Nowadays, CO_2 free generation remains at around 60%, depending on the availability of renewable energy sources. On the other hand, analyzing the data set collected on the maximum renewable generation produced in Spain, it can be seen that it also follows a growing trend (see Fig. 1(b)), up to 539.9 GWh generated in 2018.

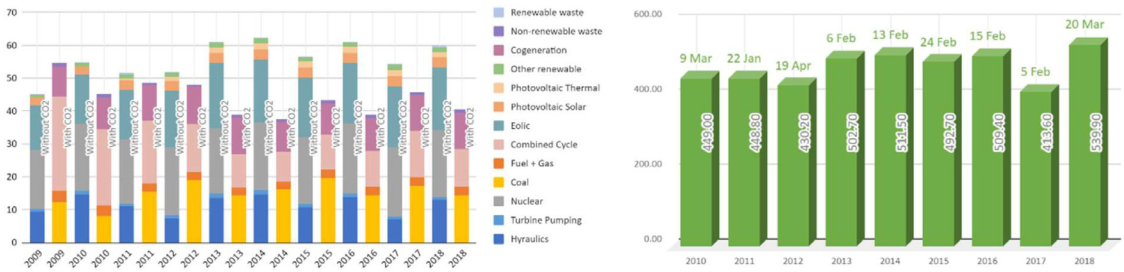

Fig. 1. (a) Power generation in Spain, w/wo CO_2 emissions (%); (b) Peak power renewable generation in Spain (GWh). *Source:* Adapted from [3].

Europe has been promoting the development of renewable energy sources since its inception. The publication by the European Commission in 1997 of the White Paper highlighted the low use of renewable resources in the European Union, despite their abundant availability and economic potential. Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources was adopted, laying the foundations for the development of these energies in Europe. This directive set the objective of meeting 12% of energy demand and 22% of electricity consumption needs from renewable energies by 2010. However, as these objectives had not been achieved, in 2009 it was resolved to renew the European legislative framework with Directive 2009/28/EC, proposing that, by 2020, 20% of the energy consumed in the European Union should have a renewable origin.

In this context of promotion of renewable energies, also covered by a beneficial regulation, there is a growing increase in this kind of photovoltaic (PV) and self-consumption installations, even with the introduction of new models of distributed generation. So, in this context of proliferation of renewable energies and distributed generation, what benefits do this type of facilities provide? Are they economically sustainable?

This article proposes an analysis of the levelized costs associated with this type of technology in the region of León and the economic benefits that such implementation could bring. To complete the proposed objective, first, in the Material and Methods section, the possible and selected topologies of photovoltaic installations are described, and the calculation methodologies applied to estimate the feasibility of these installations are presented, based on several parameters. Subsequently, in the Results section, the data obtained from the proposed calculations are displayed and analyzed, and an interpretation is given, also completed in the Conclusions section.

2. Material and methods

The PV facilities can be configured according to different topologies. Some self-consumption PV installations cannot inject surplus energy to the external grid, using anti-spill systems, dynamic inverters, or energy storage systems, as was reached by Uddin et al., in 2017 [4]. On the other hand, grid-connected PV plants, are allowed to inject all their production of the surplus to the external grid. Moreover, it must be highlighted that, although their size and costs are greater, they benefit from economy scales, increasing the profitability of grid-connected PV plants [5], as Bakos stated in 2008, and as it is considered.

Branker et al. [6] established, in 2011, among the methods for calculating the viability of a power plant, one of the most widely used and precise is the LCOE, because it allows to show the viability of a plant compared to grid parity, not only focusing on profitability from an economic or financial point of view, showing the plant promoter the minimum cost of sale or energy transaction mechanism. The LCOE defines the price at which each unit of energy produced must be sold, to offset the O&M costs and recover the investment, throughout the useful life of the plant, discounted at a rate that defines the profitability of the project, provides a comparison of the performance of different technologies for energy production, regardless of their technical characteristics or the regulations in force, which may be diverse and varied, and is essentially defined as the ratio between the total cost of the installation over its lifetime and the total energy produced updated during this time [7], as Darling et al. stated in 2008, and as it can be seen in Eq. (1).

$$LCOE = \frac{Total\ life-time\ discounted\ costs}{Total\ life-time\ discounted\ energy\ production}. \quad (1)$$

According to the research of Kumar Sahu (2015) [8], in order to calculate the annual costs of the plant, the expenditures must be distributed and updated over the expected years of operation. These costs are referred to in the present value using the Capital Recovery Factor, or CRF, and its calculation is reflected in Eq. (2).

$$CRF = \frac{i \cdot (1+i)^n}{(1+i)^n - 1}, \quad (2)$$

where i is the discount rate and n is the evaluated period (years). The annual costs are the O&M costs and the calculation of the annualized initial, according to Eq. (3).

$$Actualized\ Costs = (CAPEX \cdot CRF) + OPEX. \quad (3)$$

In a simplified way, the initial investment to be made in the installation can be approximated by the cost per square meter of the PV station, multiplied by the power plant active PV area, as seen in Eq. (4).

$$CAPEX = Unitary\ CAPEX \cdot PV\ modules\ area. \quad (4)$$

The effective energy produced by the solar PV modules can be calculated as a function of the average solar radiation per sq. meter received at the installation site over a year. This solar radiation must be multiplied by the average efficiency (η) of the solar panels installed, as is shown in Eq. (5).

$$Energy = Avg\ Solar\ Irradiation \cdot PV\ modules\ area \cdot \eta \quad (5)$$

It is assumed that the O&M costs equal to 3.5% of the investment, and that the modules have an efficiency of 10%.

The average solar irradiation is taken from the database of the Photovoltaic Geographical Information System of the European Commission (PVGIS) [9] in the period from 2007 to 2016, as is reflected in Eq. (6).

$$Avg.\ Irradiation = \frac{\sum_{i=1}^{n} Annual\ irradiation}{Number\ of\ years}. \quad (6)$$

The average annual irradiation has been calculated for each site in the study (León, Astorga and Ponferrada).

Table 1. Input variables in the initial calculation.

Site	Average irradiation (kWh/m^2/year)	PV area (m^2)	O&M costs (€)	Annual output (kWh)	LCOE (€/kWh)
León	1,895.49	1,000.00	14,000.00	189,549.40	**0.22**
Ponferrada	1,595.80	1,000.00	14,000.00	159,580.30	**0.26**
Astorga	1,909.01	1,000.00	14,000.00	190,900.50	**0.21**

3. Results and discussion

After applying the proposed analysis, the following results have been obtained. The LCOE results depends strongly on the site studied: 1895.49 kWh/m^2/year for León, 1595.80 kWh/m^2/year for Ponferrada and 1909.01 kWh/m^2/year for Astorga. The effect that the average irradiation has on the result of the LCOE has been observed. The input variables and the results obtained according to these variables, for this initial calculation, are shown in Table 1. In the preliminary calculation, a 4.5% interest rate will be taken as a reference. Likewise, a life of 25 years is defined. On the other hand, the initial investment cost is assumed to be 400 €/m^2, and the capacity of the facility, exposed through the active PV surface it takes, is 1000 m^2. CRF is evaluated as 0.07 and the investment of €400,000 is reached, to be recovered in the 25 years of the expected useful life of the facility.

Considering the results in Table 1, it can be seen that, under the same conditions indicated as hypotheses, the LCOE can be higher than the market price for electricity, being the facilities economically viable.

After making these initial calculations, it is analyzed the evolution of LCOE according to the value of certain input variables. The discount rate is modeled with values between 1% and 10%, and it is shown in Fig. 2(a). In order to achieve the costs obtained in Astorga and León with a 5% interest rate, an interest of approximately 2.5% will be needed in Ponferrada. Another sensible variable considered in this study, in order to evaluate its effect in the LCOE, is the useful lifetime of the facility, set between 10 and 30 years (see Fig. 2(b)). The LCOE describes a decreasing function whose slope is smoothed out as the life of the project increases, noting that it is not worth proposing a time horizon for the economic investment *a priori* much higher than the useful life according to a technical point of view. The initial investment will also be a key aspect in determining the LCOE of the installation, as it has a great weight in the calculation of the annual costs (Fig. 2(c)). It can be seen that, as expected, the LCOE increases non-linearly with respect to the CAPEX, which implies that it is the most important parameter to monitor.

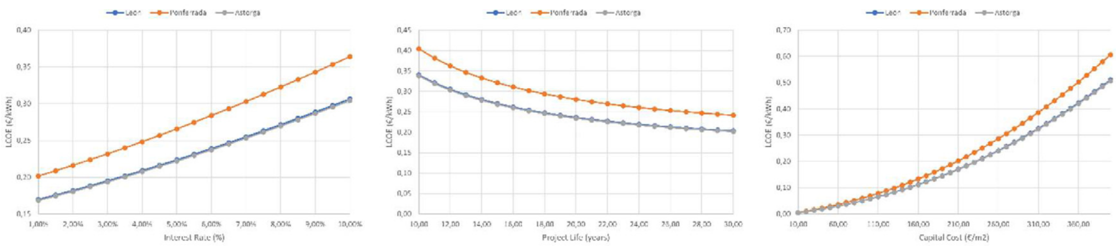

Fig. 2. (a) LCOE depending on interest rate; (b) LCOE depending on project life; (c) LCOE depending on capital cost.

In addition, a combined analysis of the influence of the useful life and the interest rate are plotted in three-dimensional surfaces in Fig. 3, and the extreme values are analyzed. An optimal result would imply to extend the life of the installation as much as possible and to obtain financing with the lowest interest rate.

4. Conclusions

This work assesses the economic feasibility of deploying large solar PV power plants at three sites in the region of León (Spain), considering a context of growth in the generation of electricity from renewable and CO_2 free energy sources, which arises as a response to the high requirements set by the European Union, in this regard aligned with the trend observed in all European countries, including Spain. The simplified calculation presented allows a preliminary and quick assessment of the grid parity of a photovoltaic plant in locations where they are not known in detail. The way in which the possibility of implementing this type of plants is studied, in order to achieve a practical decision support tool, is by means of the LCOE, which sensitivity has been also evaluated.

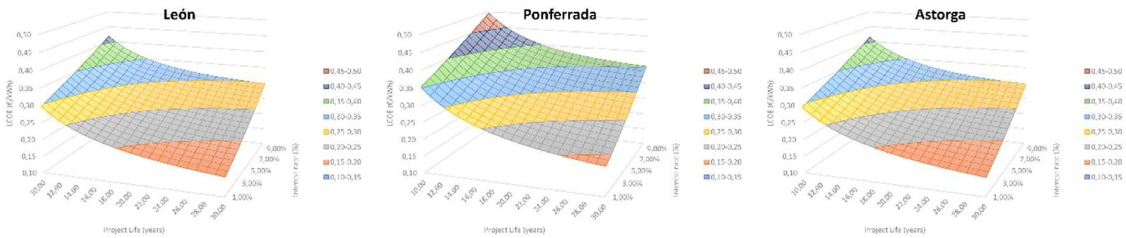

Fig. 3. Combination of project life and discount rate for the three sites.

It has been observed that the highest impact in the LCOE value is produced by the CAPEX. On the other hand, the LCOE seems to be very robust to the useful life span of the installation. This is due to the typical cost's breakdown of PV solar plants, which is characterized by very low O&M costs.

CRediT authorship contribution statement

José-Ramón Rodríguez-Ossorio: Investigation, Formal analysis, Writing - review & editing. **Alberto González-Martínez:** Investigation, Formal analysis, Writing - review & editing. **Miguel de Simón-Martín:** Data curation, Writing - review & editing, Funding acquisition. **Ana-María Diez-Suárez:** Writing - review & editing. **Antonio Colmenar-Santos:** Writing - review & editing. **Enrique Rosales-Asensio:** Validation, Writing - original draft, Conceptualization, Supervision, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Shishlov I, Morel R, Bellassen V. Compliance of the Parties to the Kyoto Protocol in the first commitment period. Clim Policy 2016;16:768–82. http://dx.doi.org/10.1080/14693062.2016.1164658.

[2] Tudisca S, Di Trapani AM, Sgroi F, Testa R, Squatrito R. Economic analysis of PV systems on buildings in sicilian farms. Renew Sustain Energy Rev 2013;28:691–701. http://dx.doi.org/10.1016/J.RSER.2013.08.035.

[3] Red Eléctrica de España. 2020, https://www.ree.es/es (accessed February 20, 2021).

[4] Uddin K, Gough R, Radcliffe J, Marco J, Jennings P. Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. Appl Energy 2017;206:12–21. http://dx.doi.org/10.1016/j.apenergy.2017.08.170.

[5] Bakos GC. Distributed power generation: A case study of small scale PV power plant in Greece. Appl Energy 2009;86:1757–66. http://dx.doi.org/10.1016/j.apenergy.2008.12.021.

[6] Branker K, Pathak MJM, Pearce JM. Pathak MJM pearce JM a review of solar photovoltaic levelized cost of electricity. Renew Sustain Energy Rev 2011;15:4470–82. http://dx.doi.org/10.1016/j.rser.2011.07.104.

[7] Darling SB, You F, Veselka T, Velosa A. Assumptions and the levelized cost of energy for photovoltaics. Energy Environ Sci 2011;4:3133. http://dx.doi.org/10.1039/c0ee00698j.

[8] Kumar Sahu B. A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. Renew Sustain Energy Rev 2015;43:621–34. http://dx.doi.org/10.1016/J.RSER.2014.11.058.

[9] EU Science Hub. Photovoltaic Geographical Information System (PVGIS) | EU Science Hub 2021. https://ec.europa.eu/jrc/en/pvgis (accessed February 20, 2021).