UiO : Department of Mathematics
University of Oslo

Uncertain Energy Systems

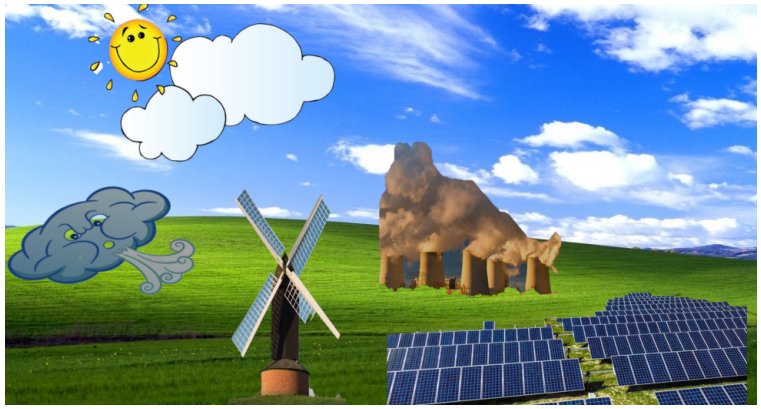
Marianne Zeyringer and **Fred Espen Benth**

EnergyForum, November 24, 2021.

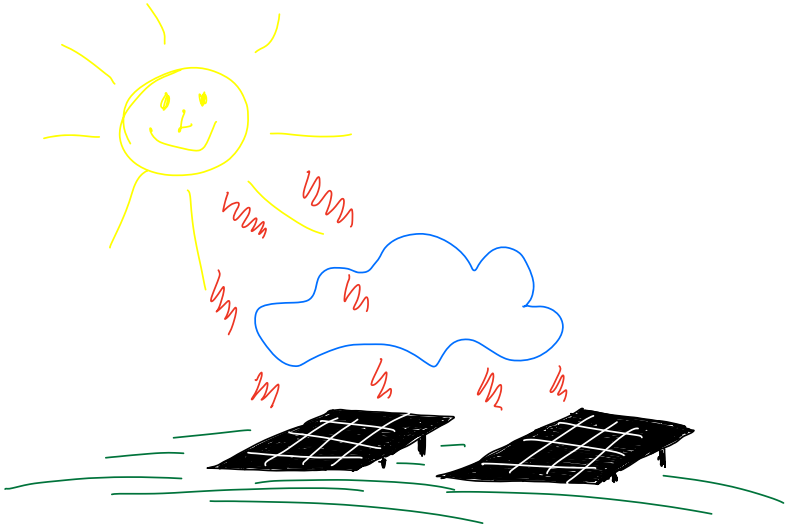
Spatus: spatio-temporal uncertainty in energy systems

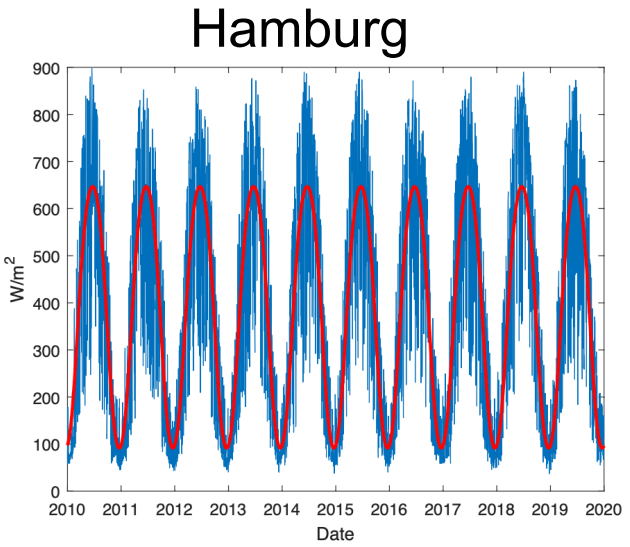
- Climate and weather data to assess and model
  - uncertainty,
  - future predictions

- Find optimal installation of renewable plants to meet:
  - emission targets
  - demand



Modeling solar irradiation





Red: mean seasonal irradiation

- Model for PV-production

$$P(t) = \alpha I(t) \times (1 - \beta(T(t) - 25))$$

Stochastic model for daily peak

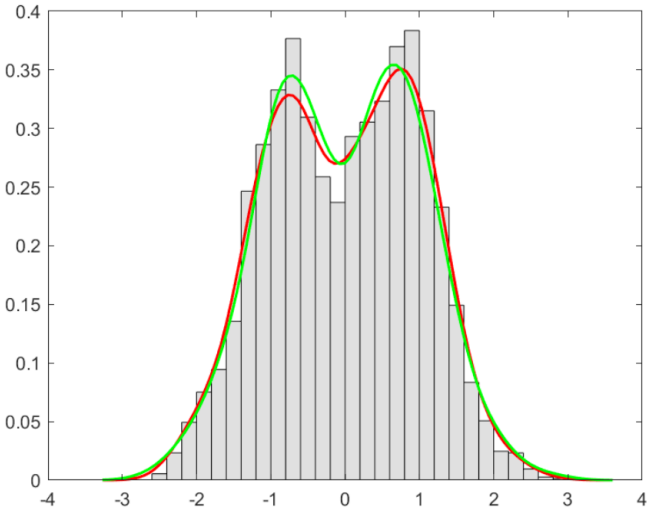
- Random fluctuations around seasonal mean

$$I(t) = S(t) + X(t)$$

- Two days memory effect
  - AR(2)-model

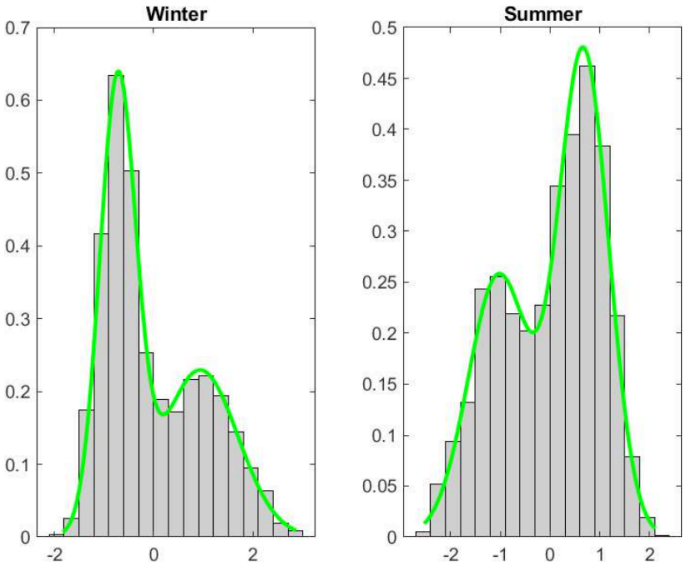
$$X(t) = \beta_1 X(t-1) + \beta_2 X(t-2) + noise(t)$$

- Seasonal effect in noise
  - Summer and winter difference
  - “Cloud" or “no-cloud” mixture



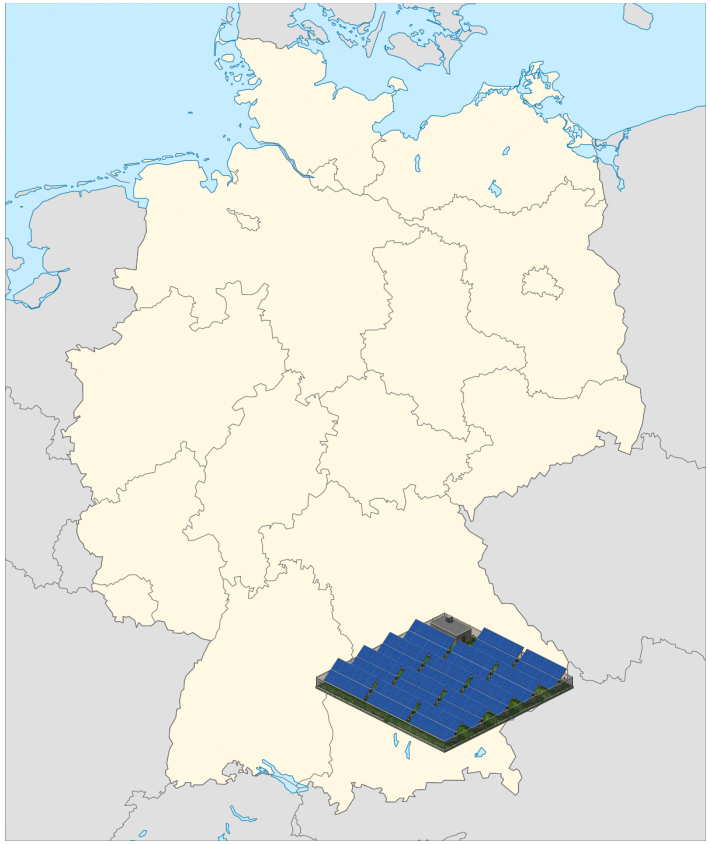
Red: empirical density residuals

Green: density simulated residuals

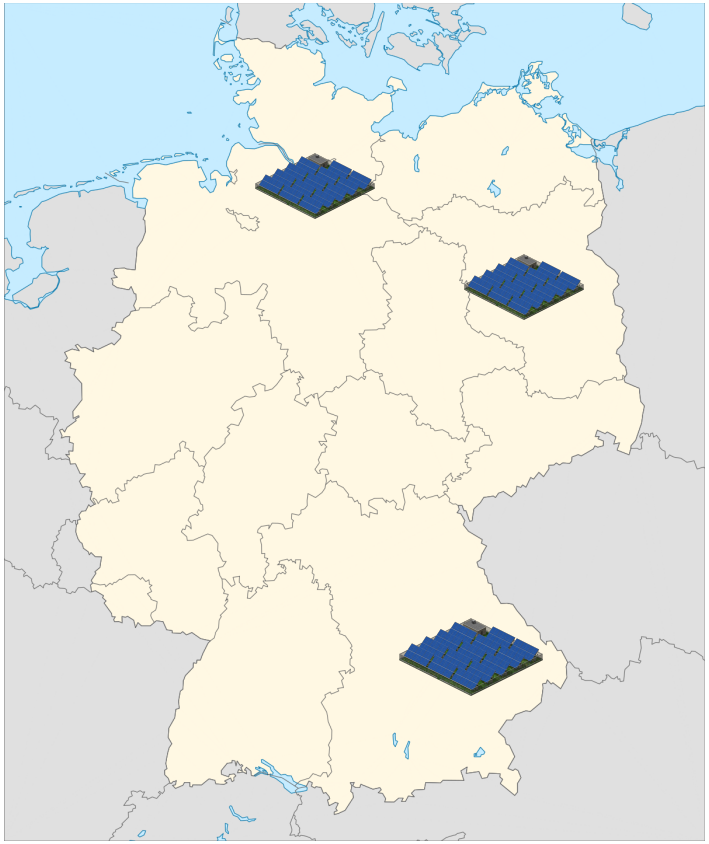


What is better?

Reduce production variability by spatial distribution of plants?

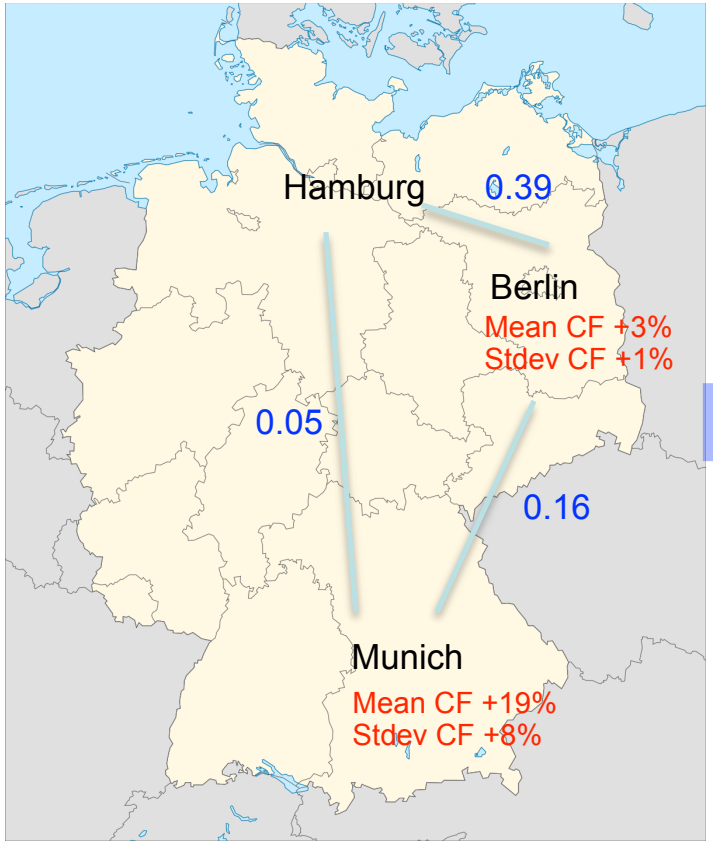


?
OR



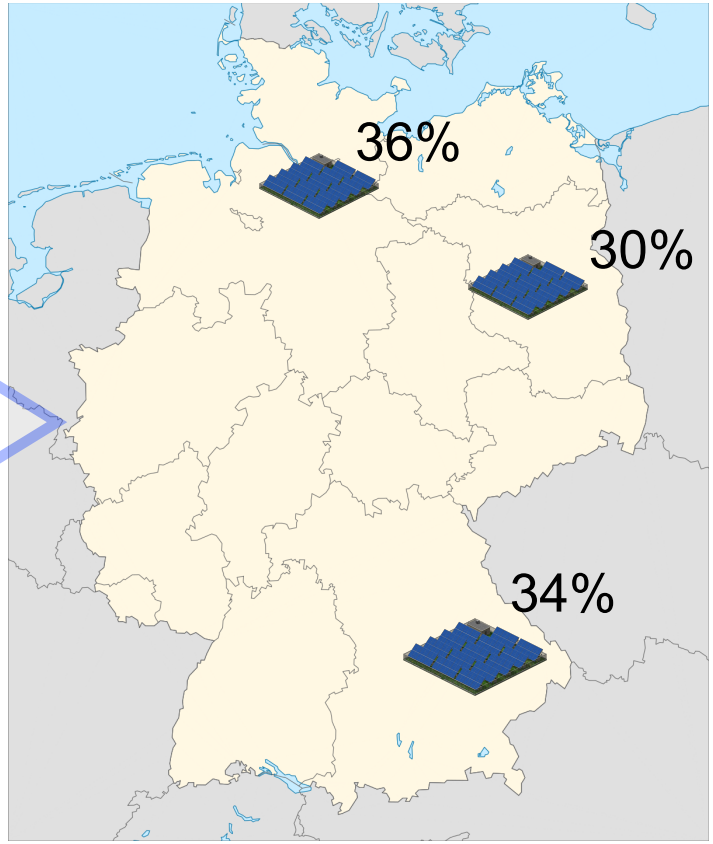
Minimize variability in PV production meeting expected demand

Mean capacity factors and uncertainty
…..relative to Hamburg



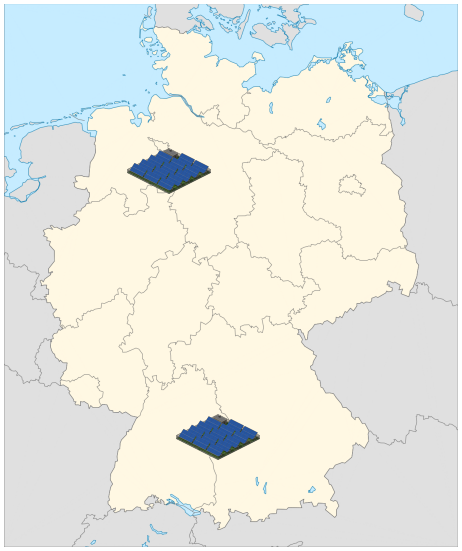
Optimal installation of PV capacity

Installed capacity



25% reduction in production uncertainty compared with “all PV in Munich”-strategy!

Spread out plants as much as possible



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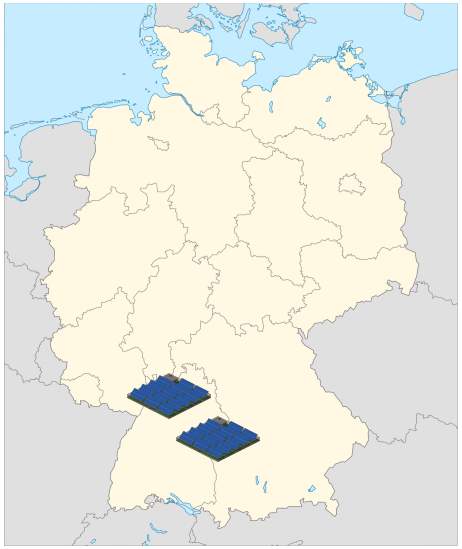
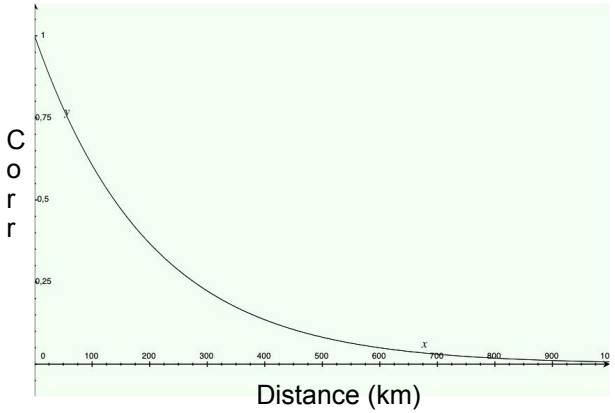
Or

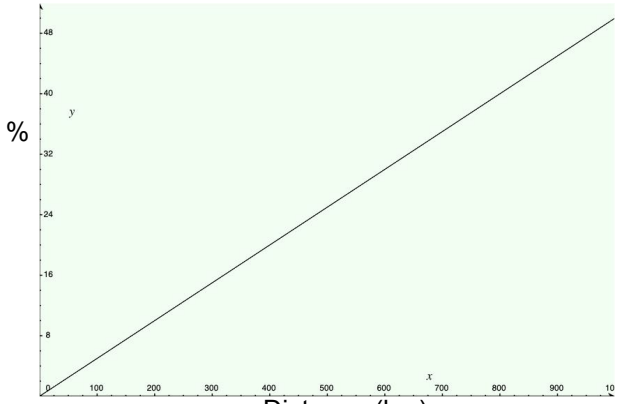


Correlation decays with distance



Distance (km)

Reduction in variability, when capacity factor means and uncertainties are equal



Distance (km)

Some references

- Larsson, Green and Benth (2021). A stochastic time-series model for solar irradiation. SSRN E-print, August.

- Benth, Christensen and Rohde (2021). Multivariate continuous-time modeling of wind indexes and hedging of wind risk. *Quant. Finance*, 21(1), 165-183.
- Benth and Ibrahim (2017). Stochastic modeling of photovoltaic power generation and electricity prices. *J. Energy Markets,* 10(3), 1-33.

THANK YOU FOR LISTENING!

Uncertain Energy Systems

Fred Espen Benth, Marianne Zeyringer

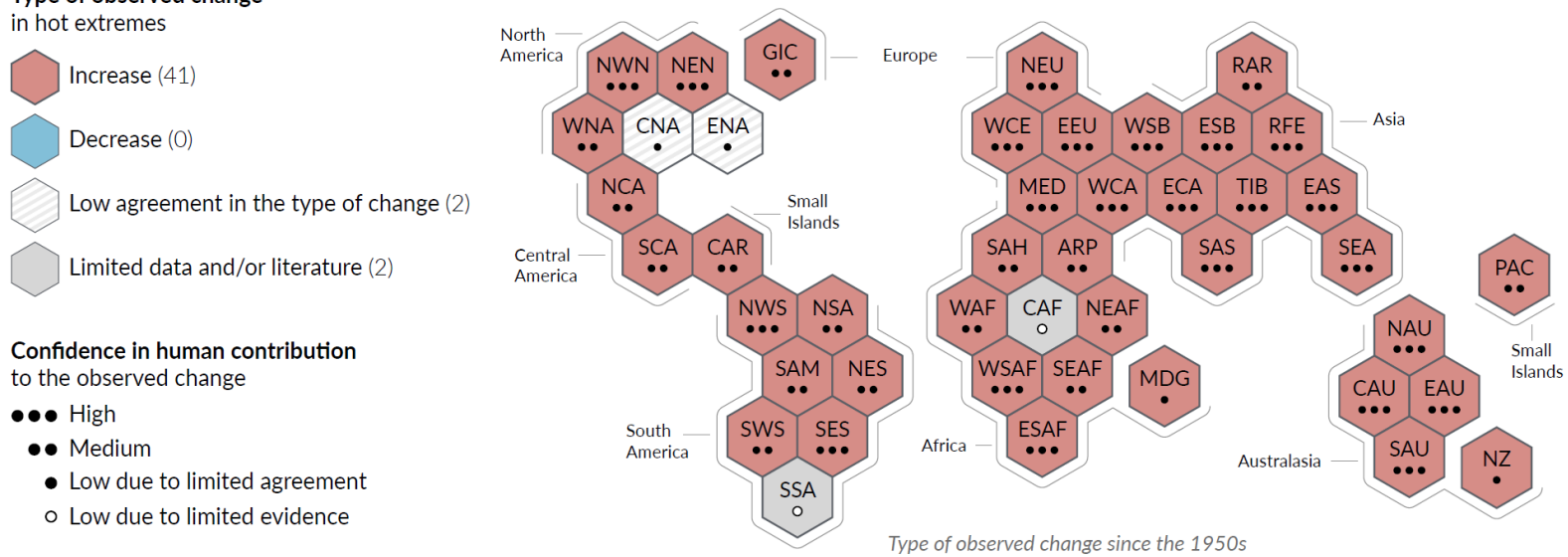
Between 1.5°C and 2°C is the tipping point for many of the most sensitive ecosystems in the polar regions, the permafrost, swamps, alpine regions and coral reefs.

At 2°C warming, many of these will cease to exist.

Joeri Rogelj (Climate Scientist at Imperial College)

Climate change is already affecting every inhabited region across the globe with human influence contributing to many observed changes in weather and climate extremes

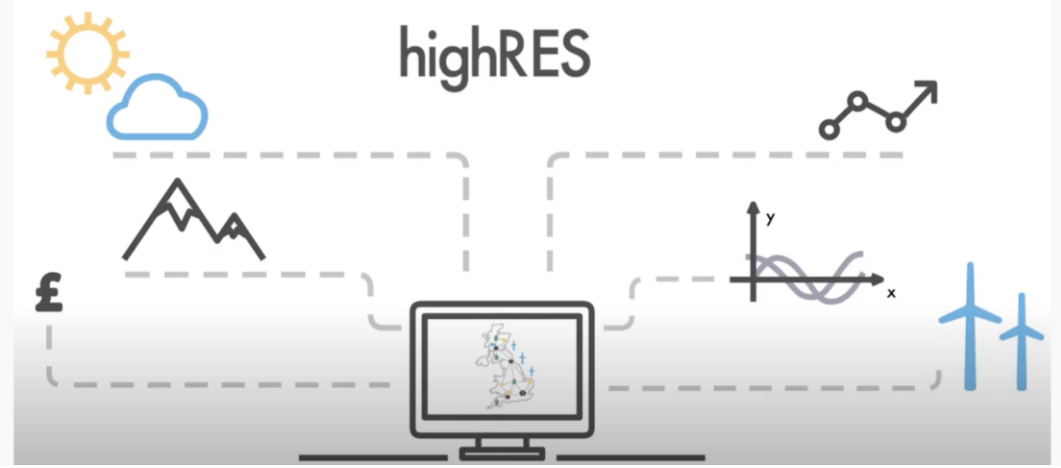
a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s

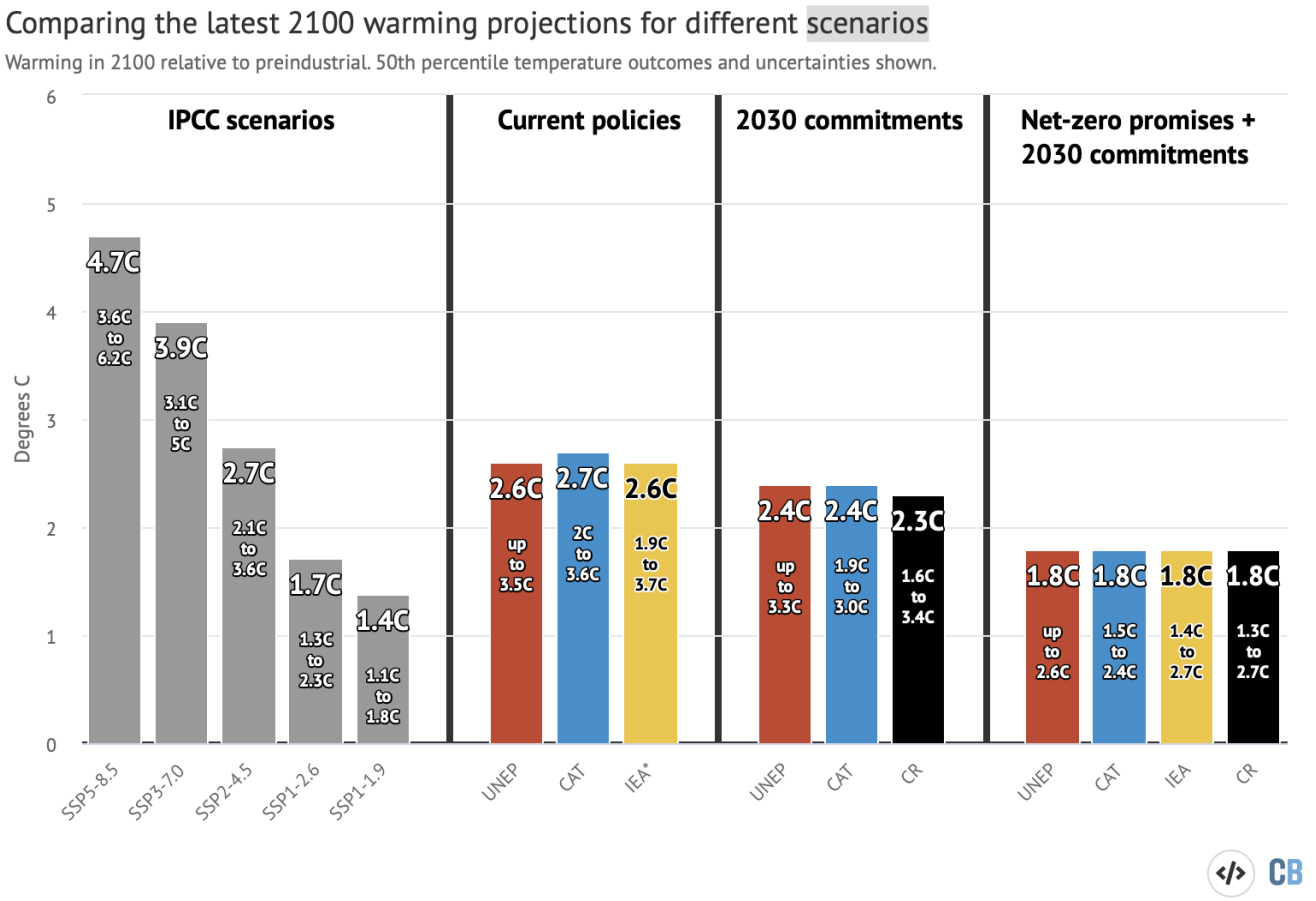
Energy system transition

- Energy production accounts for 72% of all GHG emissions
- Demand reduction + Electrification with wind and solar energy



https://www.nature.com/articles/s41560-018-0172-6

Achieving a net zero carbon economy in Europe by the 2050s will reduce the climate risks, but not eliminate them.



Compilation of the latest 2100 median warming projections from UNEP, CAT, IEA and CR as of 9 November 2021, compared to the assessed warming values for the five shared socioeconomic pathway (SSP) scenarios highlighted in the recent IPCC AR6 WG1 report. Both central estimates and uncertainty ranges are shown. Note that the IEA current policy scenario (STEPS) is in-between policies in place today and 2030 commitments. Chart by Carbon Brief using Highcharts.

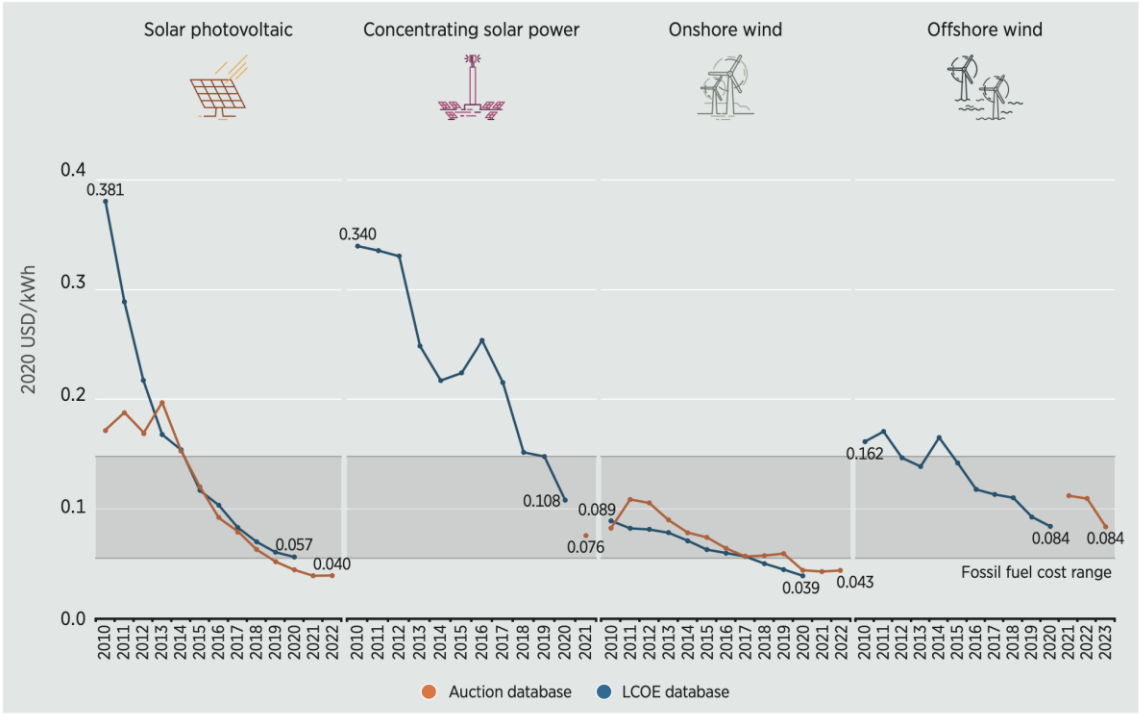
Uncertainties

Socio-political

Uncertainties

Techno-economic

Figure ES.3 The global weighted-average LCOE and PPA/auction prices for solar PV, onshore wind, offshore wind and CSP, 2010-2023



Source: IRENA Renewable Cost Database

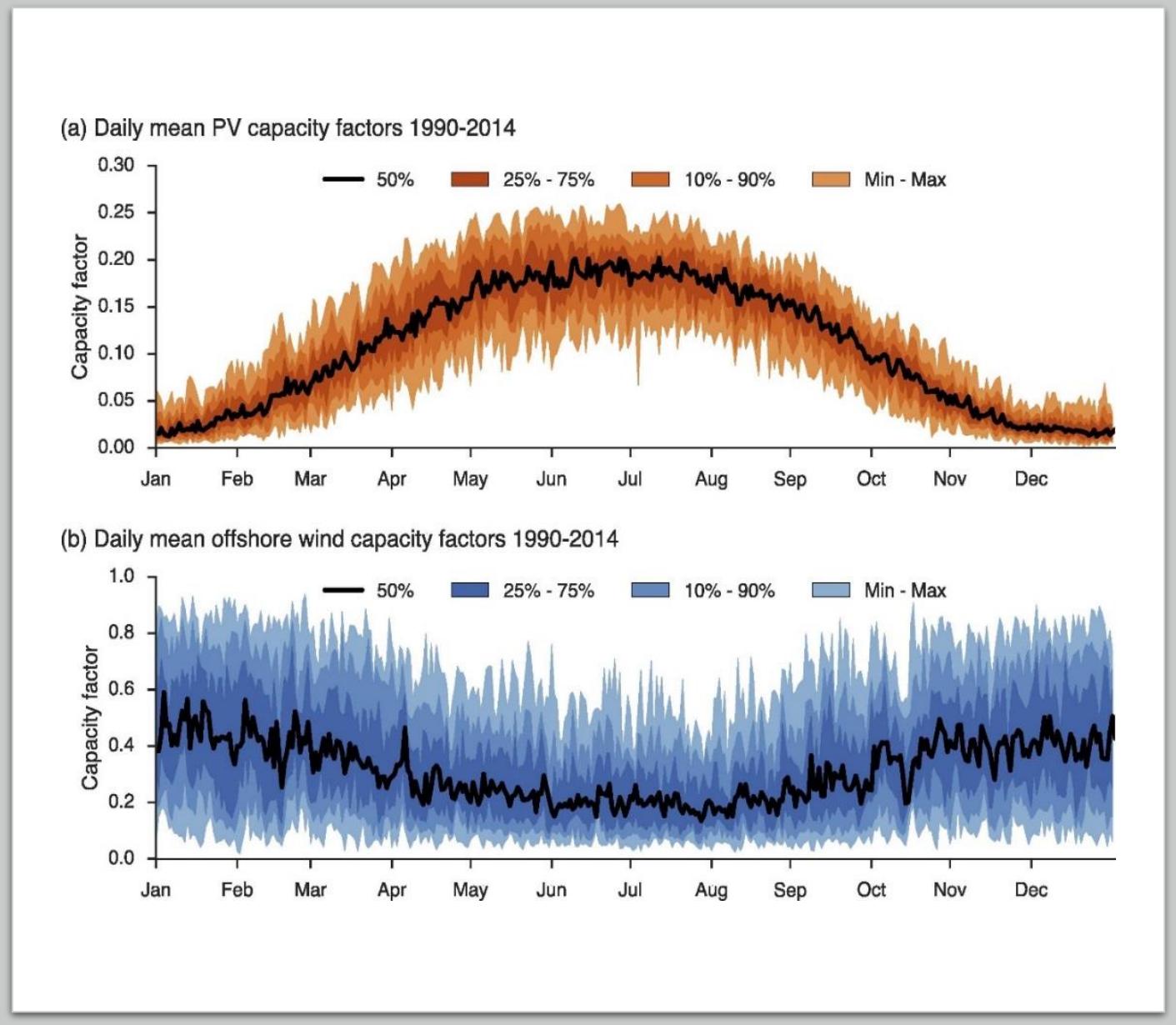
Note: The thick lines are the global weighted average LCOE, or auction values, by year. For the LCOE data, see Figure ES2 note. The band that crosses the entire chart represents the fossil fuel-fired power generation cost range.

Uncertainties

Weather and climate

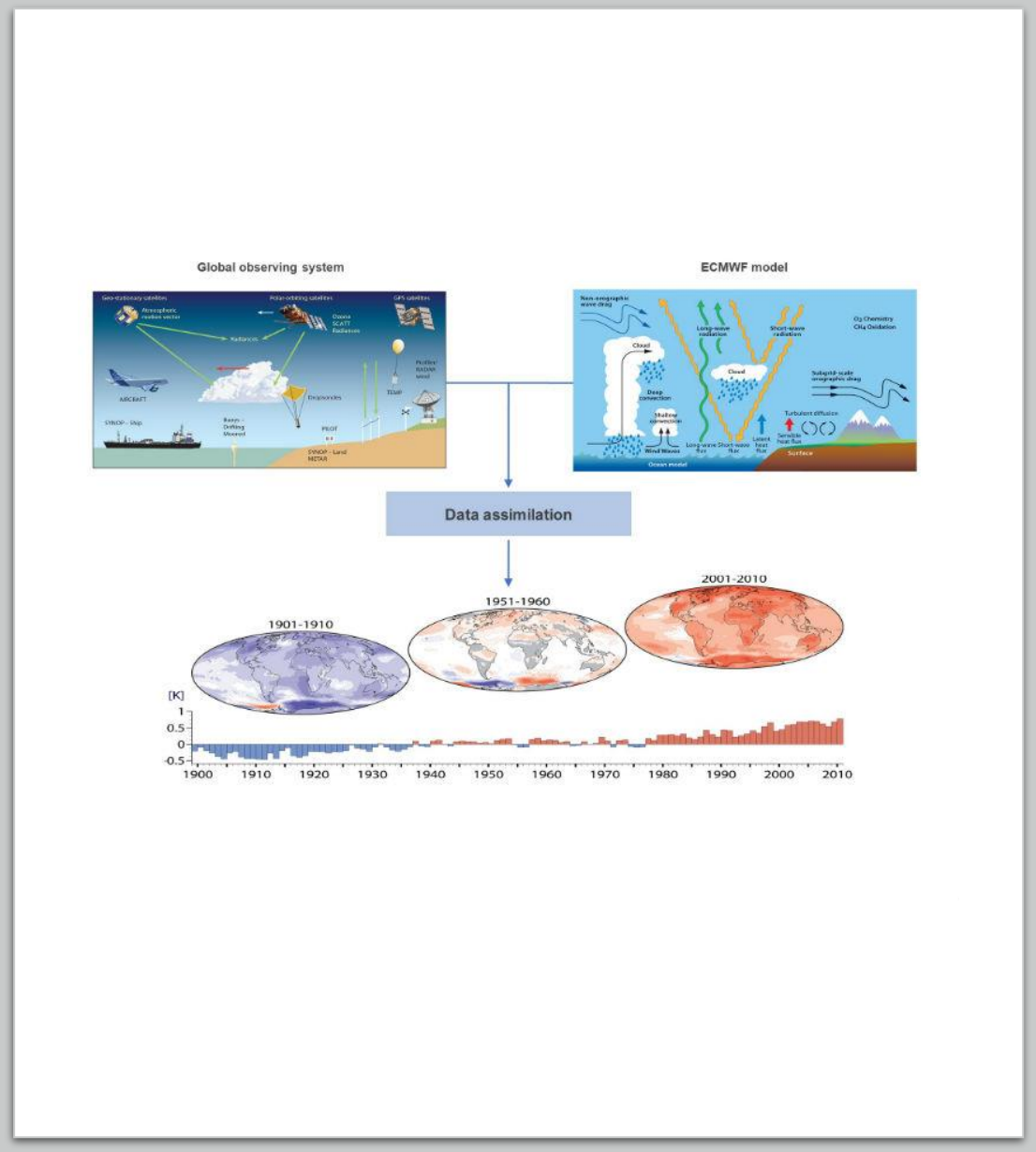
Variability

- Spatial
- Temporal
- Inter-annual

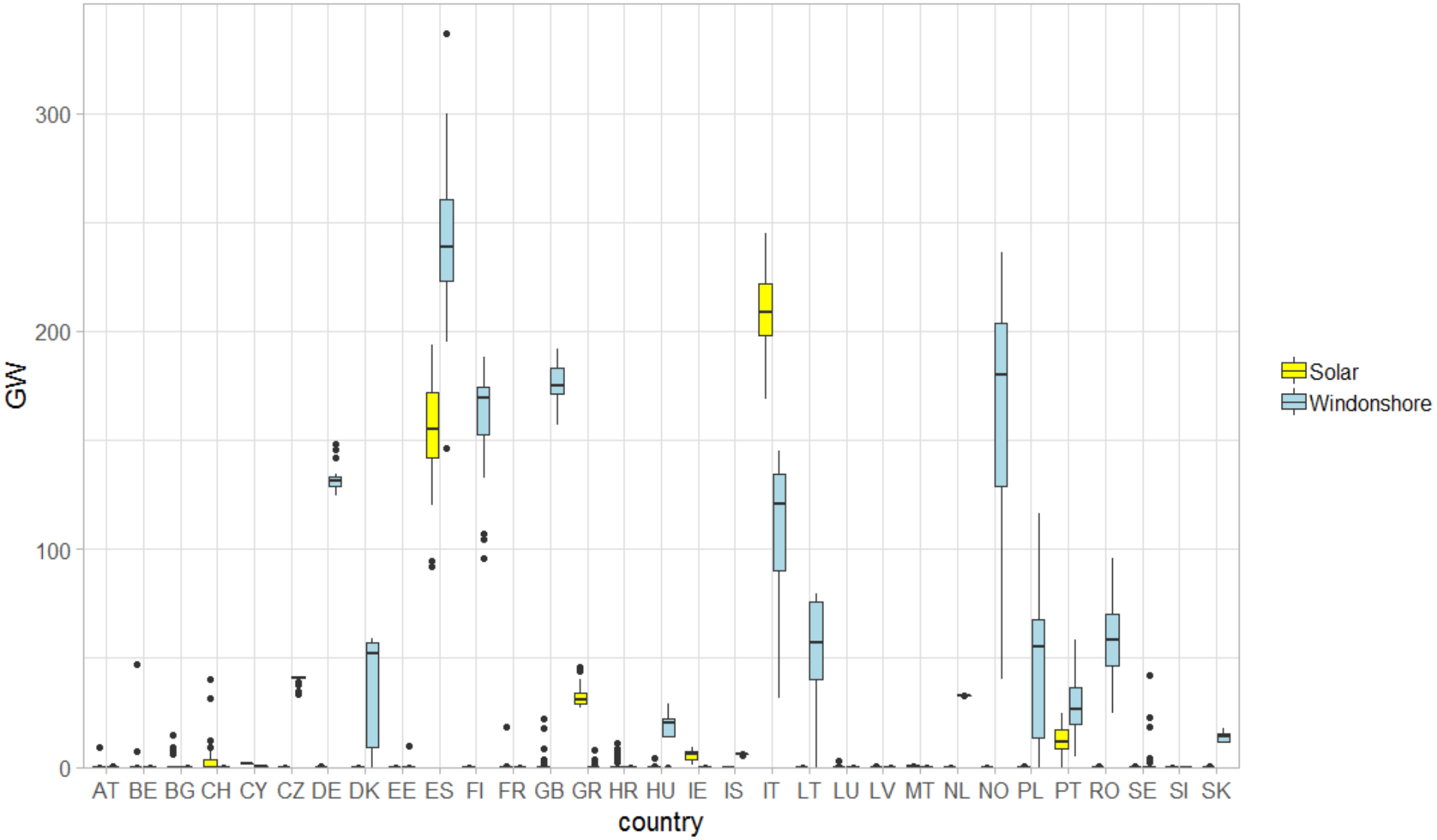


Climate reanalysis

- Climate reanalyses combine past observations with models to generate consistent (each grid point around the globe and regular output over time) time series of multiple climate variables (e.g. air temperature, pressure, wind speeds)
- ERA-5 (released end 2019): produced by ECMWF
- 0.25^{o} x 0.25^{o} resolution, with atmospheric parameters on 37 pressure levels
- Hourly
- 1950 to present

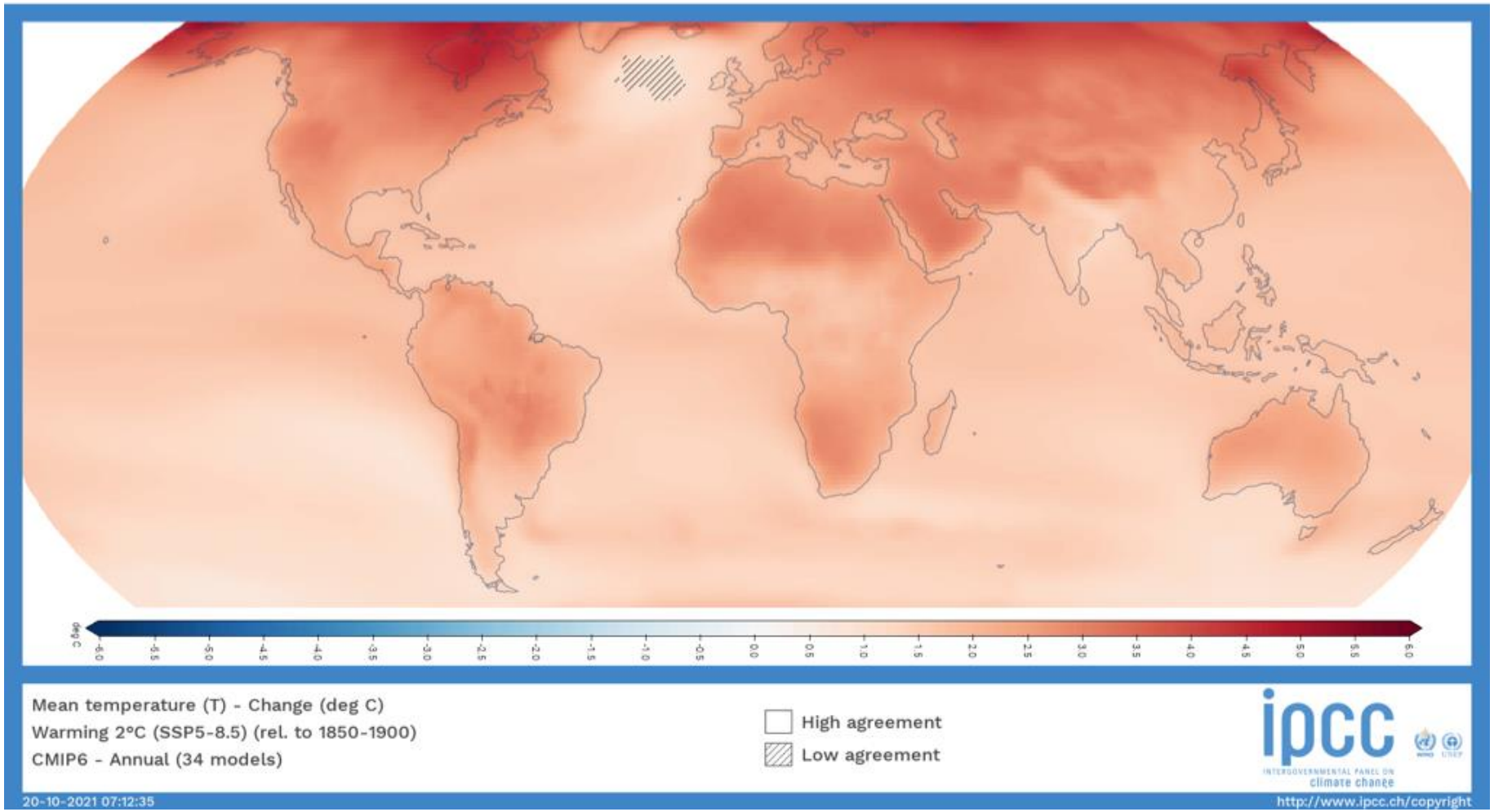


Spatial distribution of VRE capacities



- Consistent patterns:
  - Solar in the South
  - Wind energy around Europe
- Some outliers
- But strong variability (up to +80%, -150%) depending on the weather year

IPCC AR6


deg C
-6.0 -5.5 -5.0 -4.5 -4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0
Mean temperature (T) - Change (deg C)
Warming 2°C (SSP5-8.5) (rel. to 1850-1900)
CMIP6 - Annual (34 models)
High agreement
Low agreement
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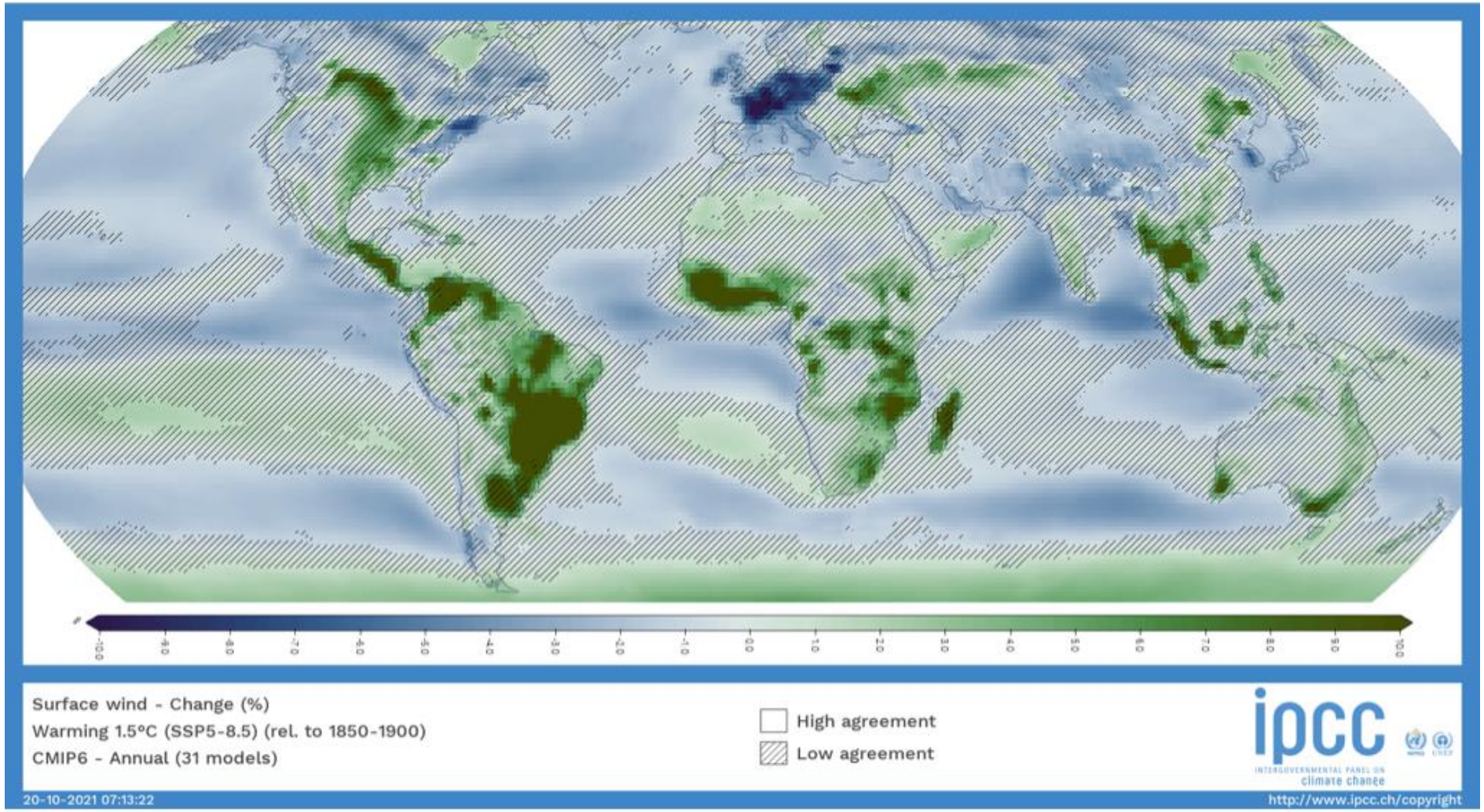
IPCC AR6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90
100
Surface wind - Change (%)
Warming 1.5°C (SSP5-8.5) (rel. to 1850-1900)
CMIP6 - Annual (31 models)
High agreement
Low agreement
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INTERGOVERNMENTAL PANEL ON climate change
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Weather and climate-resilient planning

- In renewable based energy systems, weather and climate have a crucial influence on energy supply and demand, from solar and wind generation to heating and cooling demands.
- Climate change is expected to have complex impacts on future weather-dependent energy systems through changes in mean properties, year-to-year variability, frequency and intensity of extreme events.

→mandate the need for climate-resilient system design