The economic feasibility of floating photovoltaic power plants across Europe

Leonardo Micheli

“Rita Levi Montalcini” Assistant Professor (RTDB)

leonardo.micheli@uniroma1.it

Dept. of Astronautical, Electrical and Energy Engineering (DIAEE)

Sapienza University of Rome, Italy

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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

Sole4PV
SOiling Live Estimation for PhotoVoltaics

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).

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!**

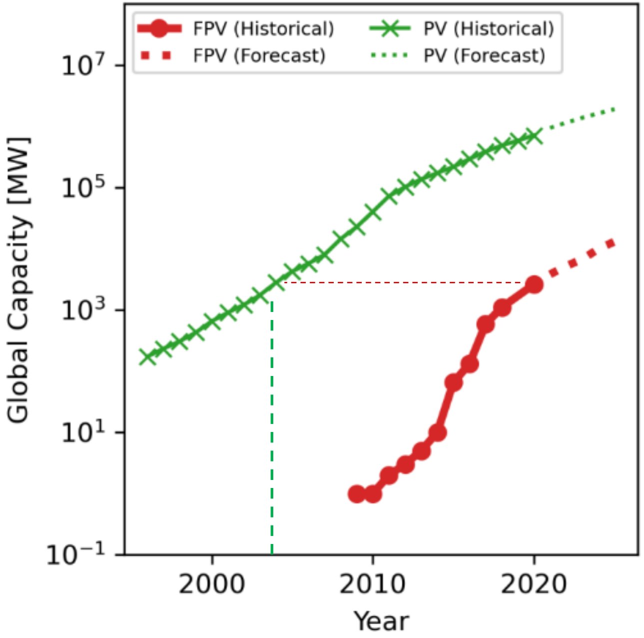
World Bank Group, ESMAP, and SERIS, “Where Sun Meets Water: Floating Solar Market Report—Executive Summary,” Washington, DC, 2018.

FPV Capacity: Status

By August 2020, FPV had reached a global **2.6 GW capacity**.

This is **twice the capacity** reported at the end of 2018.

The first system was installed in Japan in 2007.



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.

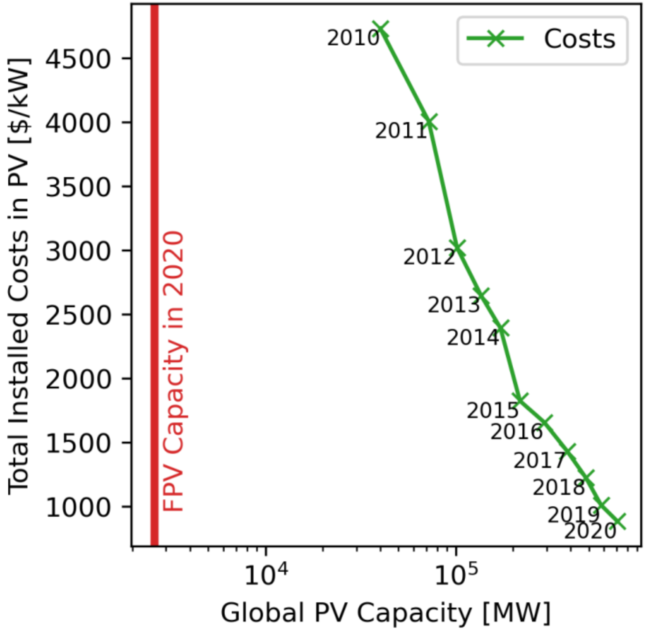
Floating PV: Capacity

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

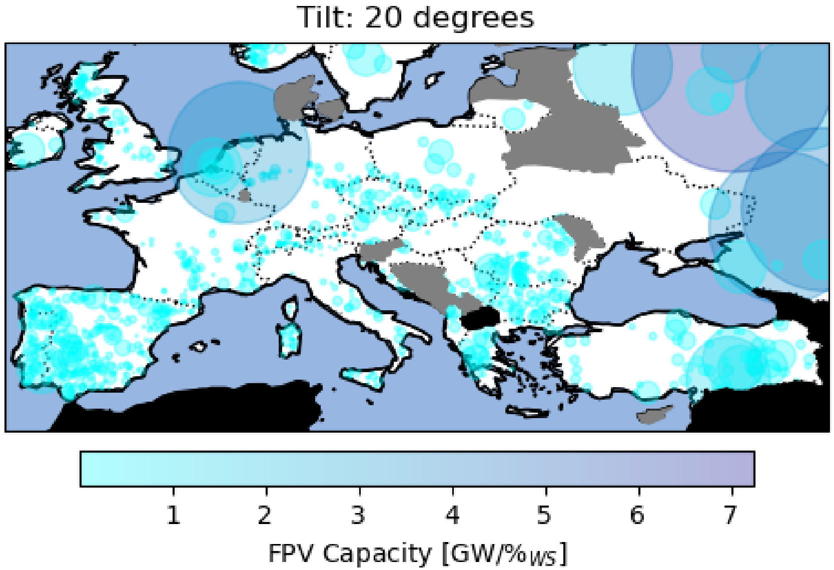


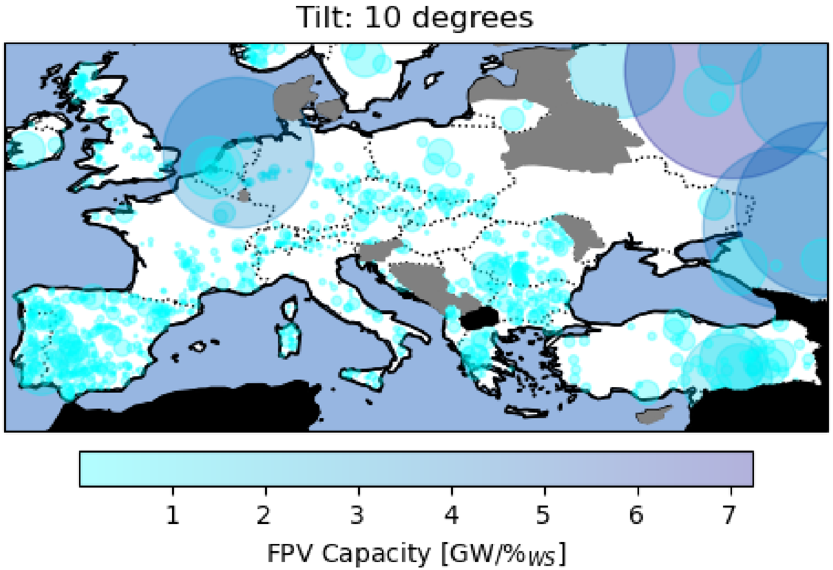
World Bank Group, ESMAP, and SERIS, “Where Sun Meets Water: Floating Solar Market Report—Executive Summary,” Washington, DC, 2018.
IRENA, “Renewable Power Generation Costs in 2020,” Abu Dhabi, 2021.

FPV Capacity: Potential in Europe

List of reservoirs downloaded from **Global Reservoir and Dam Database** (GRanD).

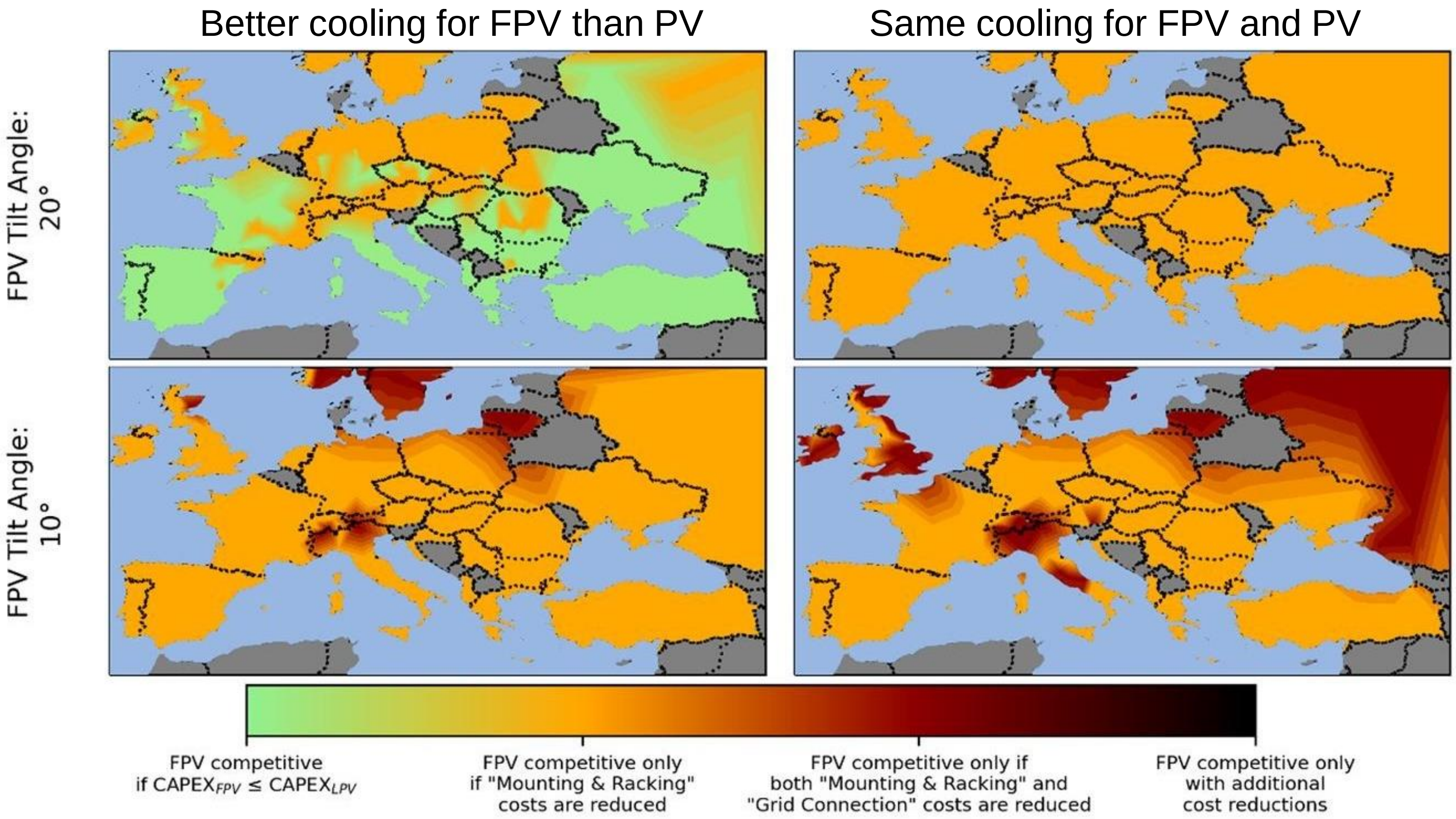
Suitable reservoirs identifying by applying Spencer's filters
(excluding reservoirs with surface < 1ha, depth < 2m, or used for recreation, navigation, and fishing)





EU member states could host, on 1% of their water reservoir surface:
13-12 GW/%$_{WS}$ of FPV mounted at 10-20 degrees.

Previous Work: FPV vs. PV yield



L. Micheli, D.L. Talavera, G. Marco Tina, F. Almonacid, and E.F. Fernández, Sol. Energy 243, 203 (2022)

Motivation

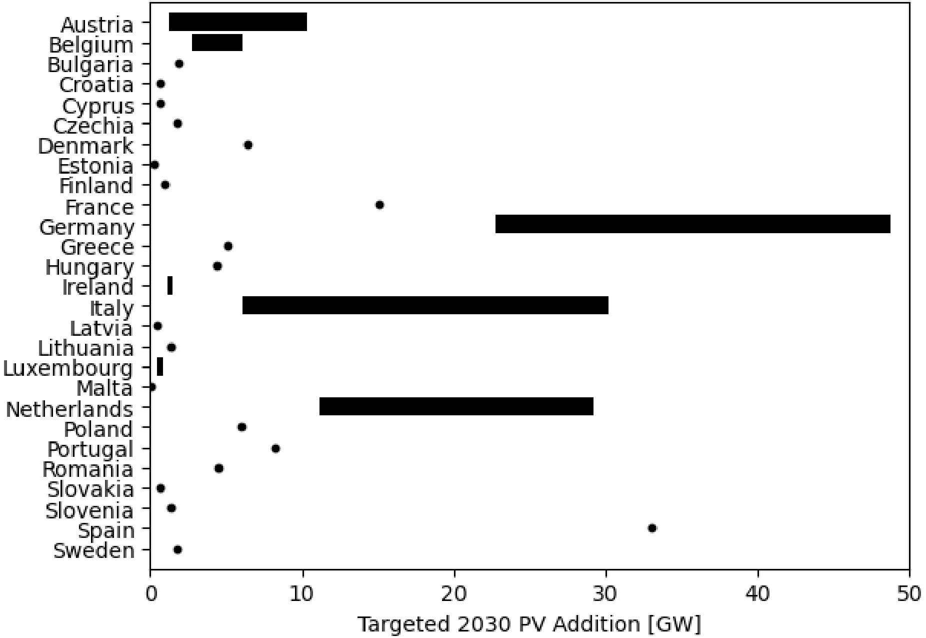
In reality, investments in FPV will occur if they are **profitable**, independently of the cost-competitivity with LPV. In addition, factors such as the **need for water preservation** or the **scarcity of land** might favor the installation of FPV over LPV.

L. Micheli, D.L. Talavera, G. Marco Tina, F. Almonacid, and E.F. Fernández, Sol. Energy 243, 203 (2022)

FPV: Motivation

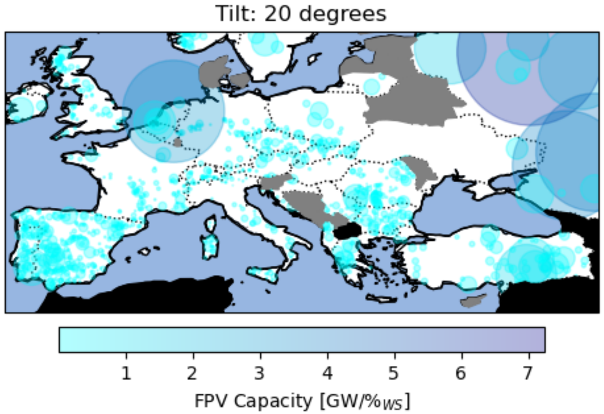
EU plans deploying between **140 and 222 GW** of new PV power plants by 2030.

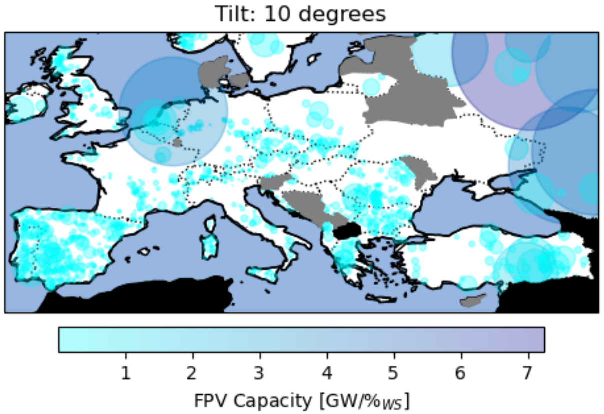
➔ 2555 to 4050 km^2 of new PV plants



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

FPV Capacity: Potential in Europe





EU member states could host, on 1% of their water reservoir surface:
13-12 GW/%$_{WS}$ of FPV mounted at 10-20 degrees.

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

L. Micheli, D.L. Talavera, G. Marco Tina, F. Almonacid, and E.F. Fernández, Sol. Energy 243, 203 (2022)

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Research Questions

Which is the bankability of FPV?

➔ Analysis of **Levelized Cost of Electricity** (LCOE), **Net Present Value** (NPV) and the **Internal Rate of Return** (IRR) over various European countries.

L. Micheli, D.L. Talavera, Under Review

Methodology: Economics

The Levelized Cost of Electricity (**LCOE**) quantifies the cost of producing a kWh of electricity over the PV system lifetime.

The lower, the better.

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

Discount: opportunity cost of capital
(inflation, risk free rate of return, equity risk premium)

Methodology: NPV and IRR

The Net Present Value (**NPV**): difference between the present values of the cash flows (in and out) throughout the PV lifetime.

NPV>0 ➔ Profitable investment. The larger, the better.

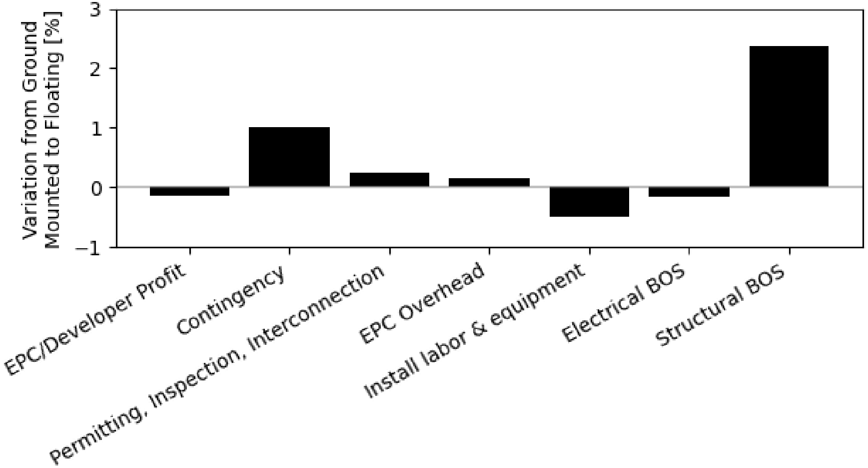
$$NPV = -Installation\ Costs + \sum \frac{Yearly\ Revenues - Yearly\ O\&M\ Costs}{Discount}$$

The Internal Rate of Return (**IRR**) expresses the profitability expected from the system or investment. It represents the discount rate (d) that will make NPV=0.

Methodology: NPV and IRR

When moving from land to water, some Capital Expenditure (CAPEX) categories change, others are invariant.

E.g., balance-of-system and contingency costs for FPV are expected to raise by **50 to 100%**.



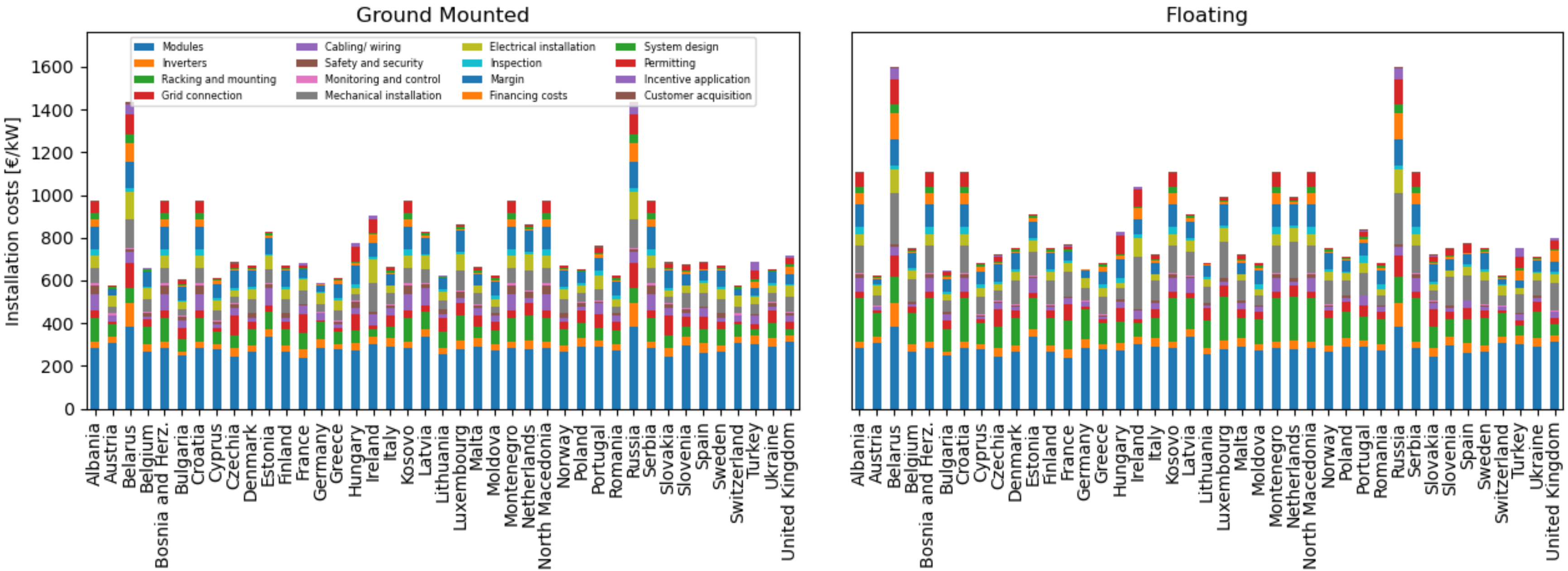
CAPEX category-specific “conversion factors” were calculated

➔ LPV cost breakdown is converted into a FPV cost breakdown for each country.

V. Ramasamy and R. Margolis, Floating Photovoltaic System Cost Benchmark : Q1 2021 Installations on Artificial Water Bodies (Golden, CO, 2021).

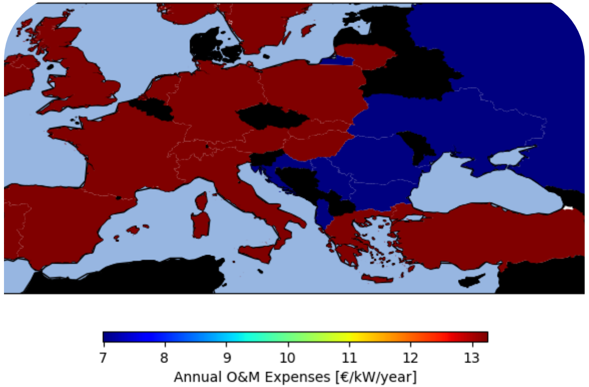
Methodology: CAPEX

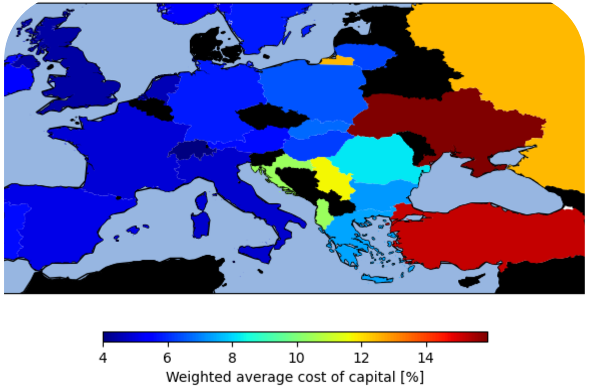
This way, the country-specific installation costs can be estimated.

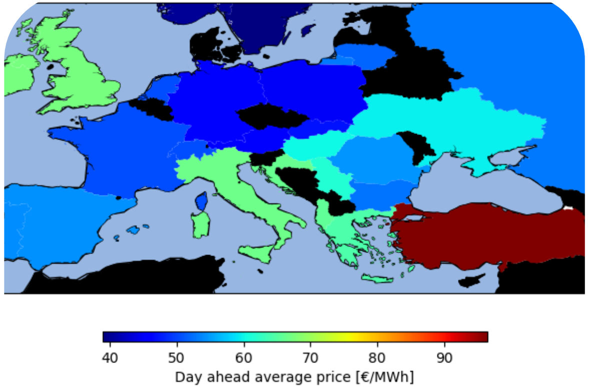


IRENA, Renewable Power Generation Costs in 2021 (2022).

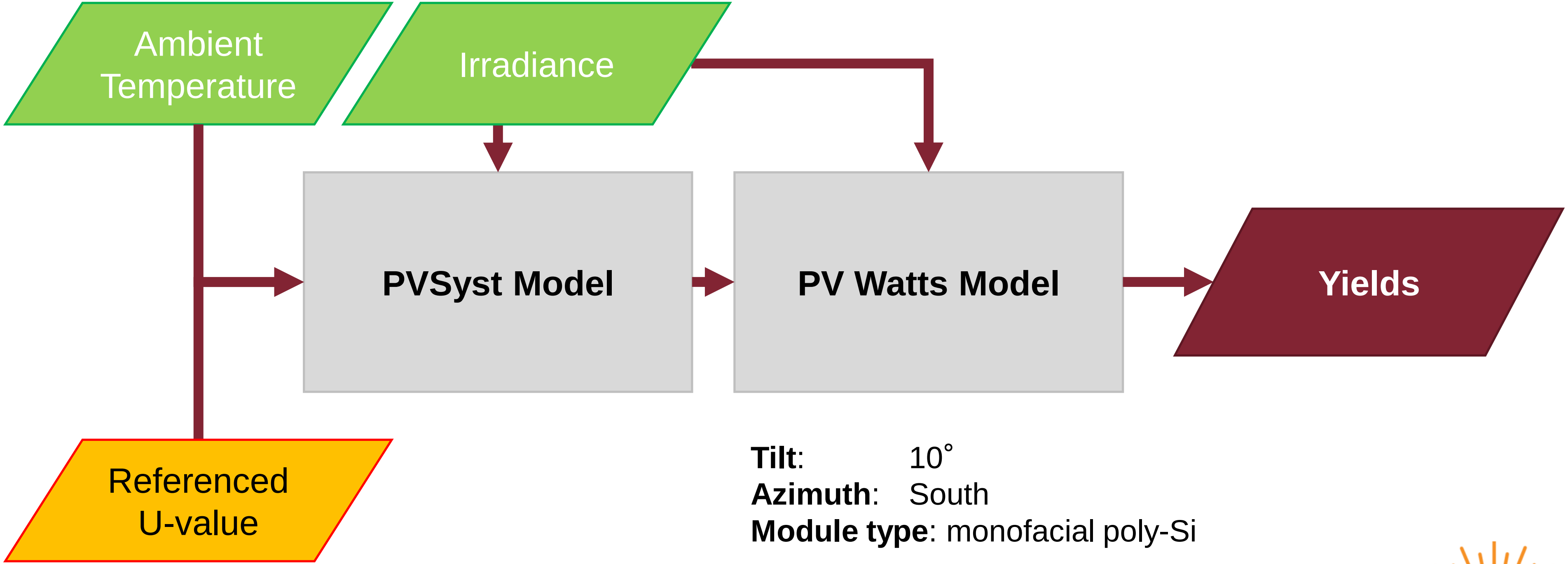
Methodology: Additional parameters







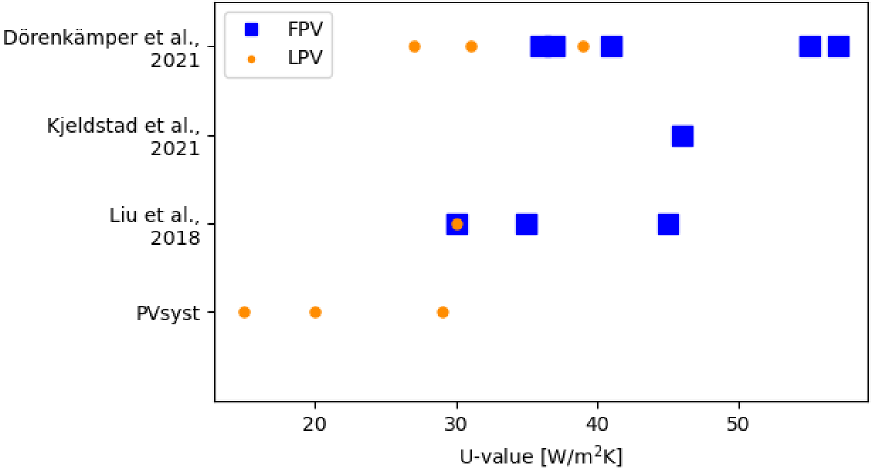
Methodology: Energy Yield



Tilt: 10˚
Azimuth: South
Module type: monofacial poly-Si

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

Methodology & Literature Review



The cell temperature (Tc) can be calculated using PVSyst model:

$$T_C = T_a + \frac{\alpha E(1 - \eta_m)}{U}$$

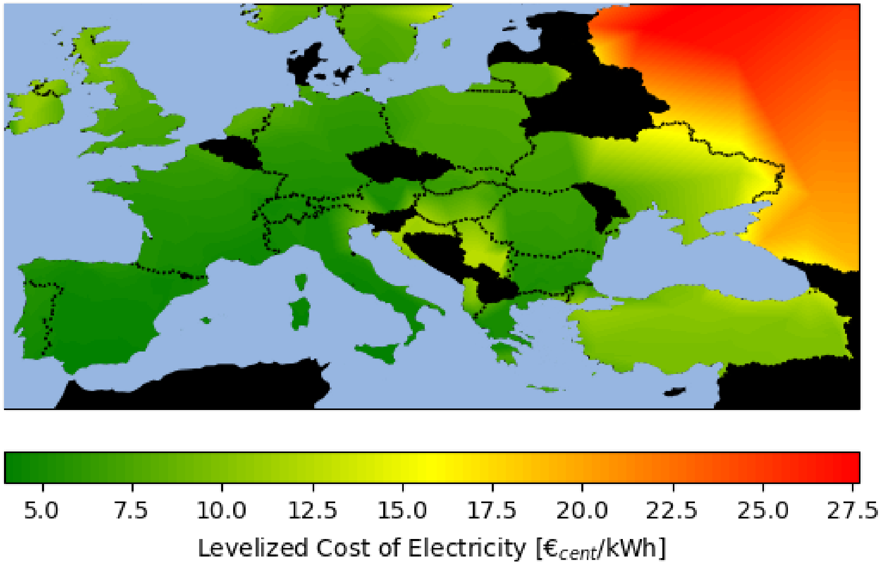
In baseline scenario:

56 W/m^{2}K

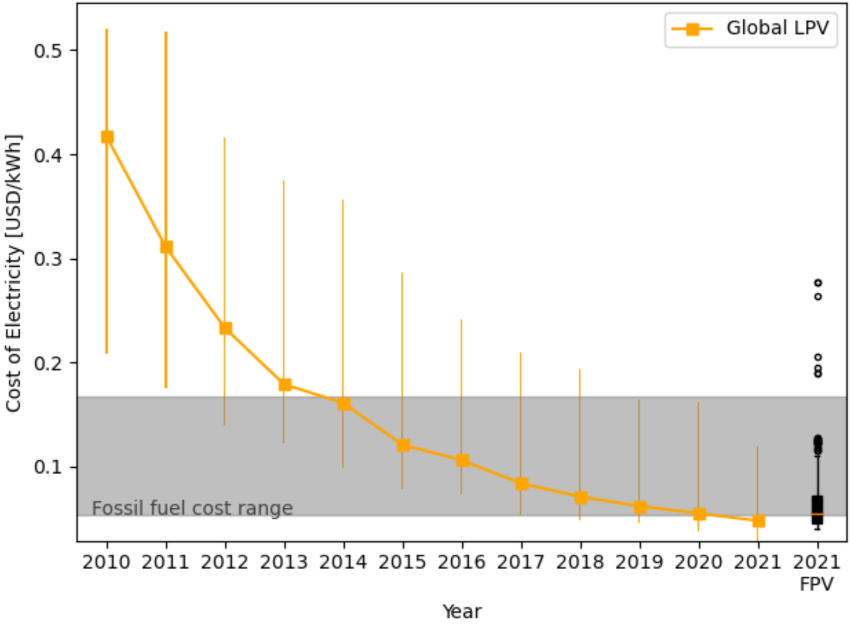
M. Dörenkämper, A. Wahed, A. Kumar, M. de Jong, J. Kroon, and T. Reindl, Sol. Energy **219**, 15 (2021).
T. Kjeldstad, D. Lindholm, E. Marstein, and J. Selj, Sol. Energy **218**, 544 (2021).
H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, Prog. Photovoltaics Res. Appl. **26**, 957 (2018).

Results: LCOE

The LCOE of FPV varies from 4.0 to 27.7 €$_{\text{cents}}$/kWh.



Own elaboration from IRENA data



IRENA, Renewable Power Generation Costs in 2021 (2022).

Results: LCOE

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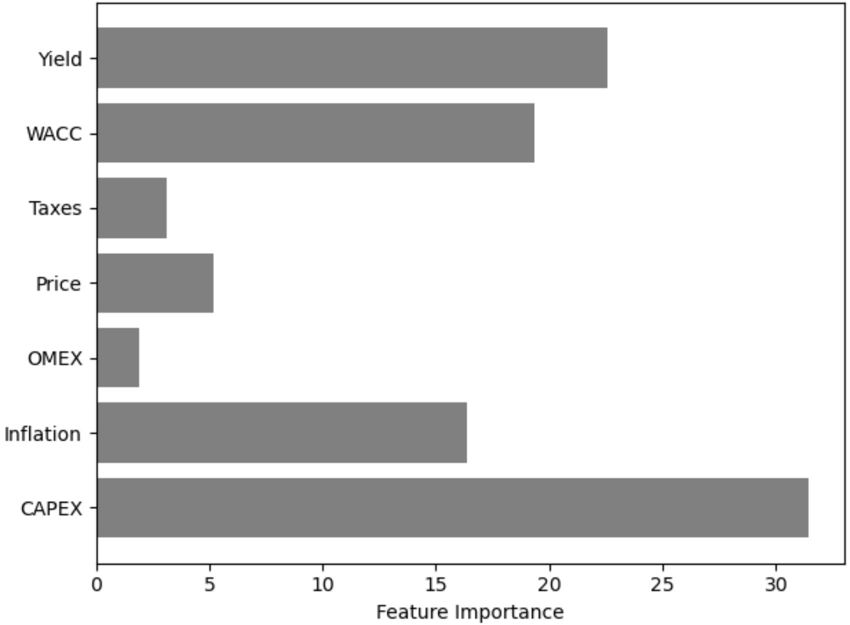
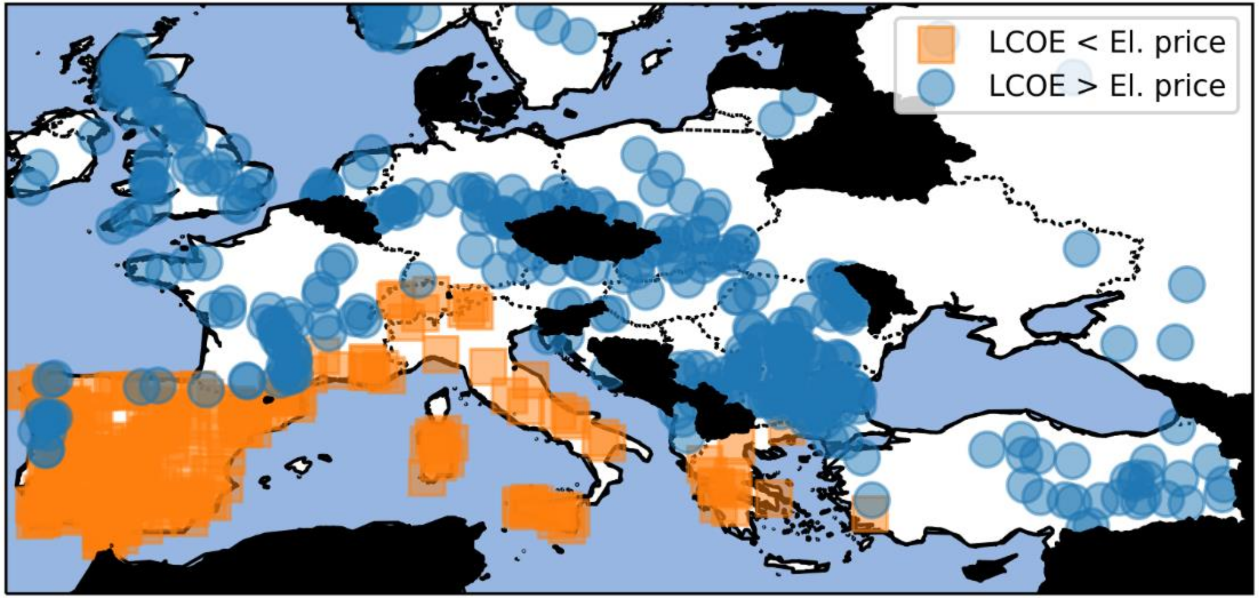


CAPEX, **yield** and **WACC** are the most impactful parameters for the LCOE.

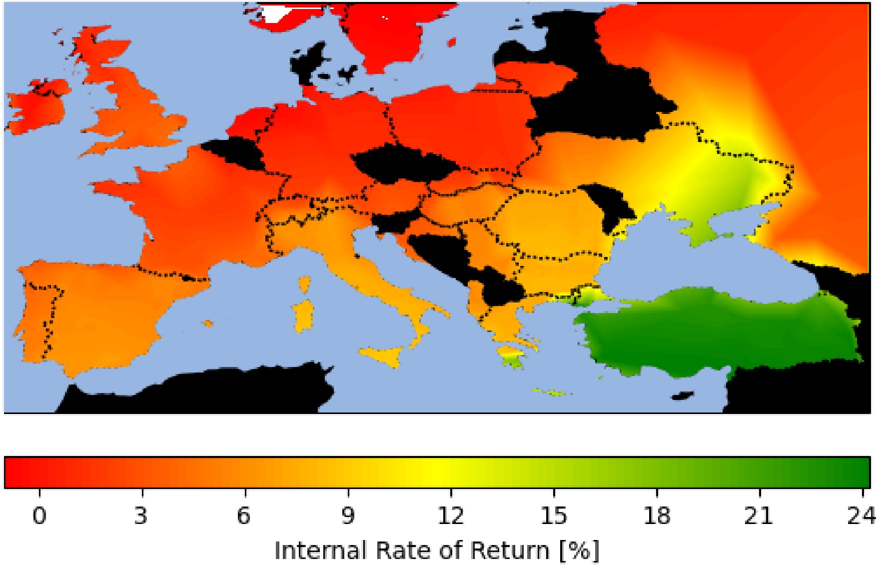
Results: LCOE vs Electricity Price

In Italy, Greece, and most of Spain: **LCOE < electricity price**.

➔ Likely included in the energy mix!



Results: IRR

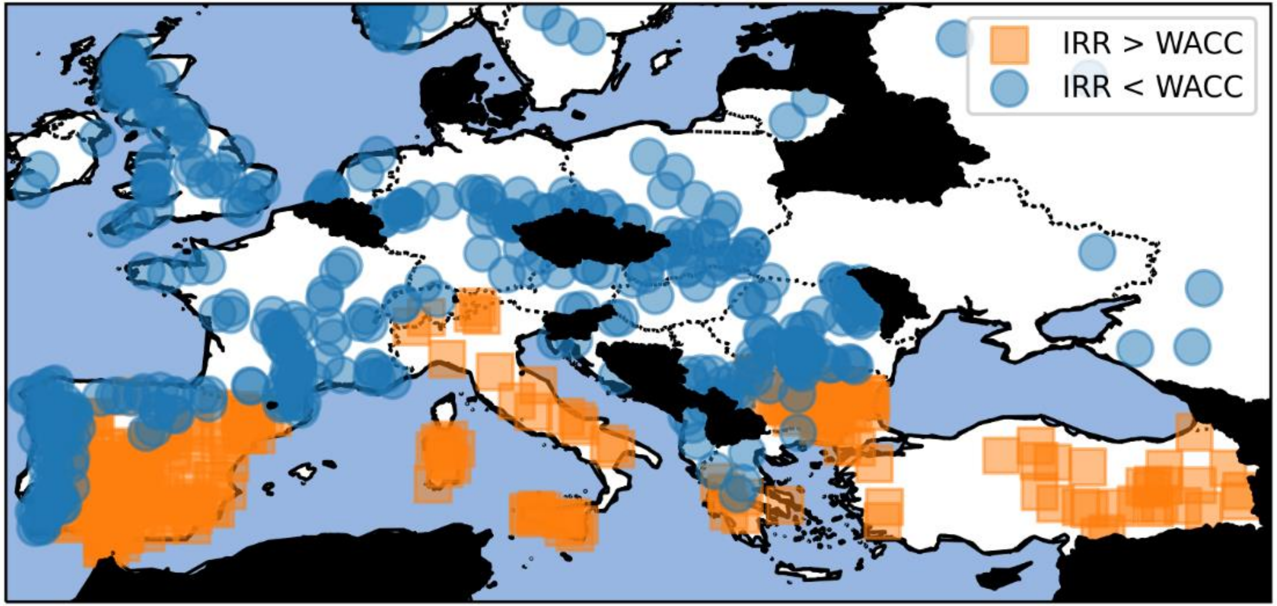


The IRR can be as high 24 % (Turkey): high electricity price and yields.

Most impactful parameters for the IRR are **energy yield**, **CAPEX**, and **electricity price**, followed by inflation, OMEX, and tax rate.

Results: IRR vs. WACC

Typically, capital funds are acquired through loans. The costs is defined as WACC.
IRR > WACC ➔ return on investment > loan interests.



Sensitivity Analysis: Effect of temperature and tilt angle

Additional scenarios have been modelled

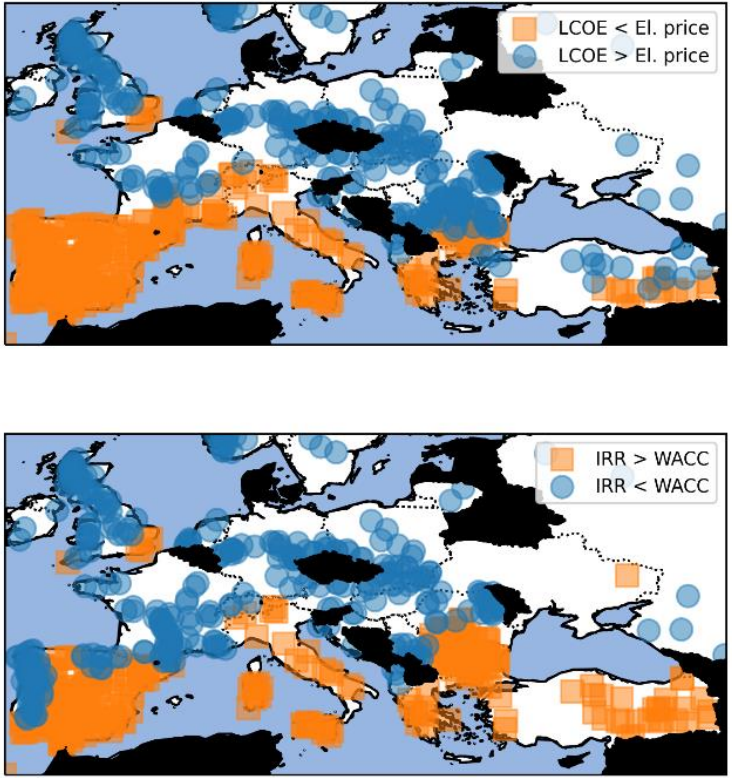
Scenario	Tilt Angle [°]	U-values [W/m²K]
Baseline	10	56
Best	20	56
Worst	10	39

The **energy yield** increases:

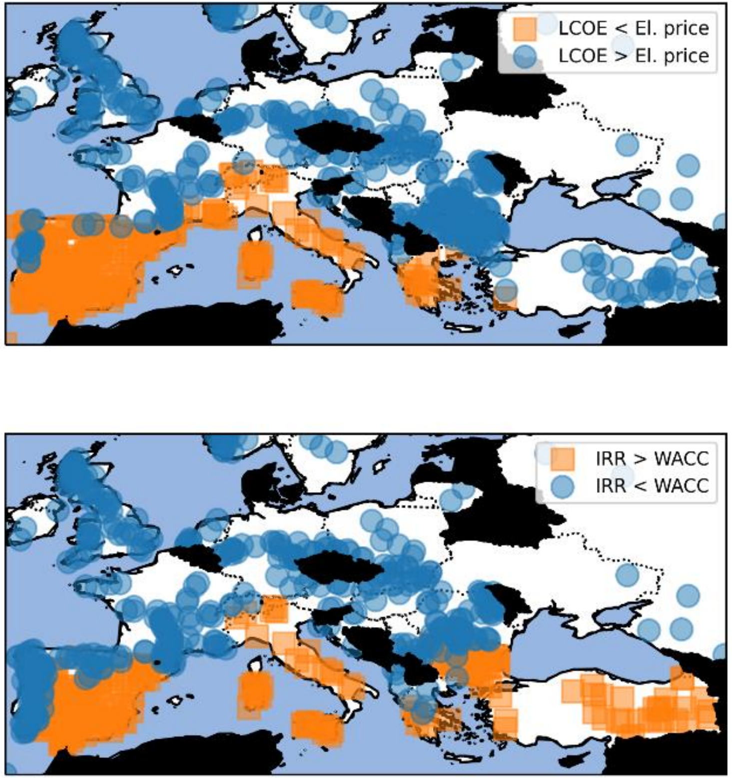
- With the **tilt angle**
- With the **U-value**

Sensitivity Analysis: Effect of temperature and tilt angle

Best scenario

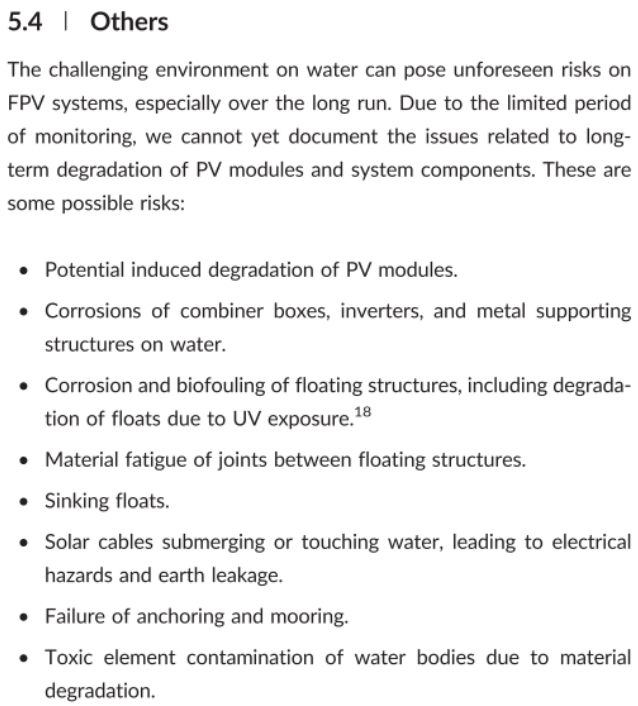


Worst scenario



Sensitivity Analysis: Effect of degradation

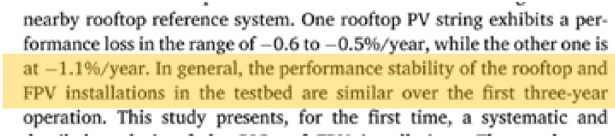
Due to limited data, long-term performance and loss information are lacking.



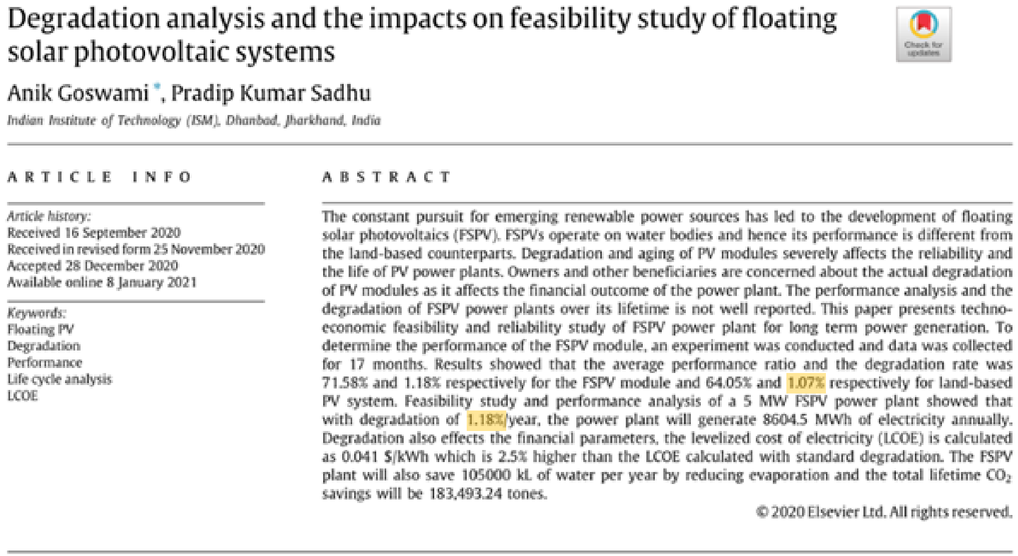
5.4 | Others

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

Anik Goswami *, Pradip Kumar Sadhu
Indian Institute of Technology (ISM), Dhanbad, Jharkhand, India

A R T I C L E I N F O

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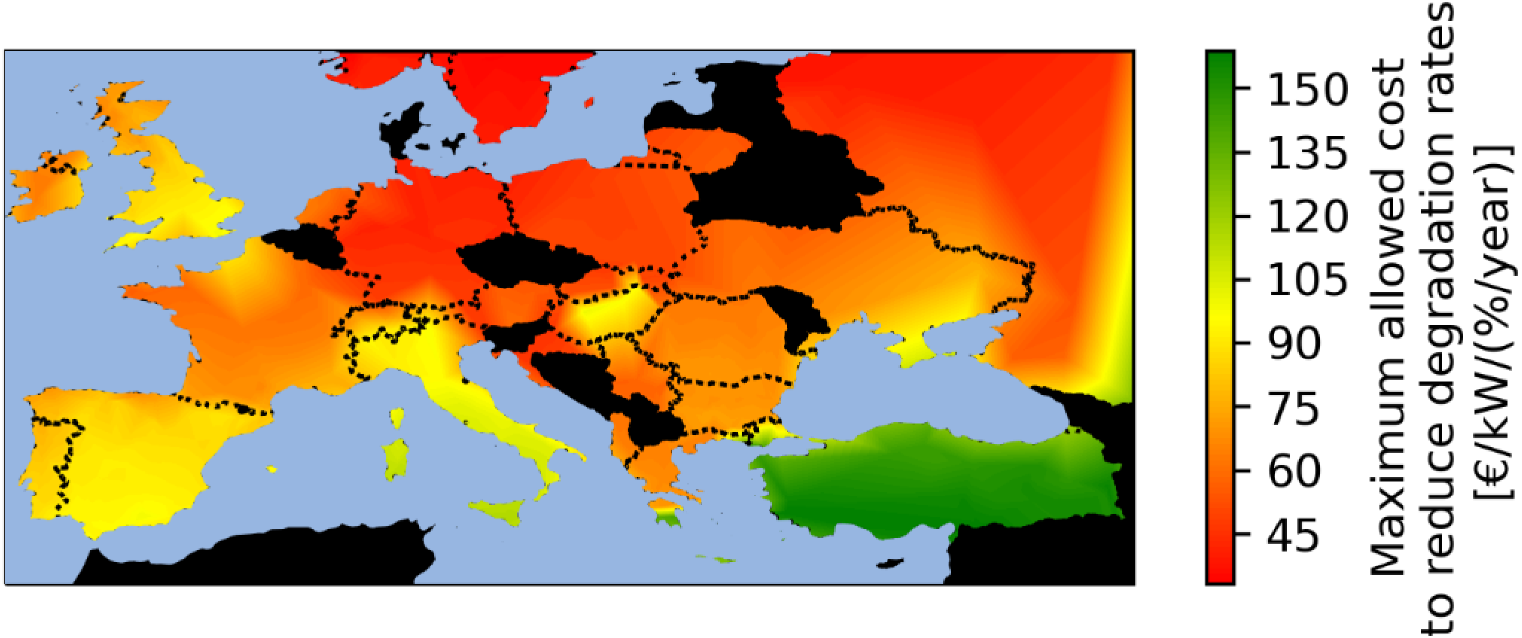
A B S T R A C T

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.

Goswami and P.K. Sadhu, Sustain. Energy, Grids Networks 26, 100425 (2021).IRENA, “Renewable Power Generation Costs in 2020,” Abu Dhabi, 2021.
H. Liu, V. Krishna, J. Lun Leung, T. Reindl, and L. Zhao, Prog. Photovoltaics Res. Appl. 26, 957 (2018).

Sensitivity Analysis: Effect of degradation

Which is the maximum additional investments, in €/kW, that can be made to return a profit through a reduction in degradation rates?



Conclusions

- This study analyses the cost competitiveness and profitability of FPV in Europe.
- FPV is favoured in countries with lower CAPEX, higher yields, and/or lower WACC, and can compete with the cost of traditional LPV.
- Maximum IRR where electricity prices are high (e.g. Turkey).
- The highest allowances for improving system performance are available in those countries where the potential is higher, such as Turkey, Italy, and Spain.

Grazie mille!

Leonardo Micheli, leonardo.micheli@uniroma1.it

Dept. of Astronautical, Electrical and Energy Engineering (DIAEE)
Sapienza University of Rome, Rome, Italy

Thanks to co-author:
Diego L. Talavera, dlopez@ujaen.es

IDEA Research Group, University of Jaén, Jaén, Spain

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