Faculty of Engineering
School of Photovoltaic and Renewable Energy Engineering

Global photovoltaic potential in climate change scenarios: role of aerosols and associated costs

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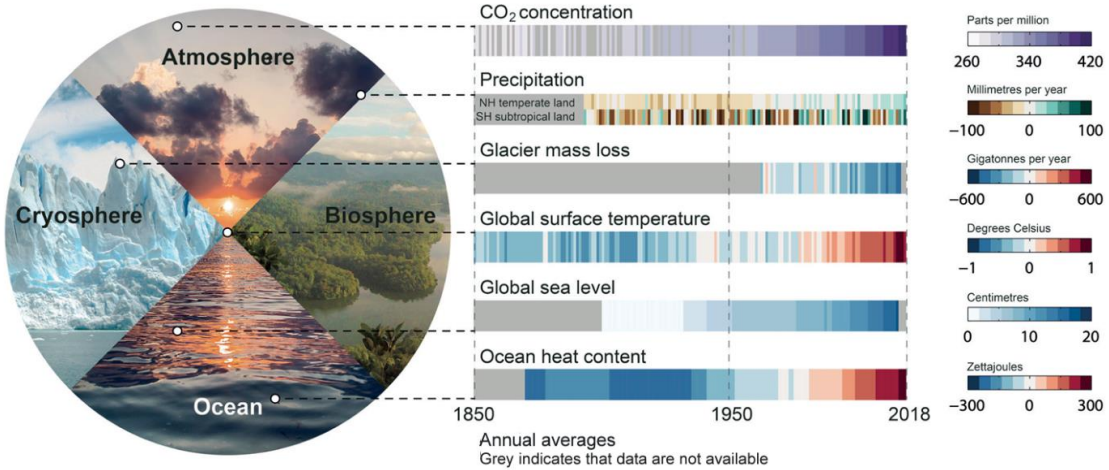
Changes are occurring throughout the climate system

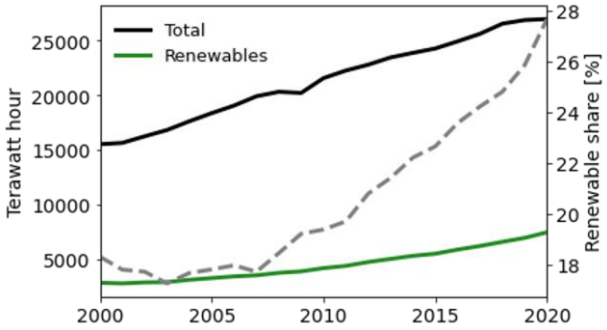


Six key indicators of ongoing changes since 1850 through 2018. Each stripe indicates the global annual mean anomaly for a single year, relative to a multi-year baseline (except for CO2 concentration and glacier mass loss, which are absolute values). **Source: IPCC (2021).**

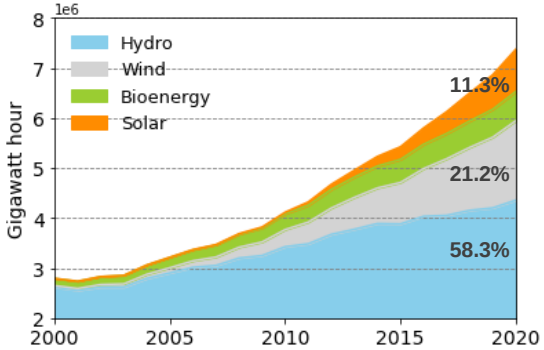
IPCC, 2021. Climate Change 2021: The Physical Science Basis. Working Group I Contribution to the IPCC Sixth Assessment Report.

Uptake of renewable energy technologies is spreading rapidly worldwide, and future expansion is expected.

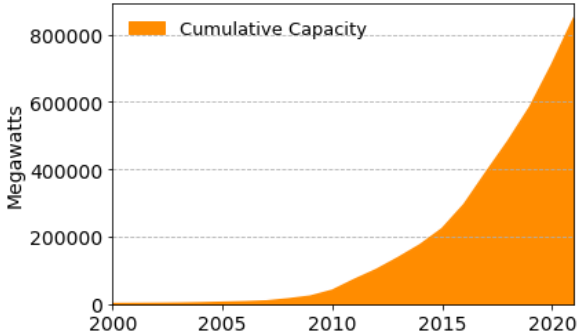
Worldwide electricity generation



Electricity generation from renewable sources



Solar photovoltaic installations



Renewable sources are modulated by climate ⟷ **Climate change can affect future production**

IRENA (2022), Renewable energy statistics 2022, International Renewable Energy Agency (IRENA), Abu Dhabi

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Main objective

Quantify the impacts of different climate change scenarios in the PV energy production worldwide, focusing on the role of **atmospheric aerosols**

Role of aerosols in solar energy generation:

- Aerosols direct/indirect radiative effects: radiation scattering and absorption/ modification of cloud properties
- Soiling: accumulation in PV panels

Renewable sources are modulated by climate ⟷ **Climate change can affect future production**

Long-term climate projections from CMIP6:

11-members ensemble:

Model	Institute, Country	Resolution (°lat x °lon)
ACCESS-CM2	CSIRO-BOM, Australia	1.25 x 1.875
AWI-ESM-1-1-LR	AWI, Germany	1.865 x 1.875
BCC-CSM2-MR	BCC, China	1.0 x 1.0
CMCC-CM2-SR5	CMCC, Italy	0.942 x 1.25
CMCC-ESM2	CMCC, Italy	0.942 x 1.25
EC-Earth3	EC-Earth-Consortium, Europe	0.72 x 0.72
MIROC-ES2L	MIROC, Japan	2.8 x 2.8
MIROC6	MIROC, Japan	1.4 x 1.4
MPI-ESM1-2-HR	MPI-M, Germany	0.935 x 0.938
MPI-ESM1-2-LR	MPI-M, Germany	1.865 x 1.875
MRI-ESM2-0	MRI, Japan	1.121 x 1.125

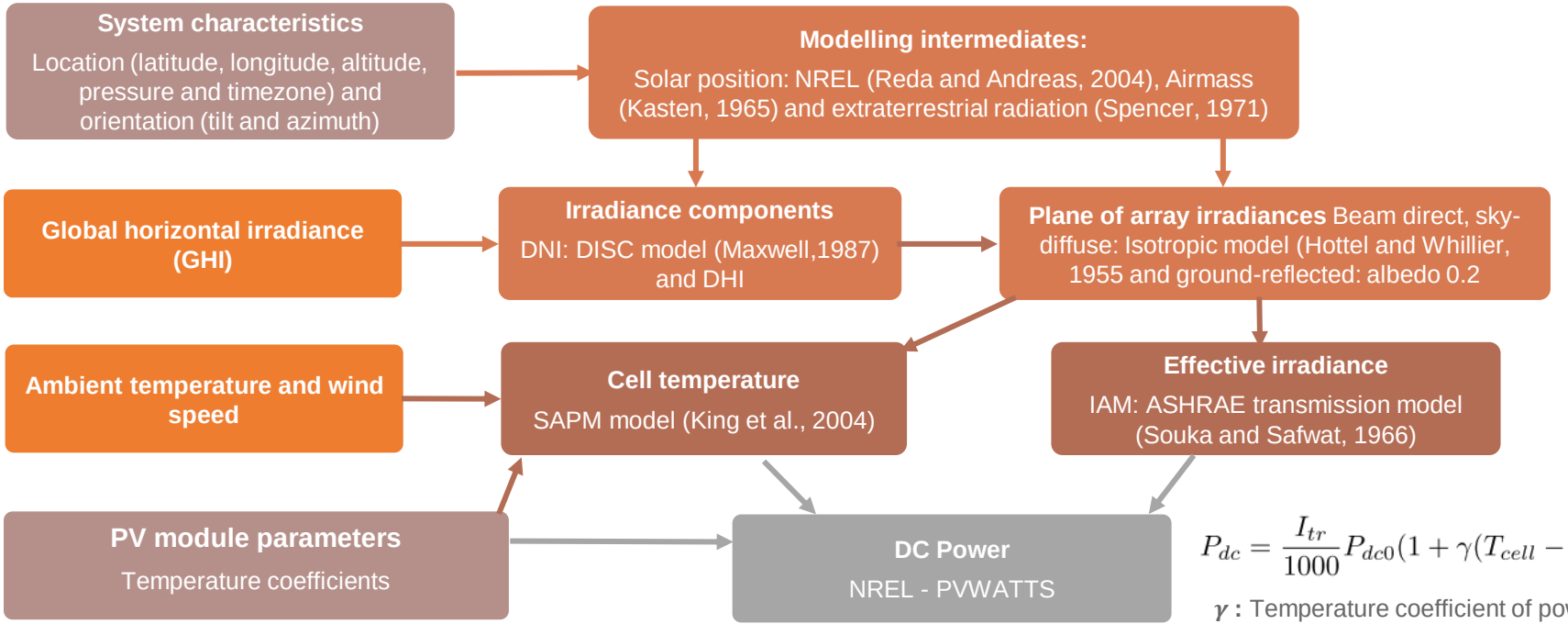
Statistical significance of the ensemble-mean calculated following Tebaldi et al. (2011)

Experiments:

Experiment	Brief description
Historical	Simulation of the recent past (1850 to 2014) with all climate forcings: volcanic, solar, and anthropogenic forcings.
SSP126	Radiative forcing of 2.6 W/m^2 by the end of 2100 following a “Green growth” path - Low GHG emissions and strong air pollution controls
SSP245	Radiative forcing of 4.5 W/m^2 and a “Middle of the road” path. - Intermediate GHG emissions and air pollution controls
SSP370	Radiative forcing of 7.0 W/m^2 and a “Regional rivalry” path **- High GHG emissions and weak air pollution controls**
SSP585	Radiative forcing of 8.5 W/m^2 by the end of 2100 and a “Fossil-fueled Development” path **- Very high GHG emissions and strong air pollution controls**

PV power-conversion model

Python-PVLIB
(Holmgren et al., 2018)



$$P_{dc} = \frac{I_{tr}}{1000} P_{dc0}(1 + \gamma(T_{cell} - T_{ref}))$$

γ : Temperature coefficient of power
γ **thin-film** = - 0.20 %/C
γ **mono-Si** = - 0.47 %/C

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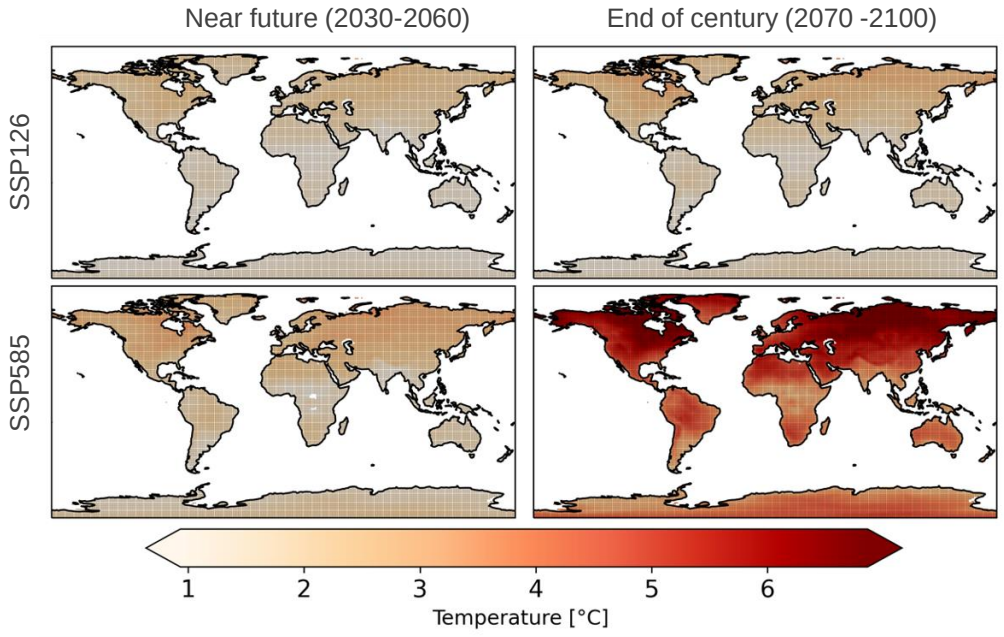
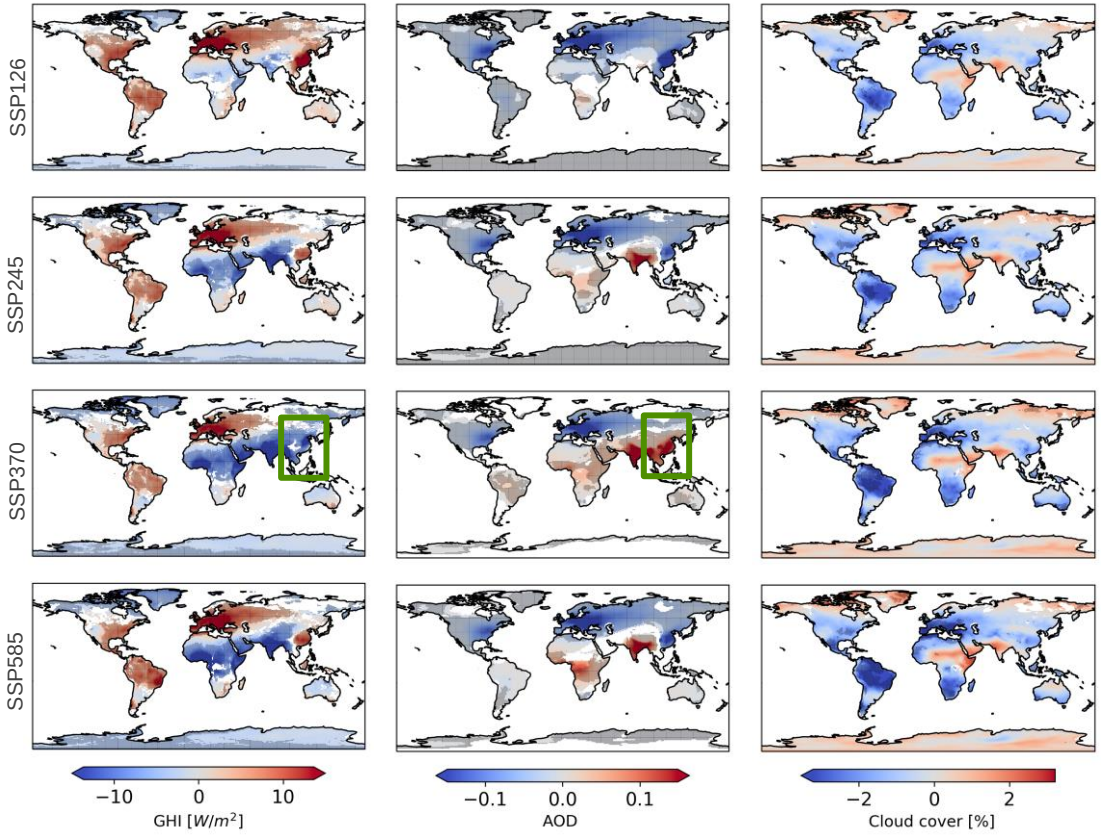
Future climate projections:

Projected changes in daytime ambient temperature (ensemble-mean)



Future climate projections: mean changes in the near future*



Significant agreement: color and stippling; **Insignificant change:** color without stippling; **Significant disagreement:** shown in white

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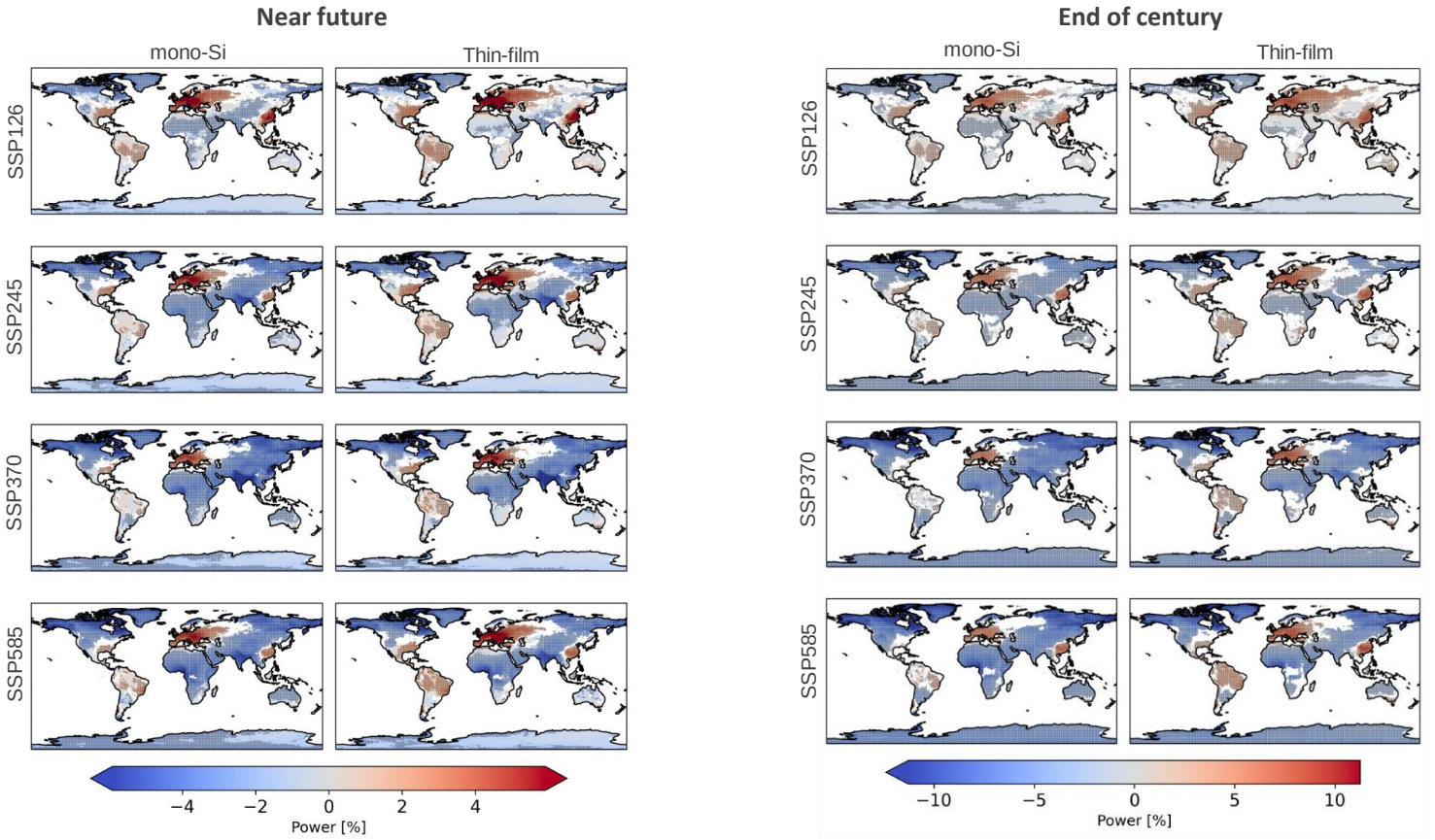
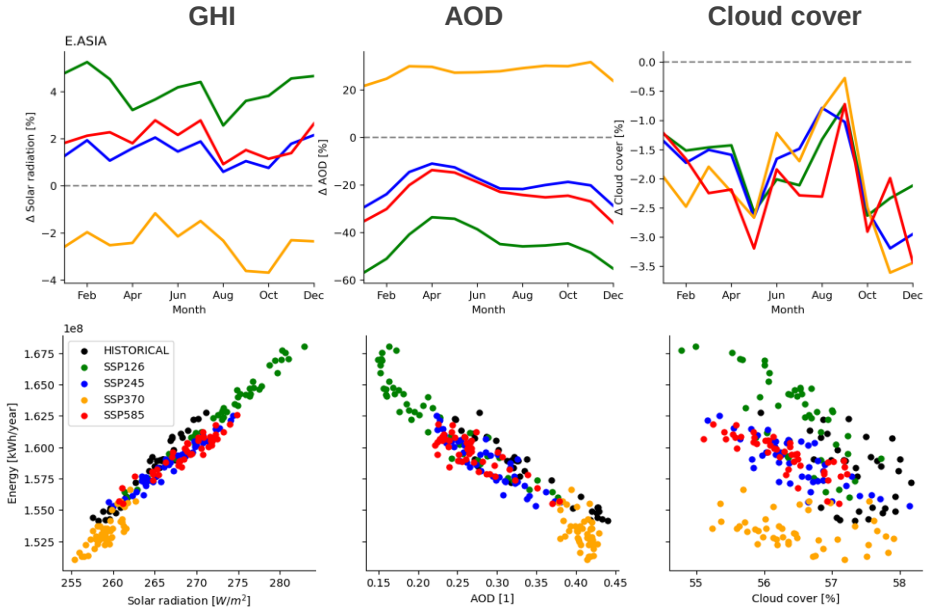
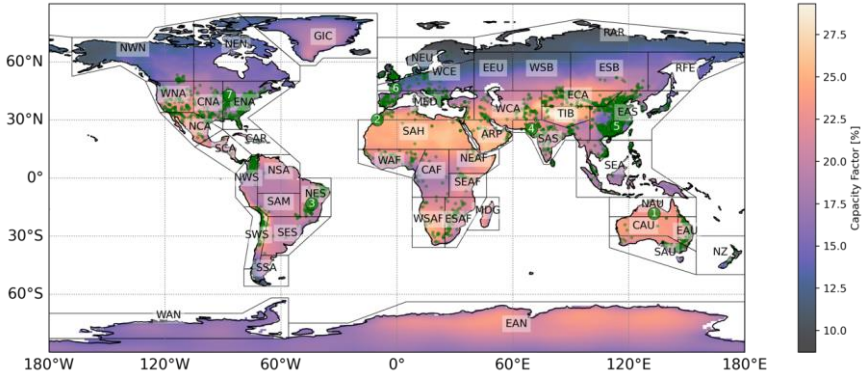
Future changes in PV power potential:



Regional analysis in East Asia:



The strong regional and inter-annual variability in the future solar resources is not only modulated by **changes in cloud cover** but by **aerosols** as well



This is the region with the highest number of future solar farms

*Plants >= 20MW in “construction,” “pre-construction” or “announced” status in the Global Energy Monitor’s Global Solar Power Tracker project (https://globalenergymonitor.org/projects/global-solar-power-tracker/) updated in January 2023.

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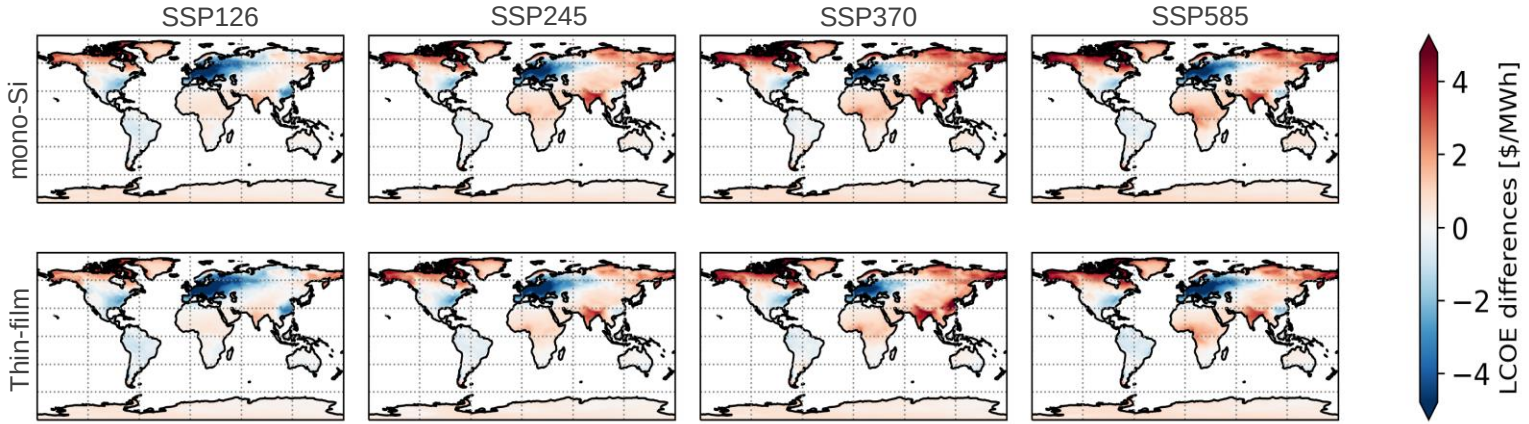
Levelized cost of energy considering a changing climate:

$$\mathrm{LCOE} = \frac{\text{Lifecycle cost (\$)}}{\text{Lifetime energy production (kWh)}}$$

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{n}(I_t + O_t + M_t + F_t)/(1+r)^t}{\sum_{t=0}^{n} E_t/(1+r)^t}$$

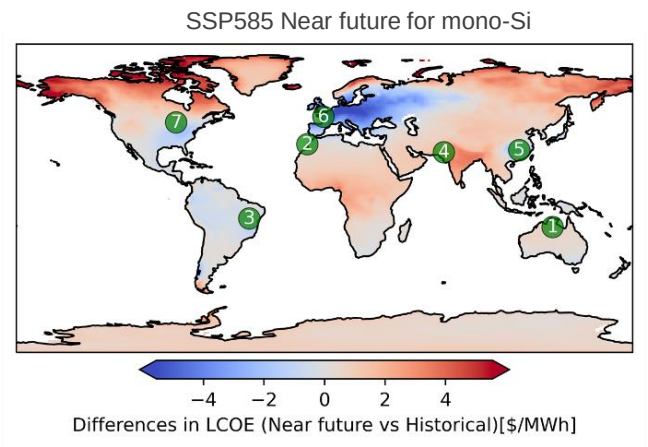
Parameters for utility-scale PV systems*:

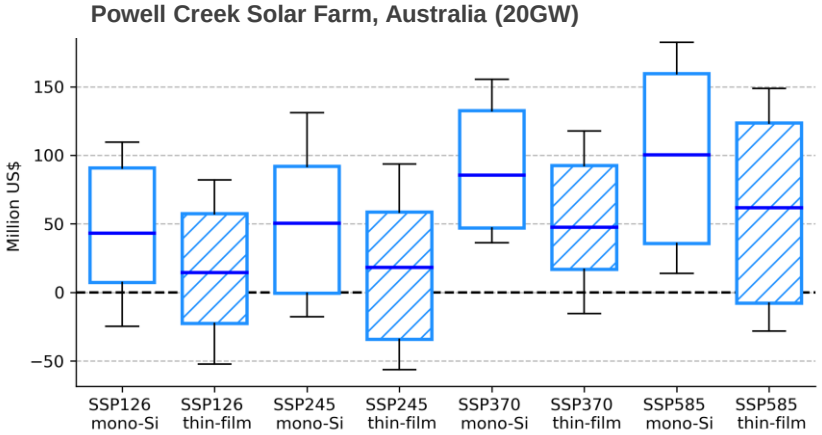
- Economic life: 30 years
- Capital costs 2021: 857 $/kW
- Operation and maintenance costs: 14.1 $/kW
- Discount rate: 7.5%*

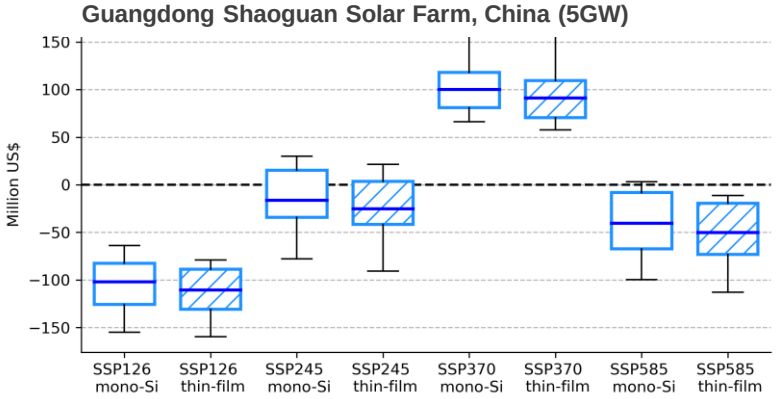


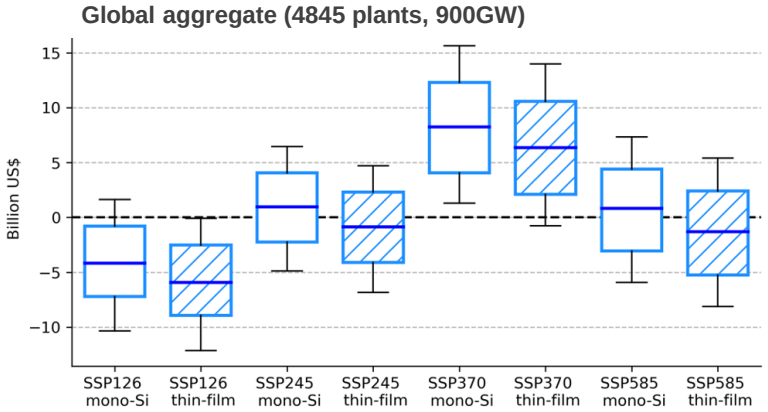
* IRENA, 2022. Renewable Power Generation Costs in 2021, International Renewable Energy Agency.

Climate-change associated costs in one-year operation of future solar farms:









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Final remarks:

- Worldwide PV potential is **resilient to climate change**, but economic impacts could still be significant in future large-scale solar farms.
- **Increases in PV power output** expected in Europe, E.N.America, E.S.America and N.W.Asia, while **reductions** dominate in the rest of the world.
- **Positive feedback:** In a low-emission future scenario, that focuses on renewables and energy efficiency, the future PV impacts are the lowest
- Aerosols highly impact PV energy in **east-Asia**, region with most upcoming solar plants
- SSP370 is the less favorable climate scenario for future PV energy. Cost savings in SSP126 compared to SSP370 could reach **12.4 billion US$ in one year**
- Improving **thermal management** in market-dominant mono-Si solar cells augment their resilience to climate change. The costs differences between mono-Si and thin-film are around 2 billion US$ in all the scenarios.

Further research: **High-resolution simulations with WRF-Solar to study the role of aerosols in PV production**

Thank you for your attention
Any questions?

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“Maximizing Photovoltaic Potential and Minimizing Costs in a Future Warmer Climate: The Role of Atmospheric Aerosols and Greenhouse Gas Emissions” is under revision in Renewable Energy journal

Pre-print is available:

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