Techno-economic potential of floating photovoltaics and the impact of its operating temperature

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Sole4PV (Soiling Live Estimation for Photovoltaics)

Project funded by the **Italian Ministry of University and Research** under the 2019 **«Rita Levi Montalcini» Program** for Young Researchers

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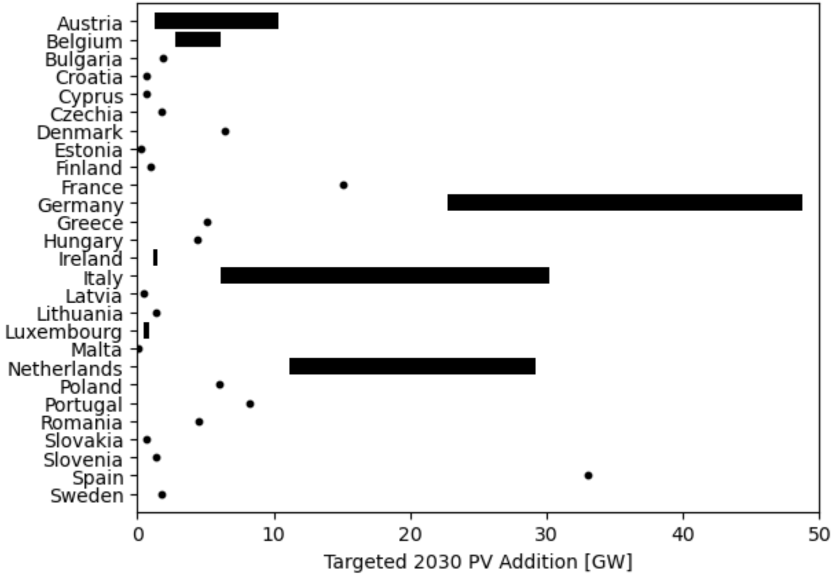
Agenda

- **Introduction**
  - 2030 EU PV goals
  - Floating PV
  - Research Questions
- **Methodology**
- **Results & Discussion**
  - Potential PV Capacity
  - Targeted Costs
  - Role of Temperature and Degradation
- **Conclusions**

2030 EU PV goals

EU plans deploying between **140 and 222 GW** of new PV power plants by 2030



➔ 2555 to 4050 km^2 of new PV plants

6 to 10% the size of Switzerland

Kougias, I. *et al. Renew. Sustain. Energy Rev.* 144, 111017 (2021)

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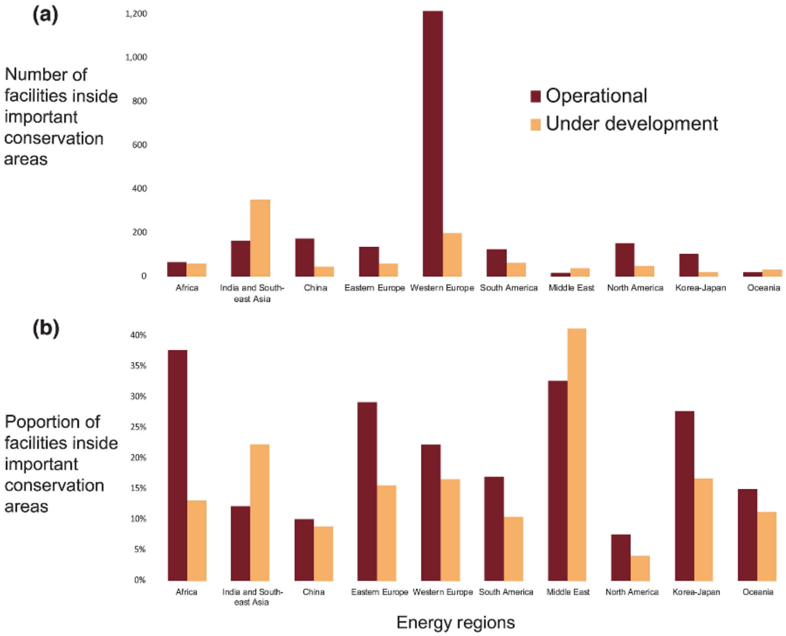
2030 EU PV goals: concerns



Europe has already the highest number of renewable systems installed in protected areas.

Rehbein, J. A. *et al. Glob. Chang. Biol.* 26, 3040–3051 (2020)
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2030 EU PV goals: concerns


Science

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HOME > SCIENCE > VOL. 370, NO. 6522 > RENEWABLES IN SPAIN THREATEN BIODIVERSITY

LETTER

Renewables in Spain threaten biodiversity

DAVID SERRANO, ANTONI MARGALIDA, JUAN M. PÉREZ-GARCÍA, JAVIER JUSTE, JUAN TRABA, FRANCISCO VALERA, MARTINA CARRETE, JOXERRA AIHARTZA, JOAN REAL, [...] JOSÉ A. DONÁZAR +14 authors Authors Info & Affiliations

SCIENCE • 11 Dec 2020 • Vol 370, Issue 6522 • pp. 1282-1283 • DOI: 10.1126/science.abf6509

379 7

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.*

2030 EU PV goals: concerns

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

RENEWABLE ENERGY >

Farmers rub their hands 'planting' solar panels

Rural land rental prices for a photovoltaic park reach 1,500 euros per hectare per year, compared to 150 to grow cereal

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.

Photo Sources: S.H. Kim, S.C. Baek, K.B. Choi, and S.J. Park, Energies **13**, (2020).
H.F. Abd-Elhamid, A. Ahmed, M. Zele ˇnáková, Z. Vranayová, and I. Fathy, Water **13**, 1 (2021).
H.S. Jeong, J. Choi, H.H. Lee, and H.S. Jo, Appl. Sci. **10**, (2020).
S.H. Kim, S.J. Yoon, W. Choi, and K.B. Choi, Sustain. **8**, 1 (2016).

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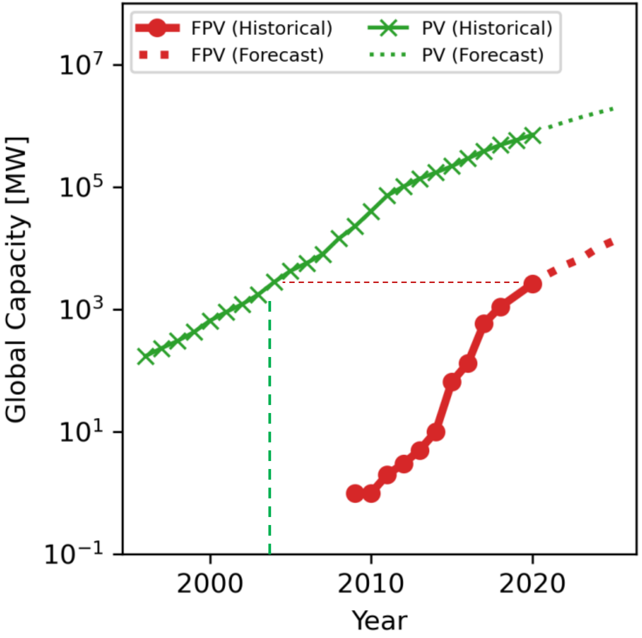
Pro/cons

- 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!**

World Bank Group, ESMAP, and SERIS, "Where Sun Meets Water: Floating Solar Market Report—Executive Summary," Washington, DC, 2018.

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.
It is expected to **double by the end of 2022**. A forecast predict **13 GW by 2025**.



Land based PV (LPV) capacity was **2.6 GW in 2003**.

Deloitte, “Technology, Media, and Telecommunications Predictions 2020,” 2022.
F. Haugwitz, “Floating solar PV gains global momentum,” *PV Magazine International*, pp. 1–10, Sep. 22, 2020.

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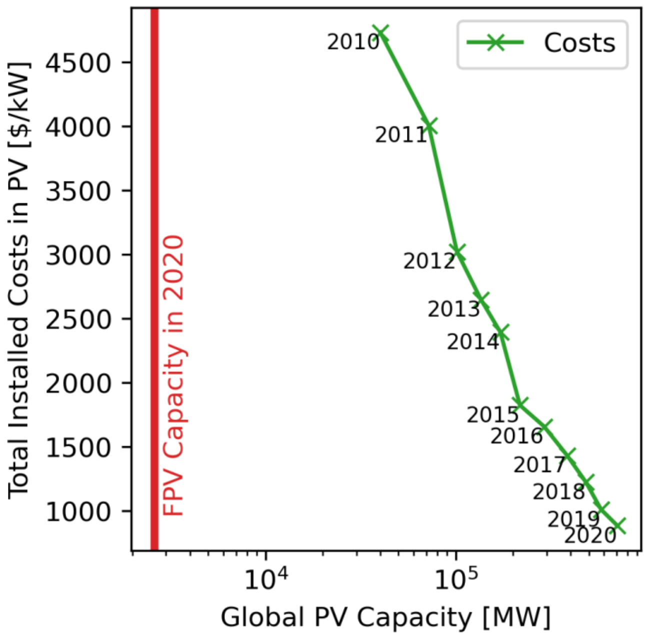
Floating PV: Capacity

FPV is reported to still have **higher installation costs than LPV**.

Cost of PV has **significantly decreased with growing capacity**.

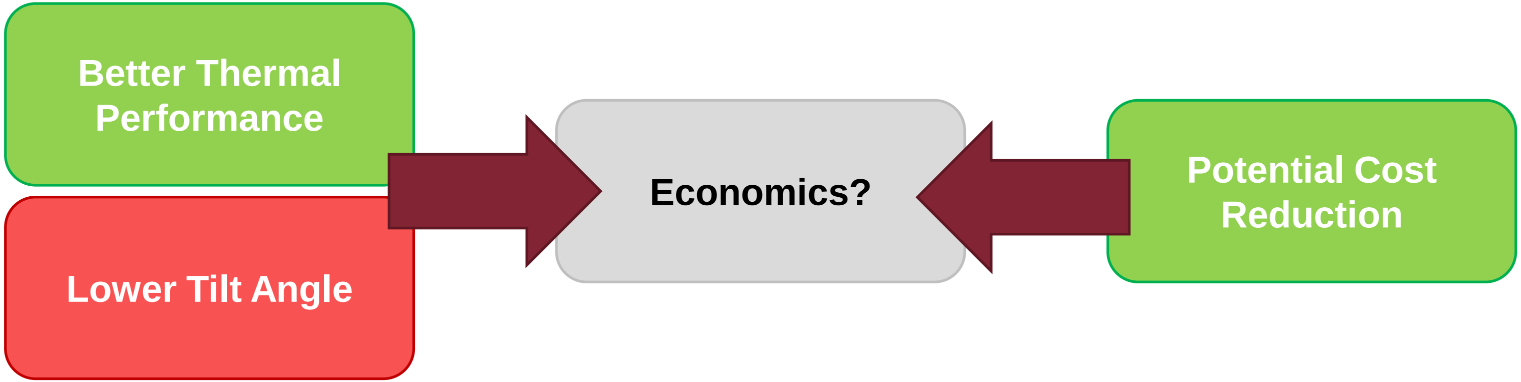
Similar decreases can also be expected for FPV.

- Economy of scale
- Maturing of technology



Research Questions

1) Which is the Floating PV potential in Europe?



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

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

Micheli, L. *Sol. Energy* 227, 625–634 (2021)

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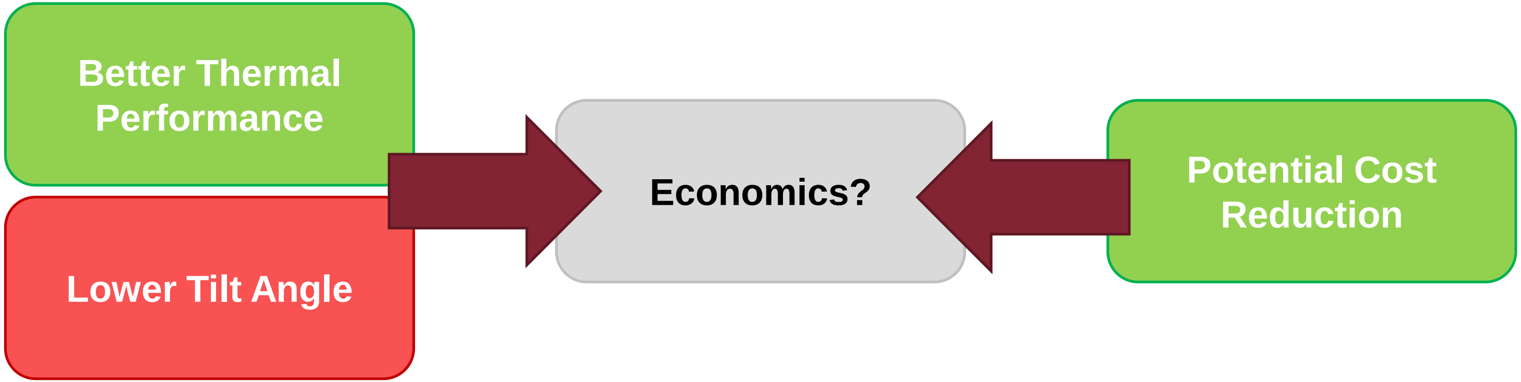

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Micheli, L. *Sol. Energy* 227, 625–634 (2021)

Methodology

We 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** ➔ <u>conservative estimation</u> of the FPV surface available.

Same filters as in Spencer et al., 2019:

- to remove duplicate reservoirs
- to reflect current industry trends (1ha surface and 2m depth minimum)
- to remove reservoirs with potentially conflicting main purposes

Spencer, R. S. *et al. Environ. Sci. Technol.* 53, 1680–1689 (2019)
Lehner, B. *et al. Frontiers in Ecology and the Environment* 9, 494–502 (2011)

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Methodology

Monofacial **Si** modules, efficiency: 21.4%

Tilt: **10°** and **20°** (not in contact with water), south facing.

[1] World Bank Group, SERIS, and ESMAP, “Where Sun Meets Water: Floating Solar Handbook for Practitioners,” Washington, DC, 2019. doi: 10.1596/32804.
[2] Silvério, N. M. et al. Energy Convers. Manag. 171, 339–349 (2018).

Methodology

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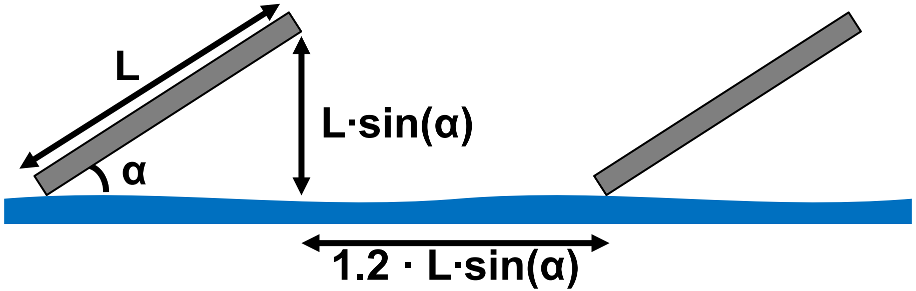
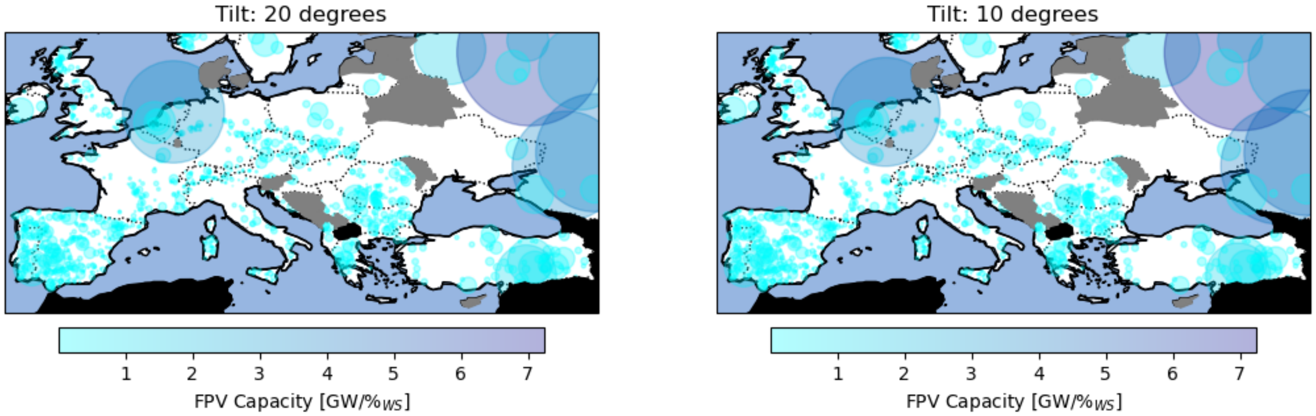
Distance between modules: **20% larger than module height**.



Micheli, L. *Sol. Energy* 227, 625–634 (2021)

Potential PV Capacity

Conservative estimation: 22500 km^2 available.



Each percentage point of water surface covered with FPV: **40 GW** at 10° or **36 GW** at 20°

At least 9% of the surface available is made of salt-water (i.e., Lake IJssel in the Netherlands), potentially exposing FPV to harsher conditions than fresh water.

L. Micheli, D. L. Talavera, G. M. Tina, F. Almonacid, and E. F. Fernández, *Under Review*

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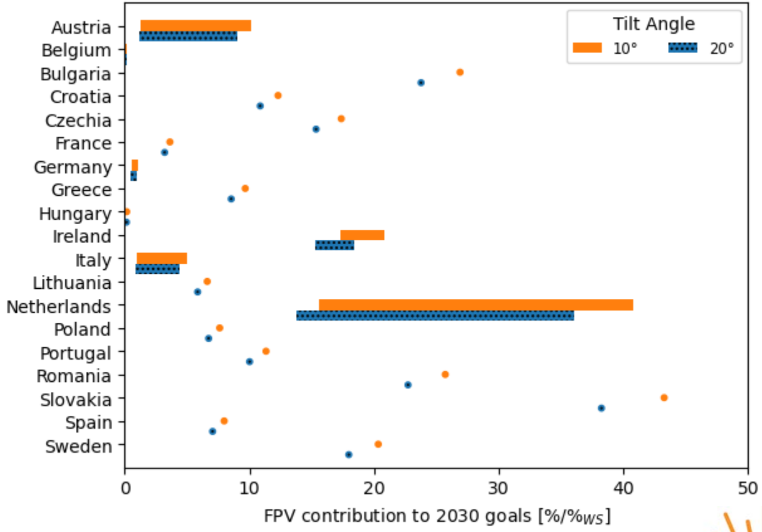
Potential PV Capacity

A third of the continental water surface is in EU member states: **13-12 GW/%$_{WS}$**.

➔ **6 to 9%** of EU 2030 goals for PV.

~16 TWh/year/%$_{WS}$ within the EU,
➔ 0.5%/%$_{WS}$ of the current demand.



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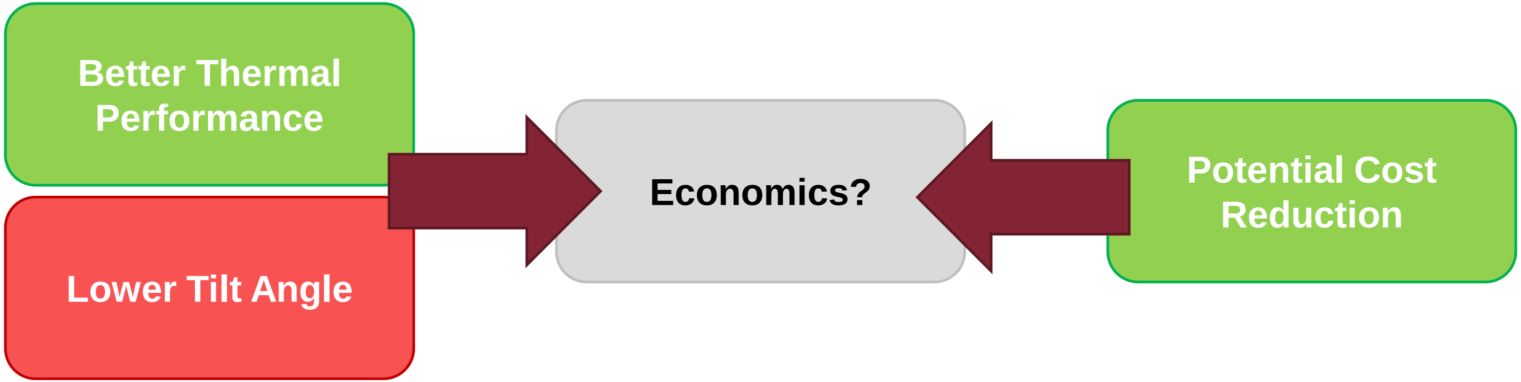

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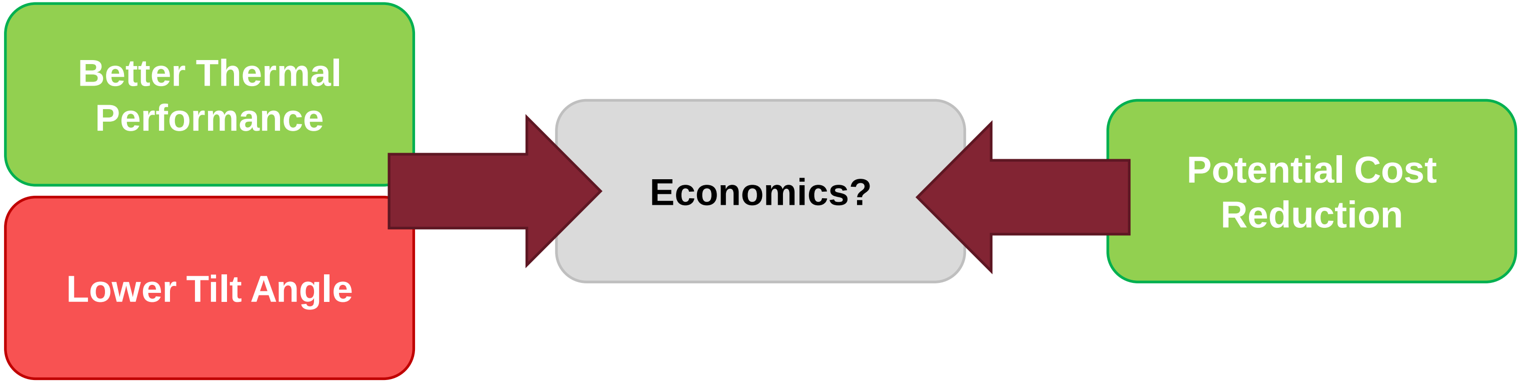

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Micheli, L. *Sol. Energy* 227, 625–634 (2021)

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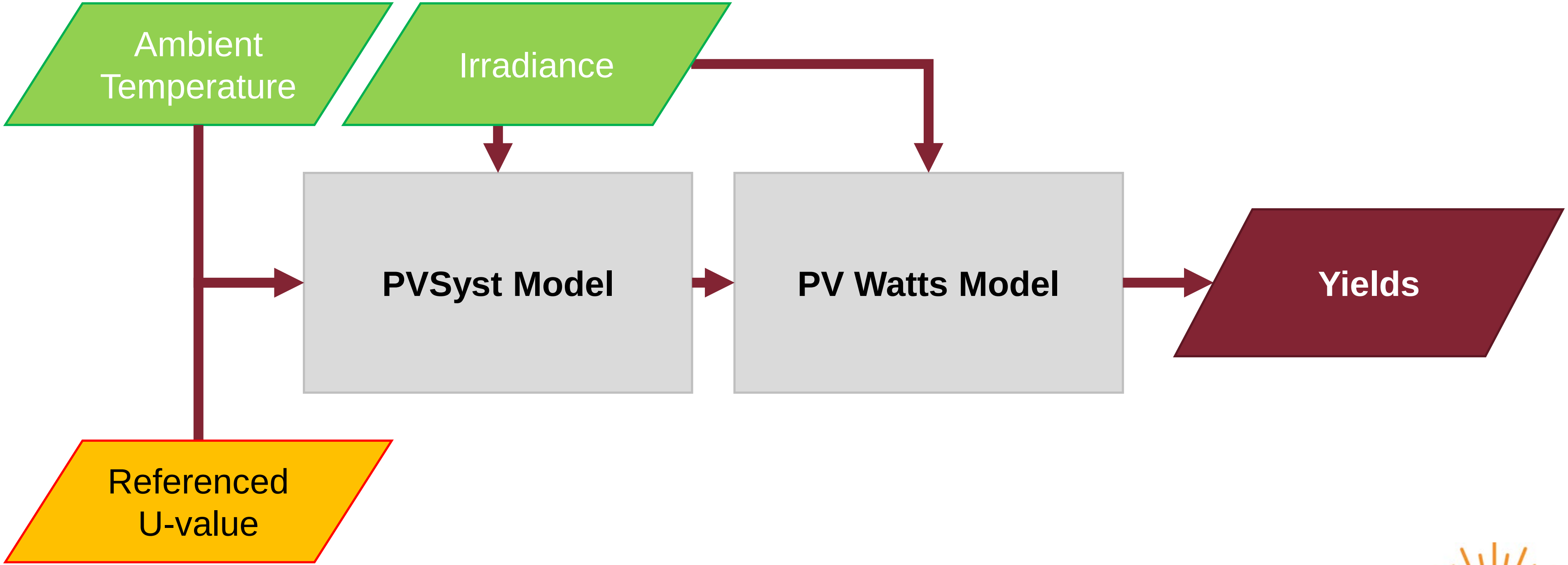
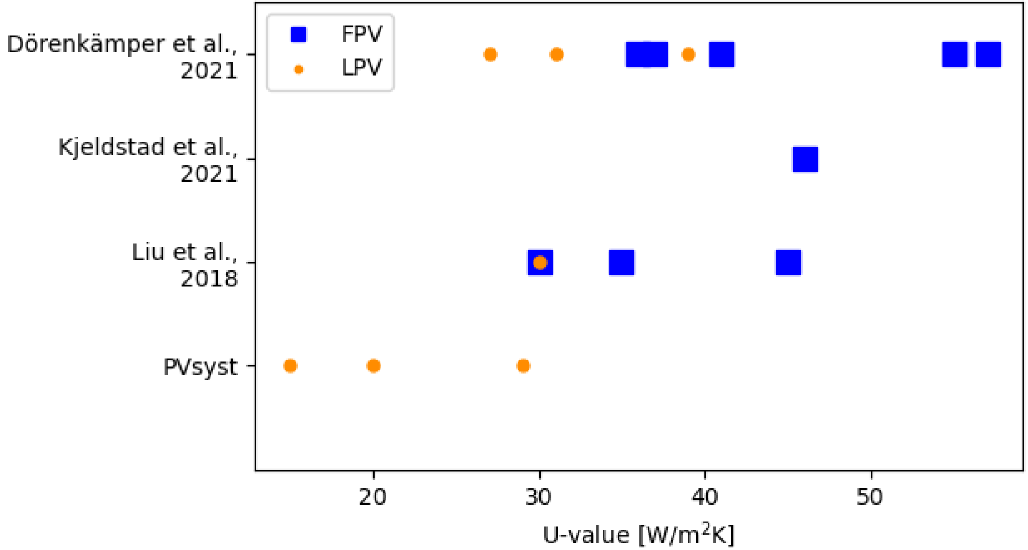


IRENA, “Renewable Power Generation Costs in 2020,” Abu Dhabi, 2021.
Micheli, L. *Sol. Energy* 227, 625–634 (2021)

Methodology & Literature Review

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



		FPV U-value	
		56 W/m²K	39 W/m²K
LPV U-value	29 W/m²K	**Scenario A** significantly better cooling in FPV	**Scenario C** better cooling in FPV
	39 W/m²K	**Scenario B** better cooling in FPV	**Scenario D** same cooling in FPV and LPV

M. Dörenkämper, A. Wahed, A. Kumar, M. de Jong, J. Kroon, and T. Reindl, Sol. Energy **219**, 15 (2021).
T. Kjeldstad, D. Lindholm, E. Marstein, and J. Selj, Sol. Energy **218**, 544 (2021).
H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, Prog. Photovoltaics Res. Appl. **26**, 957 (2018).

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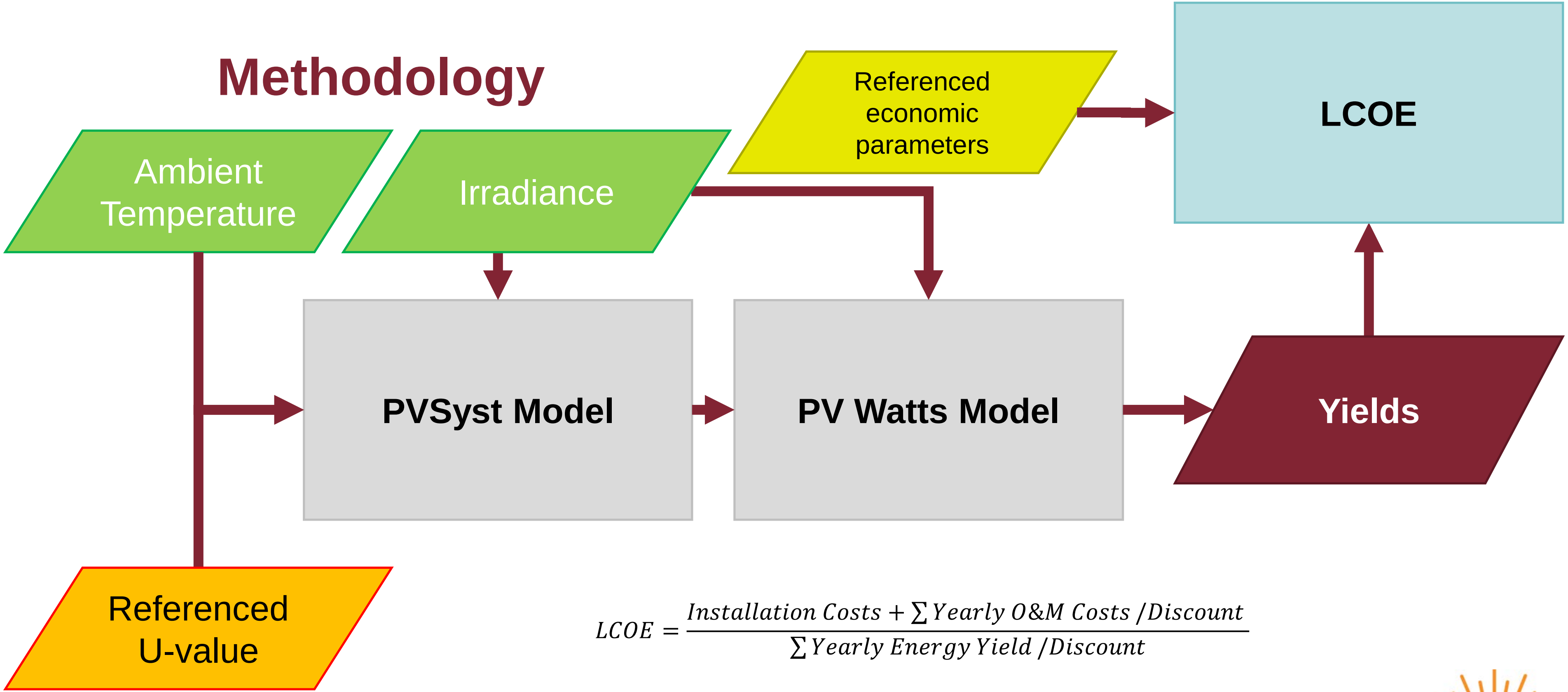
Methodology



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

IRENA, "Renewable Power Generation Costs in 2020," Abu Dhabi, 2021.
Micheli, L. *Sol. Energy* 227, 625–634 (2021)

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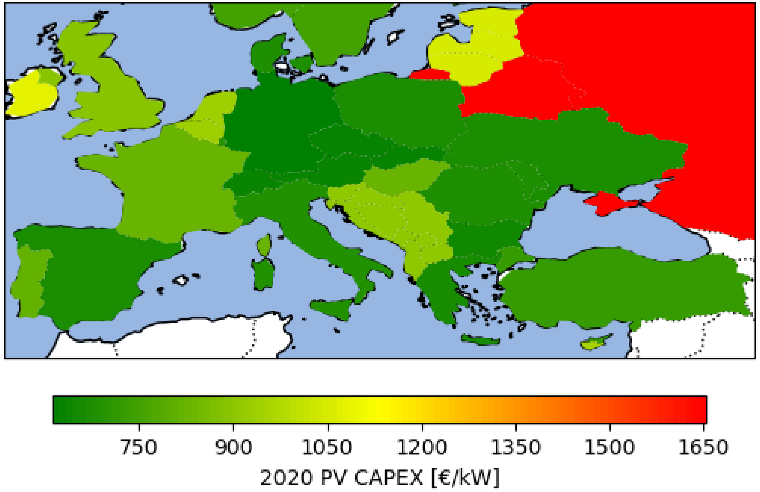
Methodology



Avg. 2020 Capital Expenditure (CAPEX) ~ 800 €/kW.

Min (Germany) ~ 600 €/kW.

Max (Russia) ~ 1650 €/kW.

IRENA, "Renewable Power Generation Costs in 2020," Abu Dhabi, 2021.

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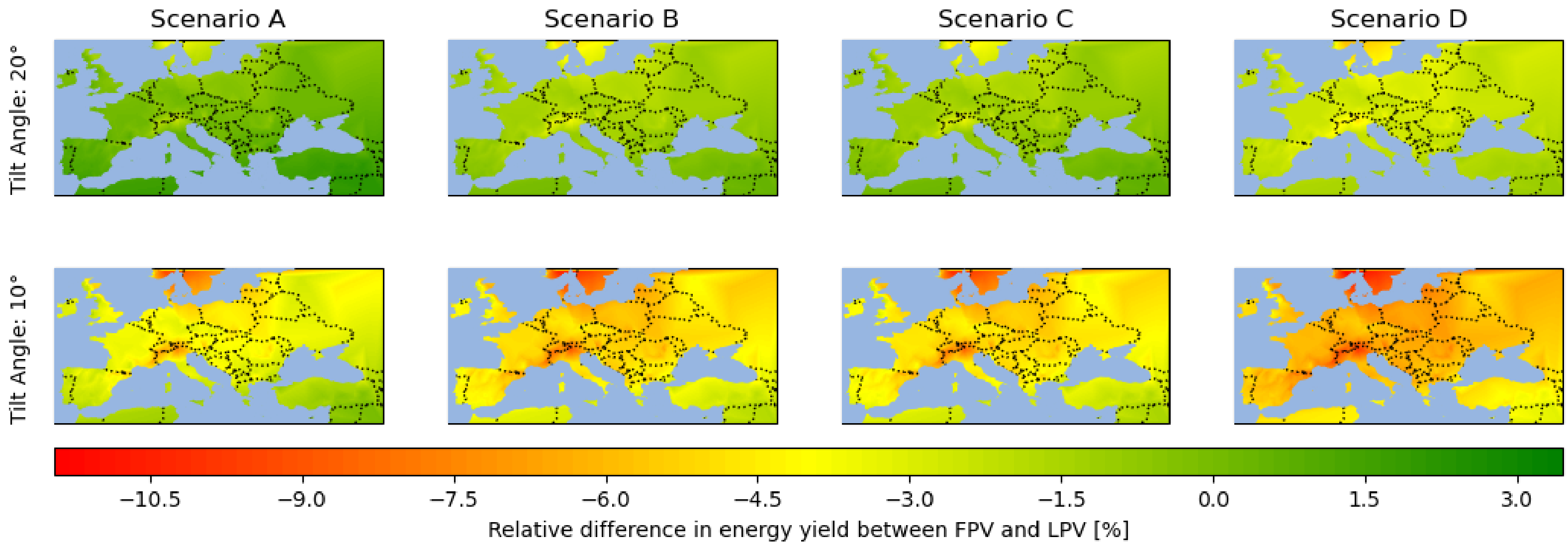
Results: Yield



Better performance in Southern countries because of
(i) **the higher Sun elevations** and
(ii) the **higher temperatures**.

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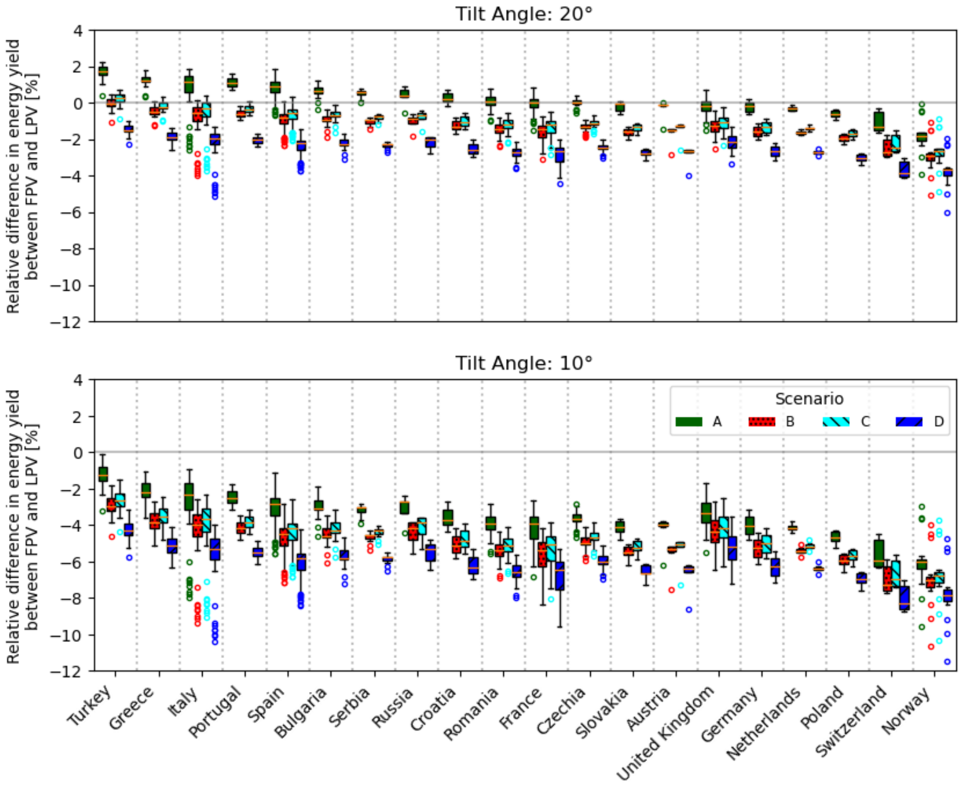
Results: Yield



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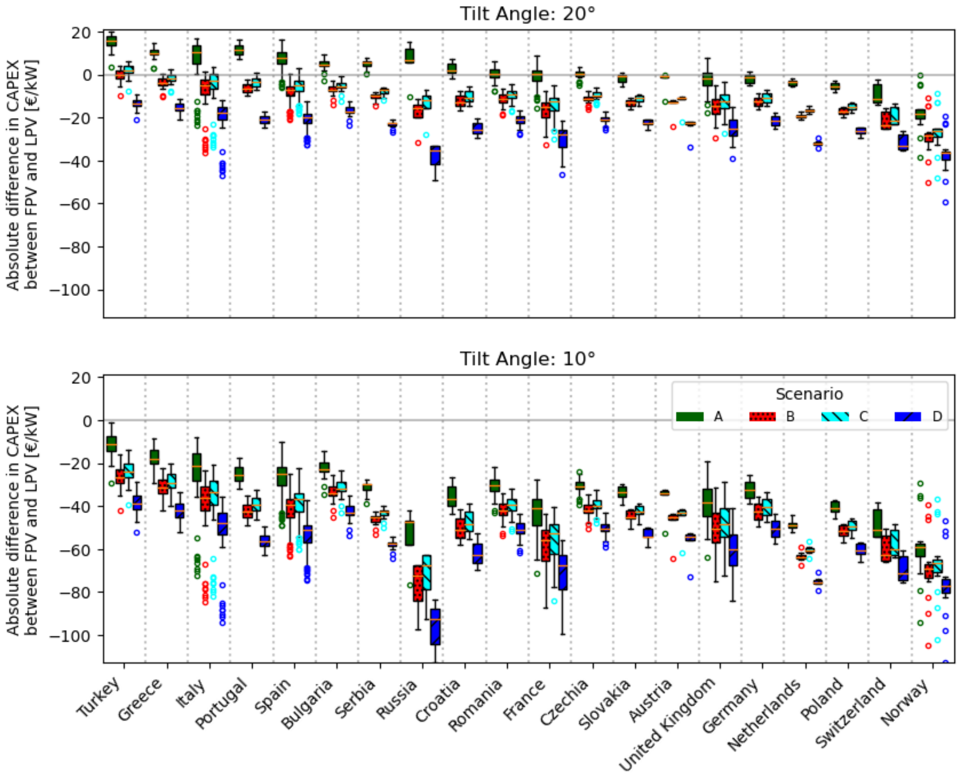
Results: CAPEX



The different yields of FPV and LPV lead to different CAPEX allowances.

Moreover, countries with higher LPV CAPEX penalize systems that have limited yields, allowing even lower CAPEX.

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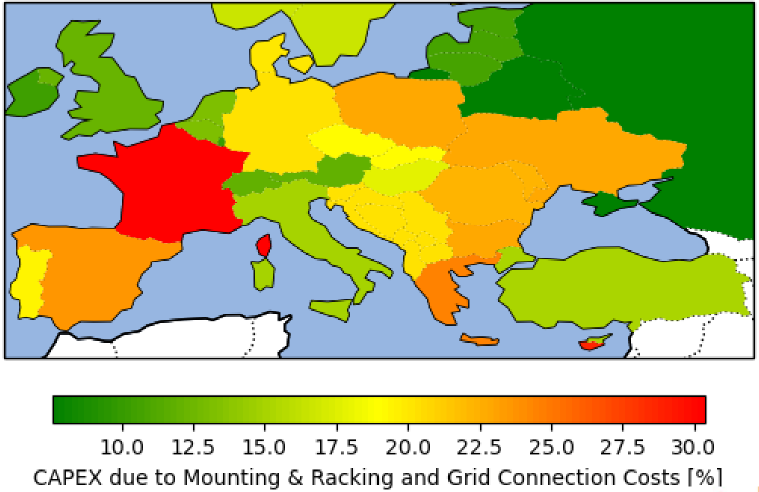
Discussion: CAPEX reduction

No foundation work needed, easy installation: **Reduction in Racking and Mounting costs**.

If existing hydropower plant infrastructures could be used: **Reduction in Grid Connection costs.**



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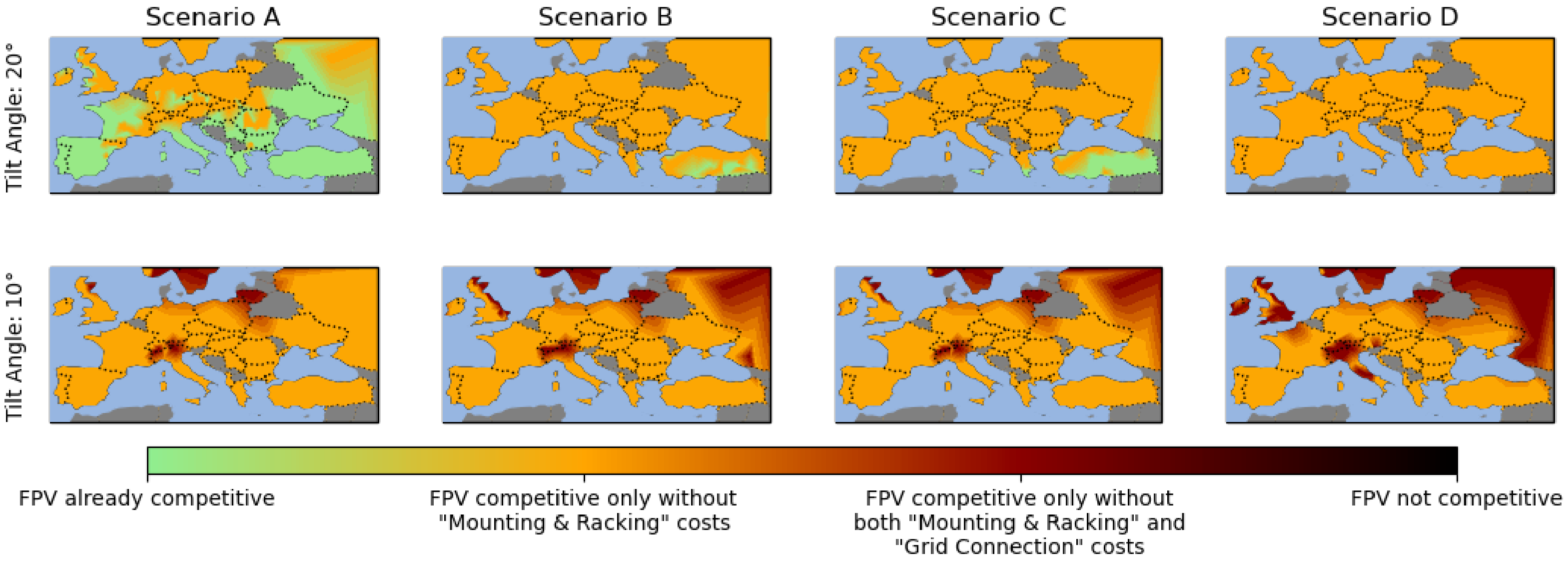
Discussion: CAPEX reduction



Lowering both costs would make FPV cost competitive also in all the investigated countries in all the modelled scenarios.

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Discussion: Assumption and limitations

- This work did not consider potential additional costs that FPV might require, during installation (e.g., for submerged cables) or during operation (e.g., increased O&M costs).
- Cost of renting land was not considered.
- The simulation considered a fixed system degradation rate (1%/year), equal for LPV and FPV.

Discussion: FPV degradation

5.4 | Others

The challenging environment on water can pose unforeseen risks on FPV systems, especially over the long run. Due to the limited period of monitoring, we cannot yet document the issues related to long-term degradation of PV modules and system components. These are some possible risks:

- Potential induced degradation of PV modules.
- Corrosions of combiner boxes, inverters, and metal supporting structures on water.
- Corrosion and biofouling of floating structures, including degradation of floats due to UV exposure.[18]
- Material fatigue of joints between floating structures.
- Sinking floats.
- Solar cables submerging or touching water, leading to electrical hazards and earth leakage.
- Failure of anchoring and mooring.
- Toxic element contamination of water bodies due to material degradation.

nearby rooftop reference system. One rooftop PV string exhibits a performance loss in the range of −0.6 to −0.5%/year, while the other one is at −1.1%/year. In general, the performance stability of the rooftop and FPV installations in the testbed are similar over the first three-year operation. This study presents, for the first time, a systematic and

Degradation analysis and the impacts on feasibility study of floating solar photovoltaic systems

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ABSTRACT

The constant pursuit for emerging renewable power sources has led to the development of floating solar photovoltaics (FSPV). FSPVs operate on water bodies and hence its performance is different from the land-based counterparts. Degradation and aging of PV modules severely affects the reliability and the life of PV power plants. Owners and other beneficiaries are concerned about the actual degradation of PV modules as it affects the financial outcome of the power plant. The performance analysis and the degradation of FSPV power plants over its lifetime is not well reported. This paper presents techno-economic feasibility and reliability study of FSPV power plant for long term power generation. To determine the performance of the FSPV module, an experiment was conducted and data was collected for 17 months. Results showed that the average performance ratio and the degradation rate was 71.58% and 1.18% respectively for the FSPV module and 64.05% and 1.07% respectively for land-based PV system. Feasibility study and performance analysis of a 5 MW FSPV power plant showed that with degradation of 1.18%/year, the power plant will generate 8604.5 MWh of electricity annually. Degradation also effects the financial parameters, the levelized cost of electricity (LCOE) is calculated as 0.041 $/kWh which is 2.5% higher than the LCOE calculated with standard degradation. The FSPV plant will also save 105000 kL of water per year by reducing evaporation and the total lifetime CO_2 savings will be 183,493.24 tones.

H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, Prog. Photovoltaics Res. Appl. **26**, 957 (2018).
Luo, W. *et al. Sol. Energy* 219, 58–64 (2021)
Goswami, A. *et al. Sustain. Energy, Grids Networks* 26, 100425 (2021)

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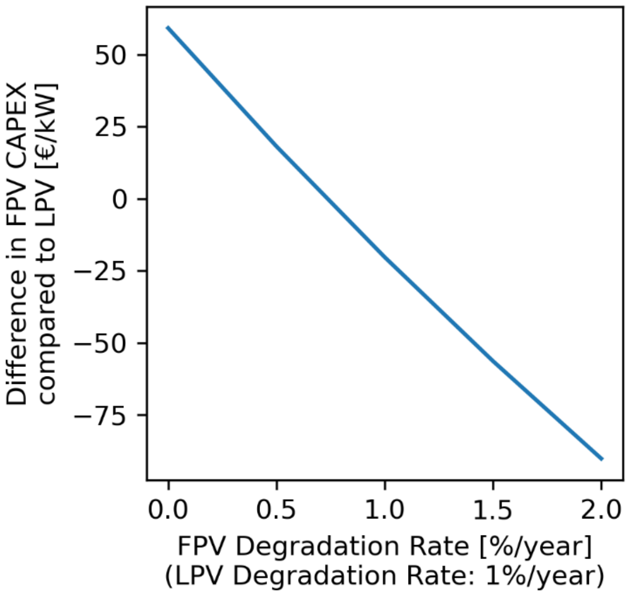
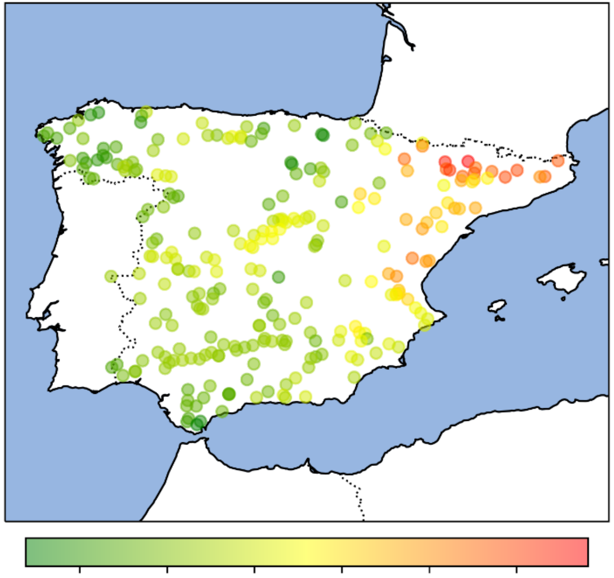
Discussion: the role of degradation



In Spain, each additional 0.1%/year in degradation costs **7.5 €/kW** of CAPEX

Micheli, L. *Sol. Energy* 227, 625–634 (2021)

Discussion: CAPEX allowance to tackle degradation



The funds available are not the same in all locations.

More allowances in:

- **South**: highest temperatures and energy yields
- **Northwest**: low irradiance, minimal difference between the most and the less performing PV installations.

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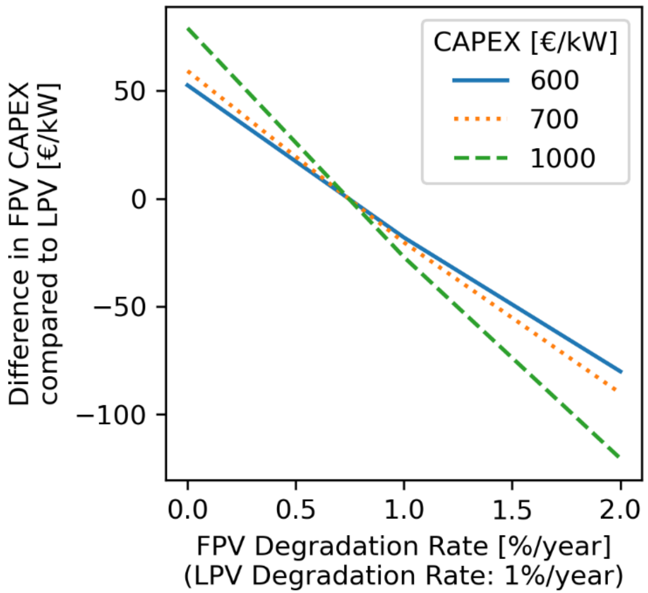
Discussion: CAPEX allowance to tackle degradation



The allowance will change also depending on the CAPEX value.

Conclusions

- FPV could contribute to the achievement of the 2030 EU targets.

- FPV could over-perform LPV in the southernmost countries.

- Potential CAPEX reductions can favour FPV deployment even in conditions of lower yields.

- Operating temperature is key in FPV performance and economics.

Future works

- Model more configurations: e.g.,
  - water-cooled modules,
  - semi-submerged modules.

- Include new field data, as they become available.

- Consider additional economic metrics, such as Net Present Value, and additional factors:
  - electricity price
  - evaporation savings

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Grazie mille!

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Giuseppe Marco Tina (University of Catania, Italy)

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