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Subject and subsection: 7.2 PV Global Issues, Policies and Strategies POSTER

Economic feasibility analysis of choices for not connected clients: photovoltaic off-grid systems, compared to grid based systems.

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ABSTRACT: Off-grid photovoltaic systems are less constrained by national regulations than their grid-connected counterparts. Off-grid systems do not depend on feed-in tariff and the analysis of their cost-efficiency is more stable along time.

This work calculates the economic parameters for two different technologies of photovoltaic systems and compares the levelized cost of electricity (LCOE), with the price of the electricity, including the cost for the connection of the system related to the distance to the grid. The results show that the sustained decline in photovoltaic module´s price contributes to subsequent decline in LCOE, whereas the increase in the price of grid electricity and materials related to the connection makes off-grid systems more cost-effective for remote areas.

Finally, to determine if the photovoltaic system could be an economic alternative for investments in remote regions, a comparison between the cost of grid extension and the LCOE of a high capacity photovoltaic system was undertaken.

1. OBJECTIVE AND PURPOSE OF THE WORK

Despite grid parity has been reached in many countries, the regulation for grid-connected photovoltaic systems is completely different depending on the country and even on the region inside a country. This situation makes complicated to state a global conclusion about the economic feasibility of a particular investment. Given the decline in prices of the elements of photovoltaic systems, and after removal of national subsidies that were previously granted to electricity consumers like irrigation users, this work is considered useful for reducing costs in remote areas not connected to the grid as well as in the agriculture field. The analysis takes into account photovoltaic emerging technologies that will make solar panels more appropriate in some cases over others, depending on their performance. Thus, we seek a formula that determines the optimal solution for each case, based on objective and reliable data.

2. MATERIALS AND METHODS

This work includes not only the calculation of LCOE based on the prices of the system and its maintenance. It also compares different photovoltaic technologies, taking into account the different rates for the degradation and the area occupied by them. Even further, a comparison that includes distances to the grid and whether the connection is made at high or low voltage is considered in the cost comparison.

Levelized Cost of Electricity: $$\mathrm{LCOE} = \frac{\sum_{t=0}^{T} (I_t + O_t + M_t)/(1+r)^t}{\sum_{t=0}^{T} E*(1-d)^t/(1+r)^t}$$

I_t: the investment of year t;
O_t: operating cost of year t;
M_t: maintenance cost of year t;
E: energy generated;
d: degradation rate;
r: discount rate;
T: lifetime or analysis period.
Payback Period (PBP): PBP = C_0/C_t

Net Present Value (NPV): $$\mathrm{NPV} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_0$$
C_t: net cash flow during the period t;
C_0: total initial investment costs;
Internal Return Rate (IRR): IRR=r, when NPV=0;

According to the previous equations and using the data of two real installations: one in Madrid and another one in Colombia, the following data (Table 1 and Table 2) were obtained.

Annual global irradiation(kWh/m2)	1793
Peak Power(Wp)	4940(1610+1680+1650)
Inverter capacity	3*1200W
DC to AC ratio (includes clipping)	1.37
Area(m^2)	45.06
Annual output(kWh)	7442.13
Subsidies (€/kWh)	0.3
Annual income(€)	2232.64
Total cost (€)	23844
Cost per peak watt (€/Wp)	4.83
Payback period(years)	10.68
Internal return rate (IRR, %)	9.59

Table 1. Summary of PV system in Madrid, Spain, installed at the end of 2012.

Annual global irradiation(kWh/m2)	1617
Peak Power(Wp)	3370(1620+1750)
Inverter capacity	2*1500W
DC to AC ratio (without clipping)	1.25
Area(m2)	39.05
Annual output(kWh)	4542.51
Industrial electricity price (€/kWh)	0.1
Annual income(€)	454
Total cost (€)	6000
Cost per peak watt(€/Wp)	1.82
Payback period(years)	13.21
Internal return rate (IRR, %)	6.46

Table 2. Summary of PV system in Popayán, Colombia, installed in June 2016.

We also analyzed which would be the LCOE of the connection of a consumer to the grid, when the grid is located far from the consumer, another analysis can be performed. In this case we compared the LCOE of two alternatives: off-grid photovoltaic system (comparing different nominal powers) and grid-connected consumer.

Installed capacity	Cost (€/Wp)	Cost of installation (€/Wp)	Cost of inverter(€ /Wn)	Discount rate (%)	Debt (%)	Degradation rate(%/year)	O&M cost (%/total initial cost)	Lifetime (years)	LCOE (€/kWh)
1 kW	0.5	0.4	0.5	6	0	0.5	0.1	30	0.1025
5 kW	0.4	0.4	0.35	6	0	0.5	0.1	30	0.0864
10 kW	0.3	0.4	0.3	6	0	0.5	0.1	30	0.0751

Table 3. Cost of different elements forming an a-Si based photovoltaic system, depending on the total installed capacity (taxes and transport excluded).

In the case of a grid-connected system, the cost of the extension (the line from the grid to the consumer) must be taken into account. Such cost depends on the voltage and on the method of transport: air or underground

	Cost of installation (€/m)
High voltage, underground	120
Medium voltage, air	20
Medium voltage, underground	80

Table 4. Cost of different types of connection to the grid.

Considering the previous values, the following results and conclusions were obtained.

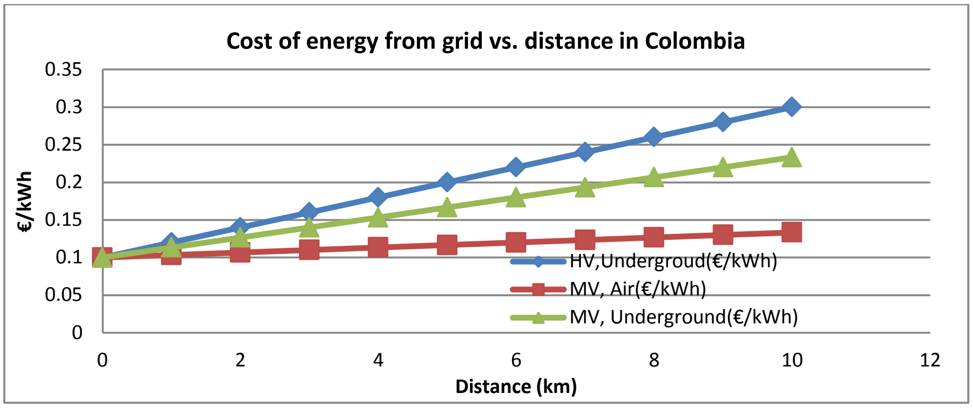

Fig.1. *Cost of grid-supplied electricity, with the cost of the connection to grid included, as a function of the distance from the consumer to the grid.*

According to Fig. 1, the distances could have a high effect on the real cost of the electricity.

3. RESULTS AND CONCLUSIONS

In the following graphs, the LCOE is analyzed for different mortgage loan interest rate, including the case of self-financing, i.e. no mortgage.

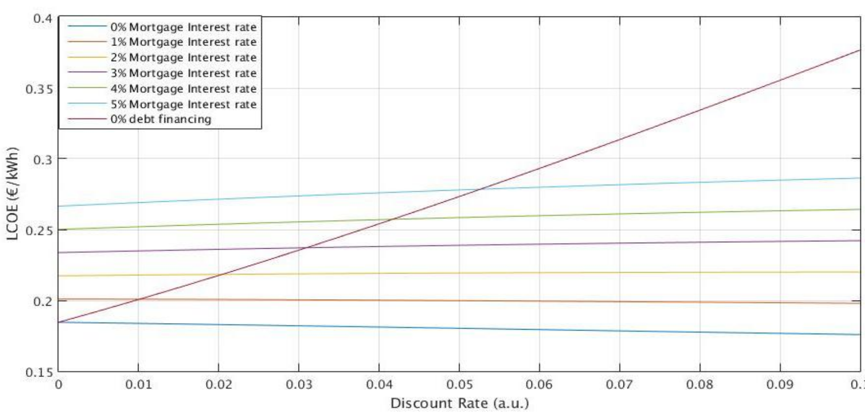

Fig.2. LCOE for 25 years lifetime of the PV system in Madrid varying mortgage interest rate and discount rate;, the inputs are: total cost of system=23844€, first year output = 7442.13kWh, degradation rate= 0.5%, operating and maintenance cost= 238.44 € per year, loan term= 25 years, the inverter´s replacement in the fifteenth year=2384.4€.

By comparing these two different PV systems, it can be observed that due to the decline in PV module´s price, as well as the price of other essential components, the LCOE of the system in Colombia is rather lower than in Madrid.

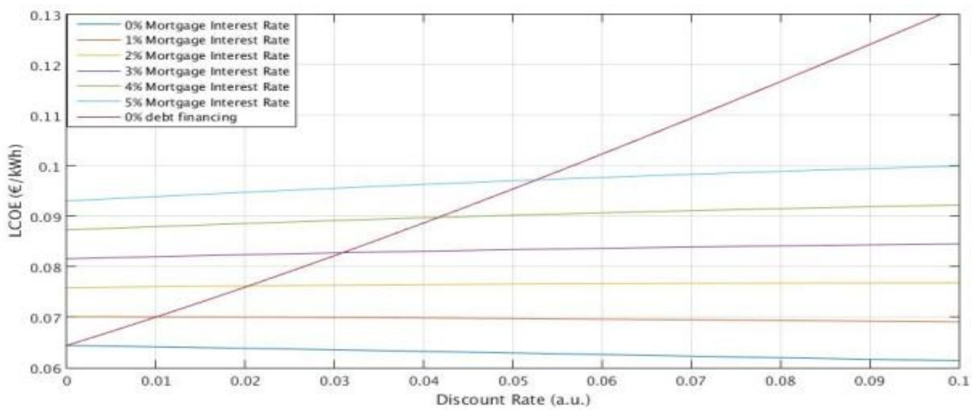

Fig.3. LCOE for 25 years lifetime of the PV system in Colombia varying mortgage interest rate and discount rate; the inputs are: total cost of system=6000€, first year output = 5364.5kWh, degradation rate= 0.5%, operating and maintenance cost= 60 € per year, loan term= 25 years, the inverter´s replacement in the fifteenth year: 600€.

However, from the point of view of a particular investor, the benefit of the investment could be more attractive. The latter is more related to the government incentive policy or the electricity price if there is no incentive. In Spain, subsides of PV system connected to the grid until 2013 would lead to a better PBP and IRR than in Colombia. Despite nowadays no feed-in tariffs are applied in either country the LCOE would be better than the price of the electricity from the grid.

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