Progress in Solar Energy to Address the Energy Crisis

International Conference and Exhibition on Renewables, "Technologies and Options for Securing Energy & Food Flows in View of the Ukrainian Crisis"

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Istanbul, Turkey, 20 - 23 September 2022

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Agenda

- Context (Less Developed Countries)
- Africa (Solar resource)
- PVGIS
- PV Diversity
  - ✓ AgriPV
- CSP Fuels
- Solar Disinfection
- Novel Solar Steam
- Solar Thermal
- Soiling of Solar
- Conclusions

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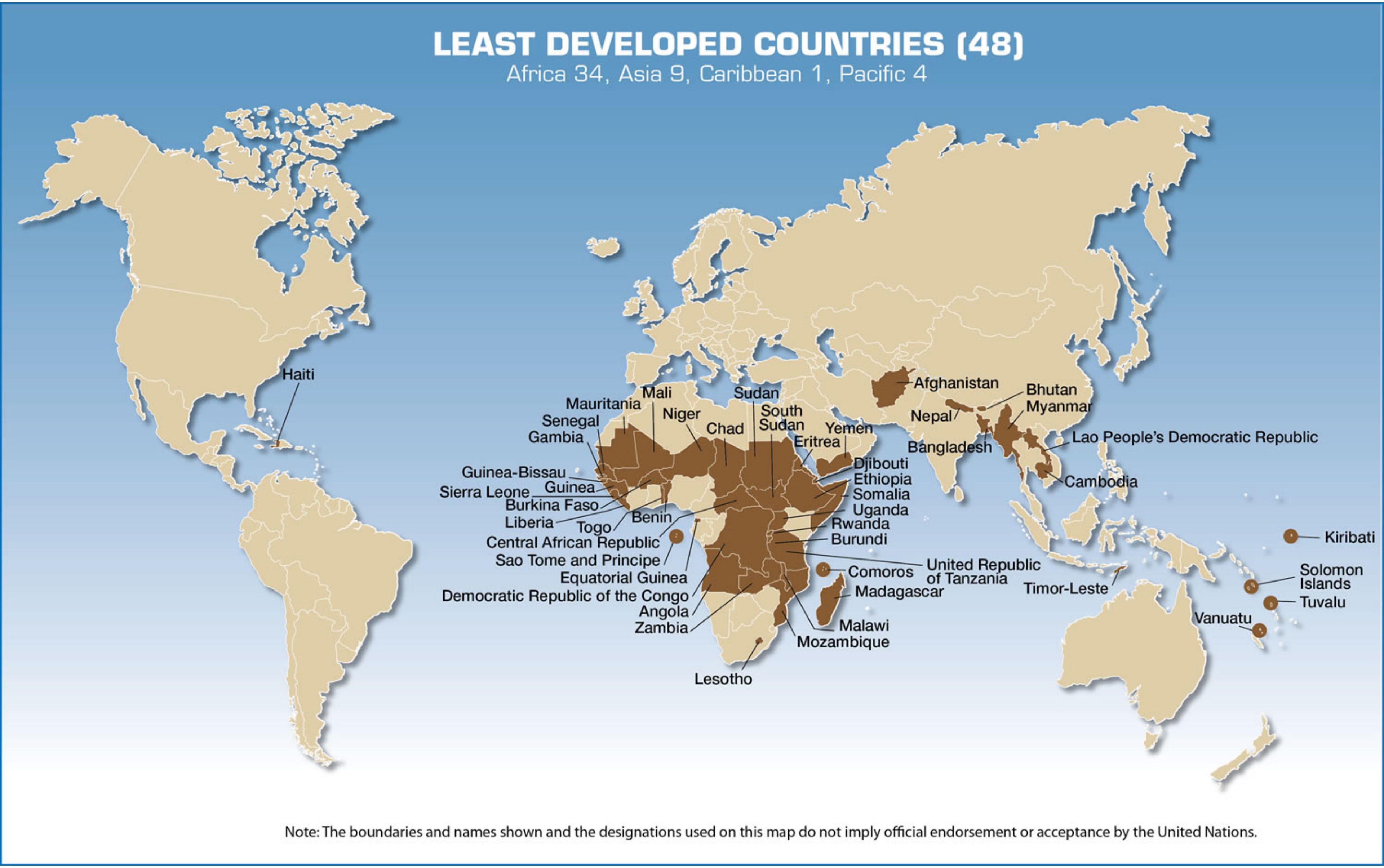
"Technologies and Options for Securing Energy & Food Flows in View of the Ukrainian Crisis", Istanbul, Turkey, 20 - 23 September 2022

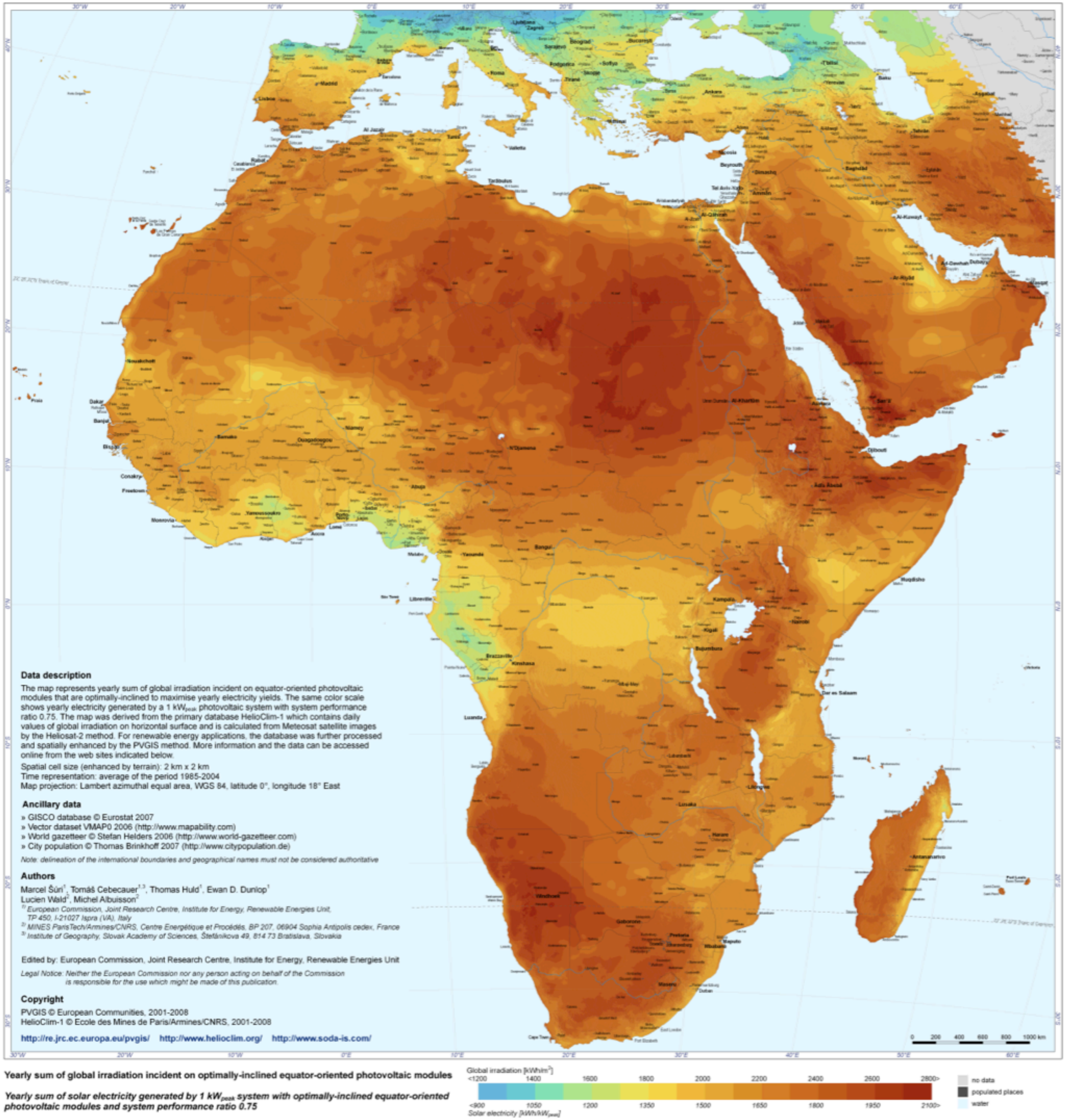


http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf

	Country	Date of inclusion on the list		Country	Date of inclusion on the list
1	Afghanistan	1971	25	Madagascar	1991
2	Angola	1994	26	Malawi	1971
3	Bangladesh	1975	27	Mali	1971
4	Benin	1971	28	Mauritania	1986
5	Bhutan	1971	29	Mozambique	1988
6	Burkina Faso	1971	30	Myanmar	1987
7	Burundi	1971	31	Nepal	1971
8	Cambodia	1991	32	Niger	1971
9	Central African Republic	1975	33	Rwanda	1971
10	Chad	1971	34	Sao Tome and Principe	1982
11	Comoros	1977	35	Senegal	2000
12	Dem. Rep of the Congo	1991	36	Sierra Leone	1982
13	Djibouti	1982	37	Solomon Islands	1991
14	Equatorial Guinea[1]	1982	38	Somalia	1971
15	Eritrea	1994	39	South Sudan	2012
16	Ethiopia	1971	40	Sudan	1971
17	Gambia	1975	41	Timor-Leste	2003
18	Guinea	1971	42	Togo	1982
19	Guinea-Bissau	1981	43	Tuvalu	1986
20	Haiti	1971	44	Uganda	1971
21	Kiribati	1986	45	United Rep. of Tanzania	1971
22	Lao People's Dem. Republic	1971	46	Vanuatu[1]	1985
23	Lesotho	1971	47	Yemen	1971
24	Liberia	1990	48	Zambia	1991

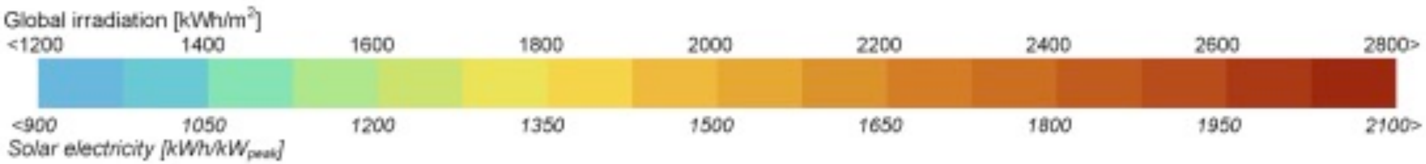
http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf

Photovoltaic Solar Electricity Potential in the Mediterranean Basin, Africa, and Southwest Asia



A useful scale

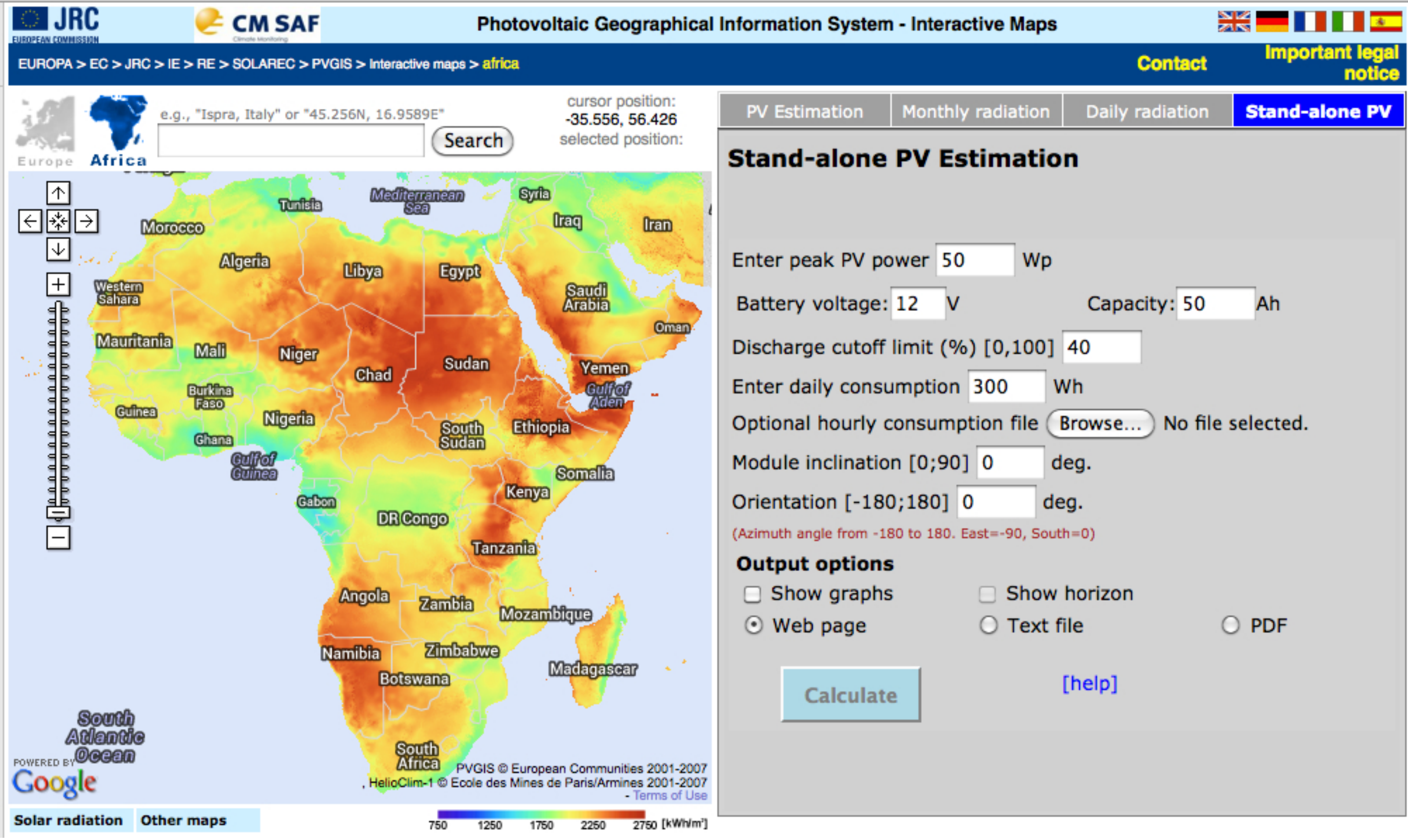
Yearly sum of global solar irradiation incident on optimally-inclined equator-oriented photovoltaic modules Units: kWh/m^2/year



Yearly sum of solar electricity generated by 1 kWp system with optimally-inclined equator-oriented photovoltaic modules and system performance ratio = 0.75. Units: kWh/kWp

Source: Huld T., Šúri M., Dunlop E., Albuisson M, Wald L (2005). Integration of HelioClim-1 database into PVGIS to estimate solar electricity potential in Africa. Proceedings from 20th European Photovoltaic Solar Energy Conference and Exhibition, 6-10 June 2005, Barcelona, Spain, http://re.jrc.ec.europa.eu/pvgis/

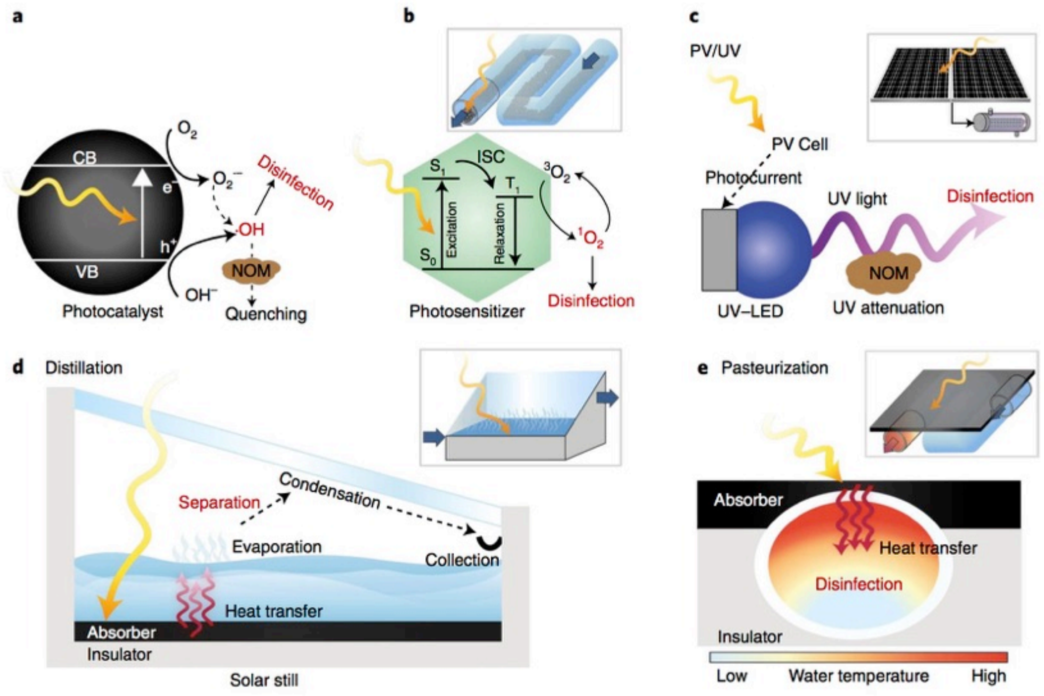
File:PVGIS Africa Solar Potential
https://commons.wikimedia.org/wiki/File:PVGIS_Africa_SolarPotential_img_v2.png



https://re.jrc.ec.europa.eu/pvg_tools/en/
and
https://joint-research-centre.ec.europa.eu/pvgis-photovoltaic-geographical-information-system_en

Just type in the coordinates of your site and choose "daily radiation" from the tabs.

Solar disinfection for drinking water treatment



Semiconductor photocatalysis to produce hydroxyl radical, dye photosensitization to produce singlet oxygen, UV irradiation using LED powered by a photovoltaic panel, distillation using a solar still, and solar pasteurization.

Jeon, I., Ryberg, E.C., Alvarez, P.J.J. et al. Technology assessment of solar disinfection for drinking water treatment. Nature Sustainability (2022). DOI:10.1038/s41893-022-00915-7, https://www.nature.com/articles/s41893-022-00915-7

Solar steam generation by heat localization

NATURE COMMUNICATIONS | DOI: 10.1038/ncomms5449

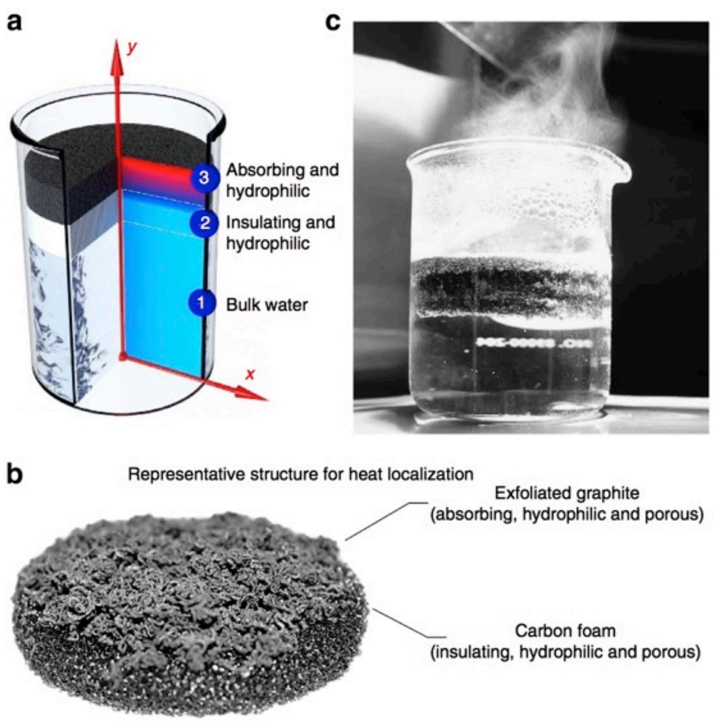


Figure 1 | Double-layer structure. (**a**) A representative structure for localization of heat; the cross section of structure and temperature

- Bulk liquid at *low* temperature
- Low optical concentration
- Solar thermal efficiency up to 85% at only 10 kW/m^2
- 64% at 1000 W/m^2 (one sun)
- Graphite-based:
- Light absorbing, hydrophilic, porous on
- thermally insulating, hydrophilic and interconnected pores.

Ghasemi, H., Ni, G., Marconnet, A. et al. Solar steam generation by heat localization. Nature Commun. 5, 4449 (2014). https://doi.org/10.1038/ncomms5449

Photovoltaics

There are now a diversity of form factors and products

AgriPV

BIPV

Bifacial PV

Floating PV

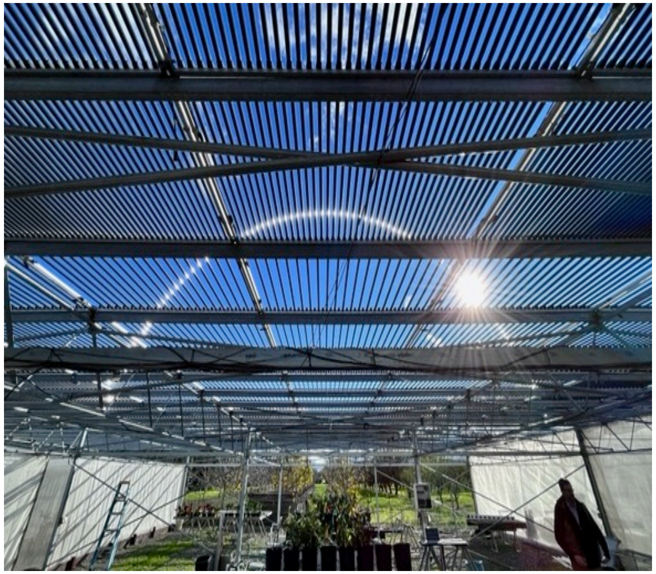
Integrated Photovoltaics – Areas for the Energy Transformation
https://www.ise.fraunhofer.de/en/key-topics/integrated-photovoltaics.html

Some examples of Agrisolar systems

Sun'Agri system over Grapes (France)

Jack's Solar Garden - Uses trackers (US)

System for growing vegetables (US)

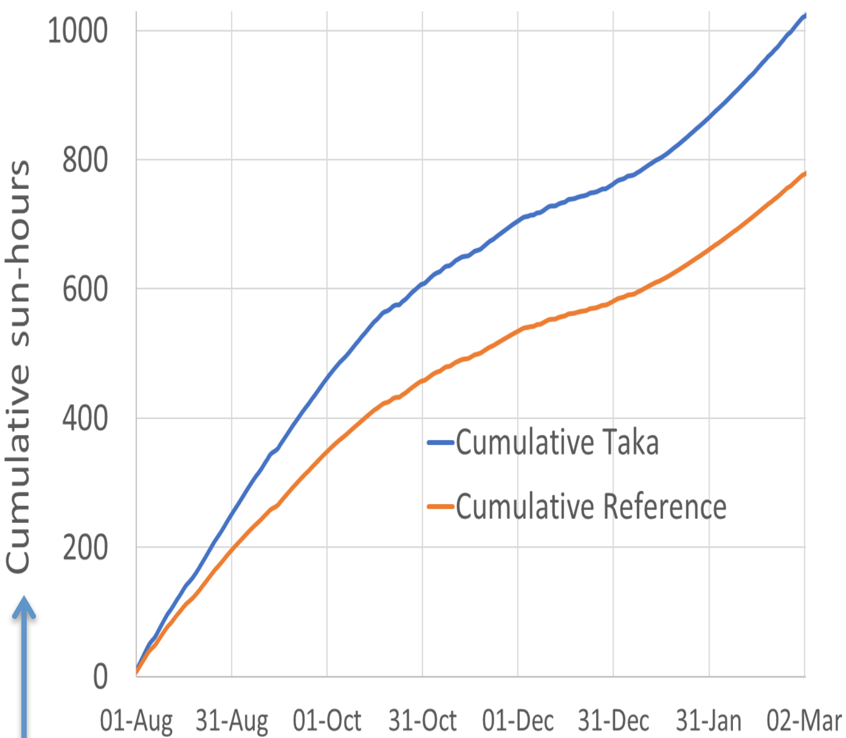


New: glass PV tubes (US, Taka Solar)

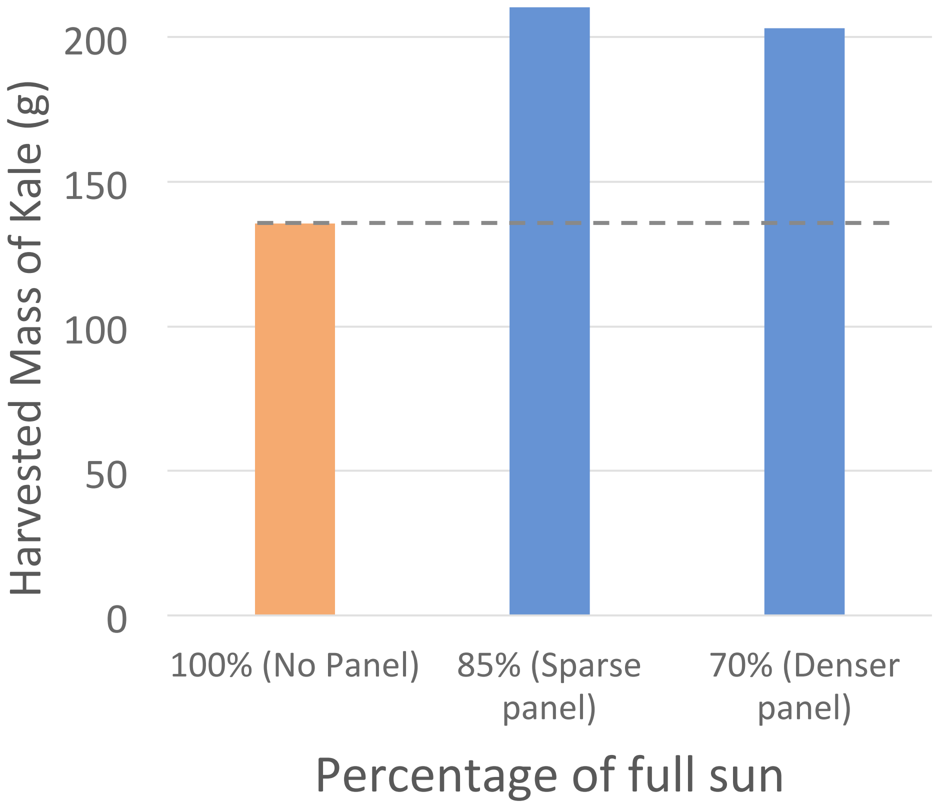
Background: https://www.nrel.gov/news/program/2022/growing-plants-power-and-partnerships.html

Performance of PV tube solar (US)

+25% energy per Watt from sun tracking
+5% energy from reduced soiling



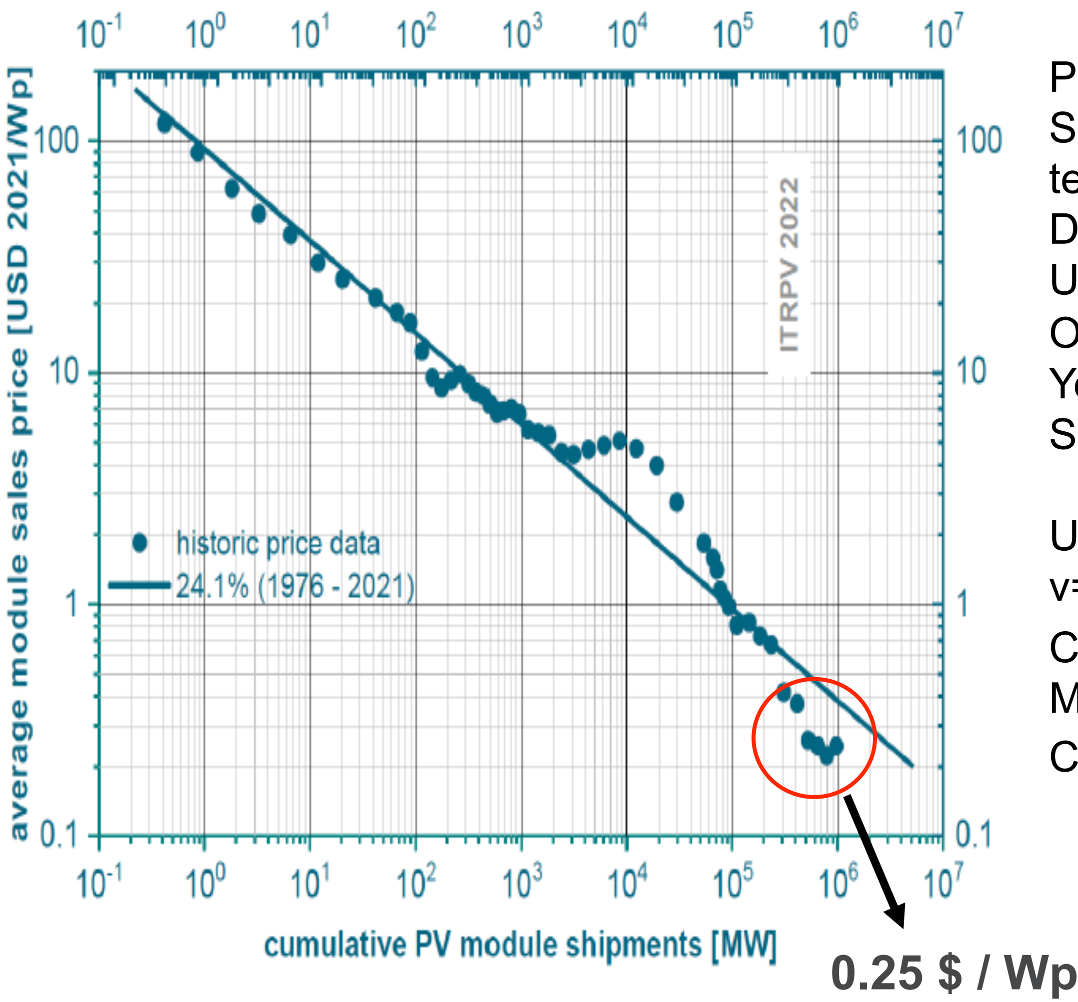
+50% crop yield under partial shading from tubes



Source: Dr. Christopher Barnes, email: chris@takasolar.com

Units: kWh/kWp

PV module costs (history)



Professor Dr. Ivan Gordon,
Status of crystalline-silicon PV technology,
DAY 13, PART-2 Virtual Learning University (VLU)
Online Opening Lectures - Academic Year 2021-2022
Saturday, October 30, 2021

URL: https://www.youtube.com/watch?v=_Z41x4dcAGg

Courtesy of Prof. Dr. Ahmed Ennaoui, Morocco

Source: ITRPV roadmap, 13th edition, March 2022

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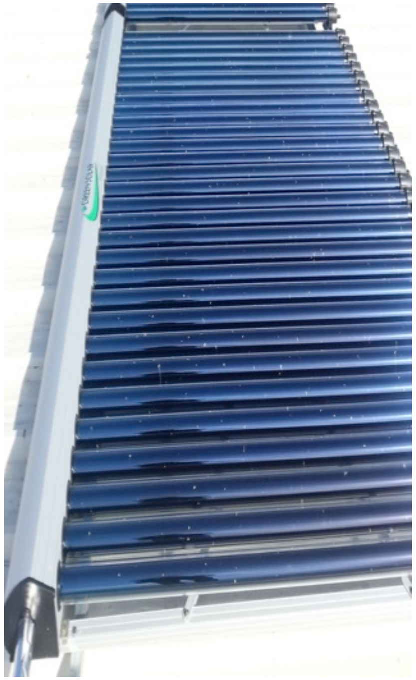
Making jet fuel from sunlight and air

a b

Demonstrated the operation of the entire thermochemical solar fuel production chain, from H_2O and CO_2 captured directly from ambient air to the synthesis of drop-in transportation fuels (for example, methanol and kerosene), with a modular 5 kW thermal pilot-scale solar system operated under field conditions. (ETH, Zurich)

Remo Schäppi, **Aldo Steinfeld, et al**. Drop-in Fuels from Sunlight and Air. Nature, 2021; DOI: https://doi.org/10.1038/s41586-021-04174-y

Solar Evacuated (thermal) Tube Array vs. Flat Panel Solar Water Heating



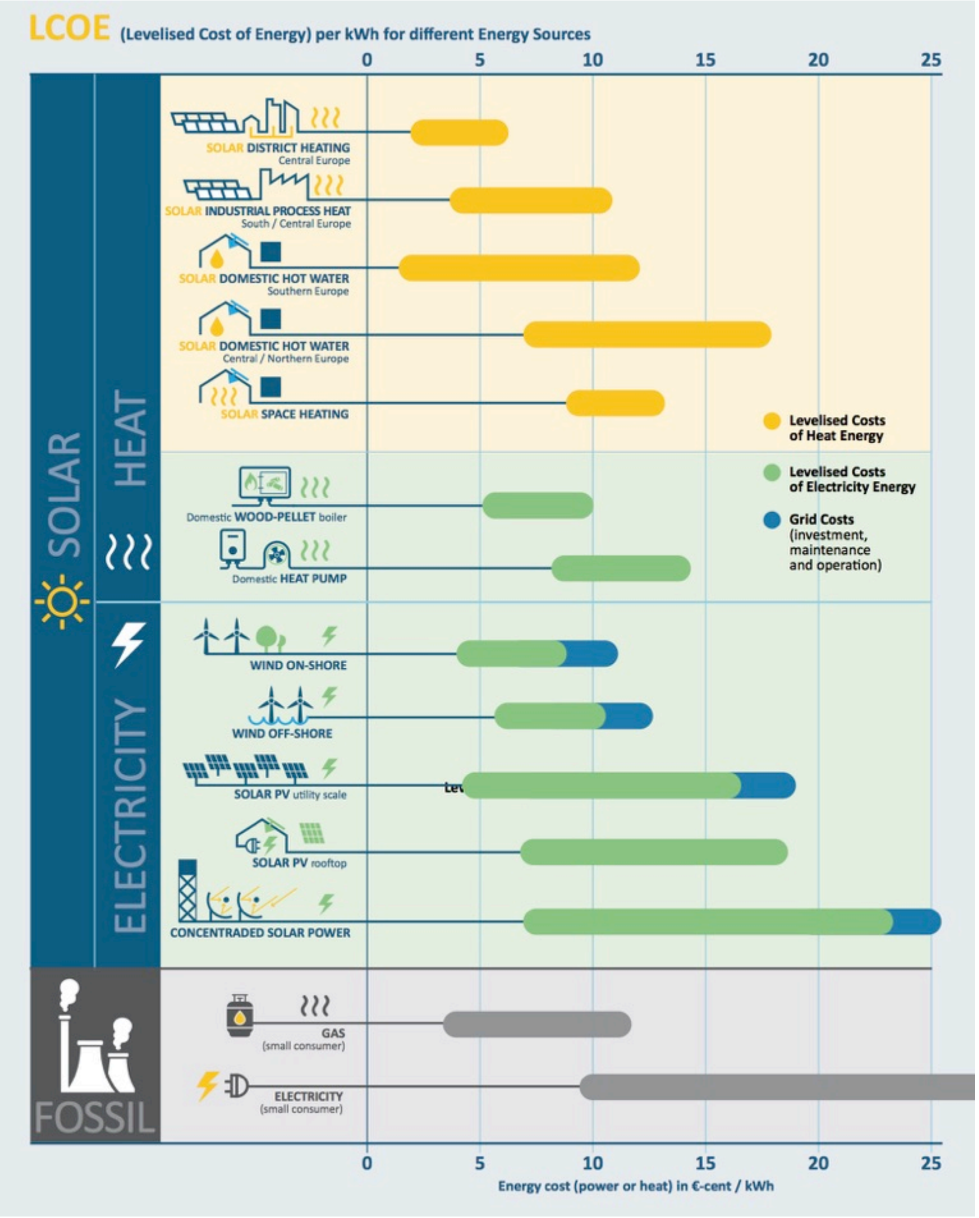
Works well in cold climates

Source: https://www.sciencedirect.com/topics/engineering/evacuated-tube-collector

Energizing Europe with Solar Heat: A Solar Roadmap for Europe

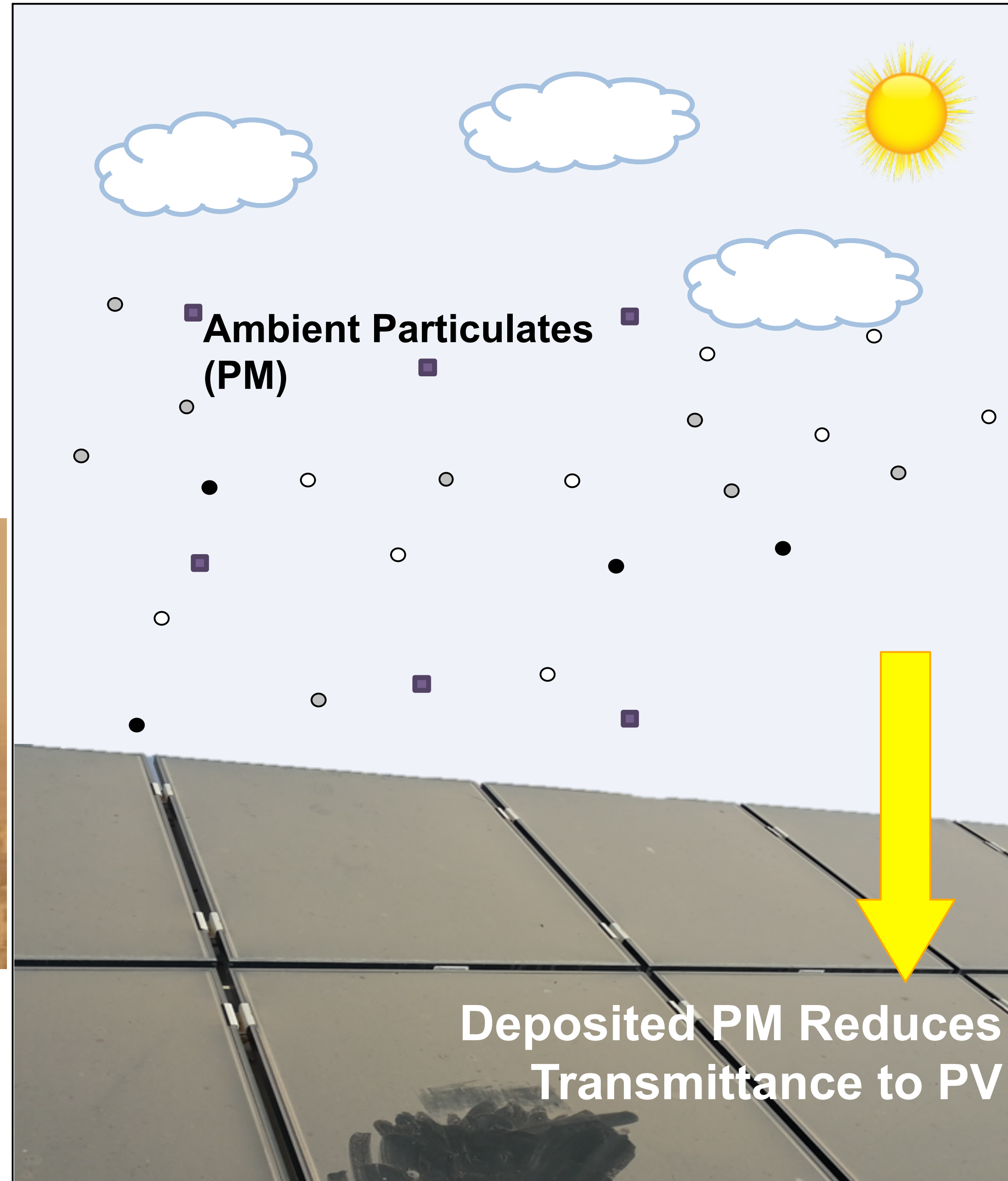
Compare with REPowerEU: affordable, secure and sustainable energy for Europe

- Heat is important



https://**solarthermalworld.org**/wp-content/uploads/2022/06/Solar-Thermal-Roadmap-2030.pdf

Soiling


Ambient Particulates (PM)
Deposited PM Reduces Transmittance to PV

Immediate Actions

Klemens Ilse, Leonardo Micheli, et al.,Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation, Joule, Volume 3, Issue 10, 2019, Pages 2303-2321. https://doi.org/10.1016/j.joule.2019.08.019.

Soiling: Definition

Accumulation of dust, dirt and particles on the surface of PV modules or CSP mirrors.

Drop in power output: can be > 50%.

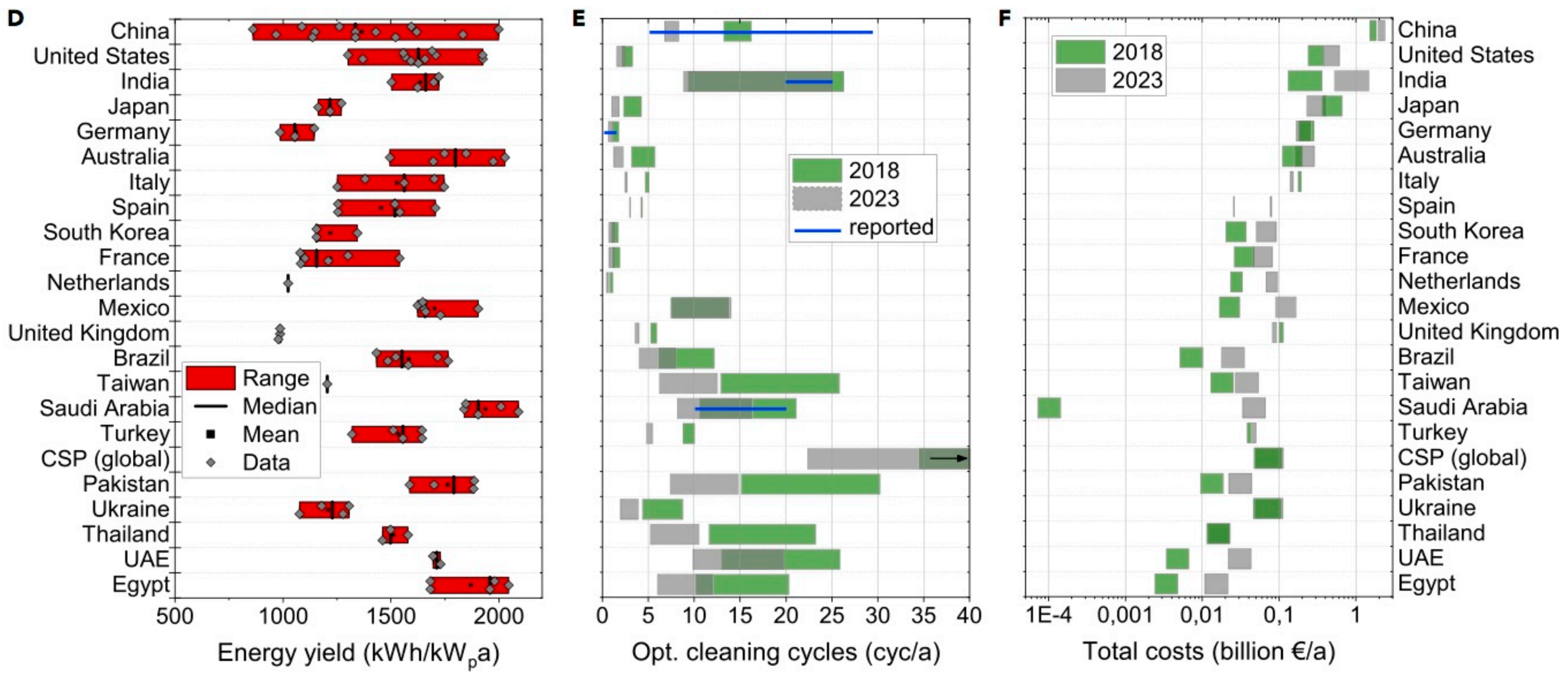
Drop in energy yield: 0 to 6% in the U.S.

4 to 7% loss in 2023.

➔ **4 to 7 billion € lost**[1] in 2023.

1. The 3-5 billion € loss due to soiling was calculated for a cost of electricity of 0.03 €/kWh. The cost in Europe now is approx. 10 times higher, so we are probably facing higher losses than forecasted, at least for the EU.

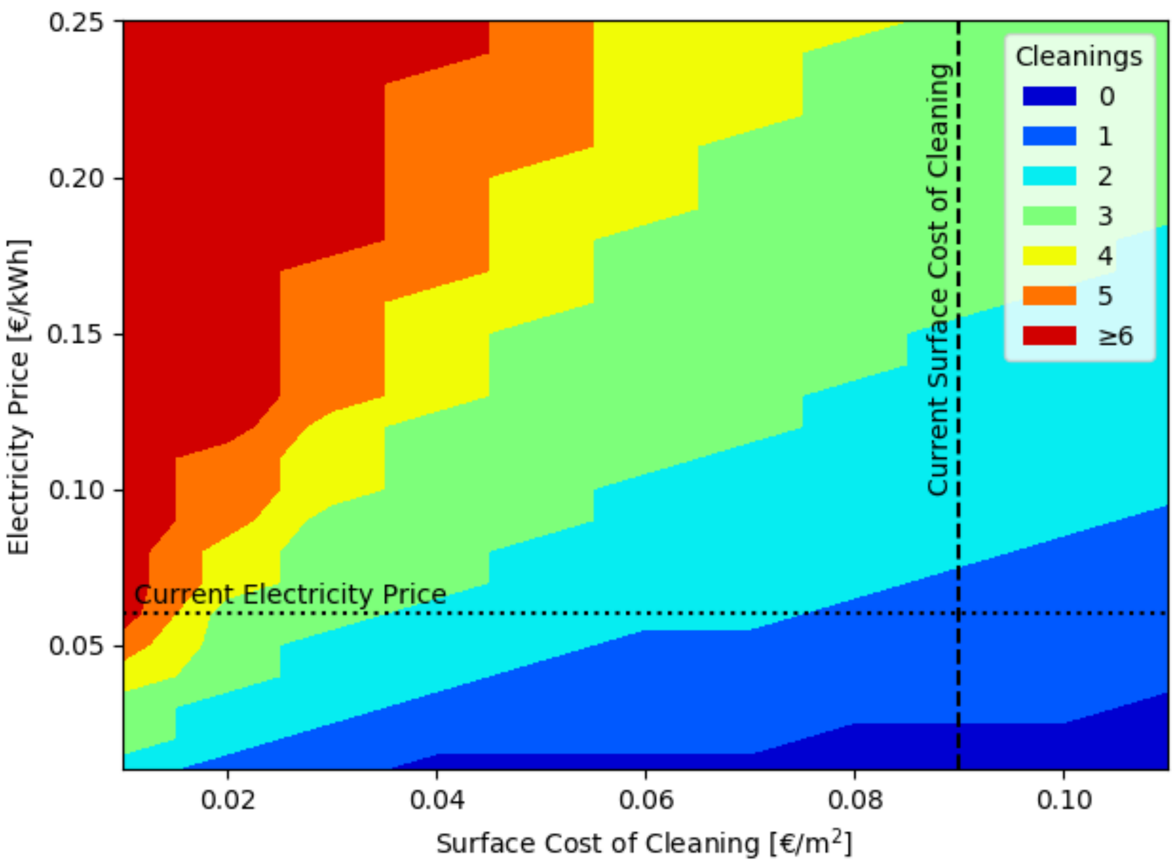
Soiling's Impact II



Impact of Soiling on Solar Power Generation
(D) Typical energy yield in kWh/kWp for representative locations.
(E) Calculated range of optimal number of yearly cleaning cycles (bars) and actual range of typical yearly cleaning cycles reported in literature (blue lines). The arrow indicates that for CSP, the numbers are out of range and (up to 85 in 2018 and 55 in 2023).
(F) Minimum expected financial losses due to soiling calculated from optimum cleaning cycles.

Klemens Ilse, Leonardo Micheli, et al.,Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation, Joule, Volume 3, Issue 10, 2019, Pages 2303-2321. https://doi.org/10.1016/j.joule.2019.08.019.

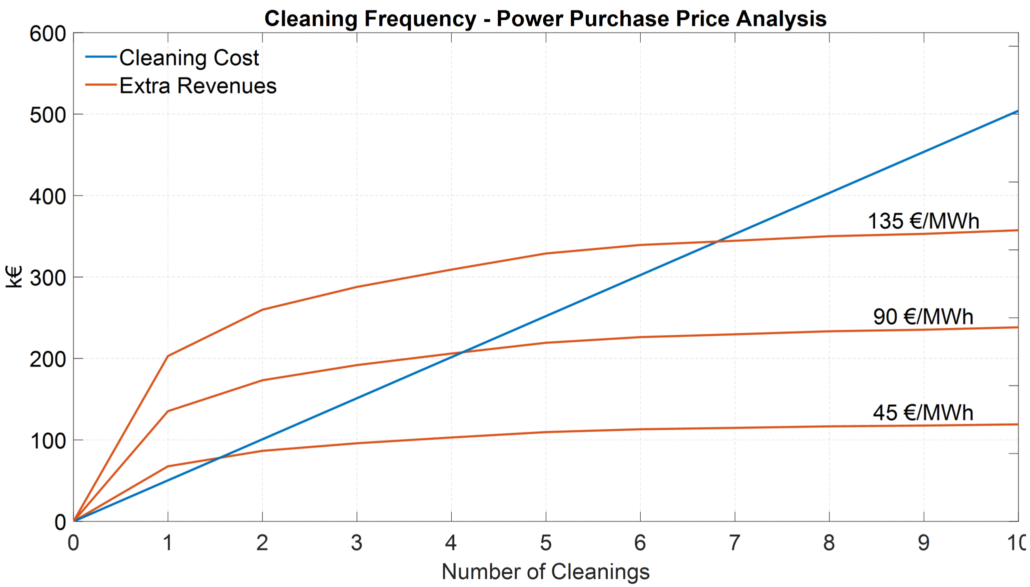
Higher Elec. Prices Allow for More Frequent Cleanings.



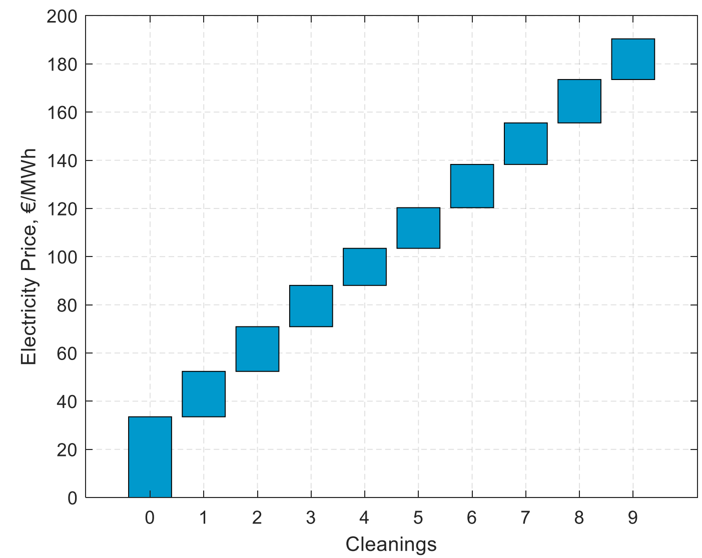
Optimal number of cleanings to maximize the Net Present Value (NPV) depending on both variable electricity price and cost of cleanings for the glass surface. The vertical dashed line and the horizontal dotted line show one example for a cost of **one** annual cleaning and the corresponding electricity price, respectively.

Source: Leonardo **Micheli**, et al., Economics of seasonal photovoltaic soiling and cleaning optimization scenarios, Energy, Volume 215, Part A, 2021, 119018, https://doi.org/10.1016/j.energy.2020.119018.

Soiling (CSP)



Below, the range of electricity price that gives a balance between cleaning costs and extra revenues is shown for each number of monthly cleanings.



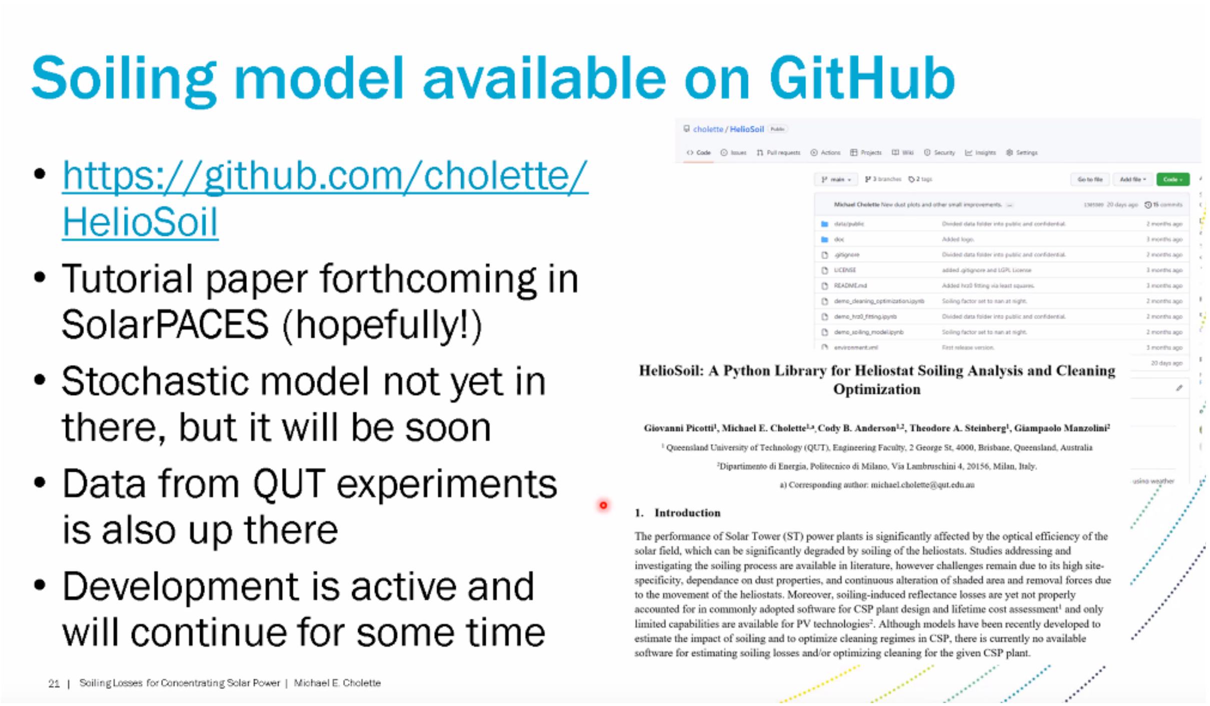
Each additional cleaning (monthly in this case) provides less economical benefit, however, for high enough electricity prices, a higher number of cleanings that improve the overall optical efficiency and hence the electricity generation is then profitable. In the figure above is shown the comparison between cleaning costs and extra revenues obtained at different electricity prices.

Soiling model available on GitHub, https//github.com/cholette/HelioSoil

Tutorial paper in SolarPACES

Picotti, G., Binotti, M., Cholette, M.E., Borghesani, P., Manzolini, G., Steinberg, T., 2019. Modelling the soiling of heliostats: Assessment of the optical efficiency and impact of cleaning operations. AIP Conf. Proc. 2126, 3004. https://doi.org/10.1063/1.5117555

Soiling Model (CSP)



Soiling model available on GitHub, https//github.com/cholette/HelioSoil

Tutorial paper in SolarPACES

Prof. Michael Cholette, PhD, and Giovanni Picotti, Ph.D., Faculty of Engineering, Queensland University of Technology, Papers (via QUT ePrints): http://eprints.qut.edu.au/view/person/Cholette,_Michael.html; ResearchGate: https://www.researchgate.net/profile/Michael_Cholette

Acknowledgments

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Sole4PV

SOiling Live Estimation for PhotoVoltaics

Thank you.

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