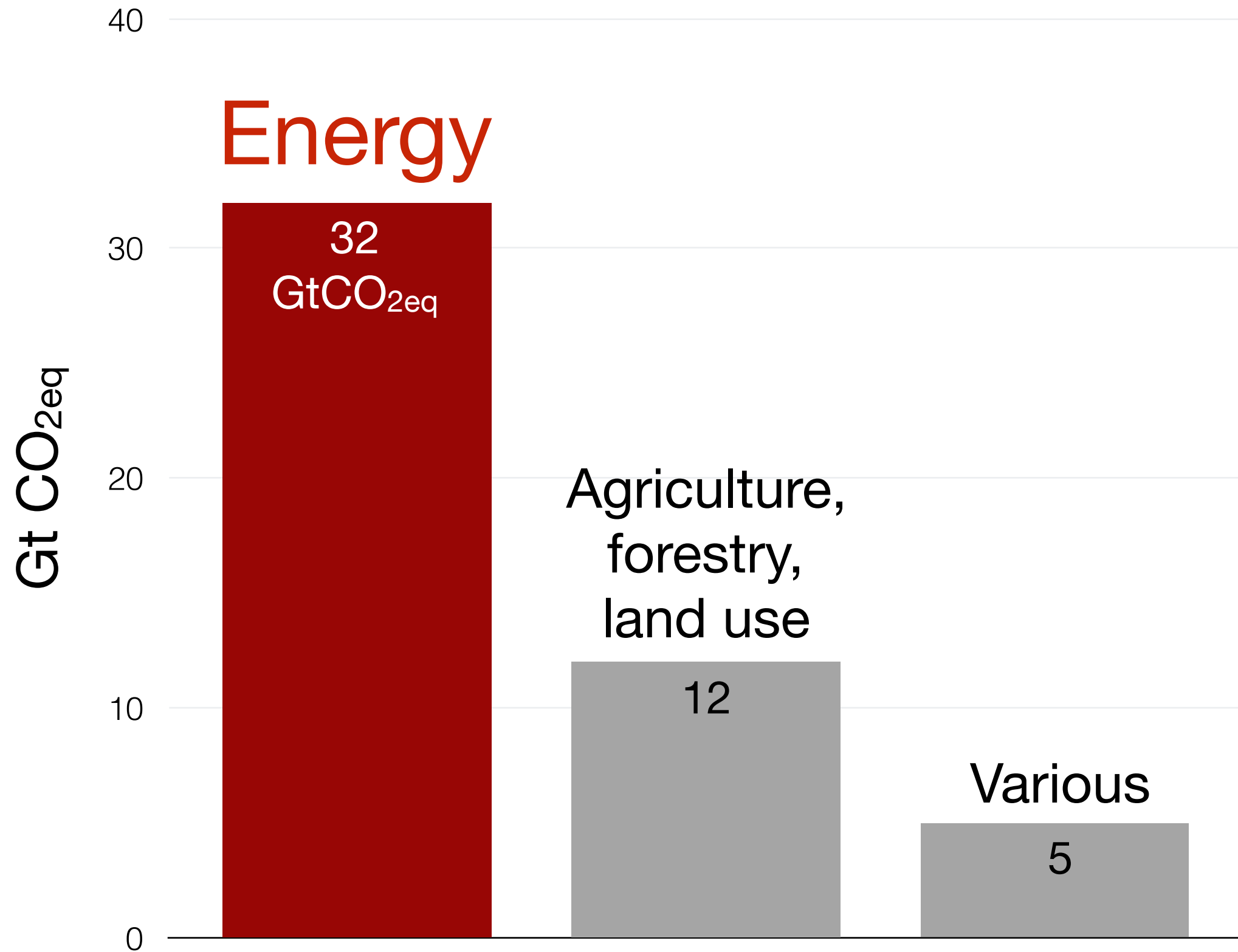


# Using reanalysis for wind and solar power simulations: the Renewables.ninja project



# Annual greenhouse gas emissions (2010)



# Eliminating energy emissions

Total power available (terawatts)



World demand  
**15**



Biomass  
**9**  
(92 theoretical)



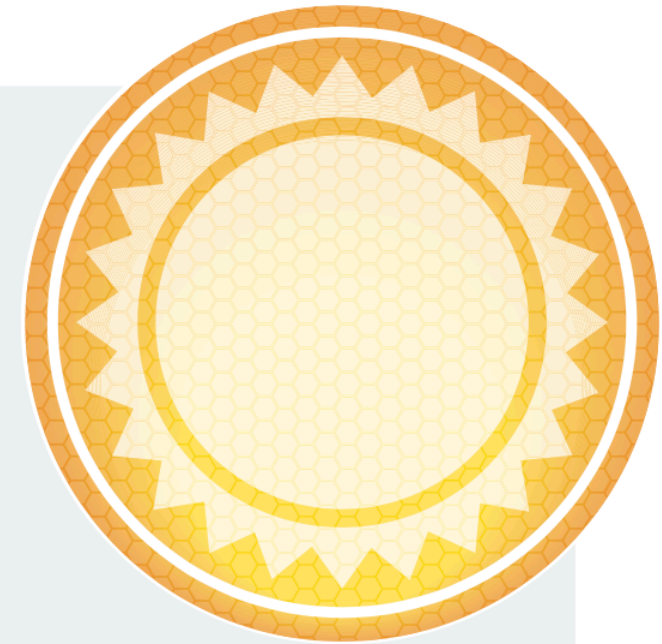
Wind  
**20**  
(190 theoretical)



Hydroelectric  
**1.6**  
(4.7 theoretical)



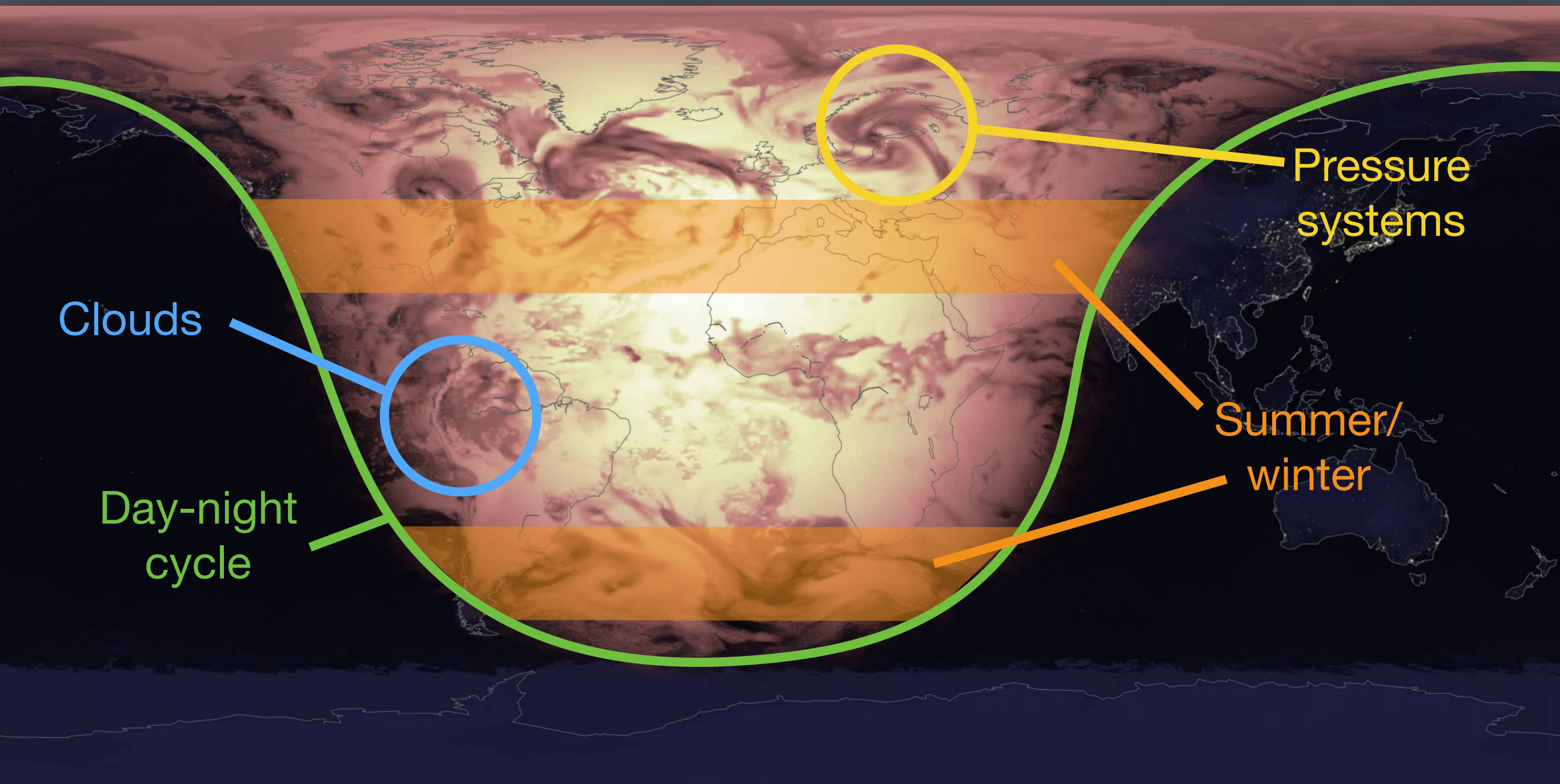
Geothermal  
**3.8**  
(42 theoretical)



Solar  
**>50**  
(101,000 theoretical)



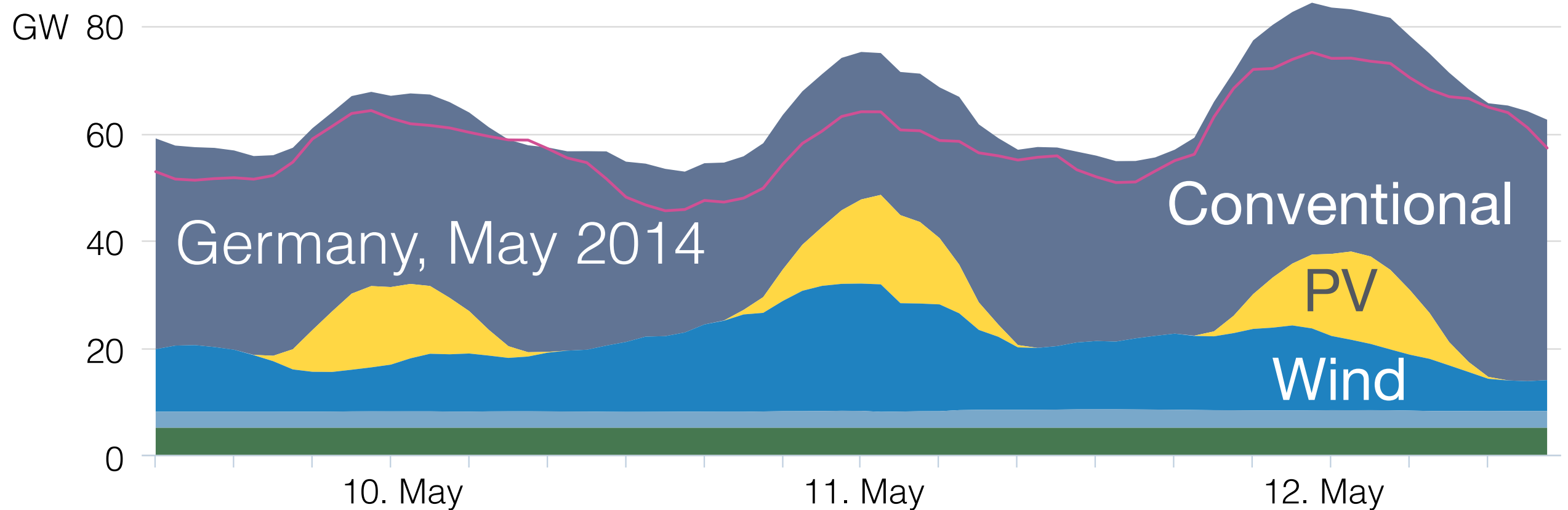
# Variability is a key problem



- ① Short-term    ② Diurnal    ③ Multi-day    ④ Seasonal    ⑤ Long-term



# 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

# We need data on solar and wind generation

- Use measured meteo station data
  - Very limited spatial coverage, varying quality
- Use satellite imagery
  - Limited spatial and temporal coverage
  - Directly applicable to photovoltaics (PV) only, not wind
- Pay for commercial data
  - Aimed at industry and project developers
  - Investment-grade results = investment-grade costs
- Reanalysis data is attractive – **but can it be trusted?**
  - Data is cleaned and organised
  - Global or regional spatial coverage over multiple decades
  - But... ‘measurements’ come from a numerical model

# How we use reanalysis data

# Bias correction: not optional

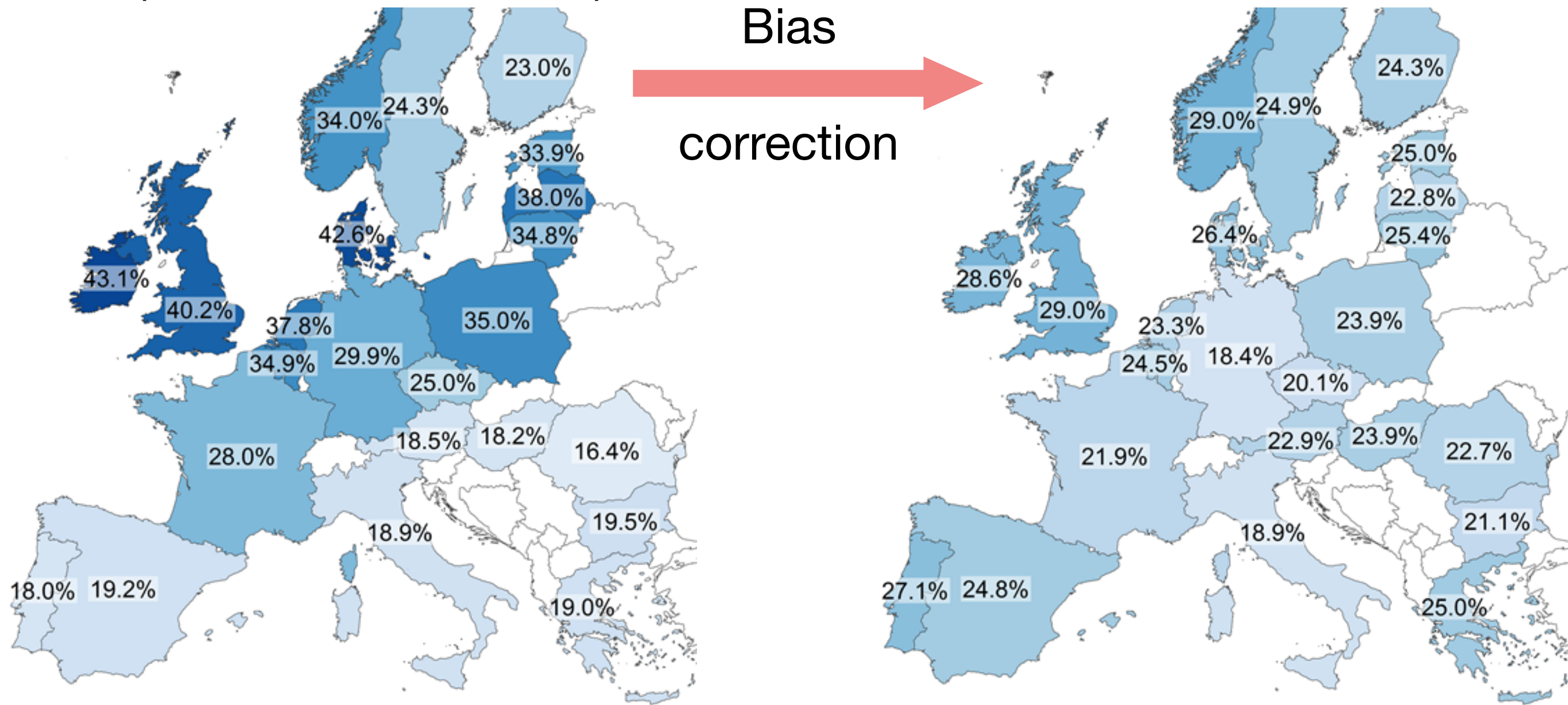
*Average wind capacity factors in Europe*

Original model  
(uncorrected MERRA)

Actual data

Bias

correction

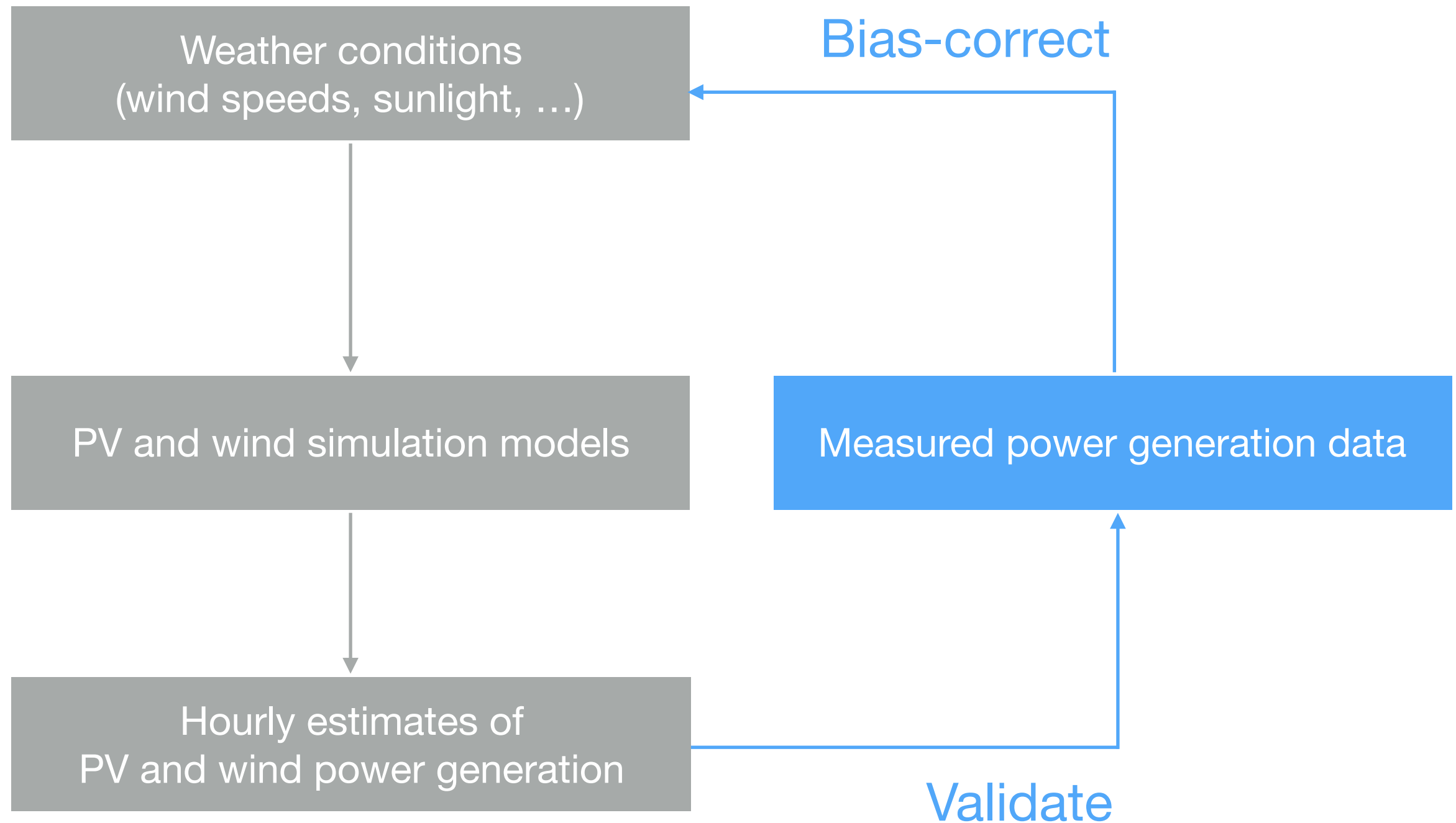




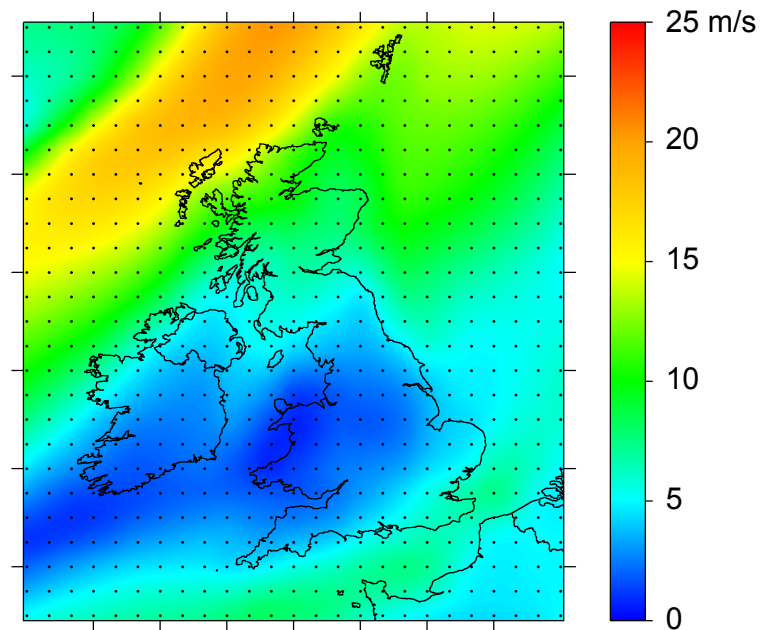
# Bias-correcting

- Reanalysis without calibration *will* get it wrong!
- Adjust wind speed / irradiance resource data up or down
- Q: But... with  $\pm 40\%$  adjustment, ***what's the point?***
- A: Bias-corrected simulations are surprisingly accurate

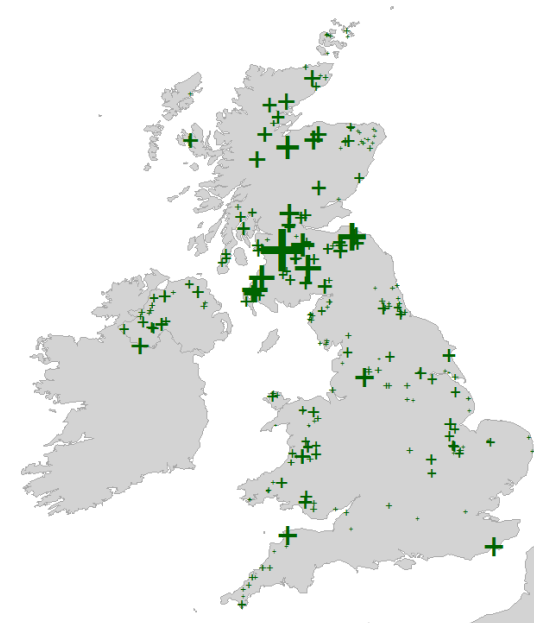
# Bias-correcting with power generation data



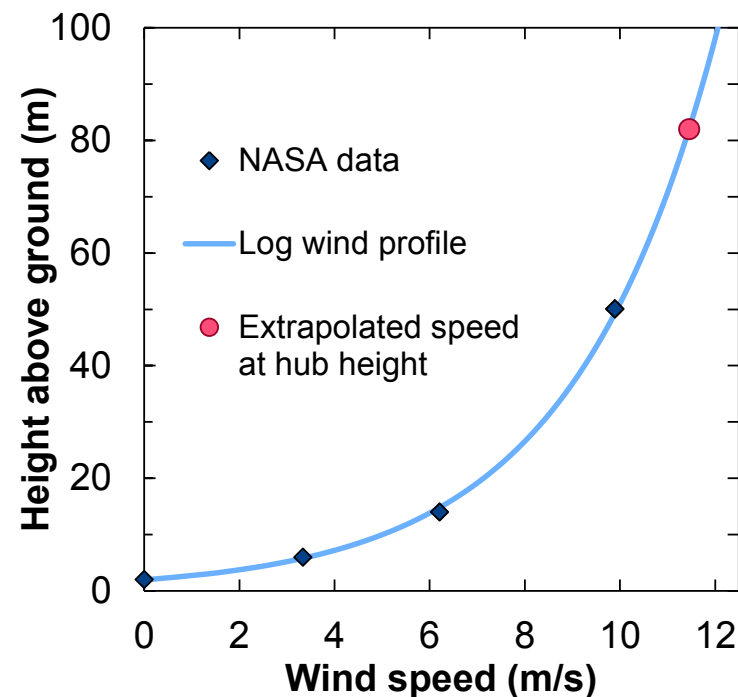
# Virtual Wind Farm Model



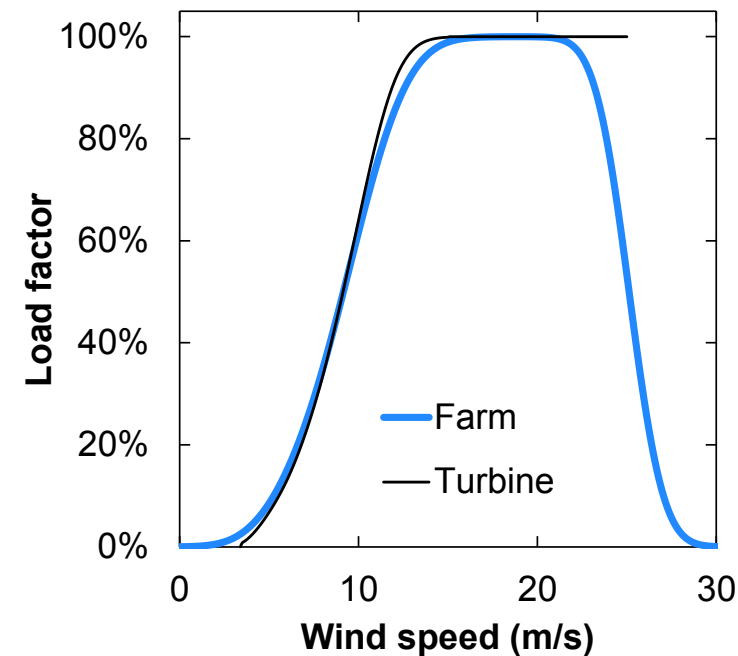
① Take hourly wind speeds from MERRA reanalysis



② Interpolate from grid points to site of actual wind farm



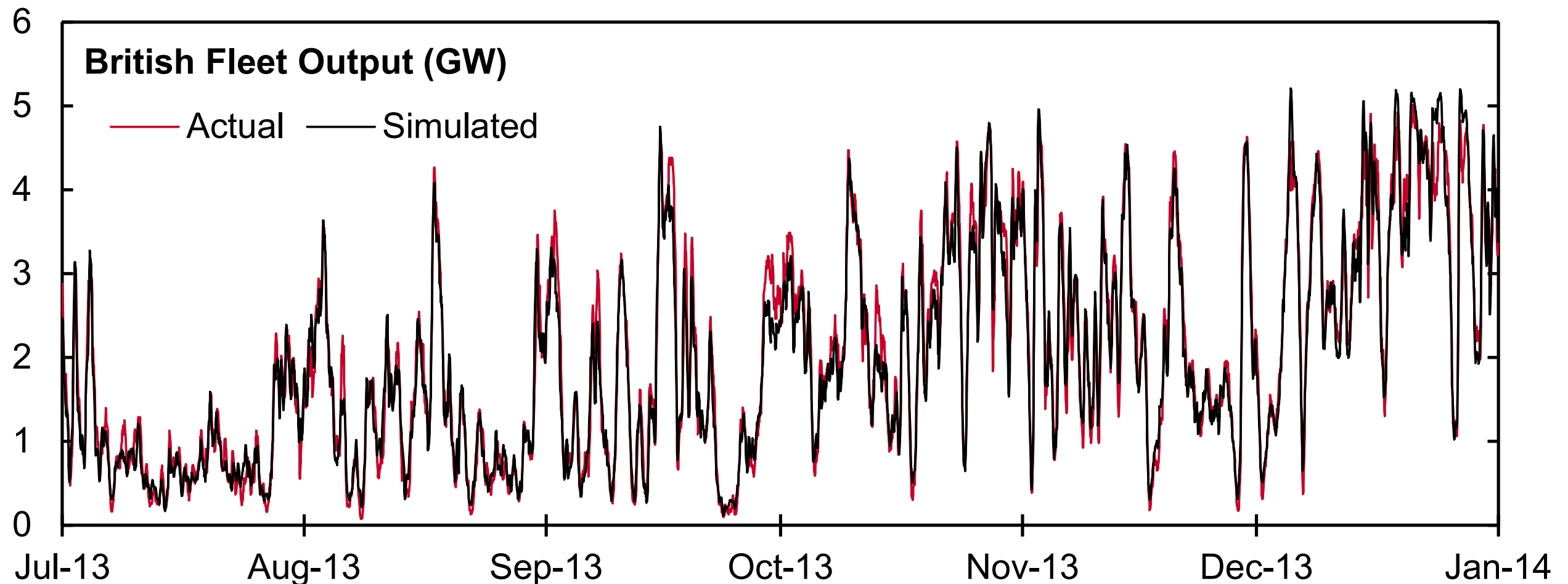
③ Extrapolate wind speeds to hub height with place- and time-specific parameters



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

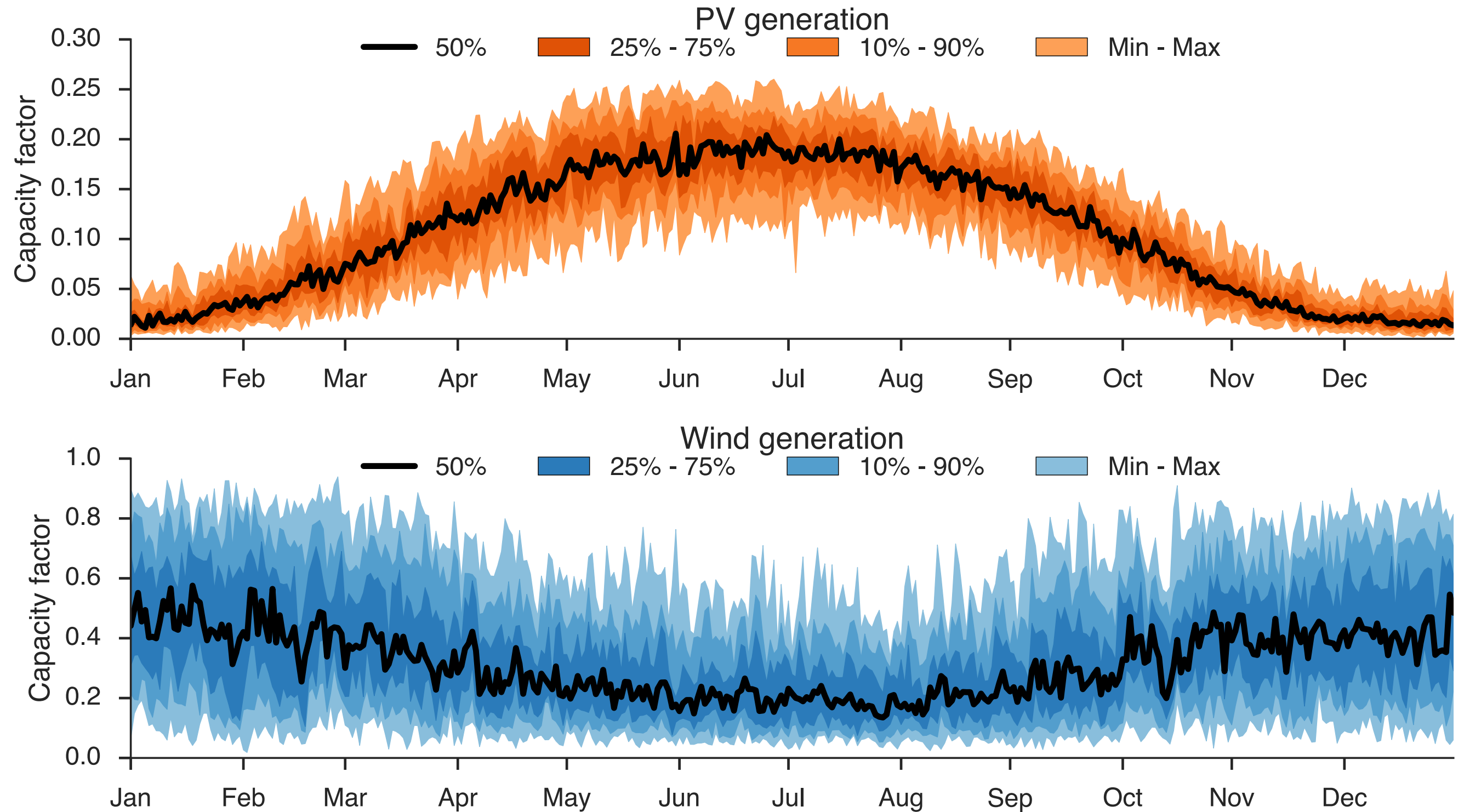
# Bias-corrected wind simulations

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





# 25 years of daily variability



Simulated UK wind and PV fleets, 1991-2015

Renewables.ninja online platform



[www.renewables.ninja](http://www.renewables.ninja)

Goal: provide easy access to high-quality validated global wind and PV simulations.

>1000 users from >250 institutions in 65 countries.

Renewables.ninja

Help ▾DownloadsNewsSign upLogin ▾

PointCountry

Search by locationSearch

Lat40.5138Lon15.3809

Solar PV>>

Dataset ⓘ

MERRA-2 (global) ▾

Select a year of data ⓘ

2014 ▾

Or choose precise dates:

2014-01-01to2014-12-31

Capacity (kW)

1

System loss (%)

10

Tracking

None ▾

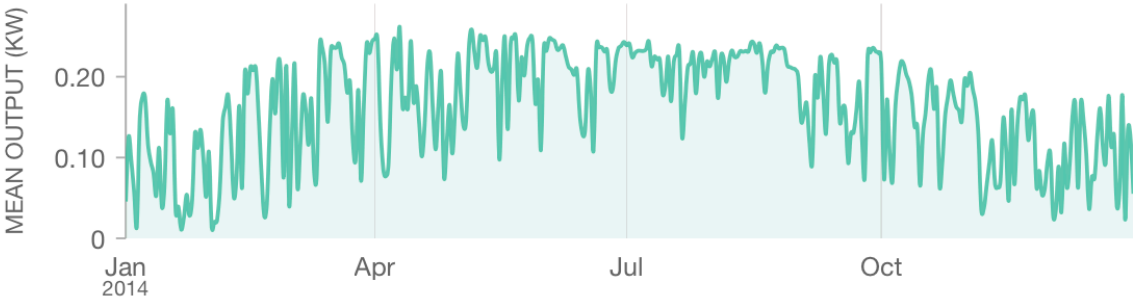
Tilt (°) ⓘ

35

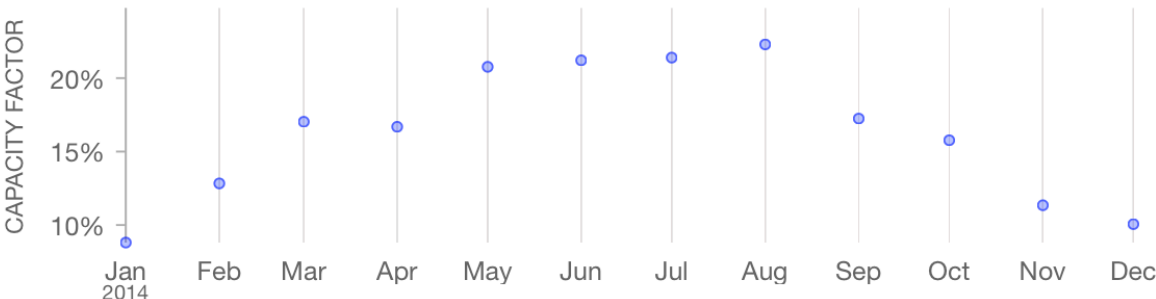
Azimuth (°) ⓘ

Results

Daily mean output



Monthly capacity factor



Total mean capacity factor: 16.3%

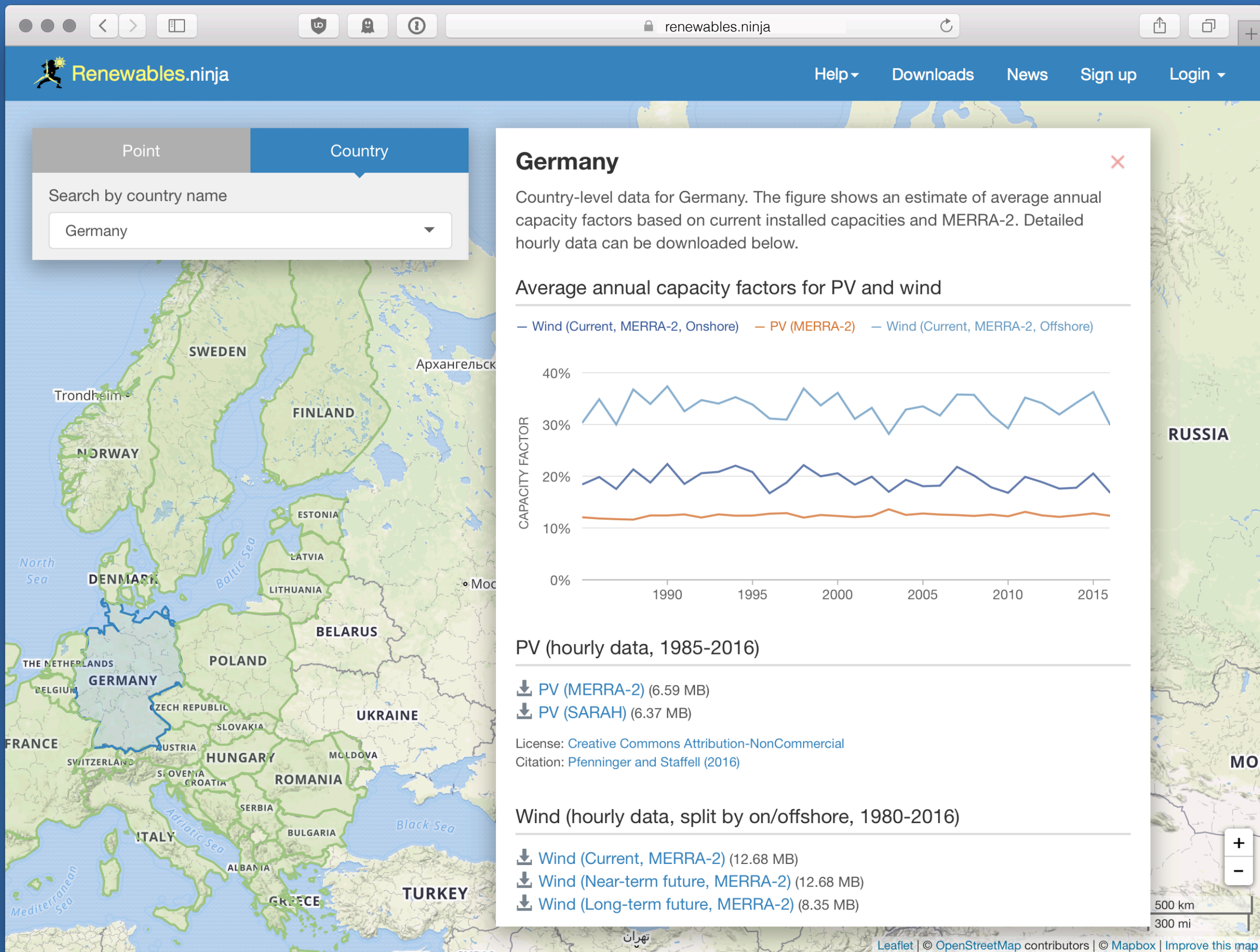
Save hourly output as CSV

License: [Creative Commons Attribution-NonCommercial](#)  
Citation: [Pfenninger and Staffell \(2016\)](#)

Map of the Mediterranean region with a location pin in Italy. Labels include SPAIN, ITALY, GREECE, TURKEY, SERBIA, BULGARIA, GEORGIA, ALBANIA, and AZERBAIJAN. Bodies of water shown are the Biscay, Adriatic, Mediterranean, Black, and Caspian Seas. A scale bar indicates 300 km and 300 mi. Map data is attributed to Leaflet, OpenStreetMap contributors, and Mapbox.

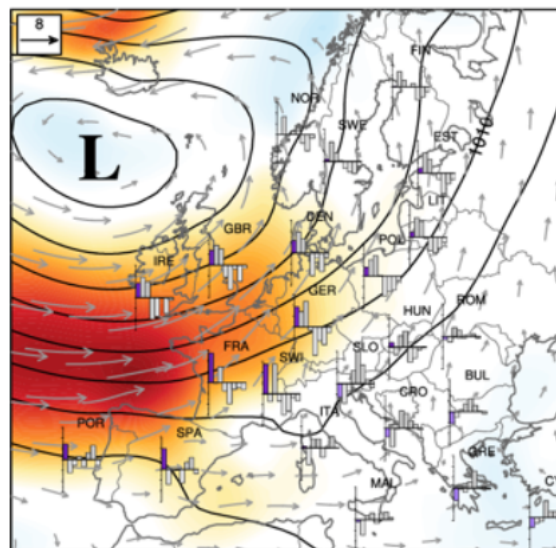
16





# Example application

Understanding weather regimes  
→ more stable wind power





## Windenergie

# “What Europe can do during North Sea wind lulls”



Irgendwo in Europa weht immer Wind - doch die Windparks ballen sich an der Nordsee. Daher schwankt die Stromproduktion stark. Eine intelligente Verteilung der Windräder könnte das Problem lösen. *Von Ralph Diermann mehr...* [ Forum ]

**Energie:** EnBW baut Windpark ohne Subventionen



# Weather regimes

Atlantic Trough

**AT**

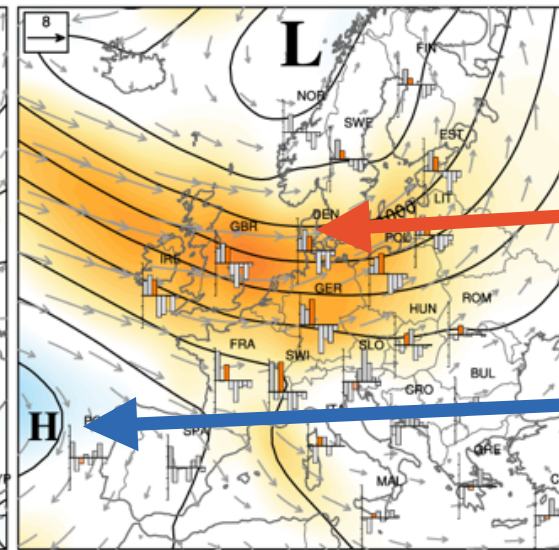
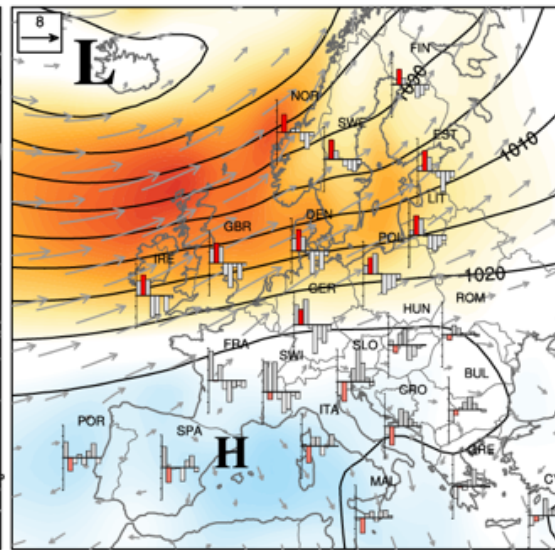
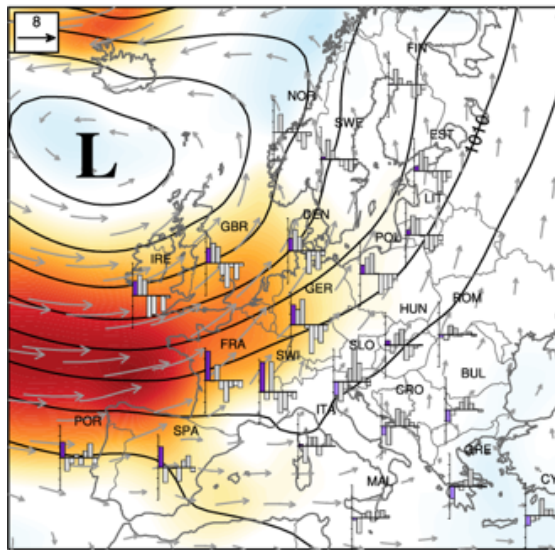
Zonal

**ZO**

Scandinavian Trough

**ScTr**

Cyclonic



red shading:  
high wind

blue shading:  
low wind

Atlantic Ridge

**AR**

European Blocking

**EuBL**

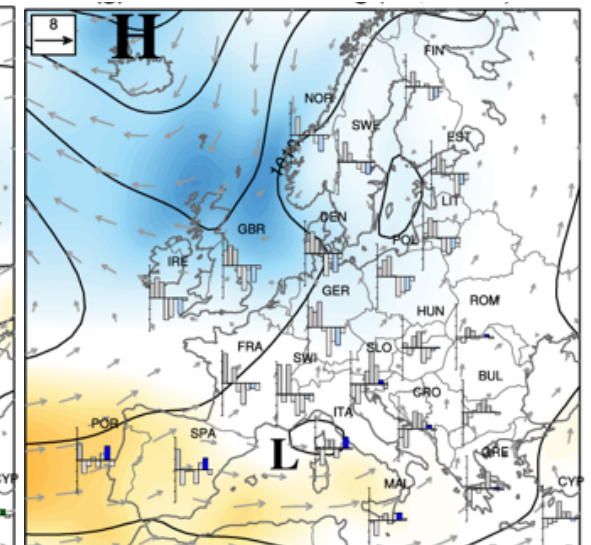
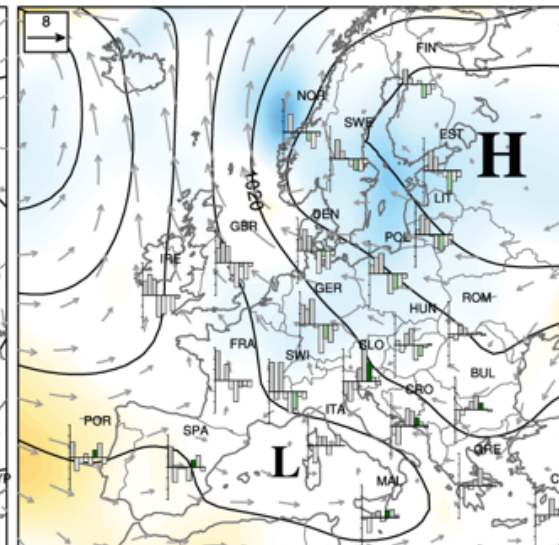
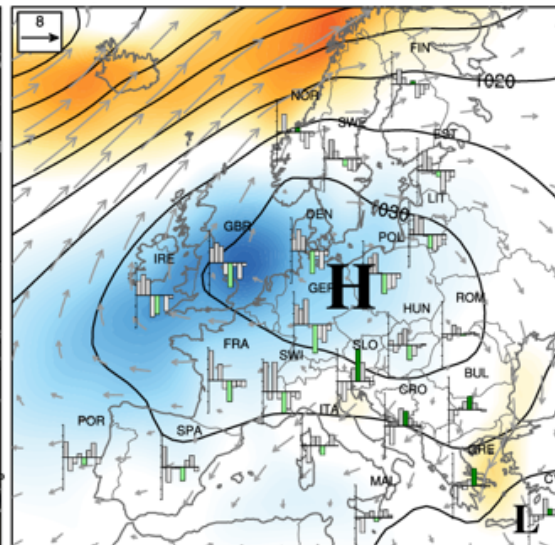
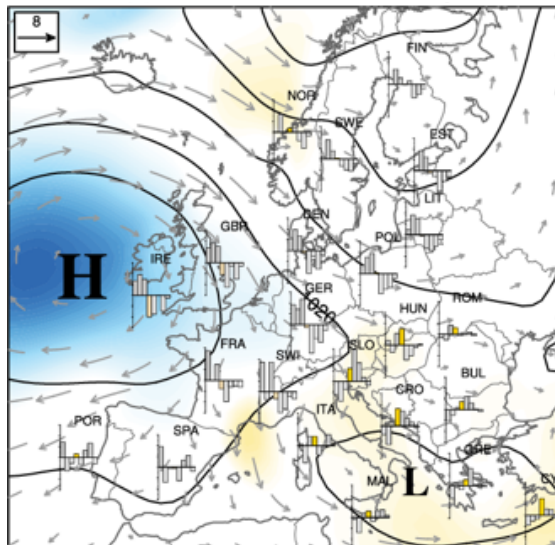
Scandinavian Blocking

**ScBL**

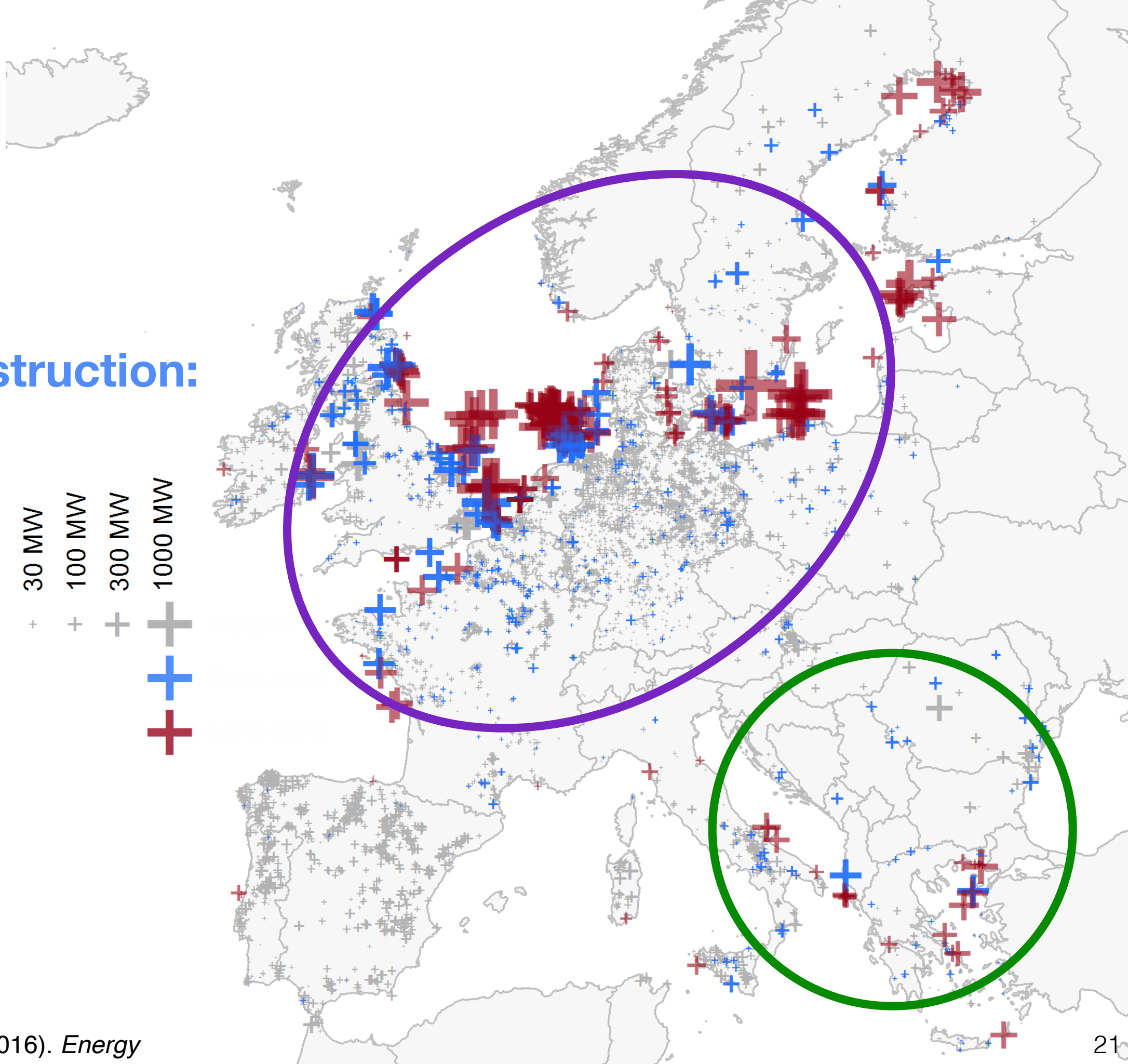
Greenland Blocking

**GL**

Blocked







Existing:

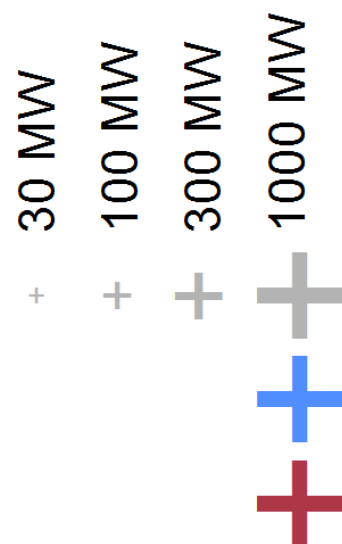
+ 135 GW

Under construction:

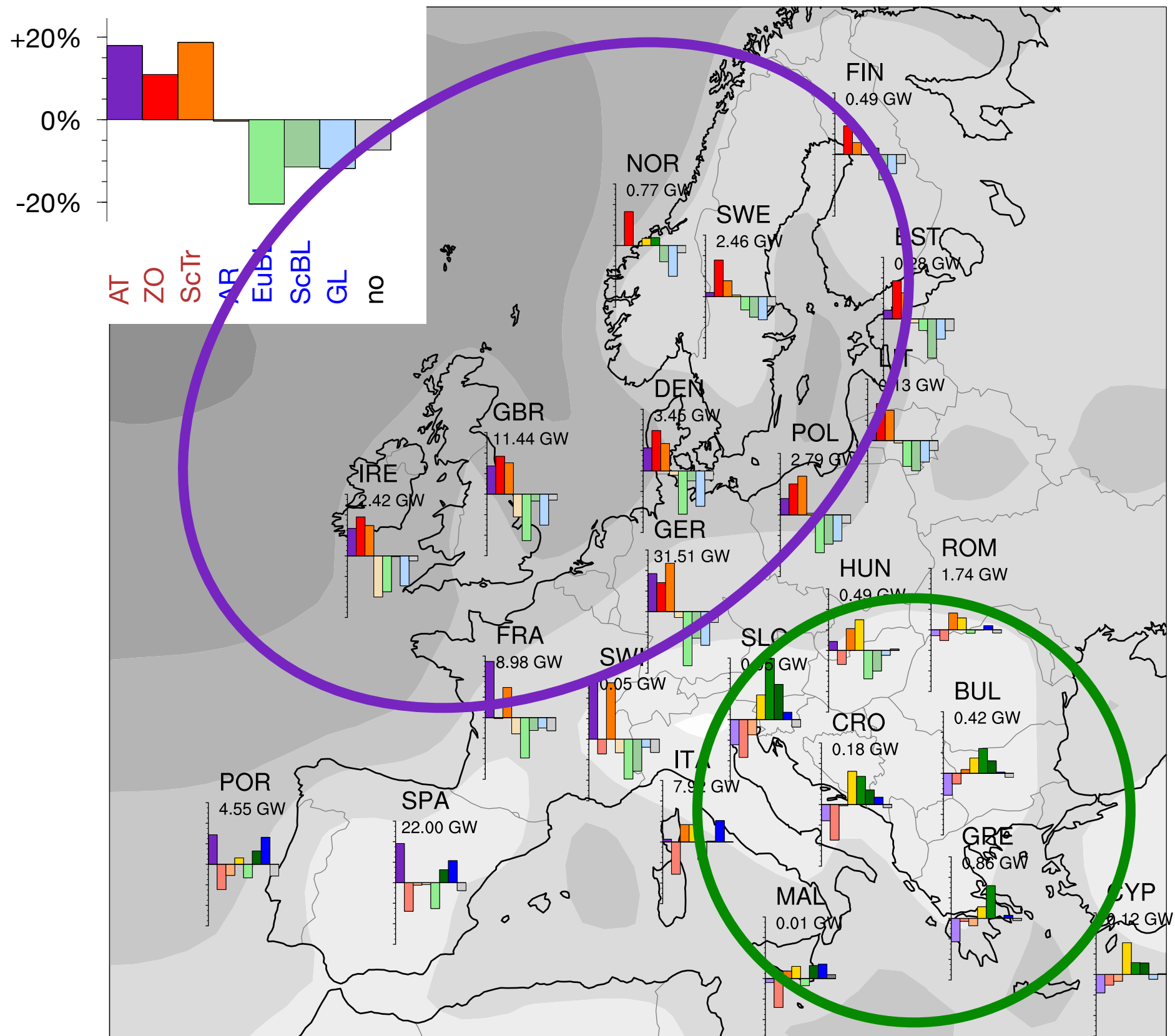
+ 44 GW

Planned:

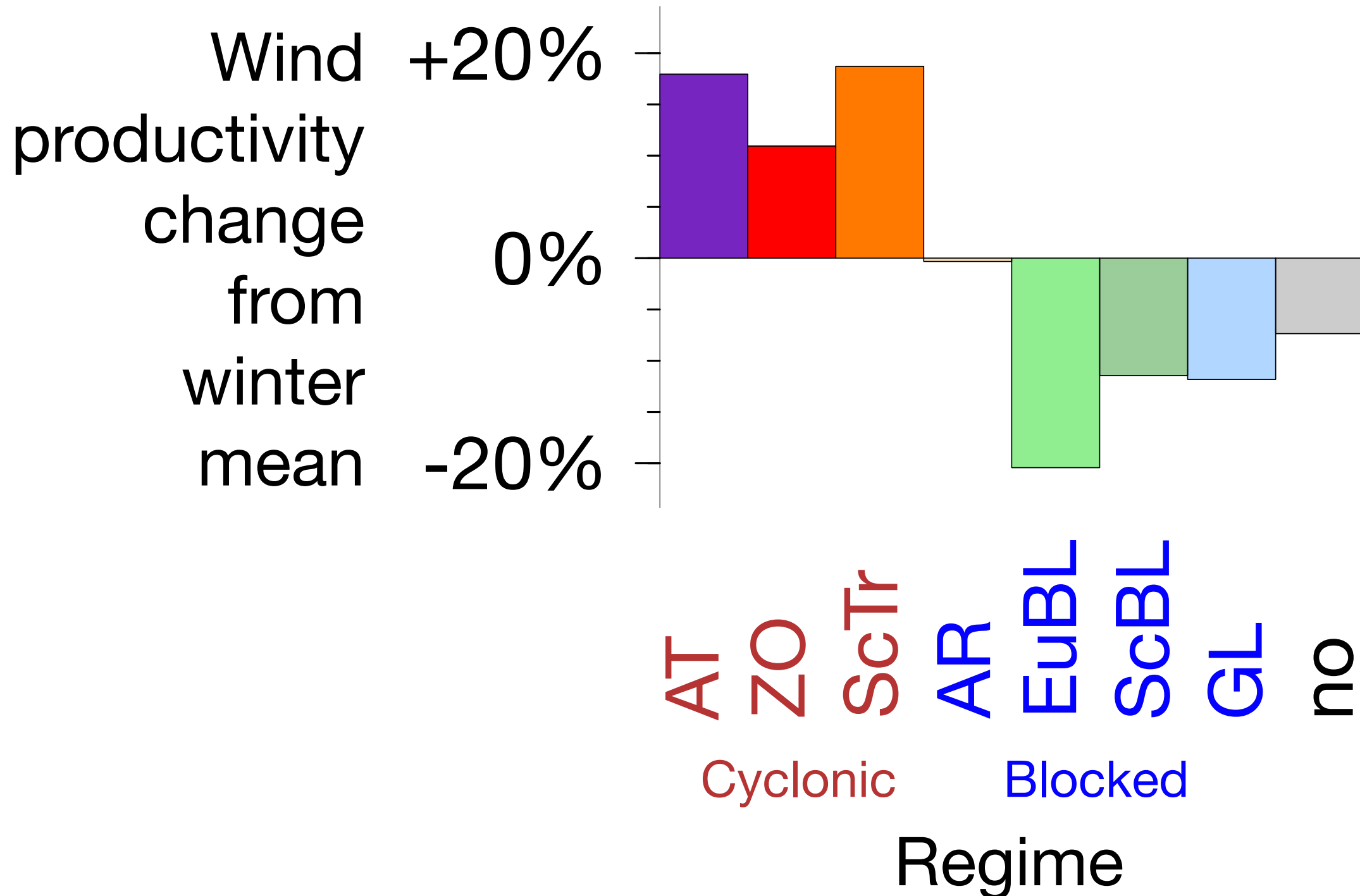
+ 93 GW



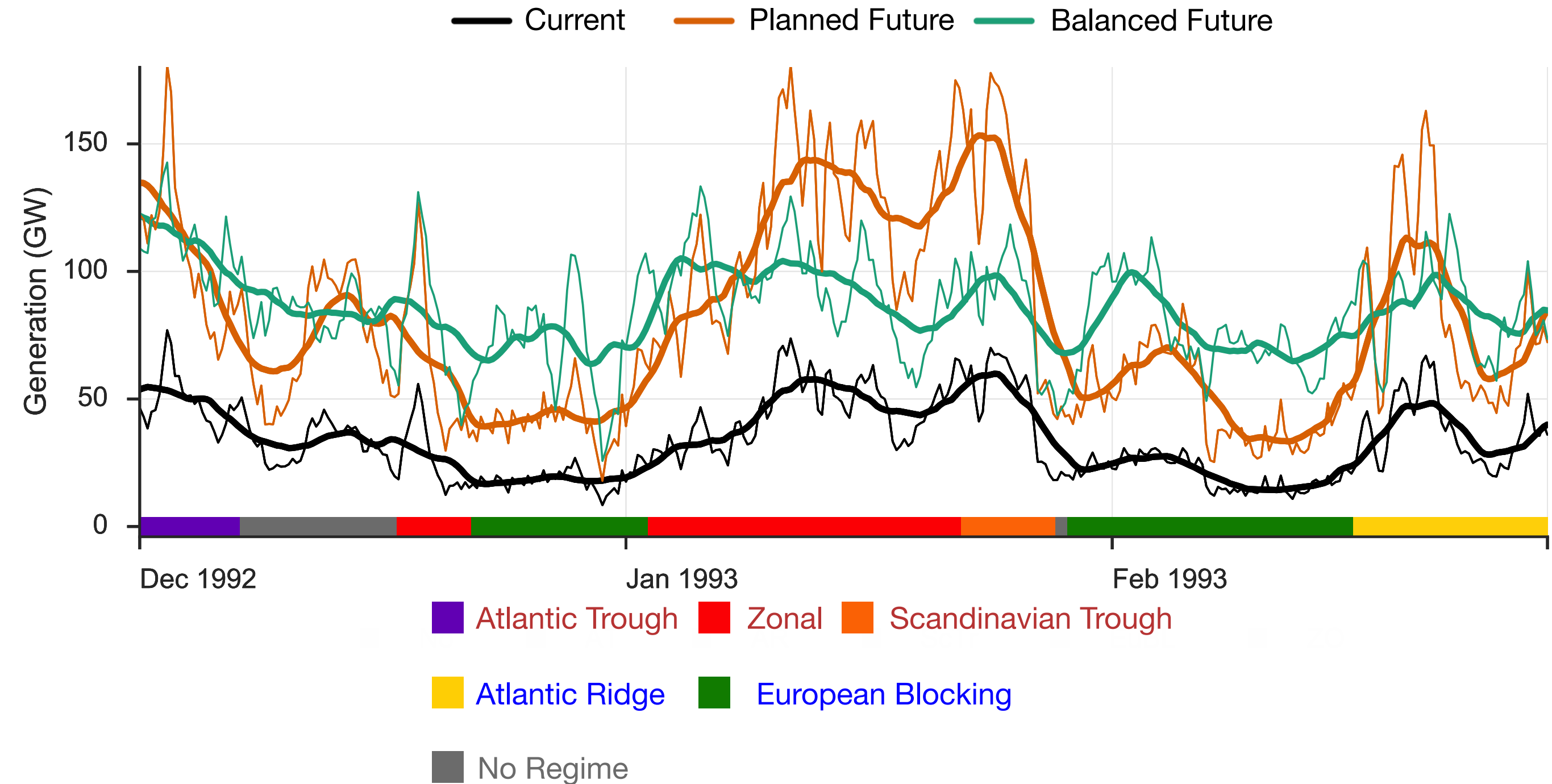
## Mean EU-wide wind output



# Mean EU-wide wind output



# Balanced deployment of wind



# Discussion

- Solar and wind power are growing rapidly and will continue to do so. Accurate data is needed to plan and implement this energy transition. Reanalysis can provide it.
- This implies that more work on areas beyond e.g. precipitation and temperature, such as cloud cover, would be particularly useful.
- Energy researchers would benefit from a better understanding of the applicability of global vs regional reanalyses.
- Also: intercomparison of reanalyses and uncertainty quantification.

# Thanks for your attention



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[www.renewables.ninja](http://www.renewables.ninja)

[www.pfenninger.org](http://www.pfenninger.org)

- Publications describing the methods and publications based on Renewables.ninja data:  
<https://www.renewables.ninja/documentation/science>
- Stefan Pfenninger and Iain Staffell (2016). *Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data*. Energy 114, pp. 1251-1265.  
[doi.org/10.1016/j.energy.2016.08.060](https://doi.org/10.1016/j.energy.2016.08.060)
- Iain Staffell and Stefan Pfenninger (2016). *Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output*. Energy 114, pp. 1224-1239. [doi.org/10.1016/j.energy.2016.08.068](https://doi.org/10.1016/j.energy.2016.08.068)