Energy and Economic Assessment of Floating PV in Spanish Reservoirs

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Pearl PV Workshop, September 2021

Agenda

- Background
- Methodology
- Results
- Conclusions

Floating PV: Why?

Spain's Integrated National Energy and Climate Plan 2021-2030 targets to reach **39 GW of PV** installed nationwide by 2030, three times the current capacity (**12 GW**).

To achieve this, PV capacity has to increase by 3GW per year!

➔ <u>We need ~60 km^2 of land every year.</u>

Floating PV: Why?

Recent letter from Spanish researchers to Science:

Spain should adopt a more cautious approach to prevent a scenario in which energy goals are met at the expense of biodiversity. […]

Photovoltaic energy needs huge amounts of land and will mostly affect declining species of steppe birds, which are poorly represented in the Spanish Natura 2000 network.

Serrano, D. *et al.* Renewables in Spain threaten biodiversity. *Science (80-.).* **370**, 1182–1183 (2020).

Floating PV: Why?

ENERGÍA SOLAR >

Cuánto ocupan las megacentrales solares: investigadores alertan del impacto del 'boom' fotovoltaico

El Ministerio para la Transición Ecológica considera que los proyectos previstos para 2030 requieren una parte muy pequeña del territorio a escala nacional, pero admite su preocupación por que se produzca una concentración excesiva en algunos puntos

EL PAÍS

ENERGÍAS RENOVABLES >

Los agricultores se frotan las manos 'plantando' paneles solares

Los precios de alquiler de suelo rústico para un parque fotovoltaico llegan a 1.500 euros por hectárea y año, frente a los 150 para cultivar cereal

Using land for PV is **10 times more profitable** than for farming!

Álvarez, C. & Zafra, M. Cuánto ocupan las megacentrales solares: investigadores alertan del impacto del 'boom' fotovoltaico. *El Pais* (2021).
Aparicio, L. Los agricultores se frotan las manos 'plantando' paneles solares. *El País* (2020).

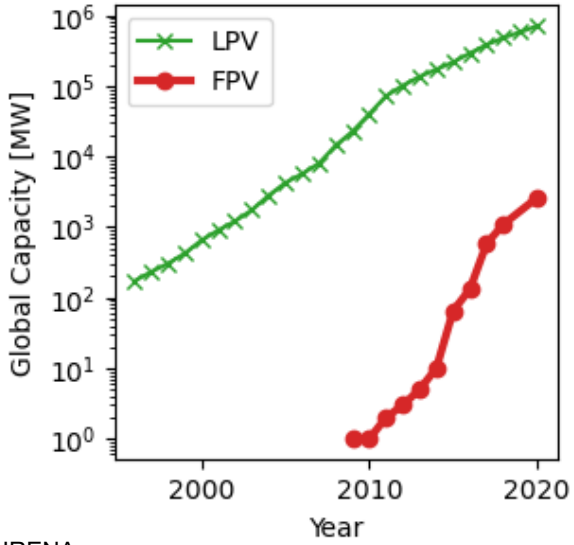
Floating PV: Definition

PV is installed on the surface of water bodies instead of land.

This work only considers water bodies in continental Spain

Floating PV: Capacity

By August 2020, FPV had reached a global 2.6 GW capacity, distributed over 35 countries.
This is twice the capacity reported at the end of 2018.
Land based PV (LPV) capacity was 2.6 GW in 2003.



IRENA

Floating PV: Pros & Cons

- The cost for renting land for PV is increasing. ➔ Lower rent installing on water!
- Use of **existing electricity transmission** infrastructure at hydropower sites. ➔ Lower costs for infrastructures!
- Expected to work at lower temperature thanks to the **cooling effects of water**. ➔ Better performance!
- **No need for major site preparation**, such as leveling or the laying of foundations. **Easy installation and deployment**. ➔ Lower installation costs!
- However, FPV modules have to be installed at **lower tilt angles** (˜10°). ➔ Worse performance!

Research Questions

1) Which is the Floating PV potential in Spain?

2) Which **Capital Expenditure (CAPEX)** can be sustained by FPV systems to be economically competitive with in-land PV (LPV)?

Capacity: Methodology

1) Which is the Floating PV potential in Spain?

Global Reservoir and Dam Database (GRanD)

The Global Reservoir and Dam Database (GRanD) v1.1 is a product of the Global Water System Project, which initiated a collaborative international effort to collate existing dam and reservoir datasets with the aim of providing a single, geographically explicit and reliable database for the scientific community.

I considered the reservoirs listed in the **Global Reservoir and Dam Database (GRanD) v1.3**.

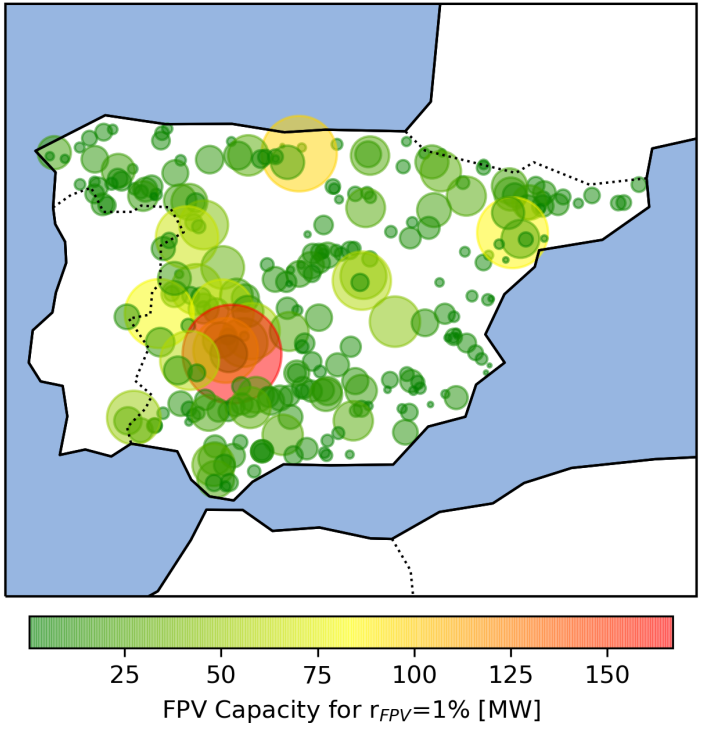
It contains a large number of information on each dam.

However, it might report only **part of the total number of dams** ➔ conservative estimation of the FPV surface available.

Lehner, B. *et al.* High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment* vol. 9 494–502 (2011).

Capacity: Results

1) Which is the Floating PV potential in Spain?

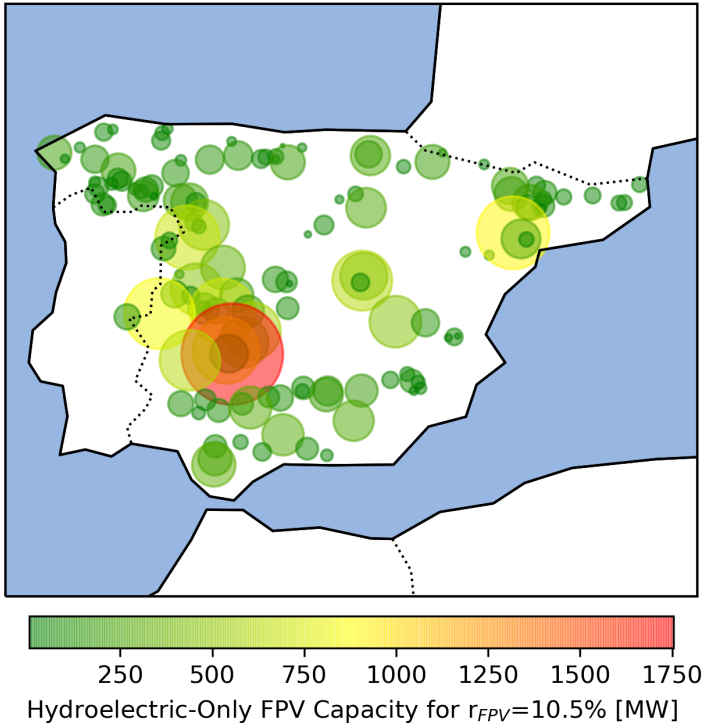


Each 1% of reservoir surface covered by PV can:

- increase the national PV capacity **by 3 GW** (25% of current capacity)
- provide **1.7% of the annual electricity demand**.

Capacity: Results

1) Which is the Floating PV potential in Spain?

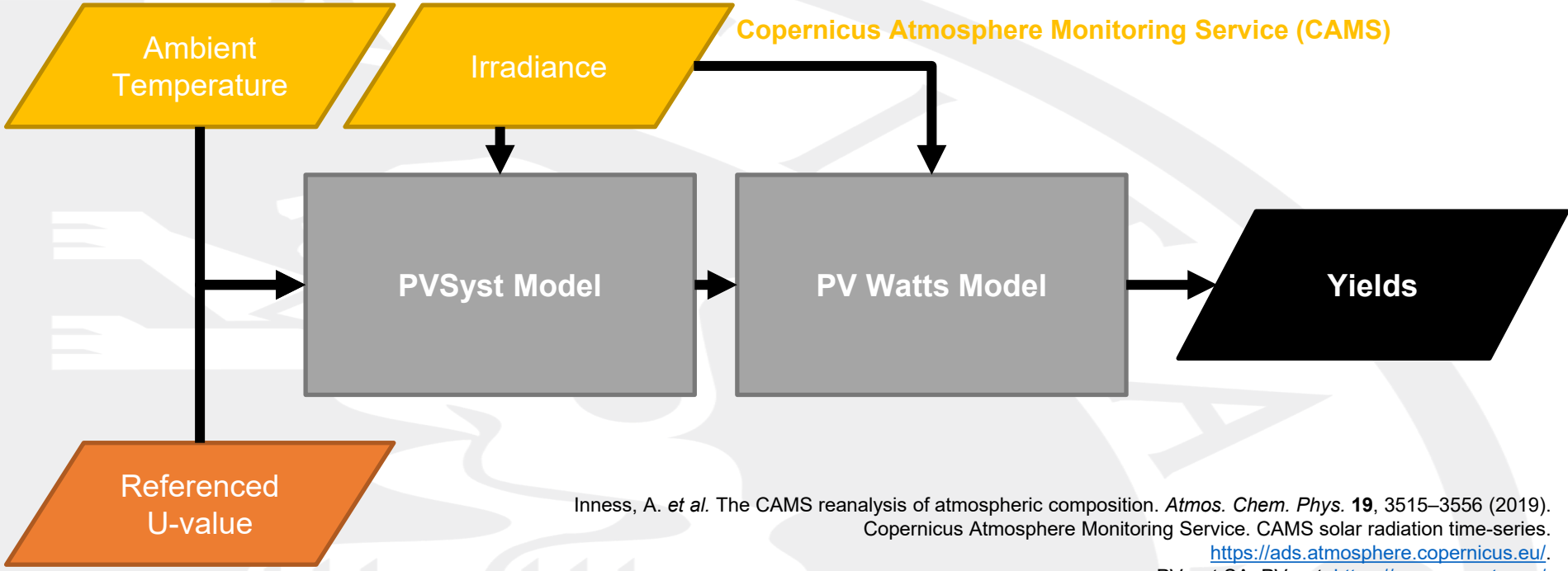


If hydro-capacity is matched:

- **10% surface** of the hydroelectric lakes;
- **20 GW of FPV**: 75% of the capacity currently missing to reach the 2030 target.
- **12% of the national electricity demand**.

Capacity: Methodology

2) Which are the maximum CAPEX allowed?



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Copernicus Atmosphere Monitoring Service. CAMS solar radiation time-series. https://ads.atmosphere.copernicus.eu/.

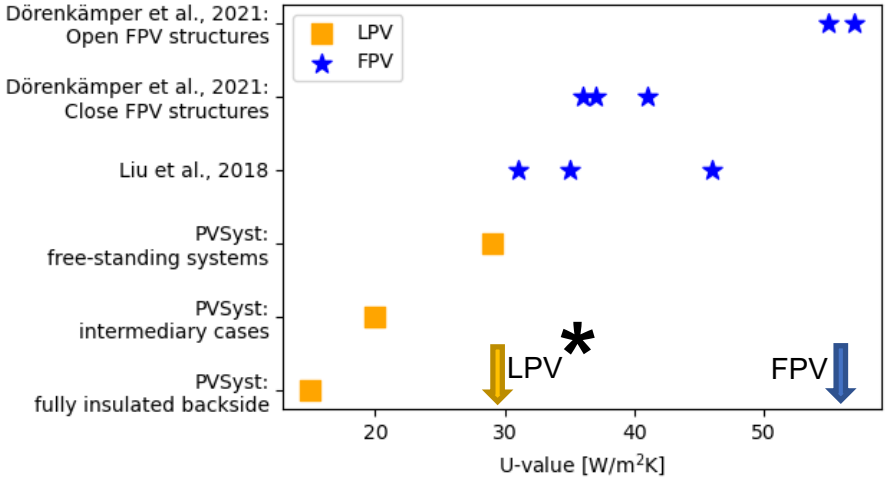
PVsyst SA. PVsyst. https://www.pvsyst.com/.

Dobos, A. P. PVWatts Version 5 Manual. (2014).

Capacity: Methodology

2) Which are the maximum CAPEX allowed?

PVSyst model: $T_C = T_a + \frac{\alpha E(1-\eta_m)}{U_c + U_v \times WS}$ → $T_C = T_a + \frac{\alpha E(1-\eta_m)}{U}$



PVsyst SA. PVsyst. https://www.pvsyst.com/.

Faiman, D. Assessing the outdoor operating temperature of photovoltaic modules. *Prog. Photovoltaics Res. Appl.* **16**, 307–315 (2008).

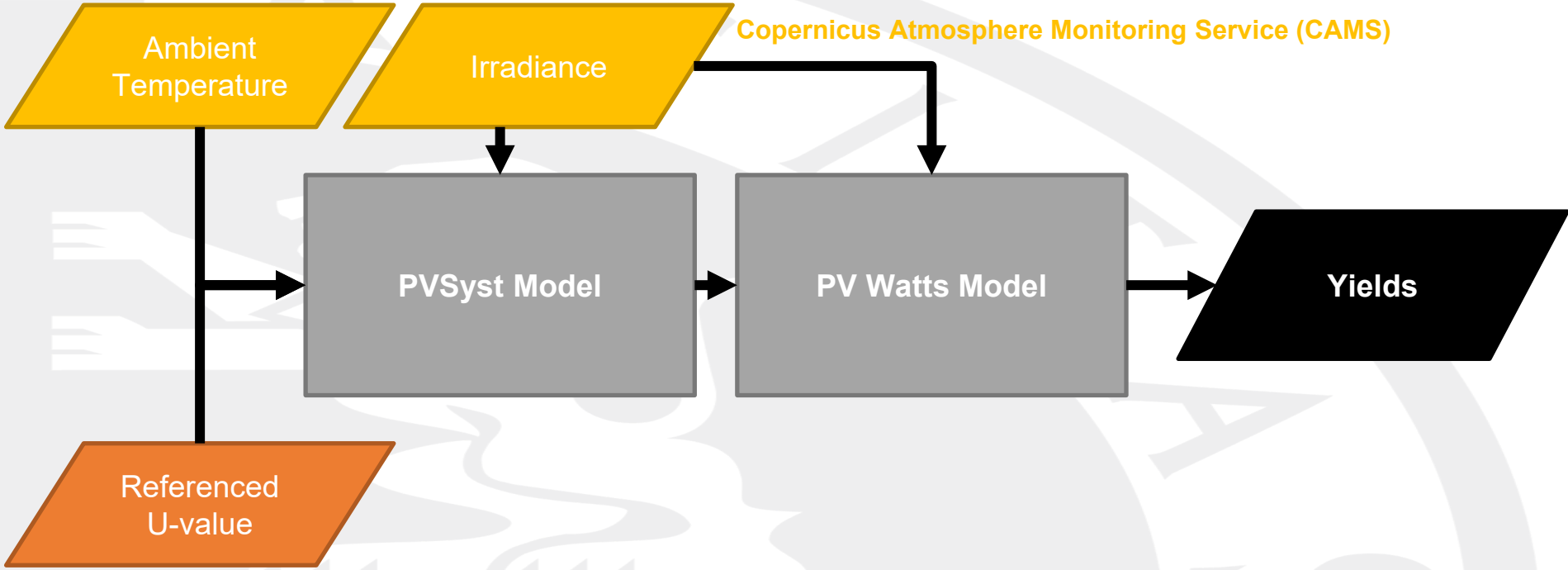
Dörenkämper, M. *et al.* The cooling effect of floating PV in two different climate zones: A comparison of field test data from the Netherlands and Singapore. *Sol. Energy* **219**, 15–23 (2021).

Liu, H., Krishna, V., Lun Leung, J., Reindl, T. & Zhao, L. Field experience and performance analysis of floating PV technologies in the tropics. *Prog. Photovoltaics Res. Appl.* **26**, 957–967 (2018).

* Peters, I. M. & Nobre, A. M. On Module Temperature in Floating PV Systems. *Conf. Rec. IEEE Photovolt. Spec. Conf.* **2020-June**, 0238–0241 (2020).

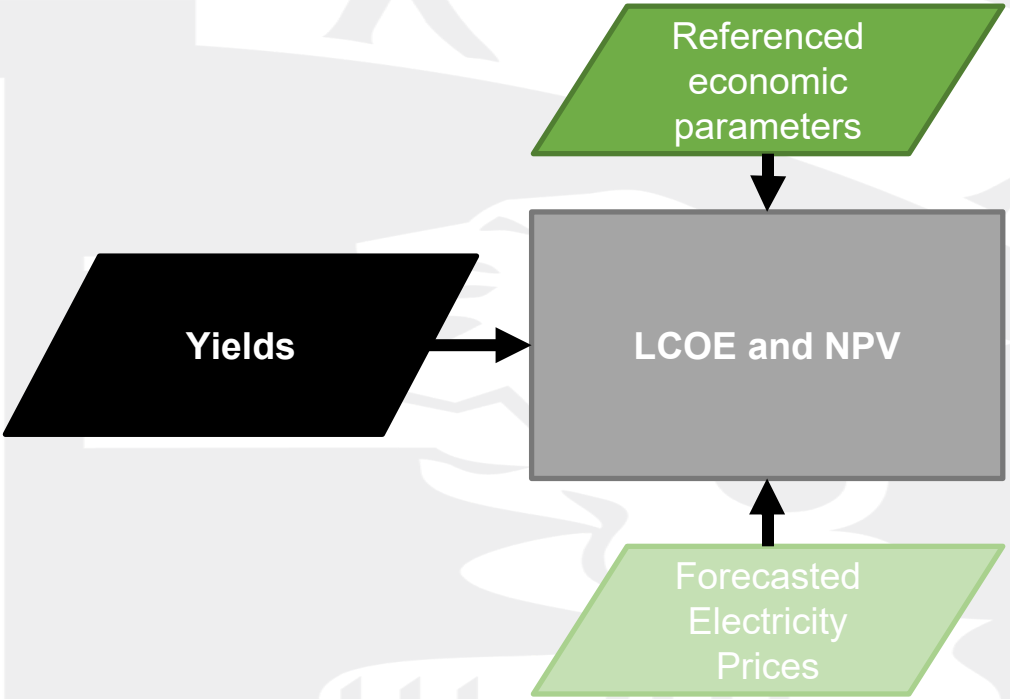
Economics: Methodology

2) Which maximum CAPEX are allowed?



Economics: Methodology

2) Which are the maximum CAPEX allowed?



The Levelized Cost of Electricity (**LCOE**) quantifies the cost of producing a kWh of electricity. The lower, the better.

$$LCOE = \frac{Installation\ Costs + \sum Yearly\ O\&M\ Costs\ /Discount}{\sum Yearly\ Energy\ Yield\ /Discount}$$

The Net Present Value (**NPV**) evaluates the profitability of an investment. The larger, the better.

$$NPV = -Installation\ Costs + \sum \frac{Yearly\ Revenues - Yearly\ O\&M\ Costs}{Discount}$$

Economics: Methodology

2) Which are the maximum CAPEX allowed?

Finding the maximum allowed for FPV so that:

$$LCOE_{FPV}(CAPEX_{FPV}) \leq LCOE_{LPV}(CAPEX_{LPV})$$

$$NPV_{FPV}(CAPEX_{FPV}) \geq NPV_{LPV}(CAPEX_{LPV})$$

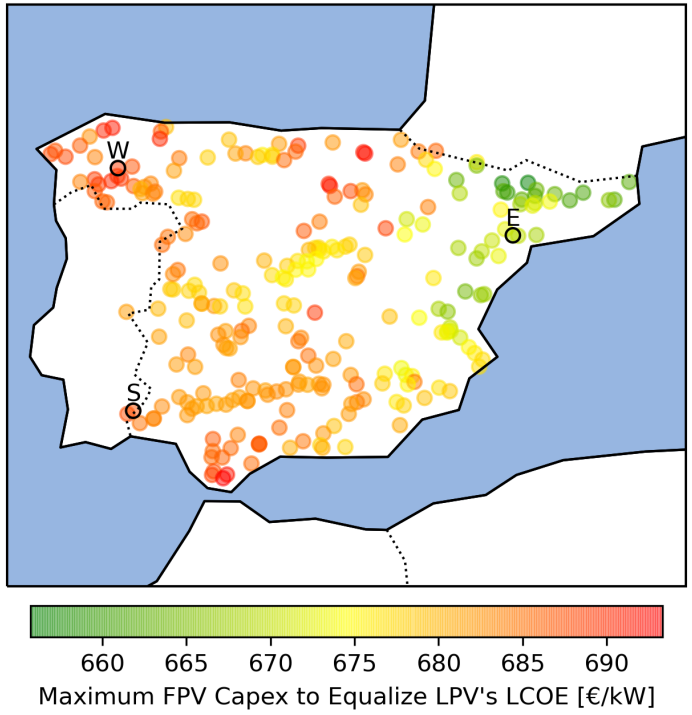
Comparing energy and economic performance of FPV and land based (LPV).

	FPV	LPV
U-value	56 W/m2K	29 W/m2K
Tilt angle	10 degrees	Latitude
CAPEX	TBD	700 €/kW

Monofacial Si module, at fixed tilt angle, south facing.

Economics: Results

2) Which are the maximum CAPEX allowed?

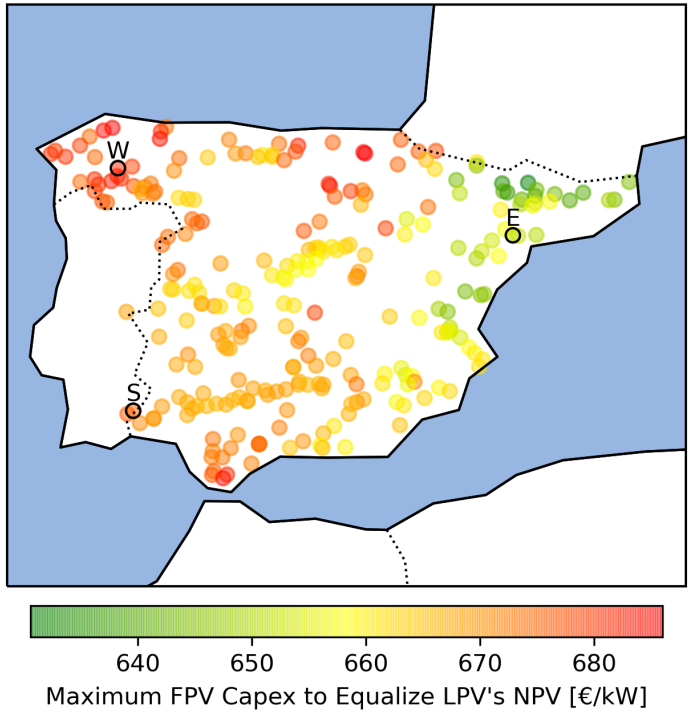


In some regions, FPV can already economically compete with LPV:

- **West**: lower PV potential
- **South**: higher temperature and irradiance
- **Northeast**: lowest ambient temperatures and intermediate irradiance values

Economics: Results

2) Which are the maximum CAPEX allowed?

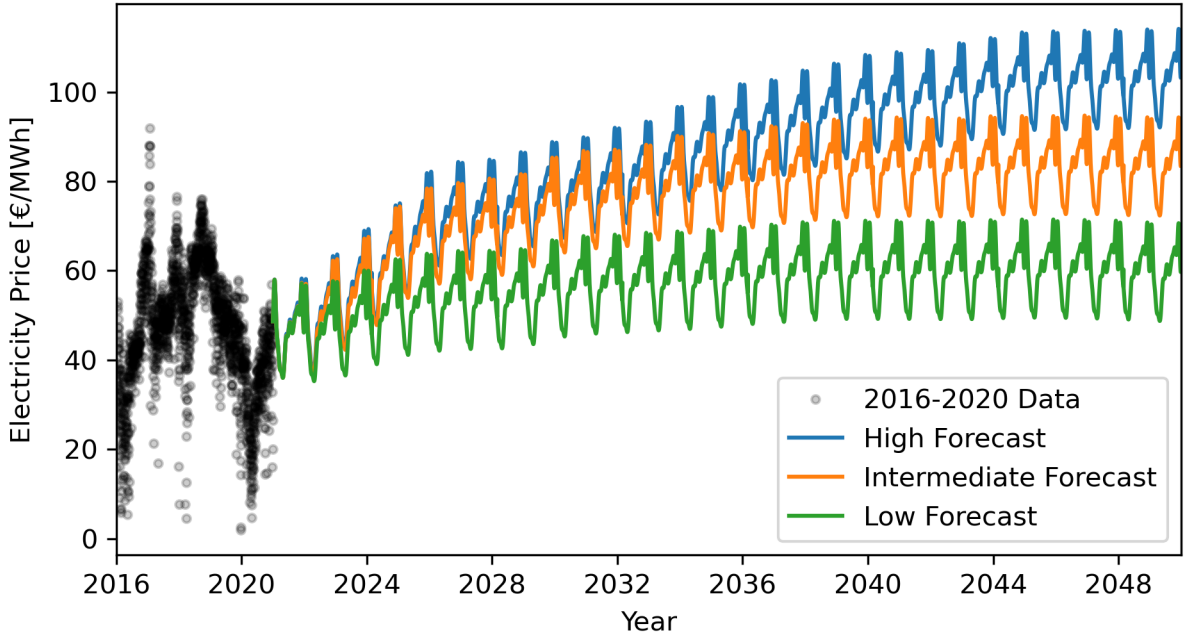


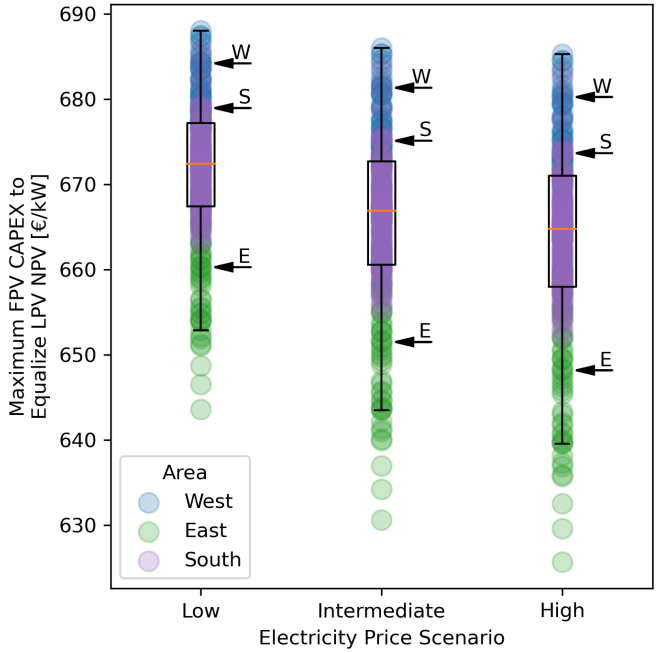
If NPV is used, the same distribution is found.

However, the allowed CAPEX are lower.

Economics: Results

2) Which are the maximum CAPEX allowed?





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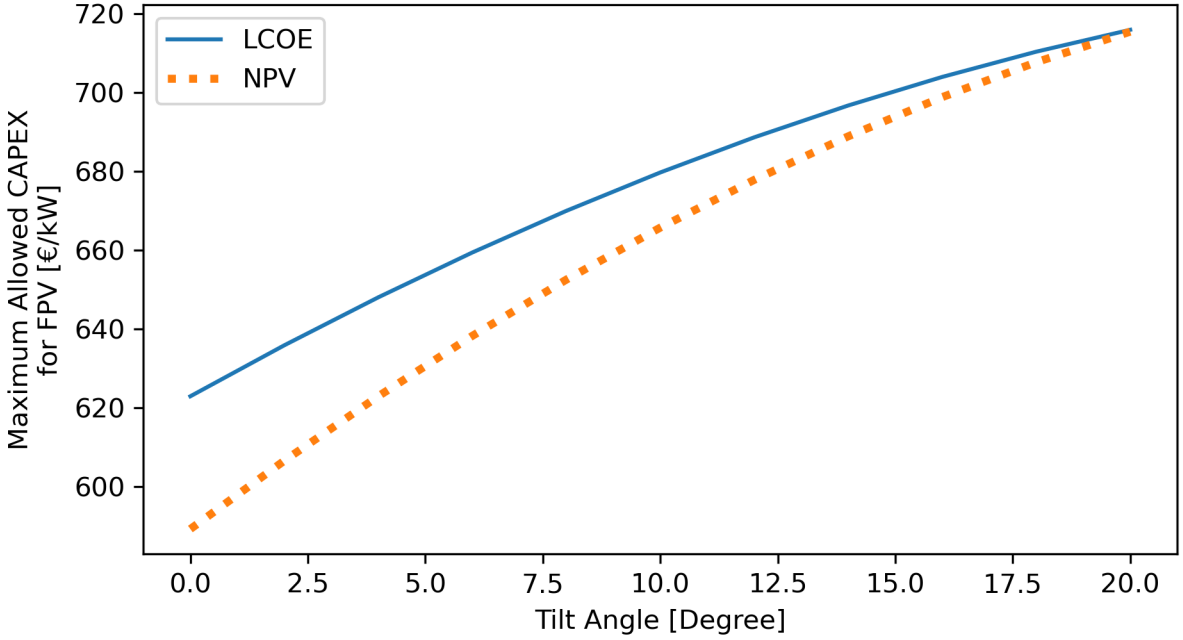
Economics: Results

2) Which are the maximum CAPEX allowed?

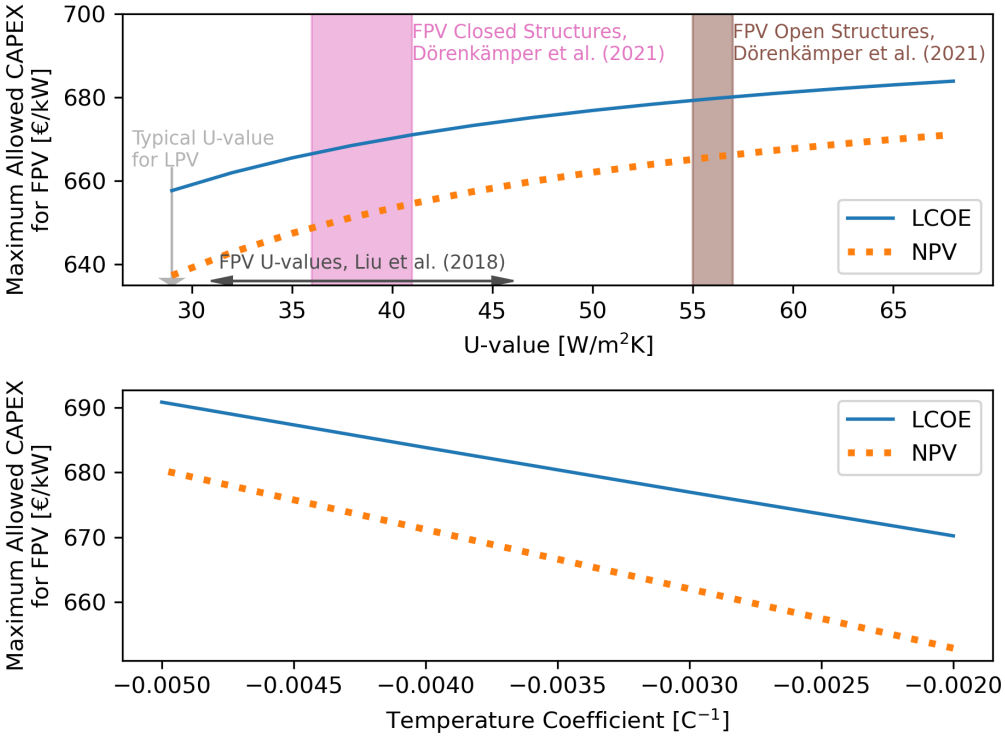


FPV would match the LPV economics at tilt angles of 16 deg – 18 deg.

However, higher tilt angles might require additional CAPEX to strengthen the FPV foundations.

Economics: Results

2) Which are the maximum CAPEX allowed?

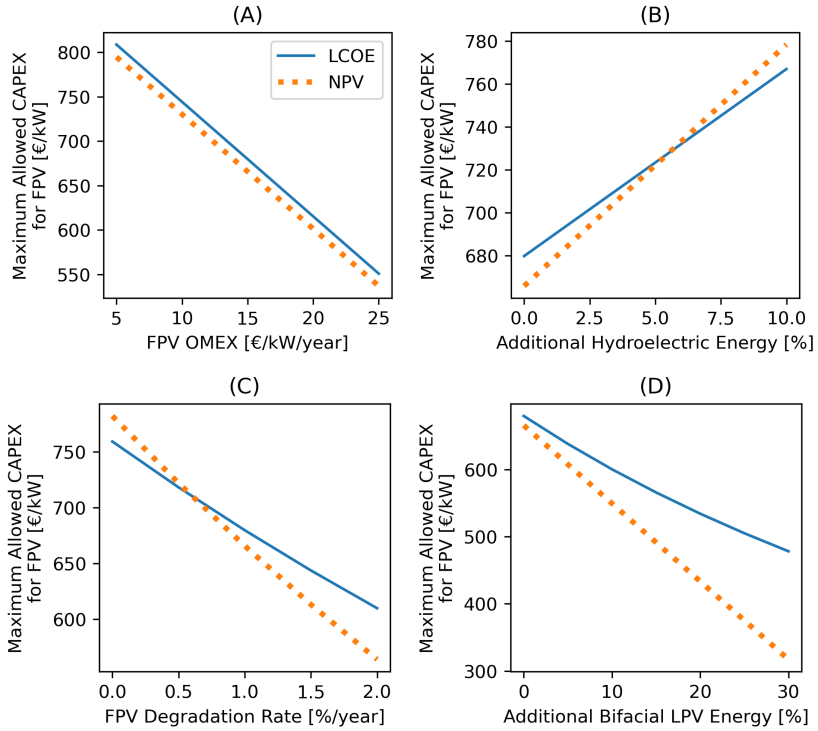


The results vary depending on all the variable in input. FPV potential increases with:

- U-value
- Temperature dependence of the PV module

Economics: Results

2) Which are the maximum CAPEX allowed?



Additional factors were also tested:

A. Different OMEX
B. Potential gain in hydro
C. Different degradation
D. Low bifaciality for FPV

Micheli, L. Energy and economic assessment of floating photovoltaics in Spanish reservoirs : cost competitiveness and the role of temperature. *Sol. Energy* **227**, 625–634 (2021).

Conclusions and future works

Floating PV can be key for future of PV in Spain.
In Spain, CAPEX of FPV should be 1 to 10% lower than CAPEX of land based PV (LPV).

Several factors can affect its competiveness:

- **Module temperature coefficient** is a key factor in determining maximum allowed CAPEX of FPV.
- The higher the **future electricity prices**, the lower the CAPEX for FPV to match LPV.

ADVANCES IN PV Tech

Thanks for your attention!

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EFQM Recognised for Excellence 5 Star - 2017

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www.sciencedirect.com/science/article/pii/S0038092X21007222

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Solar Energy
Volume 227, October 2021, Pages 625-634

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https://doi.org/10.1016/j.solener.2021.08.058