Reanalysis for wind and solar electricity simulations: challenges and lessons learned in the Renewables.ninja project

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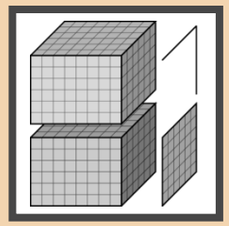
Bonn, Germany

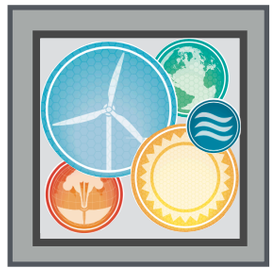
1.
Why weather matters

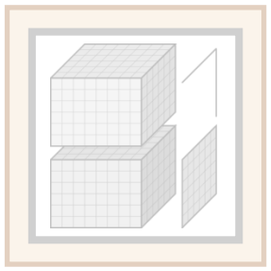
2.
How we use reanalysis

3.
Comparing reanalyses

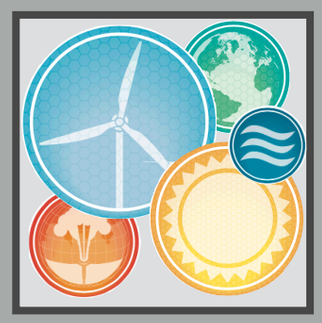


4.
The ninja project

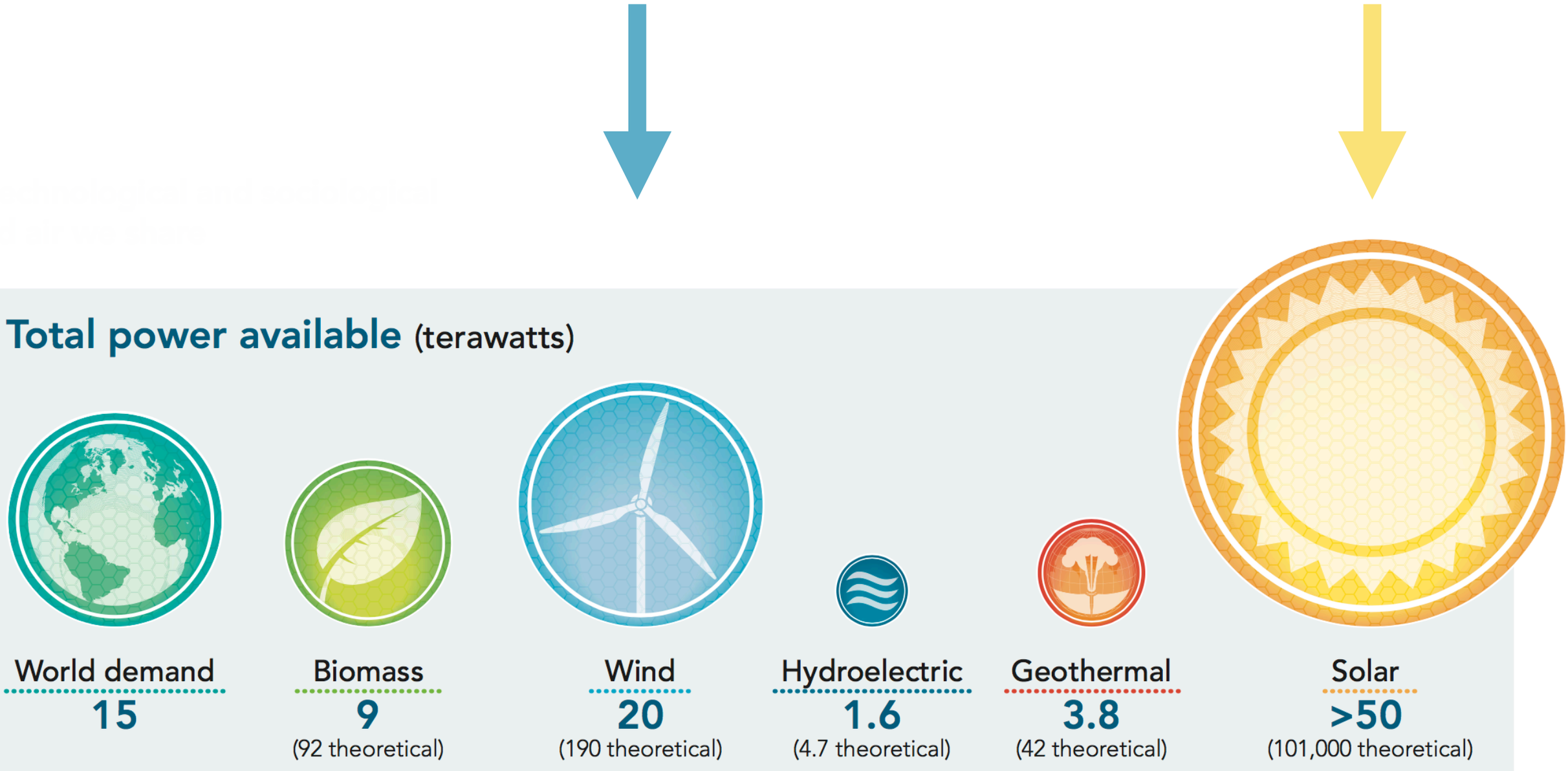





1.
Why weather matters

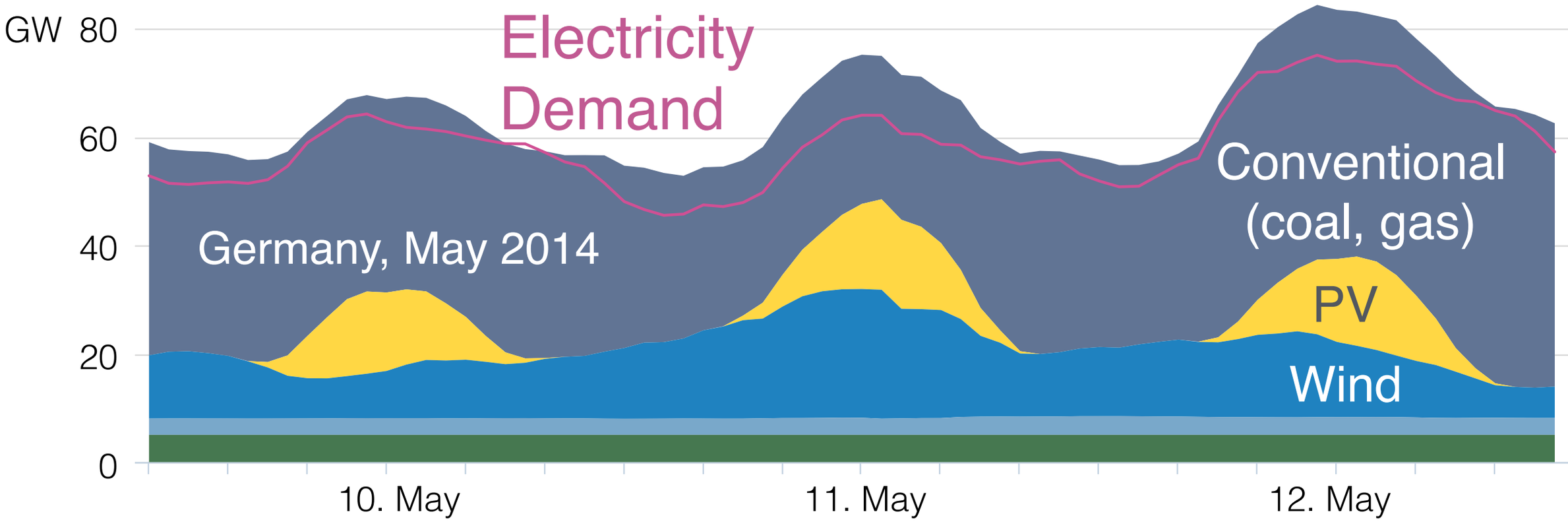


Goal: eliminate greenhouse gas emissions from the energy sector



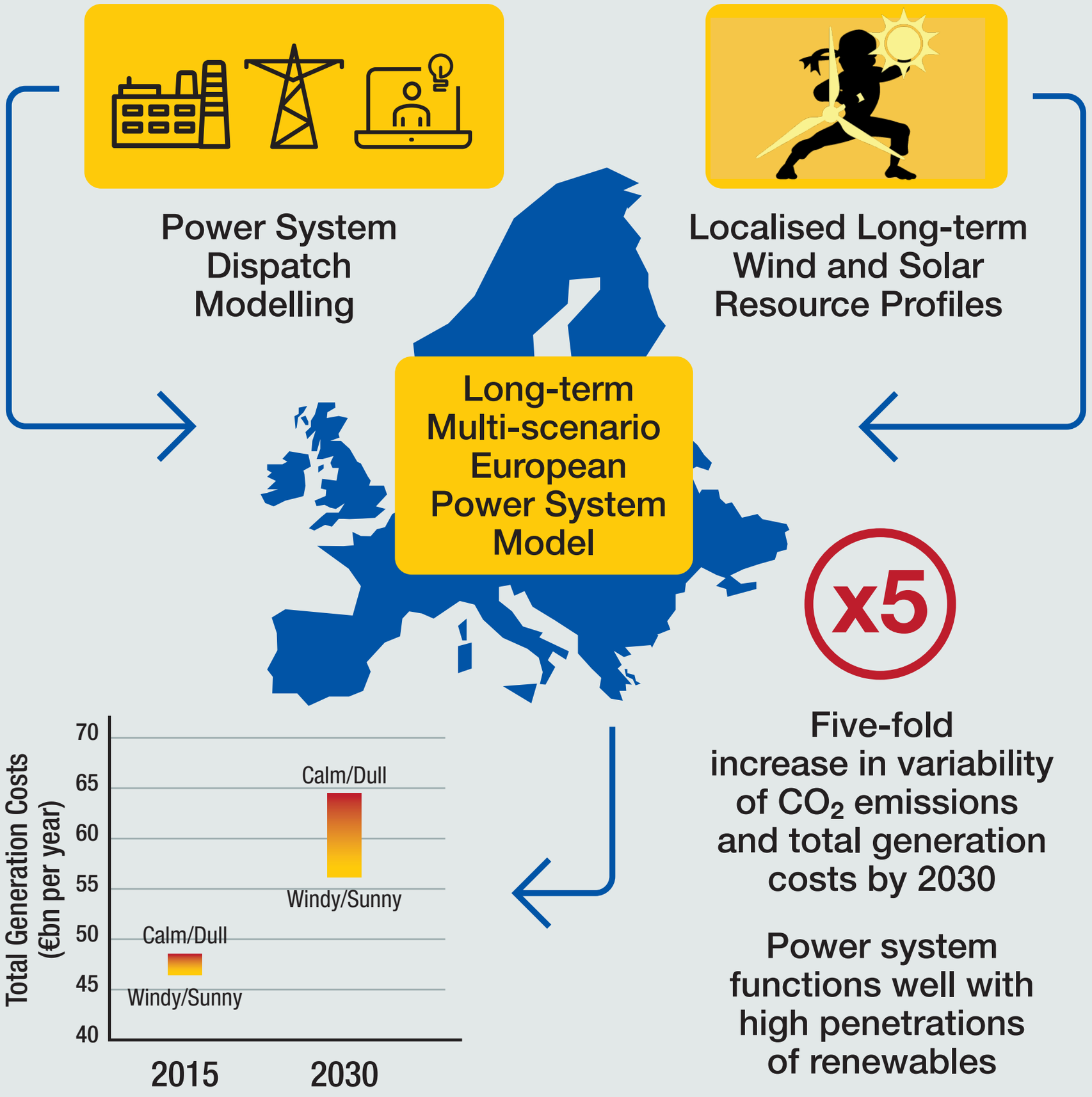
Cho (2010). *Science*

Why variability is problematic



- Demand and generation must match second by second
- Electricity is difficult to store
- Demand is not very controllable
- Power stations are not like light bulbs
- Everything must be carefully coordinated and scheduled

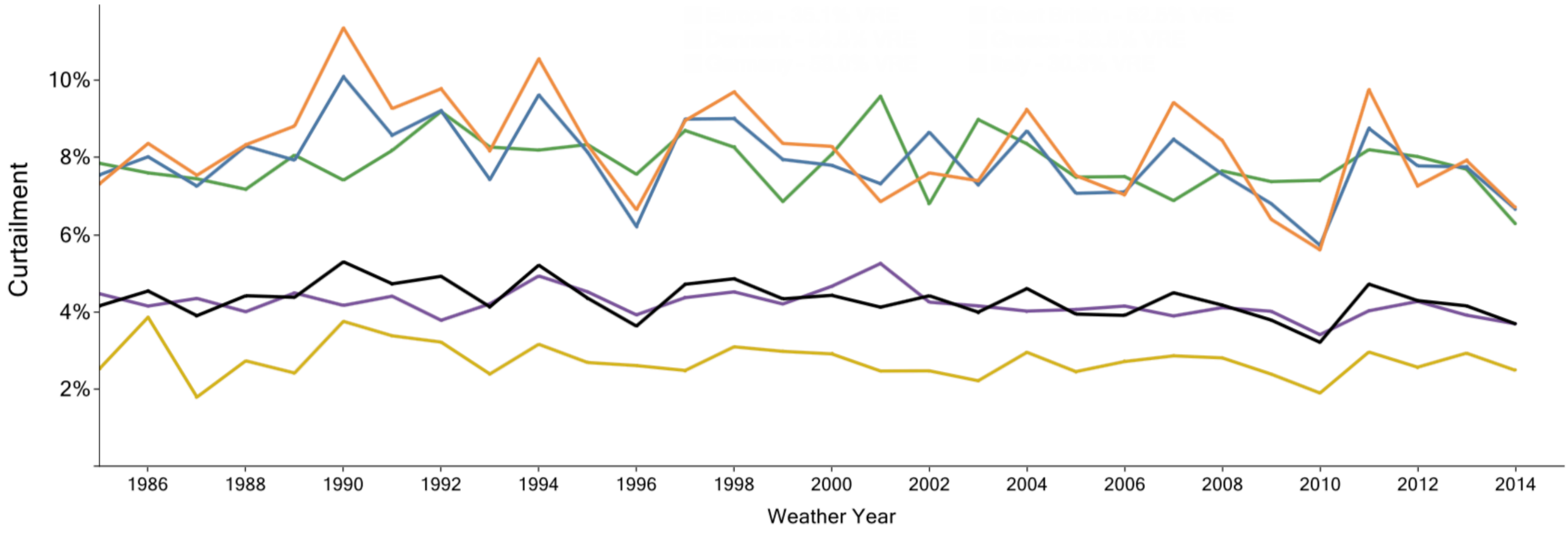
https://www.agora-energiewende.de/en/topics/-agothem-/Produkt/produkt/76/Agorameter/



Collins et al. (2018). *Joule* **[press embargo until 11:00am EST 26 July 2018]**

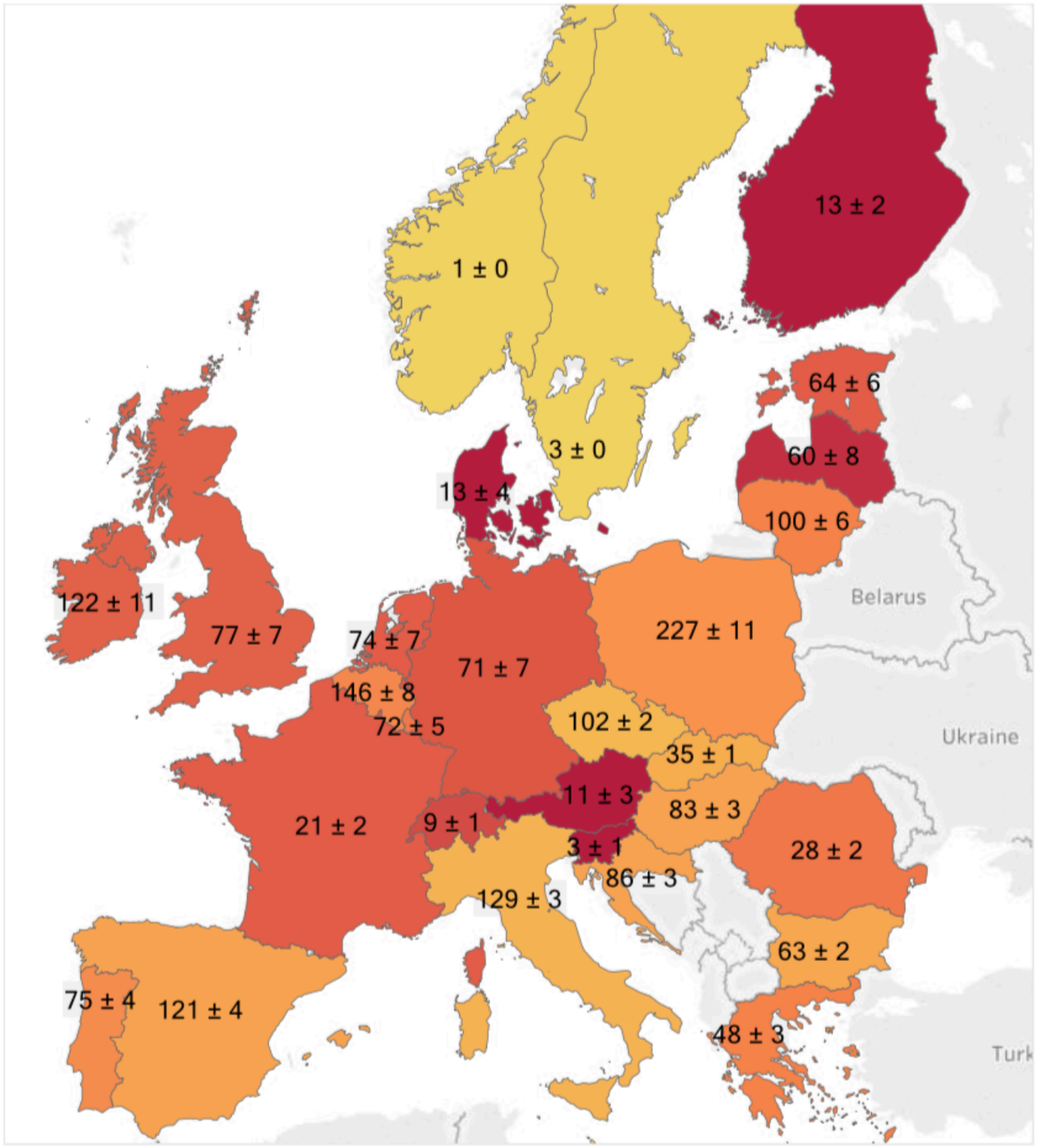
Variable weather = variable curtailment

Curtailment in ENTSO-E vision 3
(~35% of EU electricity from
solar and wind)



Collins et al. (2018). *Joule* **[press embargo until 11:00am EST 26 July 2018]**

Variability of CO_2 emissions will rise

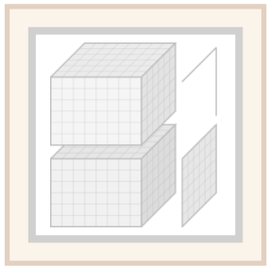


0%

Emissions intensity variability in 2030 under ENTSO-E vision 3 (30% VRE)

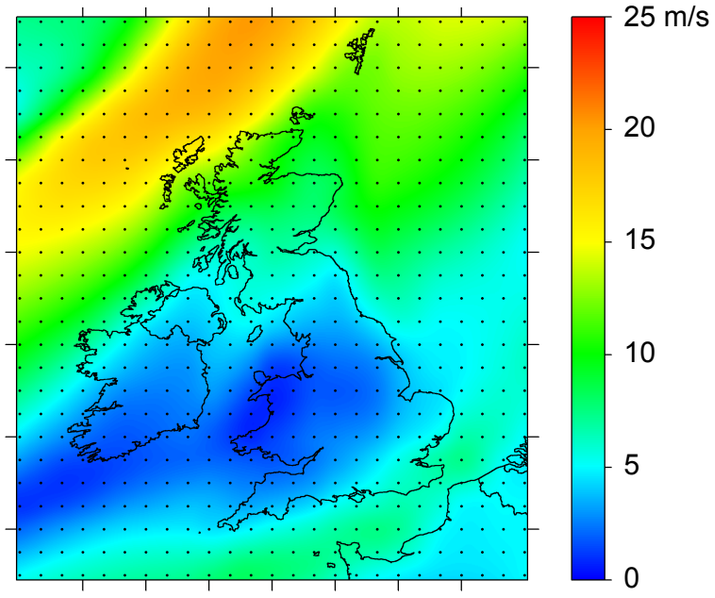
15%

Collins et al. (2018). *Joule* **[press embargo until 11:00am EST 26 July 2018]**

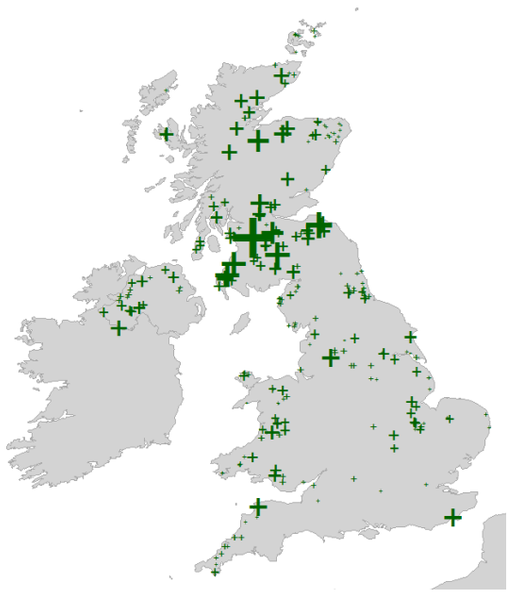




2.
How we use reanalysis

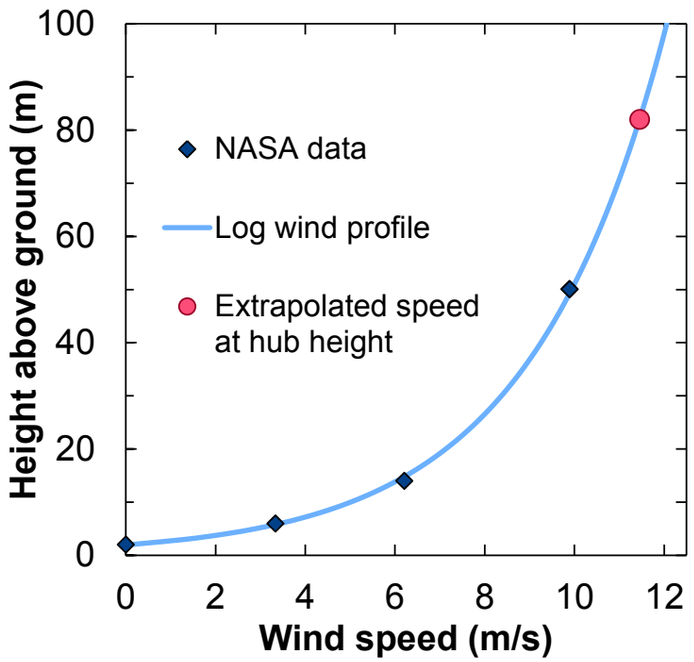
Virtual Wind Farm Model



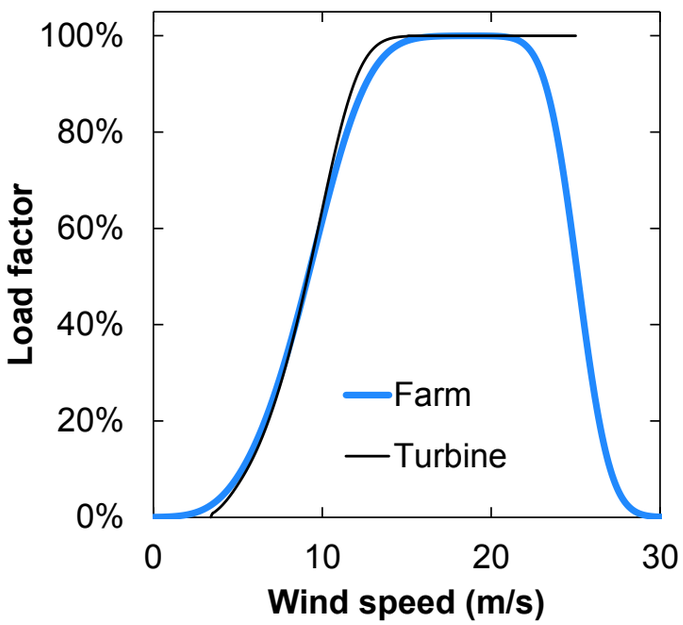
① Take hourly wind speeds from a reanalysis (originally MERRA)



② Interpolate from grid points to site of actual wind farms



③ Extrapolate wind speeds to hub height with place- and time-specific parameters



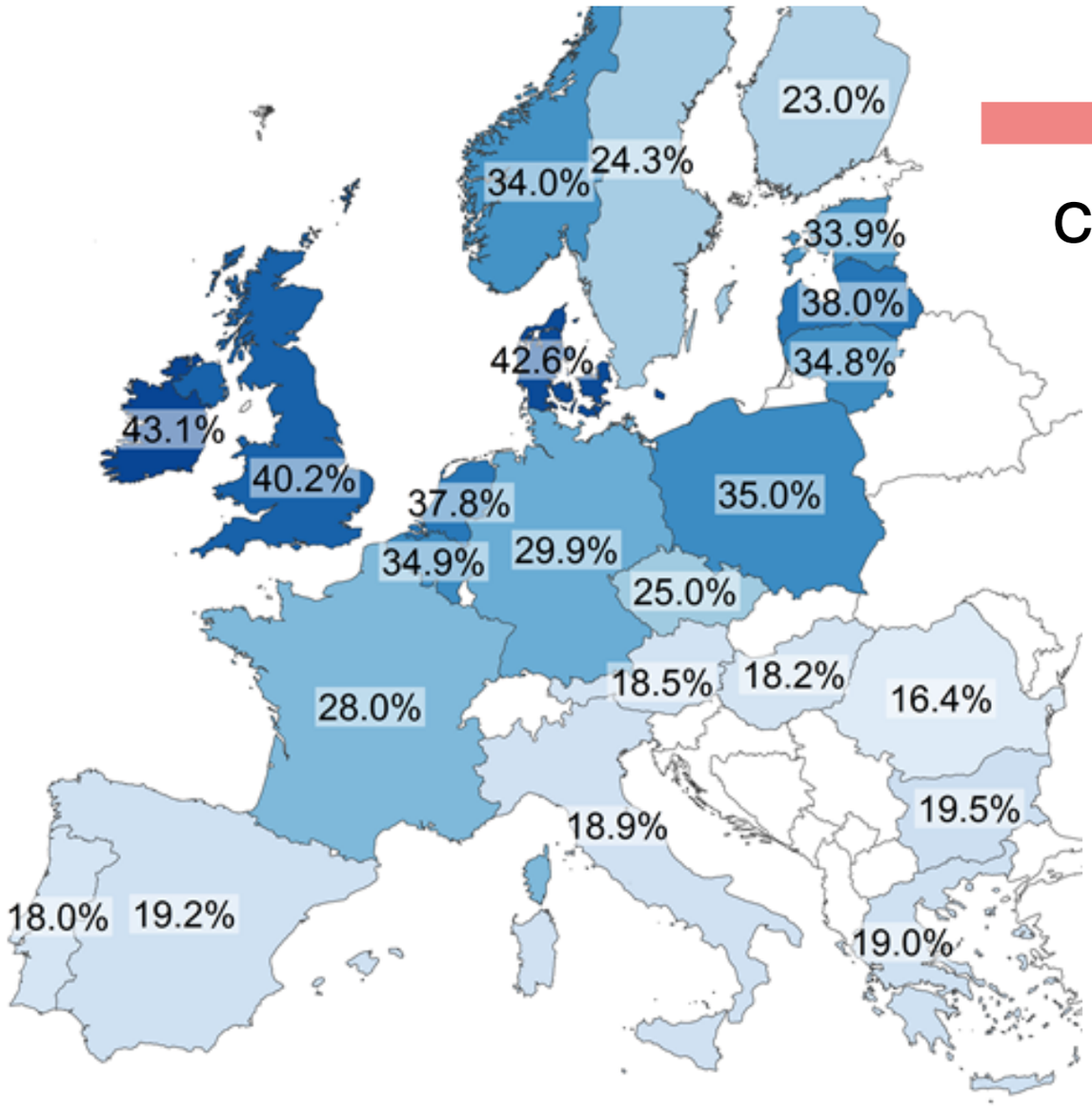
④ Convert from wind speed to power output using whole-farm power curve

Staffell and Pfenninger (2016)

Bias correction: not optional

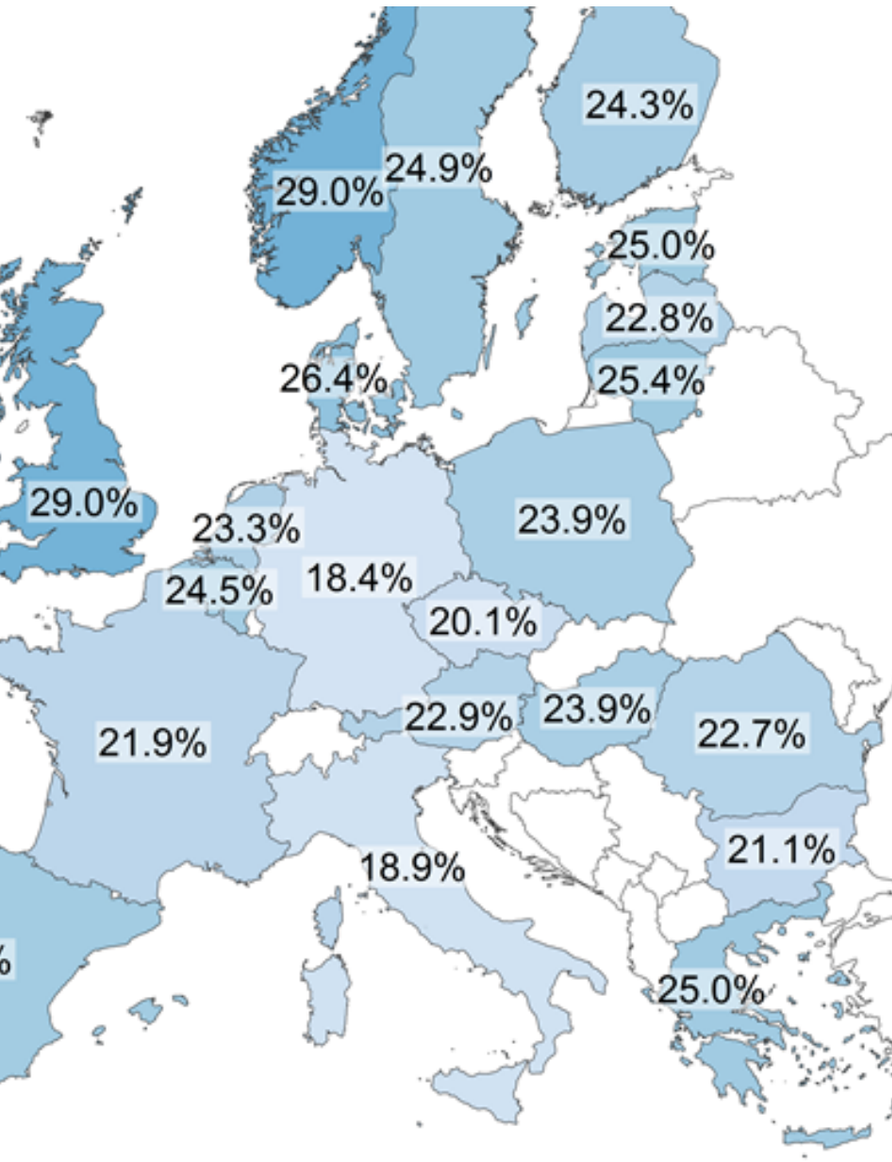
Average wind capacity factors in Europe

Original model
(uncorrected MERRA-1)



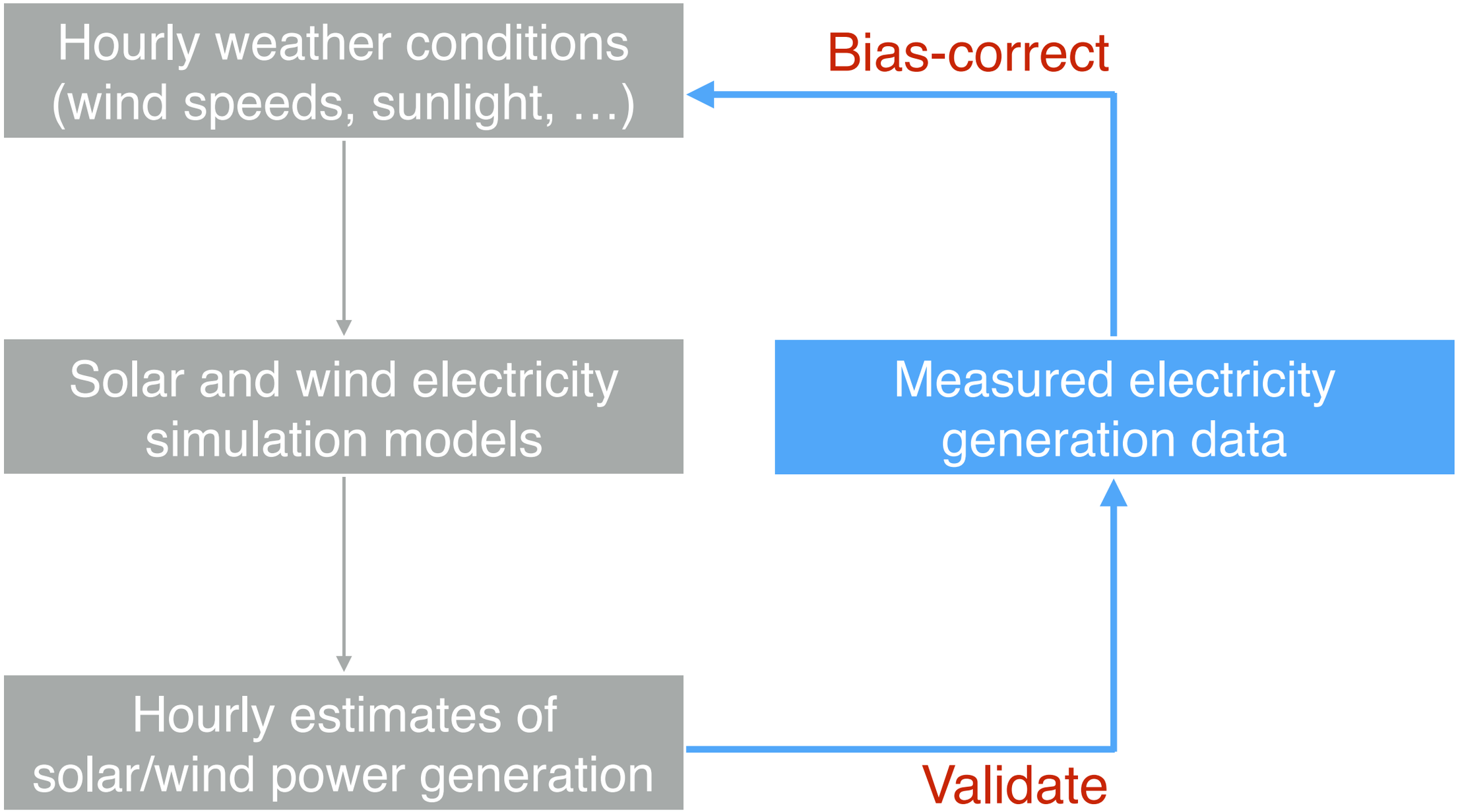
Bias correction

Actual data



Staffell and Pfenninger (2016)

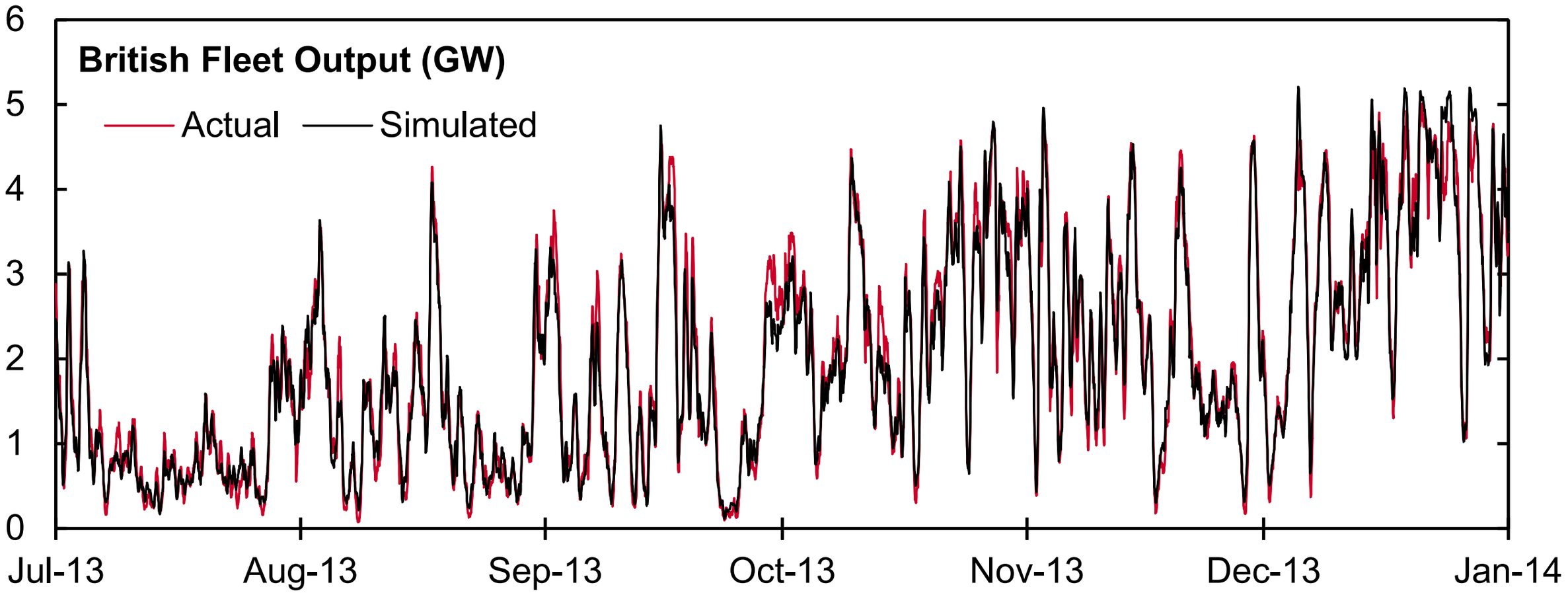
Bias correction using electric generation data



Pfenninger and Staffell (2016), Staffell and Pfenninger (2016)

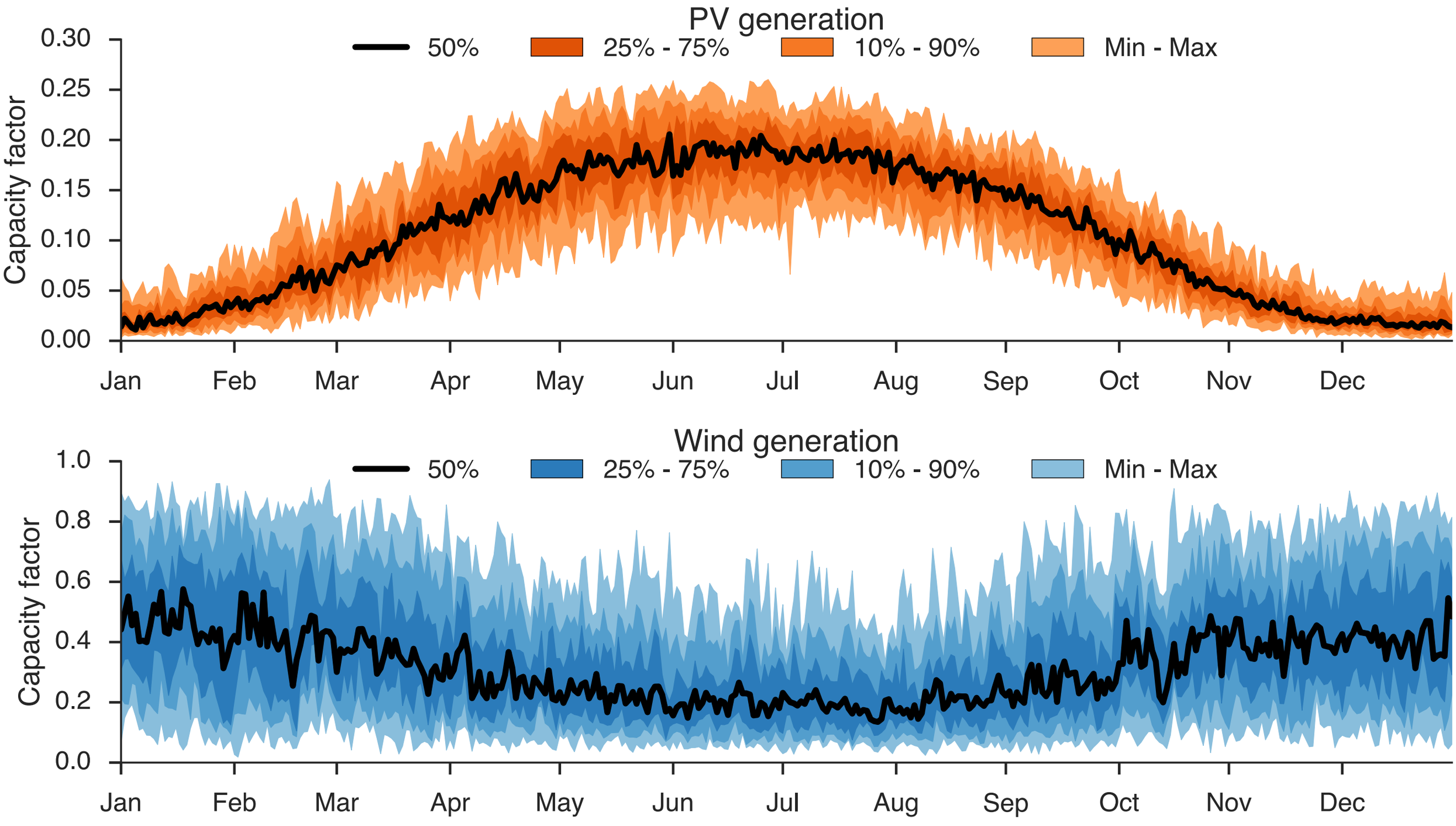
Bias-corrected wind simulations

Simulating the UK wind fleet with the MERRA reanalysis:
$R^2 = 0.95$

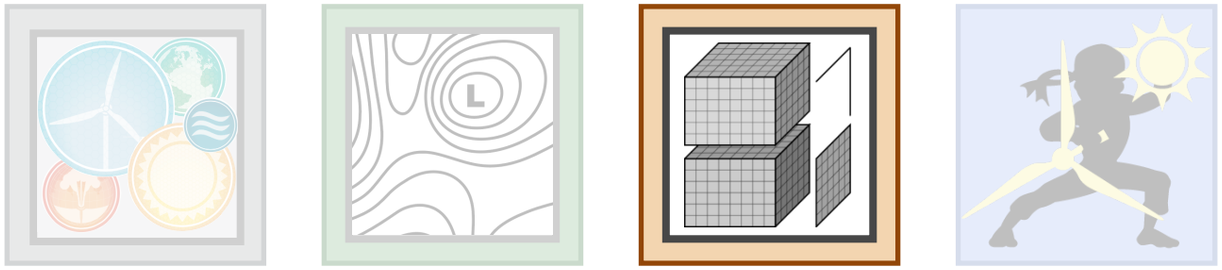


Staffell and Pfenninger (2016); actual data from Elexon & National Grid

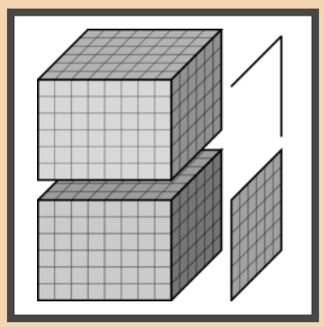
25 years of daily variability



Simulated UK wind and PV fleets, 1991-2015



3. Comparing reanalyses



(solar PV only, for now)

Image source: http://xarray.pydata.org/

Reanalysis and satellite datasets

lower resolution
more coverage

	Coverage		Resolution	
Name	**Time**	**Space**	**Time***	**Space**
MERRA-2	1980–present	Global	1 h	0.5° x 0.625°
ERA-5	2008–present* (later: from 1950)	Global	1 h	0.281° x 0.281°
COSMO-REA6	1995–2015	Regional	1 h	0.055° x 0.055°
SARAH (v1)	1983–2015	Regional	1 h	0.05° x 0.05°
SARAH (v2)	1983–2015 (soon more)	Regional	30 min	0.05° x 0.05°

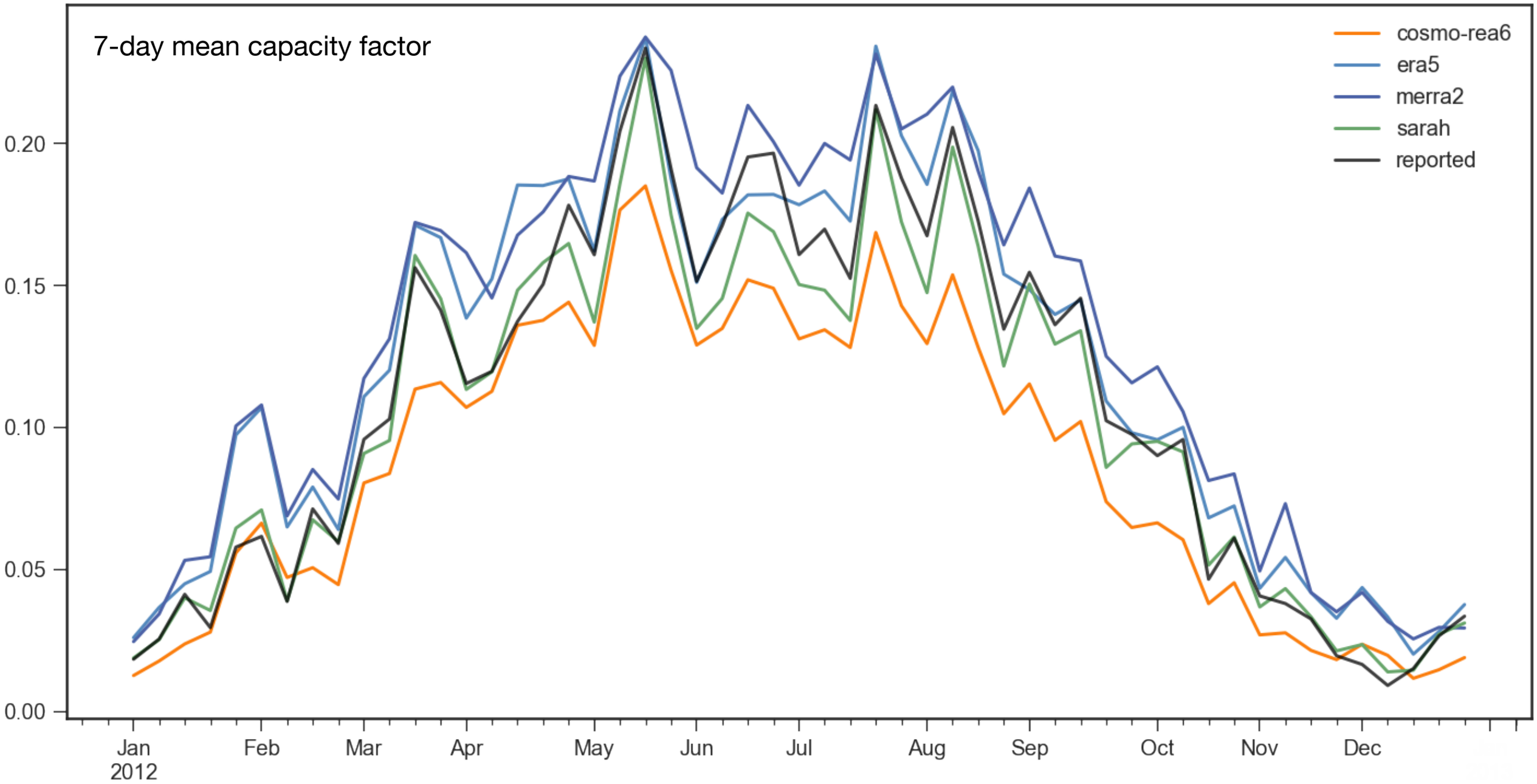
* readily available for download

higher resolution
less coverage

Urraca et al., 2018: "We conclude that **ERA5 and COSMO-REA6 have reduced the gap between reanalysis and satellite-based data**" (for solar irradiance data)

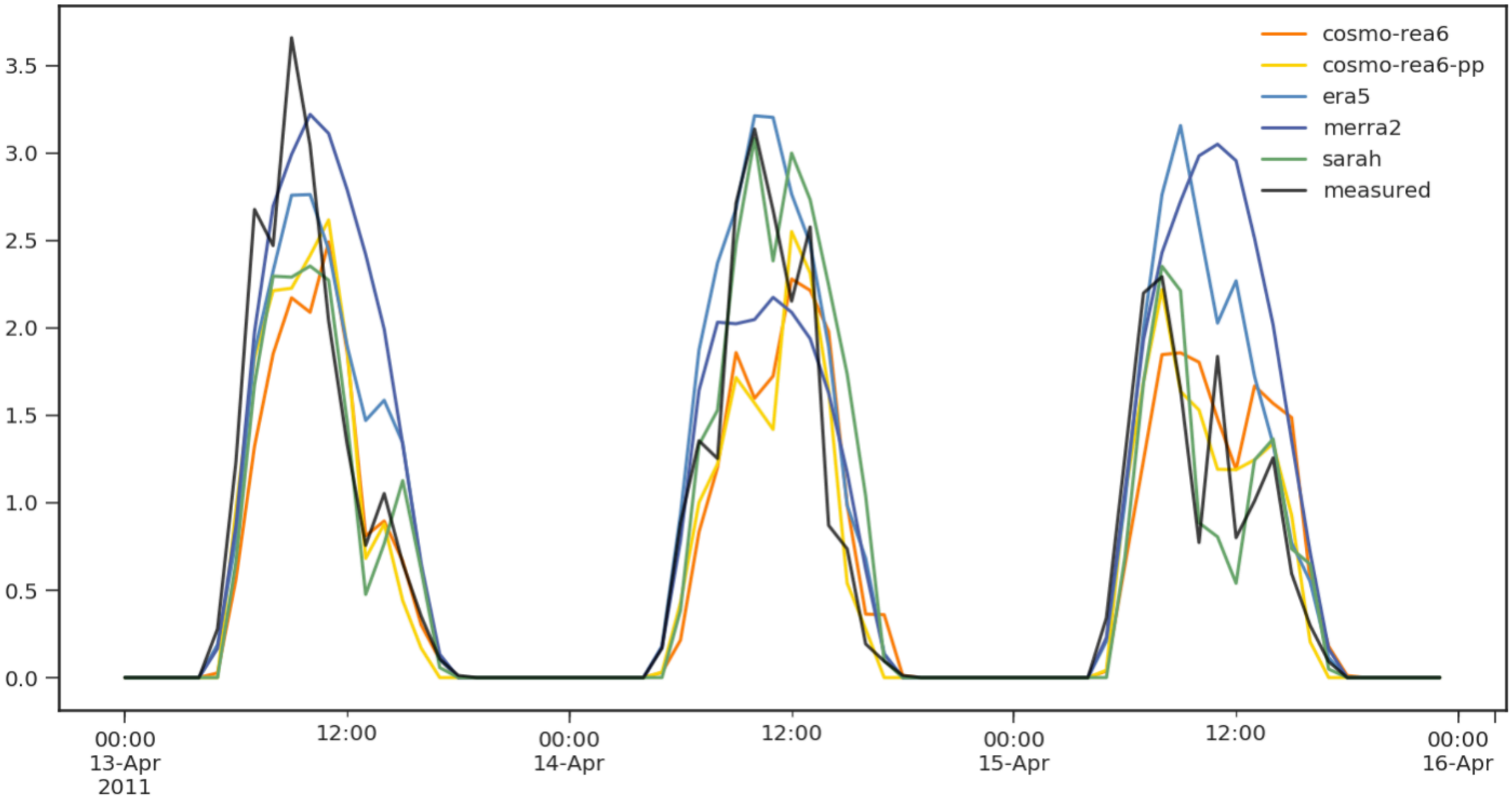
Urraca et al. (2018). *Solar Energy*
Pfenninger and Staffell. Work in progress.

Germany: PV capacity factors (2012)

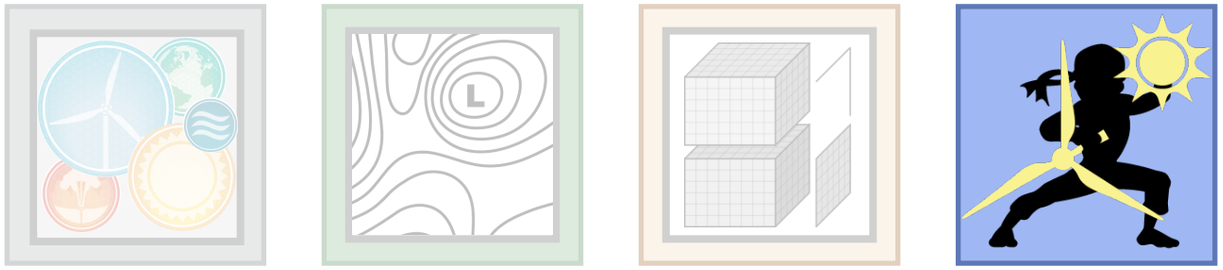


Pfenninger and Staffell. Work in progress.

Single PV system:
SARAH best, COSMO-REA6 not bad



Pfenninger and Staffell. Work in progress.
Post-processed COSMO-REA6 data from Frank et al. (2018). *Solar Energy*



4.
The ninja project

www.renewables.ninja

Goal: provide easy access to validated wind and PV simulations worldwide.

>1500 users from >250 institutions in 65 countries.

Pfenninger and Staffell (2016). *Energy*; Staffell and Pfenninger (2016). *Energy*

renewables.ninja

Renewables.ninja

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Lat 40.5138 Lon 15.3809

Solar PV

Dataset

MERRA-2 (global)

Select a year of data

2014

Or choose precise dates:

2014-01-01 to 2014-12-31

Capacity (kW)

1

System loss (%)

10

Tracking

None

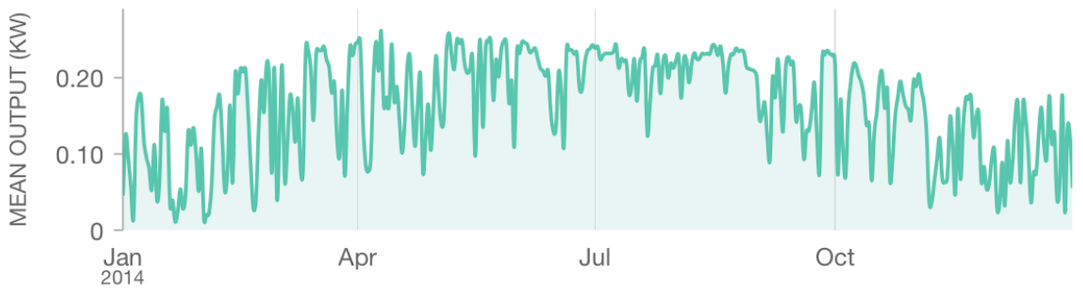
Tilt (°)

35

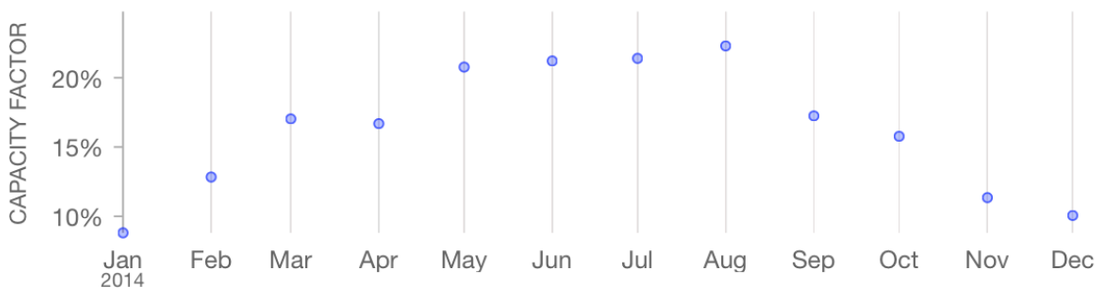
Azimuth (°)

Results

Daily mean output



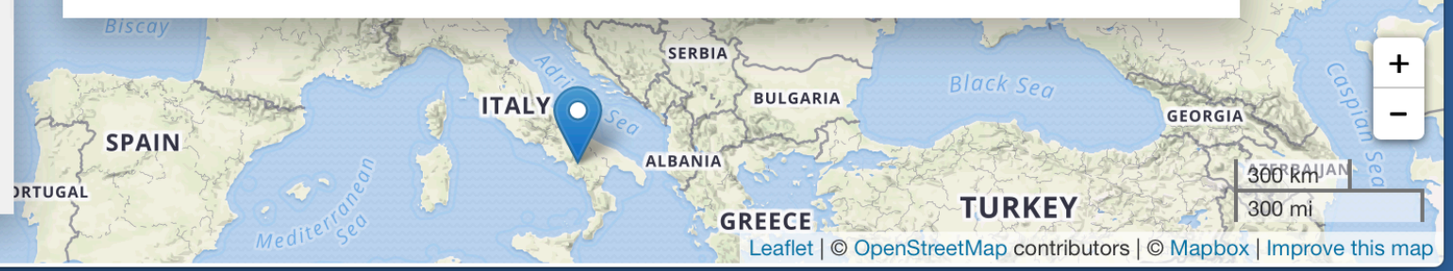
Monthly capacity factor



Total mean capacity factor: 16.3%

Save hourly output as CSV

License: Creative Commons Attribution-NonCommercial
Citation: Pfenninger and Staffell (2016)



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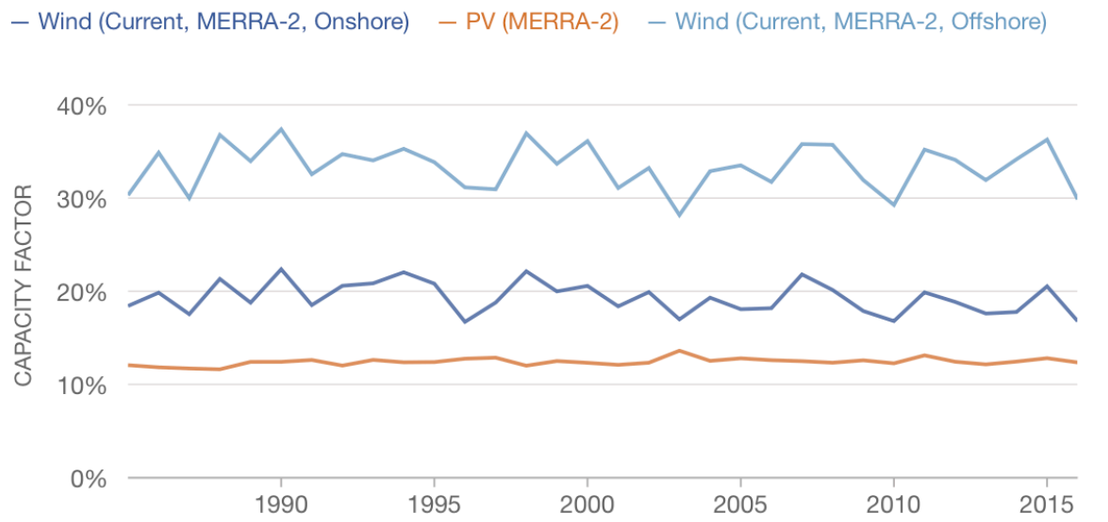
Germany

Germany

Country-level data for Germany. The figure shows an estimate of average annual capacity factors based on current installed capacities and MERRA-2. Detailed hourly data can be downloaded below.

Average annual capacity factors for PV and wind



PV (hourly data, 1985-2016)

- PV (MERRA-2) (6.59 MB)
- PV (SARAH) (6.37 MB)

License: Creative Commons Attribution-NonCommercial
Citation: Pfenninger and Staffell (2016)

Wind (hourly data, split by on/offshore, 1980-2016)

- Wind (Current, MERRA-2) (12.68 MB)
- Wind (Near-term future, MERRA-2) (12.68 MB)
- Wind (Long-term future, MERRA-2) (8.35 MB)

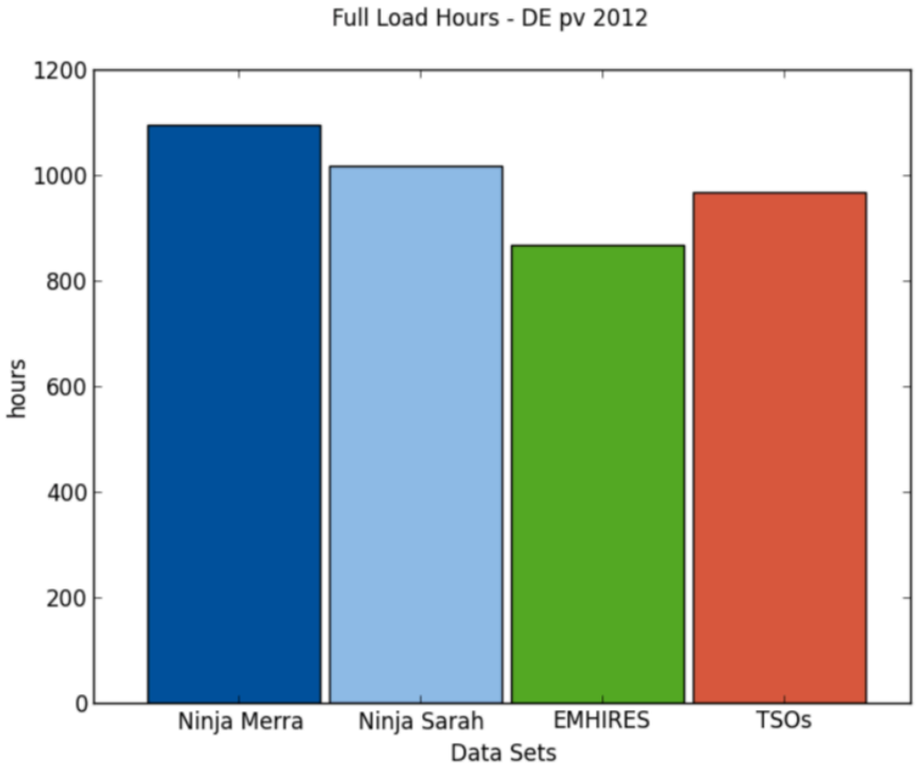
SWEDEN FINLAND NORWAY RUSSIA DENMARK ESTONIA LATVIA LITHUANIA BELARUS POLAND GERMANY UKRAINE FRANCE HUNGARY ROMANIA SERBIA BULGARIA ITALY TURKEY

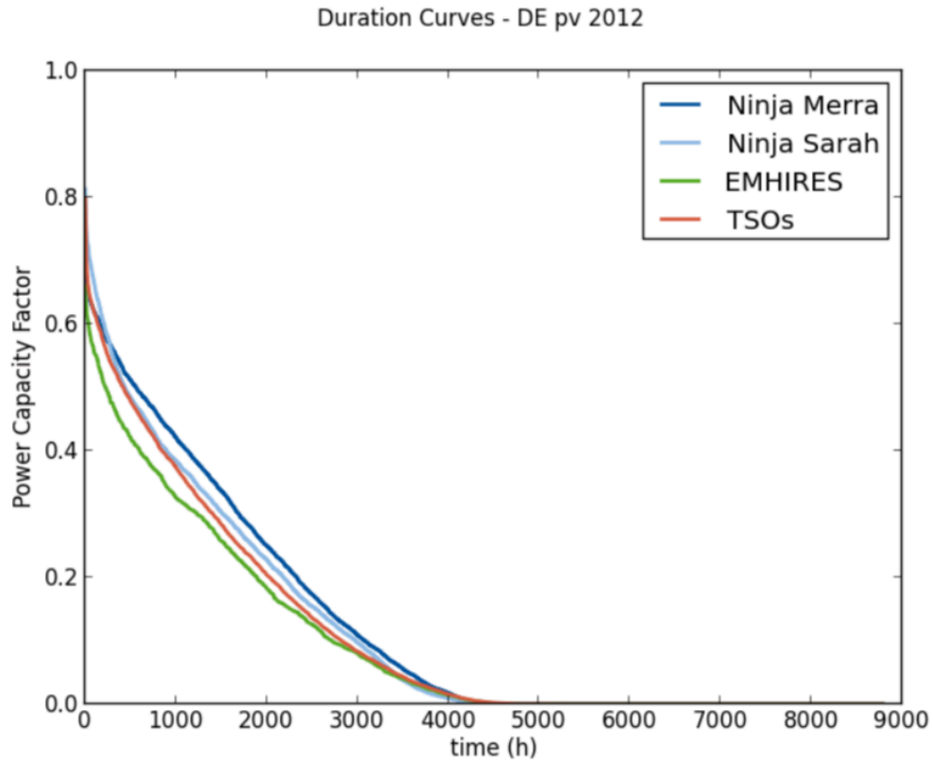
500 km
300 mi

Leaflet | © OpenStreetMap contributors | © Mapbox | Improve this map

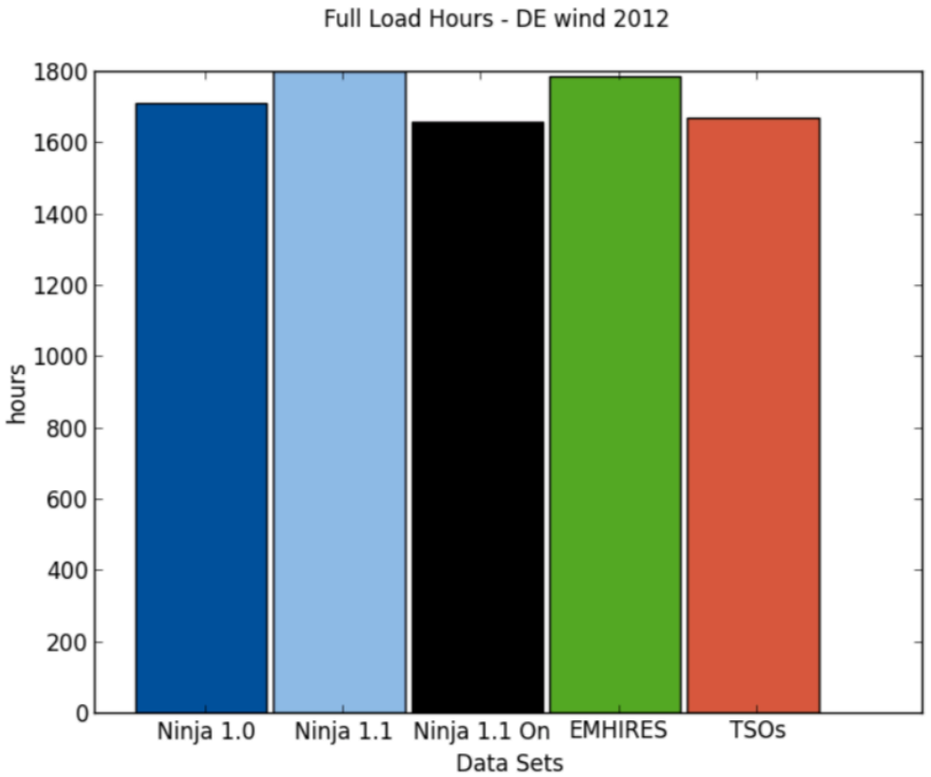
External validation — National level

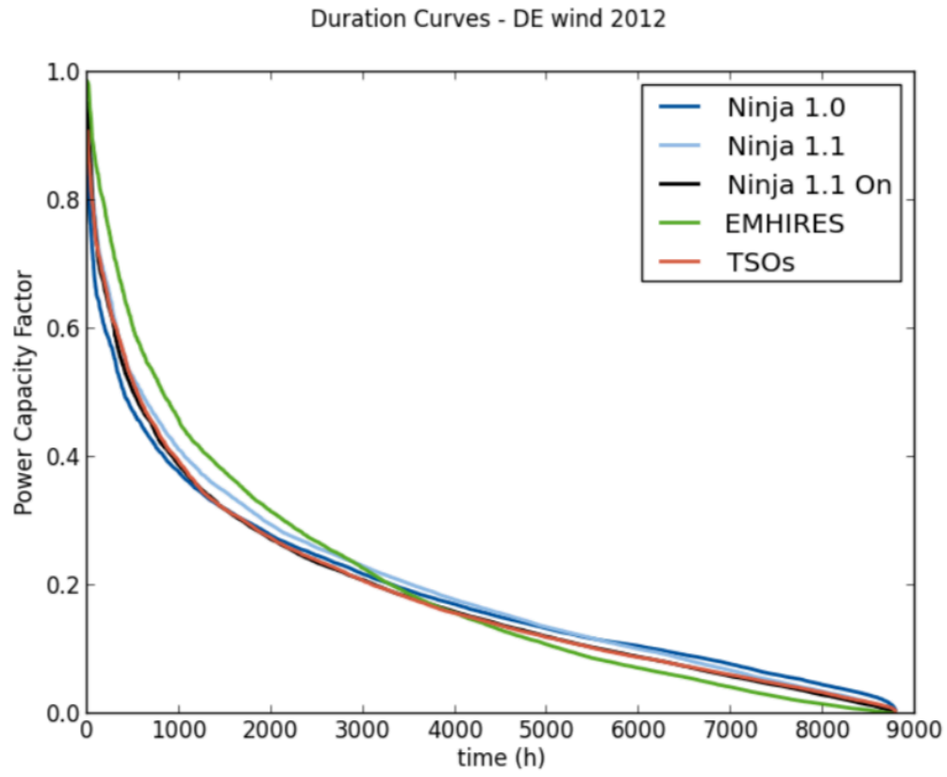
PV





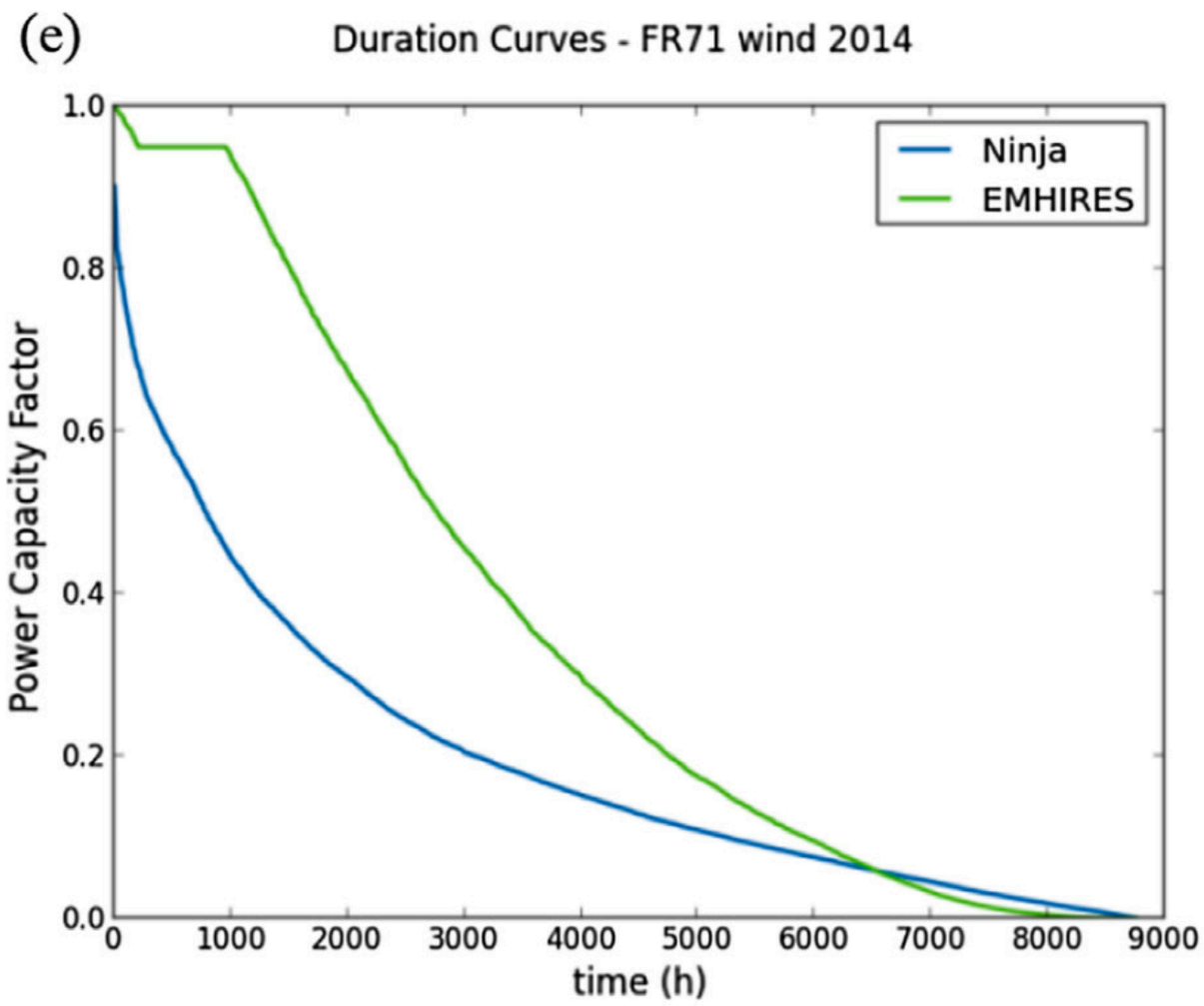
Wind

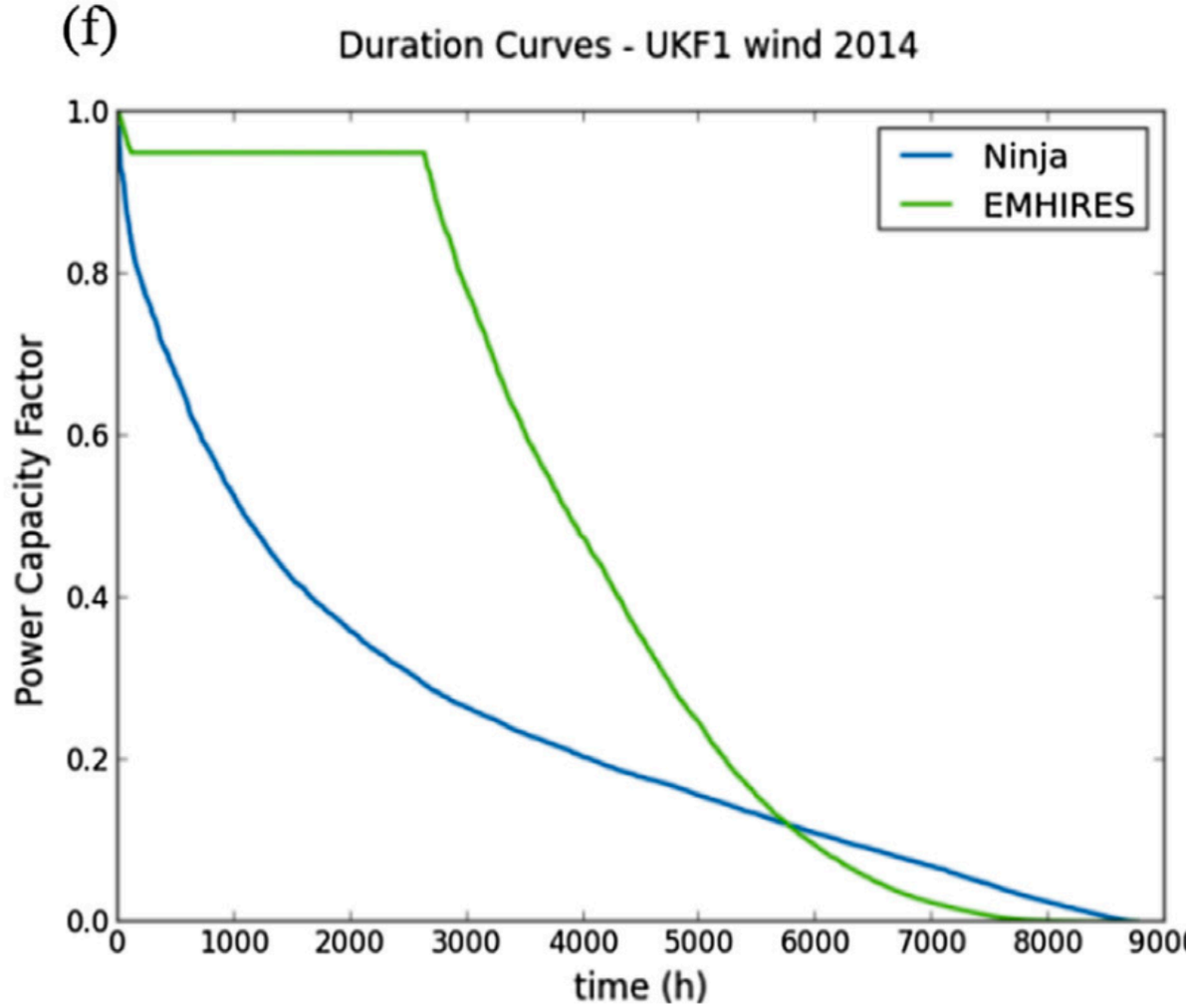




Moraes et al. (2018). *Applied Energy*

External validation — NUTS-2 level





Moraes et al. (2018). *Applied Energy*

External validation

"The lack of a **trust-worthy source of data for comparison** makes the evaluation of data quality challenging in many countries."

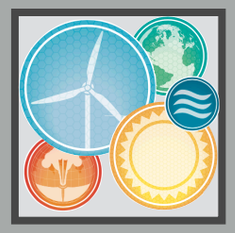
"[…] the chain of methods used to convert wind speeds and solar radiation into power outputs are decisive in this process, and the **use of reanalysis data is promising**"

Moraes et al. (2018). *Applied Energy*

Renewables.ninja: Upcoming improvements

- NUTS-2 level data for Europe should be online by end of this week
- Global country and sub-country level data (e.g. U.S. states, Chinese provinces) later this year
- New generation of reanalyses and better bias correction

1. Why weather matters



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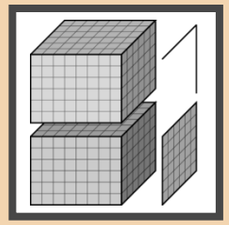

4. The ninja project

Discussion

- What is **ground truth**? Reference energy datasets → better reanalysis validation and bias correction.
- Which reanalyses have which strengths? Or, how to **choose the right reanalysis** for a particular task?
- What **improvements for energy applications** are easily possible within existing / next-gen reanalyses?

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