Solar Showdown: Comparing LCOE and other performance metrics across 6 Solar Photovoltaic Technologies

Rowena Mathew, Universite Savoie Mont Blanc, 0772027290, rowena.mathew@univ-smb.fr

Overview

The transition towards renewable energy sources has accelerated the adoption of solar photovoltaic (PV) systems globally. The European Union (EU) has mandated an increase in installed solar PV capacity to 720 GWp by 2030, four times the 2021 levels. Already 273.7 GW have been installed (IEA 2024), however the EU must now install nearly 100GWp annually to be able to achieve the goal. Countries are rapidly expanding their solar installed capacity with all types of technologies, on all available spaces. In addition to the more popular ground-mounted solar PV plants, some other PV types gaining popularity are agri-PV, floating PV, bifacial PC and rooftop solar PV (Mandys et al, 2023; Masson et al, 2024).

As countries focus on multiple PV technologies, depending on their specific contexts and needs, it is important to consider performance parameters of each technology type. This paper aims to evaluate the economic viability of six types of solar PV technologies under current market and technological condition in Europe, with a specific focus on France. Mainland and overseas France, with its diverse geography, provides a good comparative field to test regional variations.

Methods

This paper combines a comprehensive literature review with limited on-ground data received from Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA). The types of solar PV technologies have been analysed for their technical and economic performance via a list of performance metrics (Lazard, 2024; Matsuo, 2024; Vartiainen, 2020). This includes LCOE, lifetime, typical faults, life cycle analysis, performance ratio and capacity factor. This paper employs a comparative analysis framework to evaluate the Levelised Cost of Electricity (LCOE) across six solar PV technologies:

1) **Ground mounted PV** – utility scale or large scale. The most common and popular type of PV technology that sees widespread application. Data from New Caledonia Overseas Territory and South France.
2) **Agri-PV** – mounting PV above the ground on croplands. This dual use of cropland optimises renewable energy generation without compromising crop yield. Data from literature.
3) **Bifacial PV** – new and cutting edge type of PV module that captures sunlight from both surfaces. These have transparent materials on both sides of the panel, allowing sunlight to pass through leading to marked increase in energy yield. Data from literature.
4) **Floating PV** – PV panels that float on the surface of water. Applicable on most bodies of water, ranging from natural lakes and ponds to former mines or quarries filled with ground water. Data from South France.
5) **Rooftop PV** – PV panels set up on rooftops of buildings. Major application in urban areas where there is limited land availability. Data from South France.
6) **PV + Storage Systems** – battery storage systems are most commonly used in combination with solar technologies. Data from South France.

The LCOE for each technology type is calculated using the standard formula:

$$\frac{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where :

- C_t is the total cost (CAPEX + OPEX)
- n corresponds to the life of the project (taken as 30 years)
- E_t is the annual electricity generated (MWh)
- r is the annual discount rate (taken as 5%)

To incorporate real-world conditions, region-specific data for France was integrated, from mainland France and New Caledonia overseas territory. Data including solar irradiance levels, market-specific cost benchmarks and degradation rates were integrated. Technology-specific degradation rates were applied annually to reflect system performance over time. Sensitivity analyses were conducted to account for variability in capacity factors and capital costs. Technological distinctions, such as bifacial panel efficiency gains, water cooling effects in floating PV, and dual land use benefits in agri-PV were considered in the LCOE estimates. Presently, an LCOCE (cost of consumed electricity) is being performed to analyse benefits of battery systems.

All calculations were performed using MATLAB to ensure reproducibility and accuracy.

Results

The preliminary findings show that there are significant variations in LCOE, influenced by factors such as system design, location, capacity factor, and integration requirements. Research also highlights the regional variations in solar PV technology parameters, depending on solar irradiance and cost of capital. These regional variations are mentioned in specific sections, along with the specific conditions under which they are valid.

	Type of Solar PV Technology	**LCOE** (in €/MWH)	**Expected Lifetime** (in years)	**Carbon footprint** (in gCO2 eq / KWH)	**Energy Payback Time** (in years)	**Performance Ratio** (in %)
1	**Ground-mounted PV Plants**	€28 - €55	25–30 years	20-40 g CO_2-eq/kWh	1-3 years	80–85%
2	**Agrivoltaic (Agri-PV) Plants**	€42 - €65	20–30 years	20-45 g CO_2-eq/kWh	1.5-3 years	80–85%
3	**Bifacial PV Plants**	€33 - €51	25–30 years	15-25 g CO_2-eq/kWh	1-2.5 years	85–90%
4	**Floating PV Plants**	€37 - €75	20–25 years	49-55 g CO_2-eq/kWh	2-4 years	10-15% higher than land-based systems in same area
5	**PV + Storage Systems**	€47 - €84	20–25 years (PV), 10–15 years (Battery)	50-80 g CO_2-eq/kWh (Battery: High)	5-10 years (Storage-dependent)	70-80%
6	**Rooftop PV**	€50 - €85	25–30 years	20-35 g CO_2-eq/kWh	1-3 years	75-80%

Preliminary Conclusions

This paper shows the diverse economic dynamics of solar PV technologies, highlighting the importance of selecting configurations that align with regional condition. Ground-mounted PV remains the most cost-effective PV technology for large scale deployment, with lowest LCOE. FPVs have higher performance ratio and bifacial plants have highest energy yield and fastest energy payback time.

References

IEA. (2024). *Carbon Footprint Analysis of Floating PV Systems 2024*.

ISE Fraunhofer. (2021). *LEVELIZED COST OF ELECTRICITY RENEWABLE ENERGY TECHNOLOGIES*. www.ise.fraunhofer.de

Lazard. (2024). *LEVELIZED COST OF ENERGY ANALYSIS-VERSION 17.0*.

Mandys, F., Chitnis, M., & Silva, S. R. P. (2023). Levelized cost estimates of solar photovoltaic electricity in the United Kingdom until 2035. *Patterns*, *4*(5).

Masson, G., de l'Epine, M., & Kaizuka, I. (2024). *Trends in PV Applications 2024* (G. Masson, Ed.). https://doi.org/10.69766/JNEW6916

Matsuo, Y. (2022). Re-Defining System LCOE: Costs and Values of Power Sources. *Energies*, *15*(18). https://doi.org/10.3390/en15186845

Vartiainen, E., Masson, G., Breyer, C., Moser, D., & Román Medina, E. (2020). Impact of weighted average cost of capital, capital expenditure, and other parameters on future utility-scale PV levelised cost of electricity. *Progress in Photovoltaics: Research and Applications*, *28*(6), 439–453. https://doi.org/10.1002/PIP.3189