

Economic feasibility of developing large scale solar photovoltaic power plants in Spain

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Abstract. In 2017, electricity generation from renewable sources contributed more than one quarter (30.7%) to total EU-28 gross electricity consumption. Wind power is for the first time the most important source, followed closely by hydro power. The growth in electricity from photovoltaic energy has been dramatic, rising from just 3.8 TWh in 2007, reaching a level of 119.5 TWh in 2017. Over this period, the contribution of photovoltaic energy to all electricity generated in the EU-28 from renewable energy sources increased from 0.7% to 12.3%. During this period the investment cost of a photovoltaic power plant has decreased considerably. Fundamentally, the cost of solar panels and inverters has decreased by more than 50%. The solar photovoltaic energy potential depends on two parameters: global solar irradiation and photovoltaic panel efficiency. The average solar irradiation in Spain is 1,600 kWh m⁻². This paper analyzes the economic feasibility of developing large scale solar photovoltaic power plants in Spain. Equivalent hours between 800-1,800 h year⁻¹ and output power between 100-400 MW have been considered. The profitability analysis has been carried out considering different prices of the electricity produced in the daily market (50-60 € MWh⁻¹). Net Present Value (NPV) and Internal Rate of Return (IRR) were estimated for all scenarios analyzed. A solar PV power plant with 400 MW of power and 1,800 h year⁻¹, reaches a NPV of 196 M€ and the IRR is 11.01%.

1 Introduction

The use of renewable energies in the generation of electric power has increased considerably in recent years. Gross electricity generation in Organisation for Economic Co-operation and Development (OECD) from renewable energy sources (excluding generation from pumped storage plants) reached 2,588.3 TWh in 2016, a 3.8% increase from the 2015. This represents 23.8% of total OECD electricity production in 2016 (Fig. 1), which is the largest share of renewables in gross electricity production for any year in the renewables time series beginning from 1990 [1].

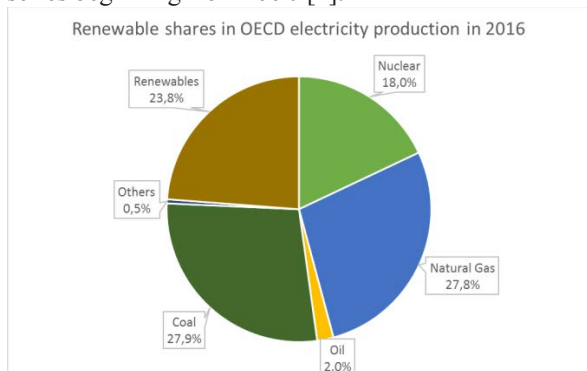


Fig. 1. Renewable shares in OECD electricity production in 2016 [1].

The increase in electricity production from renewables was mainly caused by wind and solar photovoltaic (PV). Solar PV increased by 35.0 TWh, again mainly driven by the US, which had increased electricity production from solar PV by 18.0 TWh, followed by Japan (8.0 TWh), UK (2.7 TWh) and Chile (1.3 TWh) [1].

Solar energy is currently the lowest cost power generation source in many regions of the world – and its cost continues to decrease rapidly. Solar has the potential to play a major role in the European Union meeting its 32% renewables target by 2030. Bloomberg NEF, in its New Energy Outlook 2018, anticipates that renewables will cover 87% of Europe's electricity generation by 2050 in Europe, in which 1.4 TW of solar is installed and contributes to 36% of total power generation.

The increase of renewable energy sources requires flexible energy storage systems. Pumped-storage hydropower (PSH) is the most mature and efficient technology that currently exists. Other systems, such as Compressed Air Energy Storage (CAES) plants, can also be used. Underground pumped storage power plants can be an alternative using underground space, such as closed mines. [2-6].

Fig. 2 shows the renewable energy sources in electricity in EU'28 in 2017. The share of renewable energy sources has increased from 16.97% to 30.75% in

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the period 2008-2017. It highlights, Austria, Sweden, Denmark, Latvia and Portugal, with a share in the electric mix higher than 50% in 2017. The share of renewable energies in electricity in Spain was 36.34%.

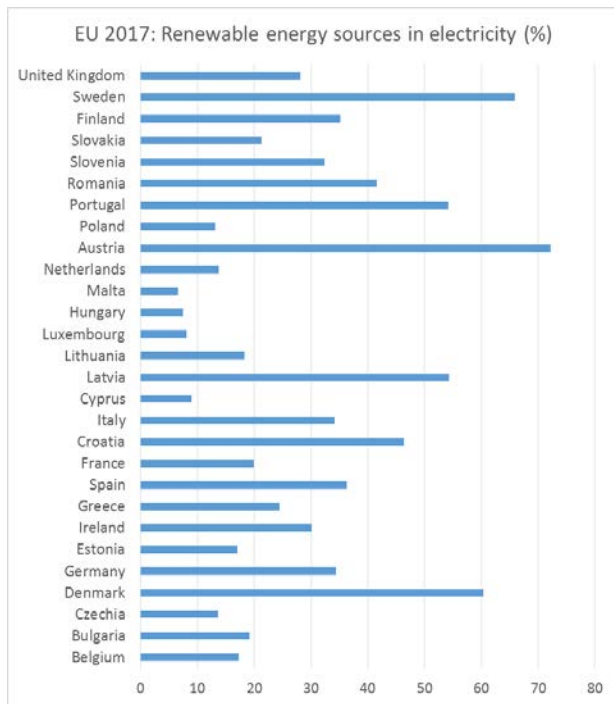


Fig. 2. Renewable energy sources in electricity in EU'28 (2017).

This paper analyzes the economic feasibility of developing large scale solar PV projects in Spain. Different output power (100-400 MW) and equivalent hours per year, depending on the situation of the solar PV power plant (800-1,800 h year⁻¹) have been considered in this study. A profitability analysis has been carried out for different prices of the electricity produced in the daily market (50-60 € MWh⁻¹). Net Present Value (NPV) and Internal Rate of Return (IRR) were obtained in all scenarios.

2 Materials and methods

2.1 Solar energy in Spain

Spain offers optimal conditions for the installation of solar PV power plants [7]. Fig. 3 shows a detailed map of the annual accumulated solar irradiation level (kWh m⁻²) for EU considering optimally-inclined PV modules [8, 9]. In Spain, the average values vary from 1,000 hours year⁻¹ (equivalent hours) on the northern and 1,700 hours year⁻¹ (equivalent hours) on the southaestern zone [10]. The national average is 1,600 kWh m⁻² [11].

Electricity generation in Spain from renewable energy spurces reached 101,6 TWh in 2018, a 40.1% of total electricity production in 2018. The total installed power in Spain reached 98.5 GW in 2018. The total power of solar PV accumulated in 2018 reached 4,436 MW (4.5% of the total installed power).

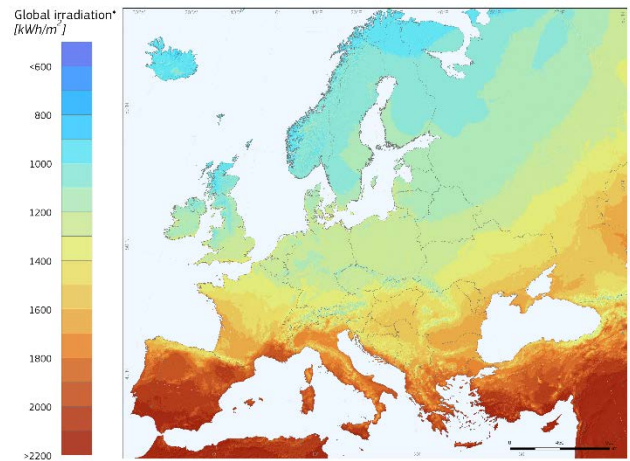


Fig. 3. Map of the annual accumulated solar irradiation level for EU. Optimally-inclined PV modules [8].

2.2 Solar energy calculator

The solar energy potential depends on two parameters: solar irradiation and PV panel efficiency. The power output of the PV is given by Eq. (1).

$$P_{PV} = \sum Y_{PV} D_f [1 + \alpha(T_o - T_{C,STC})] P_{VN} \quad (1)$$

where:

- P_{PV} : Annual PV solar power output
 - Y_{PV} : PV panel power output
 - D_f : Degradation factor (0.5% year⁻¹)
 - α : Temperature loss coefficient
 - T_o : Operating temperature
 - $T_{C,STC}$: Temperature at Standard Test Conditions (25°C)
 - P_{VN} : Number of PV panels
- The panel power output, Y_{PV} (kW) is given by Eq. (2). Finally, the total power produced by PV power (P_{PV}) plant is given by Eq. (3)

$$Y_{PV} = R_{GHI} A d_m \eta_{PV} \quad (2)$$

$$P_{SP} = P_{PV} L_{SP} \quad (3)$$

where:

- R_{GHI} : Monthly average solar irradiation (kWh m⁻²)
- A : Area of PV panel (m²)
- d_m : Number a days per month
- η_{PV} : PV conversion efficiency
- P_{SP} : Power output of solar plant (kWh)
- L_{SP} : Solar plant losses

Table 1 shows the system losses in a solar PV power plant. Considering a useful life of 25 years, the PV module degradation reaches a value of 12.5% of the total energy produced in year 25. The solar PV modules must be periodically cleaned to avoid losses in the generation of electricity. The typical power of a PV module (peak power) is 315 W, with a dimensions of 1,956x992 mm.

Table 1. Solar PV power plant. System losses

Solar PV plant system losses	
PV module degradation (D)	0.5% year ⁻¹
PV module performance due to temperature (α)	0.41% °C ⁻¹
Inverter efficiency loss	2.5-5%
Loss due to soiling of module surface	0.5-10%
AC wiring	1-3%
DC wiring	1-2.5%
Connectors	1-2.5%
System availability	1-3%

2.3 Economic evaluation: NPV and IRR

The economic evaluation consists in the analysis of the profits obtained from the solar PV power plant invested by a promoter on the basis of NPV (€) and IRR (%). NPV is calculated in the way of subtracting the investment cost (current) from the future cash flow obtained during the operation phase. IRR is used to analyze what discount rate would cause the NPV of a project to be '0'€ and then comparing the value with expected rate of return. NPV and IRR are given by Eq. (4) and Eq. (5) as follows:

$$NPV = \sum_{t=0}^n \frac{B_t}{(1+r)^t} = \sum_{t=0}^n \frac{CF_t}{(1+r)^t} \quad (4)$$

$$IRR = \sum_{t=0}^n \frac{B_t}{(1+r)^t} = \sum_{t=0}^n \frac{CF_t}{(1+r)^t} \quad (5)$$

where:

- B_t : Benefit from the perspective
- n : Project period cash flow is received
- r : Discounted rate
- CF_t : Net after-tax cash inflow-outflows during a period t

3 Results and discussion

3.1 Solar energy production

Table 2 shows the energy production (MWh year⁻¹) in a solar PV power plant depending on the equivalent hours per year (obtained by subtracting the system losses) and the installed power (MW). A typical solar PV power plant in Spain, with a power of 200 MW and 1,600 effective hours of operation, could reach up to 320 GWh year⁻¹.

Table 2. Solar energy production (MWh year⁻¹)

Equivalent hours [h year ⁻¹]	Power [MW]			
	100	200	300	400
800	80,000	160,000	240,000	320,000
1,000	100,000	200,000	300,000	400,000
1,200	120,000	240,000	360,000	480,000
1,400	140,000	280,000	420,000	560,000

1,600	160,000	320,000	480,000	640,000
1,800	180,000	360,000	540,000	720,000

Fig. 4 shows the energy production in GWh year⁻¹ for solar PV power plants with 100, 200, 300 and 400 MW of output power, considering 1,600 equivalent hours per year (typical value in the south of Spain) and a PV panel degradation of 0.5% year⁻¹. In the year 25, a reduction of income of 12.5% is produced due to this issue.

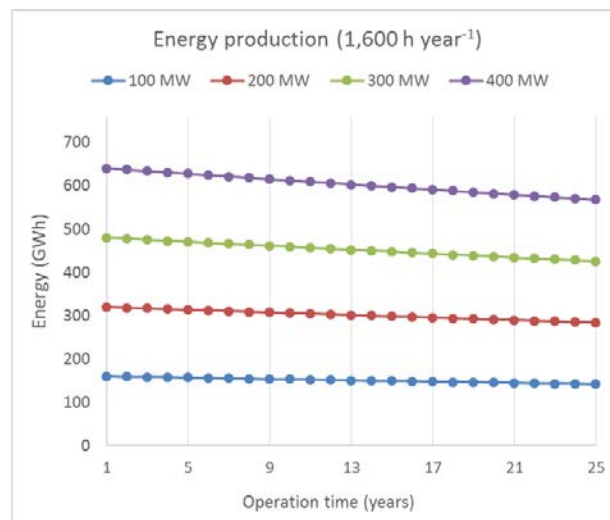


Fig. 4. Energy production (GWh year⁻¹) considering 1,600 h year⁻¹ and a degradation of 0.5% year⁻¹.

3.2 Investment and O&M costs and land-take requirements

Fig. 5 shows the summary of investment cost of a solar PV power plant with 100 MW of output power. The main cost is supply and installation of the PV panel, with a 37.9% of the total cost.

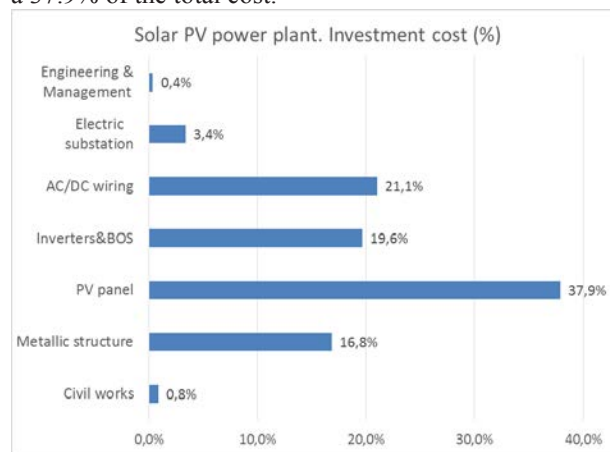


Fig. 5. Investment cost of a PV power plant with 100 MW of power. Summary of cost items (%)

Table 3 shows the investment cost, Operation and Maintenance (O&M) costs and land-take requirements for solar PV power plants for output power between 100-400 MW. A power typical power plant with a power of 200 MW has an investment cost of 141.05 M€ and requires more than 190 ha of land. The land is usually

rented during the period of operation of the PV power plant (25 years). A cost of 1,500 € ha⁻¹ year⁻¹ has been considered.

Table 3. Investment and O&M costs and land-take requirements (ha)

Output power (MW)	CAPEX (M€)	Land-take (ha)	O&M (M€ year ⁻¹)
100	70.80	190.00	0.49
200	141.05	380.00	0.87
300	210.44	570.00	1.26
400	276.05	760.00	1.64

3.3 Profitability analysis

In this section, the results obtained in the economic model are shown. Table 4 shows the main parameters that have been considered in the economic model.

Table 4. Economic model parameters

Economic model parameters	
Daily market price (€ MWh ⁻¹)	50-60
Operation time (years)	25
Equity (%)	20%
Debt (%)	80%
Loan interest rate (%)	3%
Loan term (years)	15
Depreciation (years)	25
Annual CPI (%)	2.0%

Fig. 6 shows the profitability analysis, NPV and IRR, for a PV power plant with a power of 100 MW and a daily price in the electricity market of 50 € MWh⁻¹. In a typical PV power plant in the South of Spain, with an average of 1,600 h year⁻¹, NPV is 17.4 M€ and IRR reaches 6.91%.

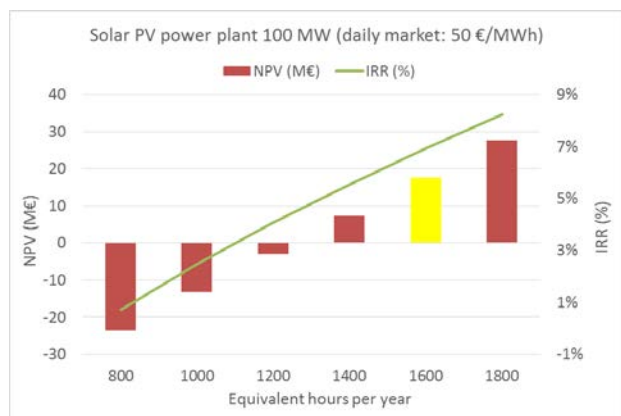


Fig. 6. Profitability analysis. PV power plant with 100 MW of power and daily market price of 50 € MWh⁻¹.

Fig. 7 shows NPV and IRR for a PV power plant with a power of 100 MW and a daily price in the

electricity market of 60 € MWh⁻¹. In this scenario, NPV increases to 34 M€ and IRR increases to 9.01%.

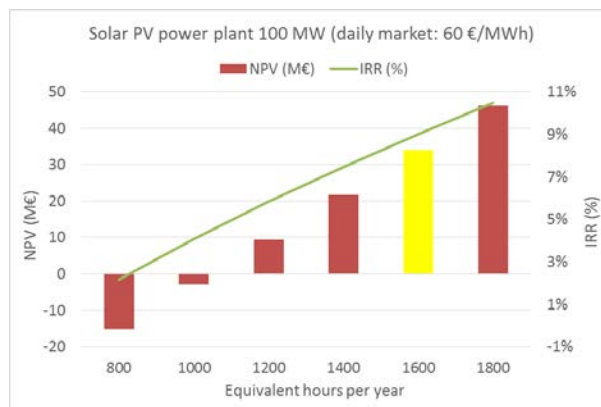


Fig. 7. Profitability analysis. PV power plant with 100 MW of power and daily market price of 60 € MWh⁻¹.

Finally, Fig. 8 shows NPV and IRR values for a solar PV power plant with 400 MW of power and a daily price in the electricity market of 60 € MWh⁻¹. In this scenario, NPV reaches 147 M€ and IRR is 9.49% for 1,600 h year⁻¹.

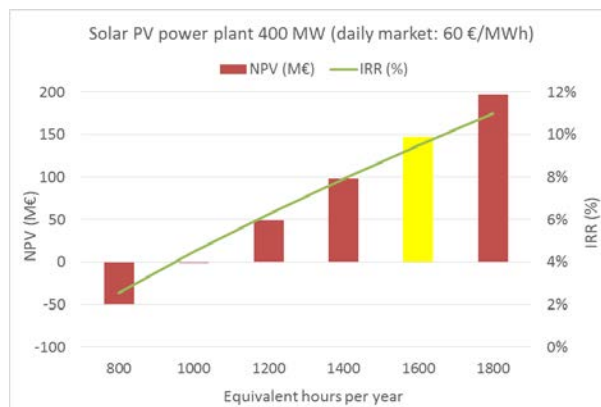


Fig. 8. Profitability analysis. PV power plant with 400 MW of power and daily market price of 60 € MWh⁻¹.

4 Conclusions

Spain offers optimal conditions for the installation of solar PV power plants. The average solar irradiation in Spain is 1,600 kWh m⁻². In this paper, the economic feasibility of large-scale solar PV power plants has been studied. PV power plants with power between 100-400 MW, with a number of equivalent hours between 800-1,600 h year⁻¹ have been considered.

The economic feasibility depends on the number of equivalent hours per year and the daily price in the electricity market. The results obtained show that the economic viability of these plants is reached for a number of hours exceeding 1,400 h year⁻¹, fundamentally in PV power plants with powers below 200 MW. In the north of Spain, with a number of equivalent hours less than 1,200 h year⁻¹, there is no profitability for the current investment cost.

In the south of Spain, with an average of 1,600 h year⁻¹, the profitability increases, reaching a NPV of 147 M€ and an IRR of 9.49% for a solar PV plant of 400 MW of power and a daily price in the electricity market of 60 € MWh⁻¹. If the power of the plant is lower, the profitability is reduced, mainly because the O&M costs are higher for each MWh produced.

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