photo: Bernhard Mühr, www.wolkenatlas.de

Balancing Europe's wind power output through spatial deployment informed by weather regimes

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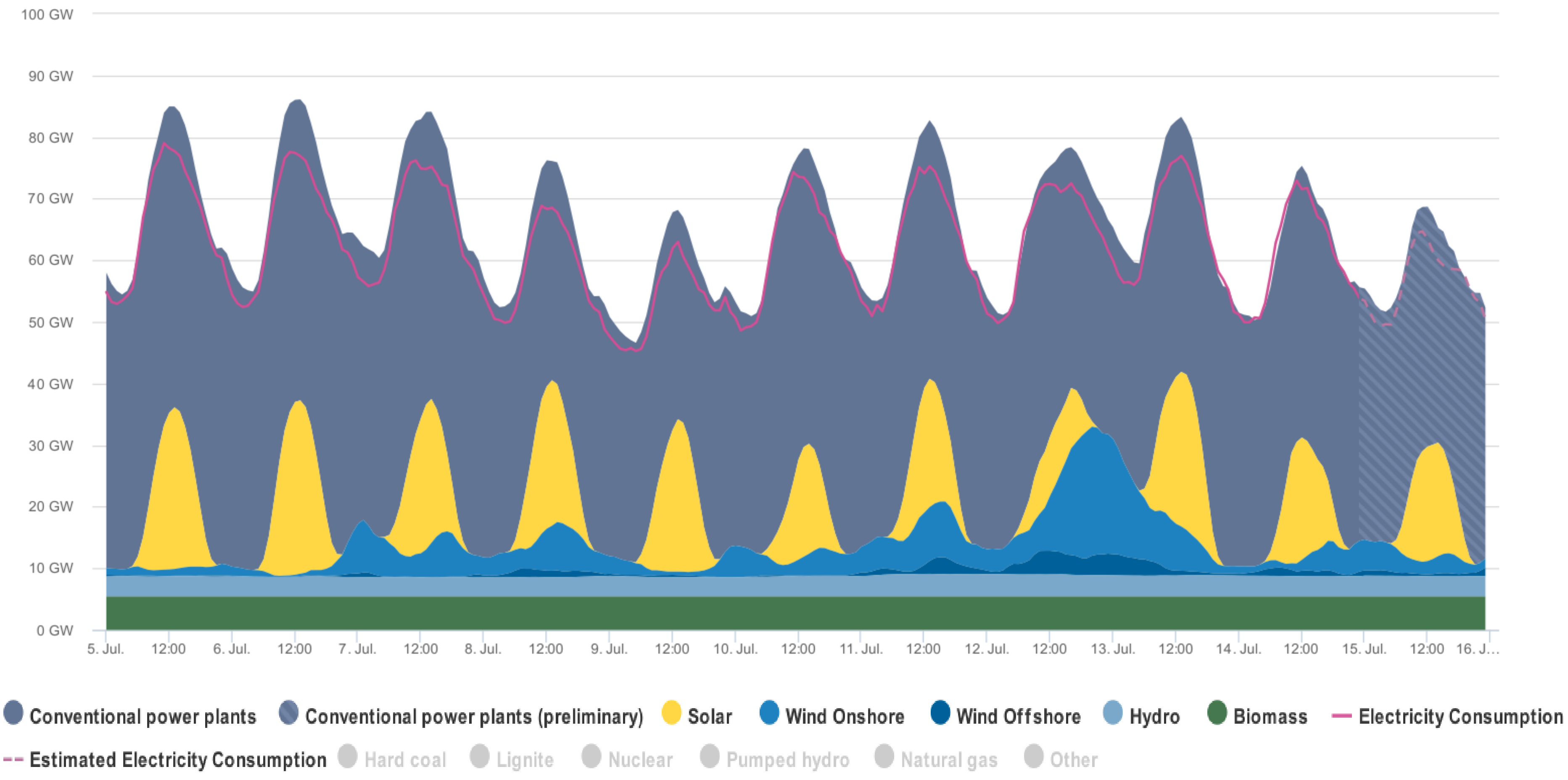
Electricity generation

short-range variability (hours – days)

- Generation mix for Germany 5.-15. July 2017

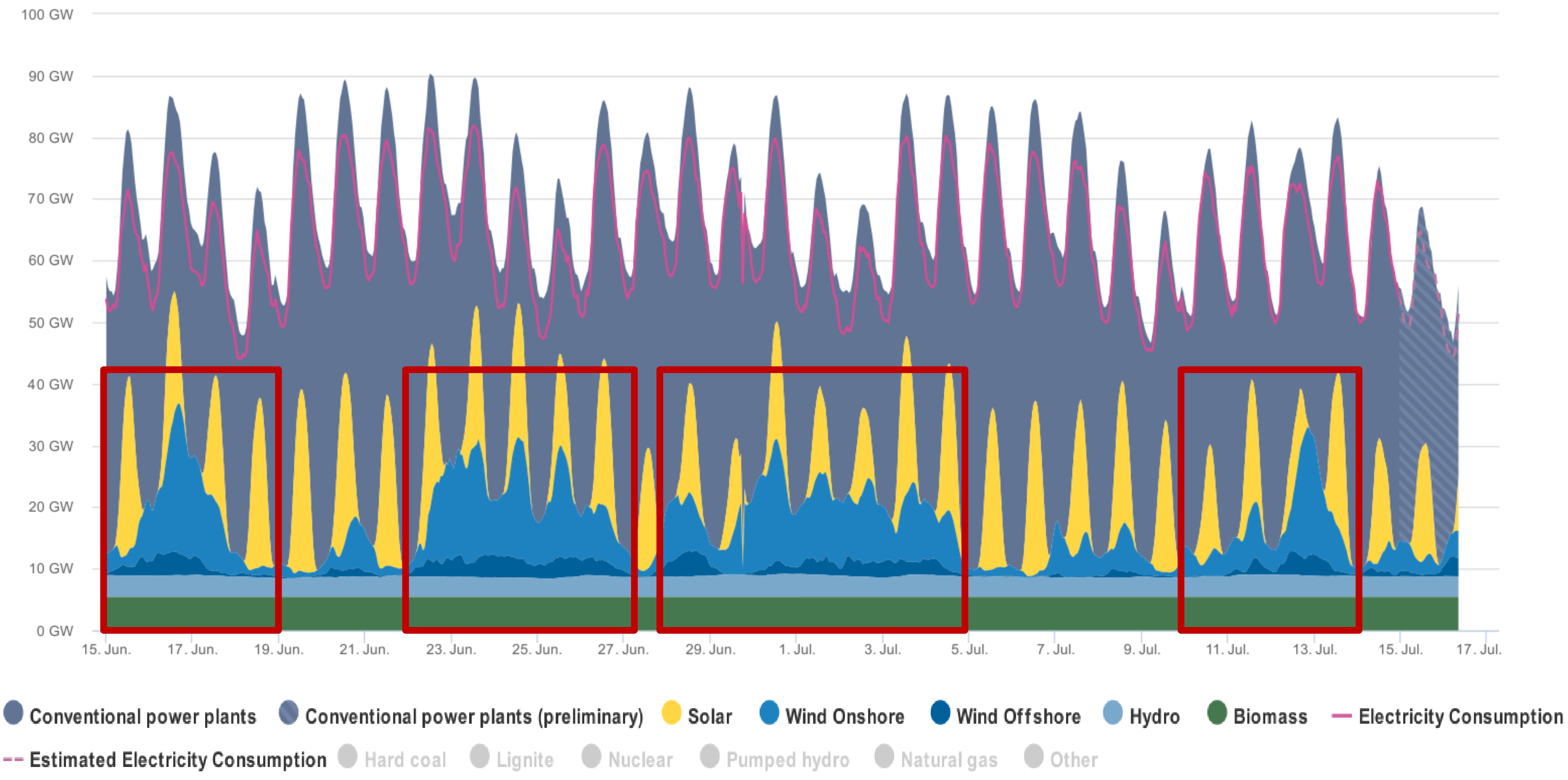


Source: https://www.agora-energiewende.de

Electricity generation

multi-day variability (days – weeks)

- Generation mix for Germany 15. June - 16. July 2017

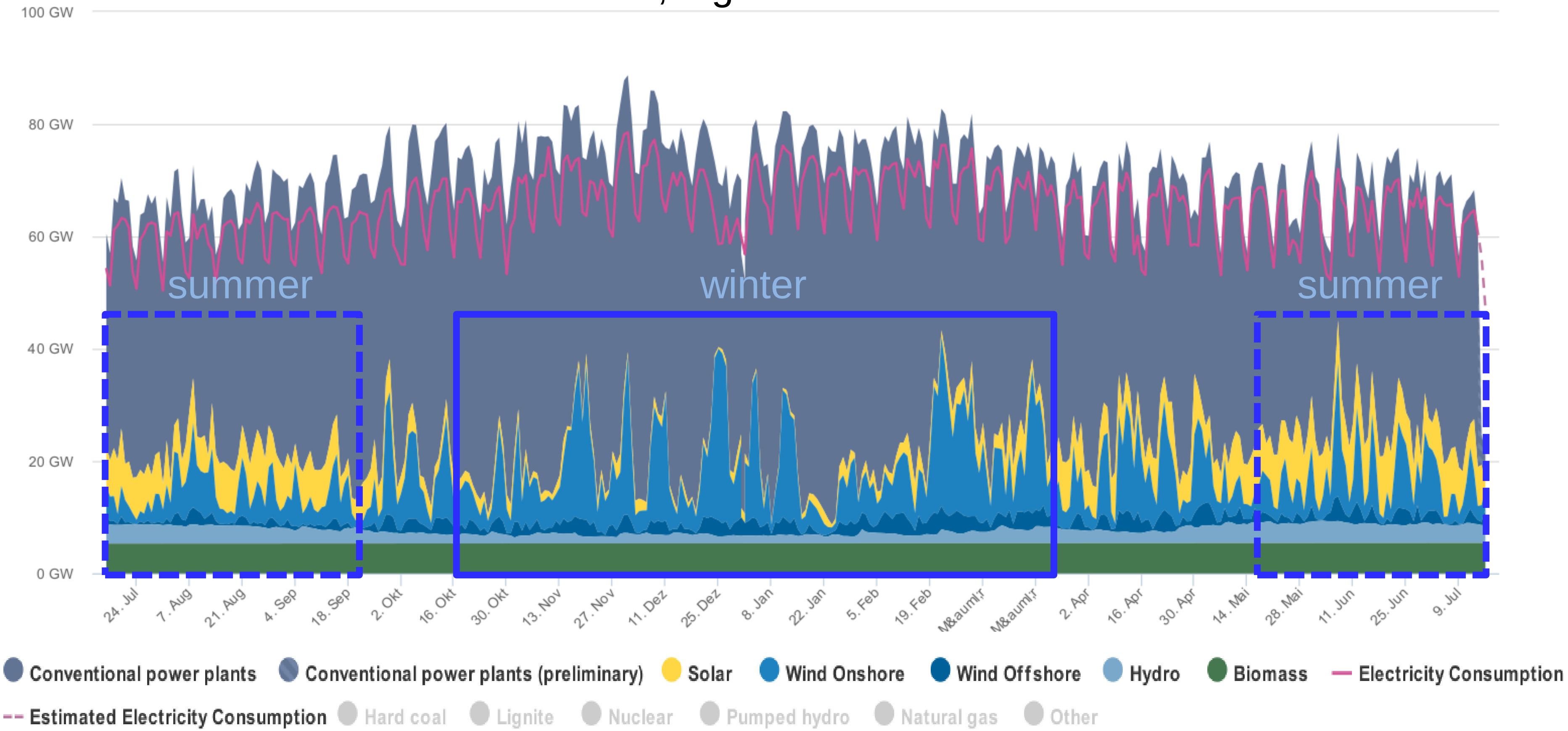


Source: https://www.agora-energiewende.de

Electricity generation

seasonal variability (months)

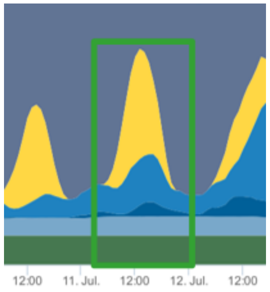
- Generation mix for Germany 15. July 2016 - 16. July 2017
- **Winter**: high wind, low solar PV
- **Summer**: intermediate wind, high solar PV



Source: https://www.agora-energiewende.de

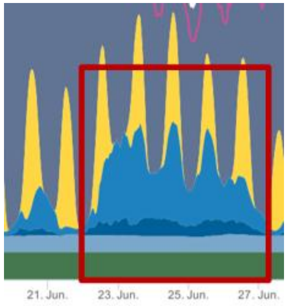
Atmospheric variability and wind power

short-range variability (hours – days)



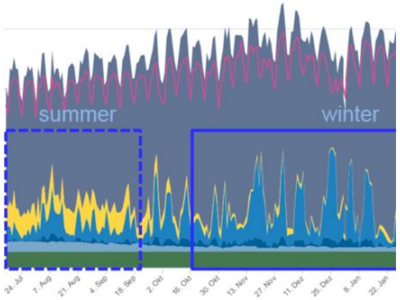
- Diurnal cycle
- local clouds
- thunderstorms

multi-day variability (days – weeks)



- Weather systems
- continent-scale **weather regimes**

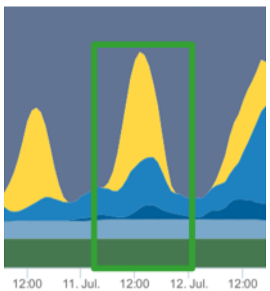
seasonal variability (months)



- seasonal cycle

Power output variability

short-range variability (hours – days)

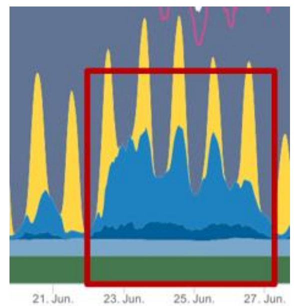


- ΔP=0-30 GW
- often matches peak demand

www.raonline.ch

Storage and flexible demand

multi-day variability (days – weeks)

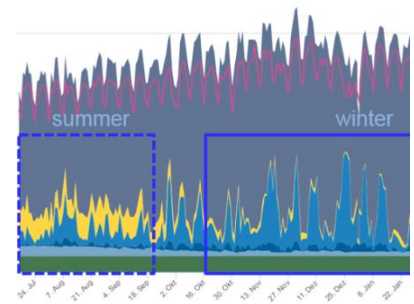


- ΔP=10-40 GW
- strong ramps
- longlasting
- Irregular occurrence

?

Large-scale storage not available currently!

seasonal variability (months)



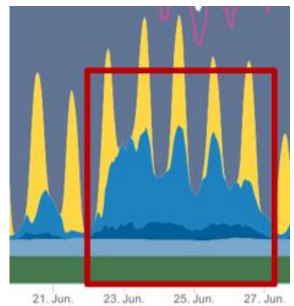
- ΔP=10-50 GW
- Regular seasonal anti-correlation of wind and solar power

Co-deployment of wind and solar PV

Scope of the study

short-range variability (hours – days)

multi-day variability (days – weeks)



seasonal variability (months)

- ΔP=0-30
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How do continent-scale weather regimes affect multi-day variability of wind and solar PV power output?

Storage and flexible demand

?

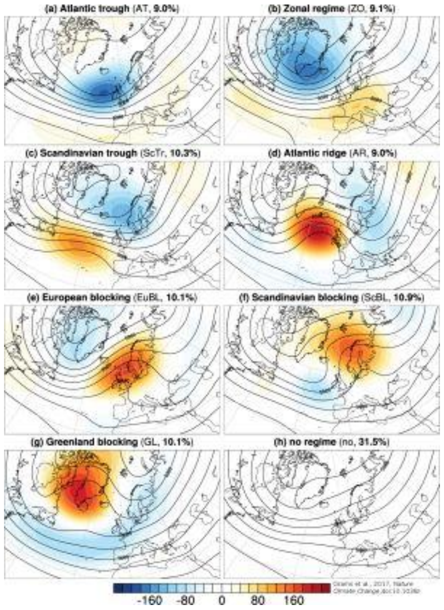
Large-scale storage not available!

Co-deployment of wind and solar PV

Approach

- year-round Atlantic-European weather regimes
- Six-hourly data based on ERA-Interim (1979-2016)

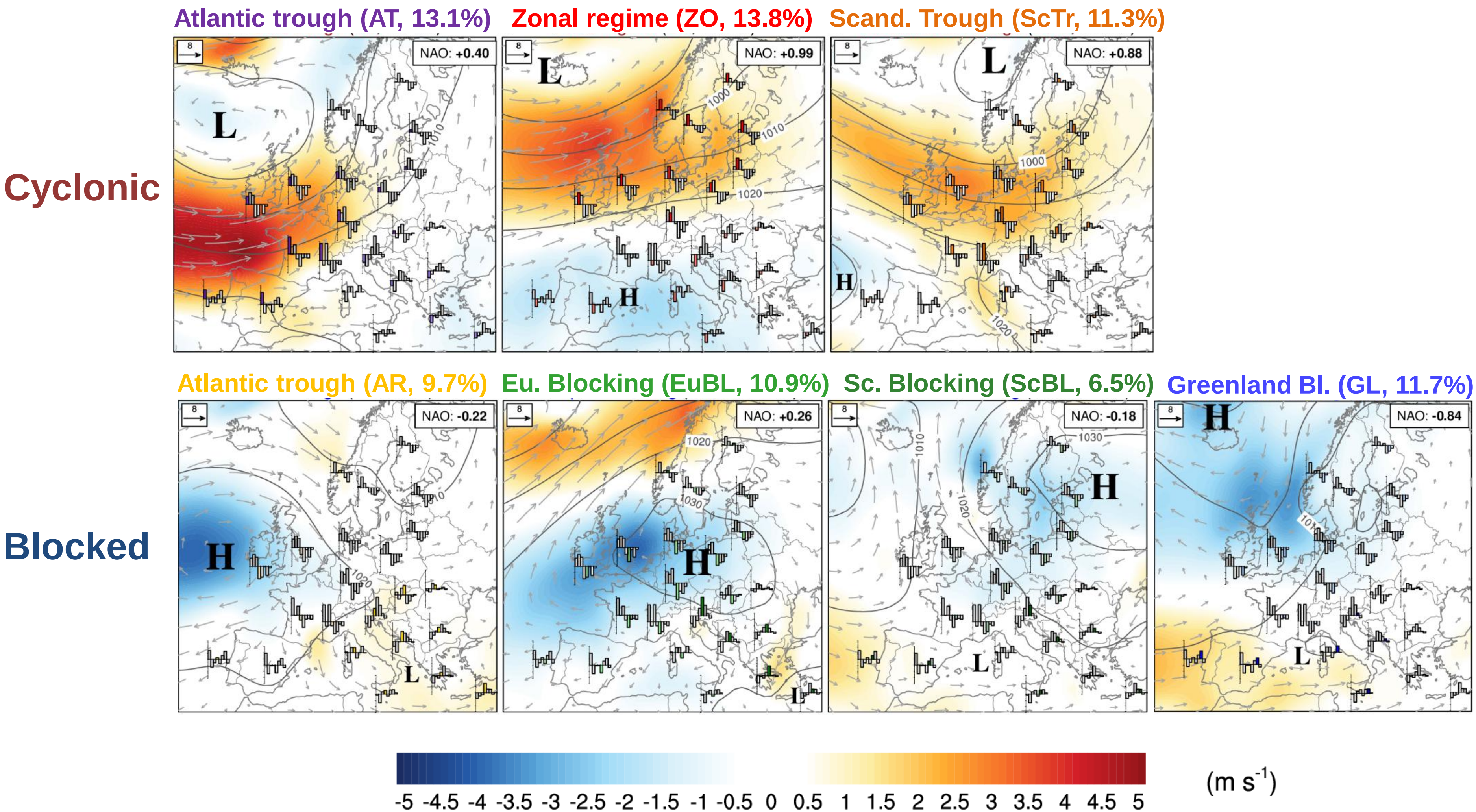
Grams et al. (2017), [doi:10.1038/nclimate3338](https://doi.org/10.1038/nclimate3338)



- Country-aggregated wind and solar PV capacity factors *CF*
- Hourly data based on calibrated [Renewables.Ninja](https://www.renewables.ninja) (1985-2016)

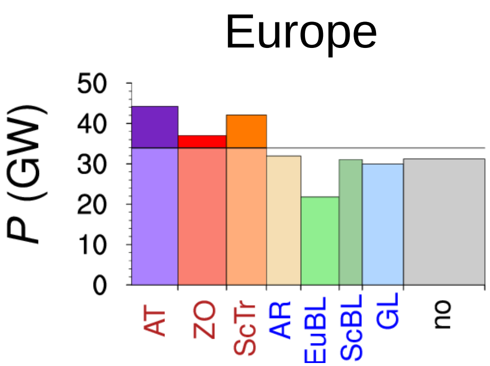
Pfenninger et al. (2016), [doi: 10.1016/j.energy.2016.08.060](https://doi.org/10.1016/j.energy.2016.08.060)
Staffell et al. (2016), [doi: 10.1016/j.energy.2016.08.068](https://doi.org/10.1016/j.energy.2016.08.068)

Modulation of 100 m wind by weather regimes



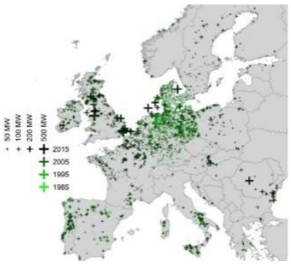
- mean 100 m wind speed anomalies wrt. winter mean for all times attributed to one of the seven weather regimes

Regimes with strongest impact on wind power



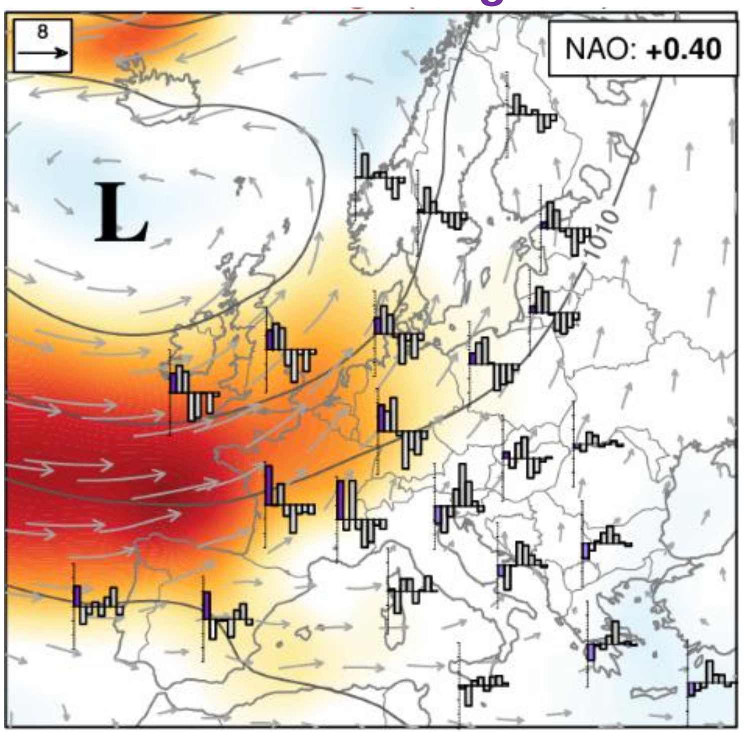
Winter mean: 34 GW

AT: 44 GW (+10 GW)
EuBL: 22 GW (- 12 GW)

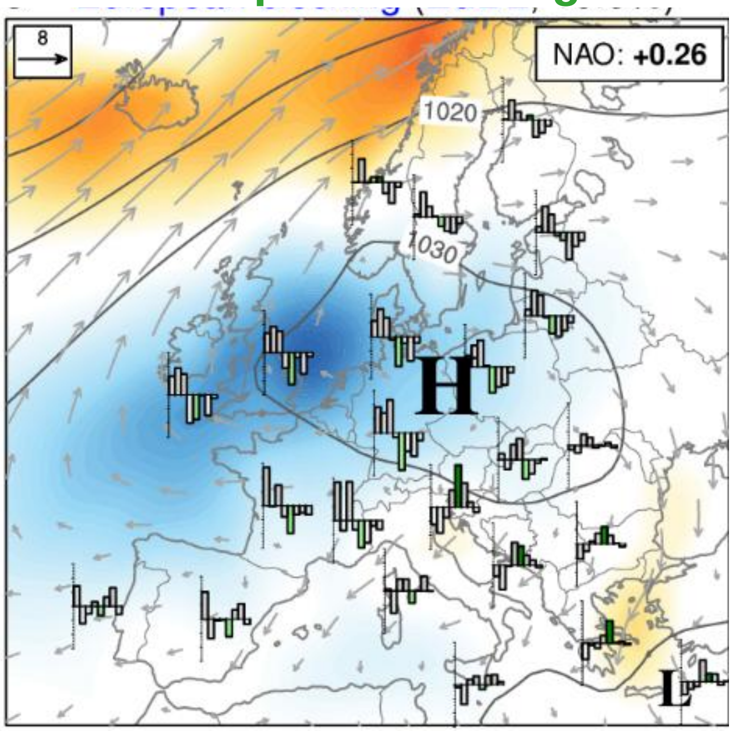


Difference of 22 GW (65% of mean production)

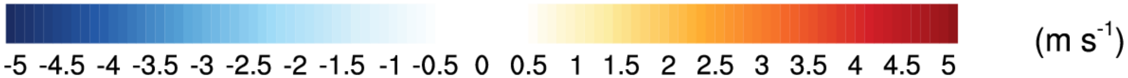
Atlantic trough



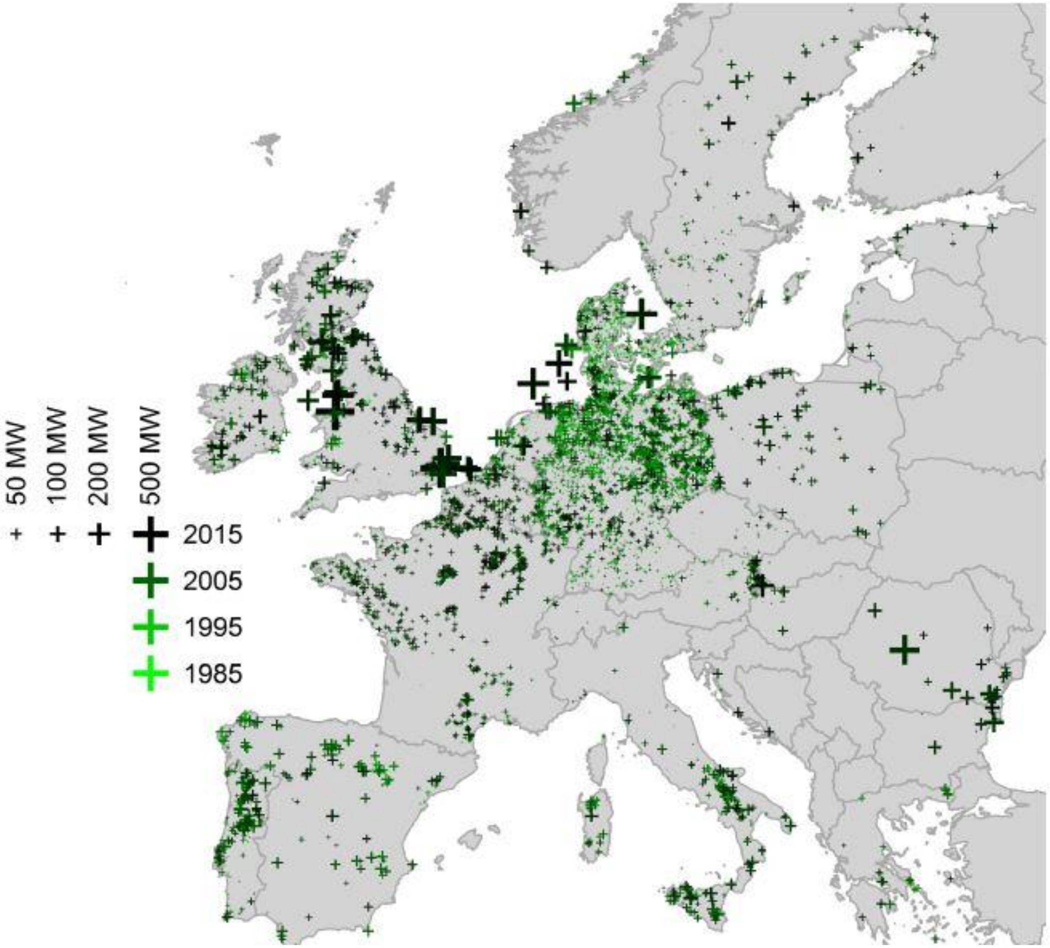
European Blocking



100 m wind

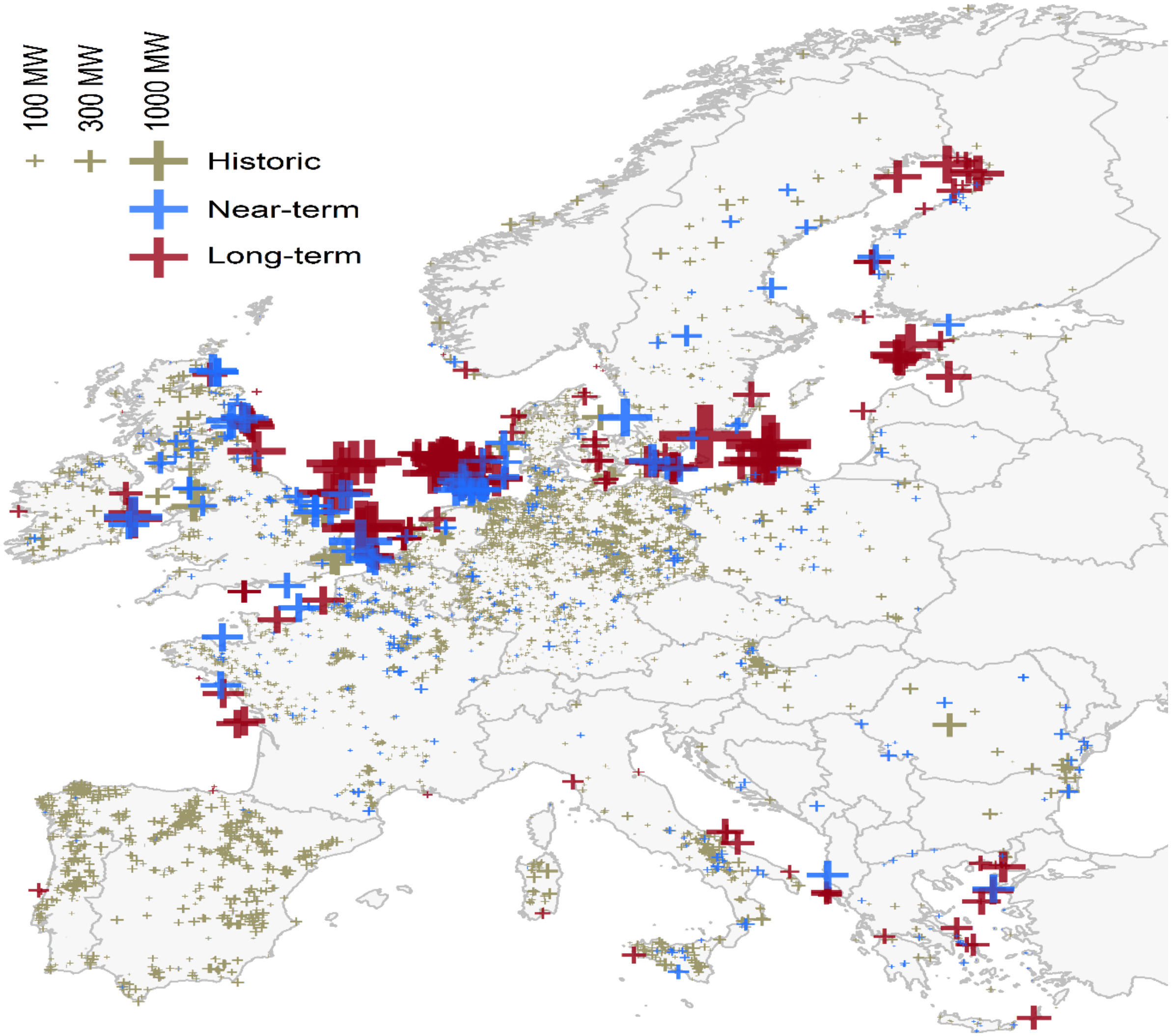


Installed wind farms (2015)



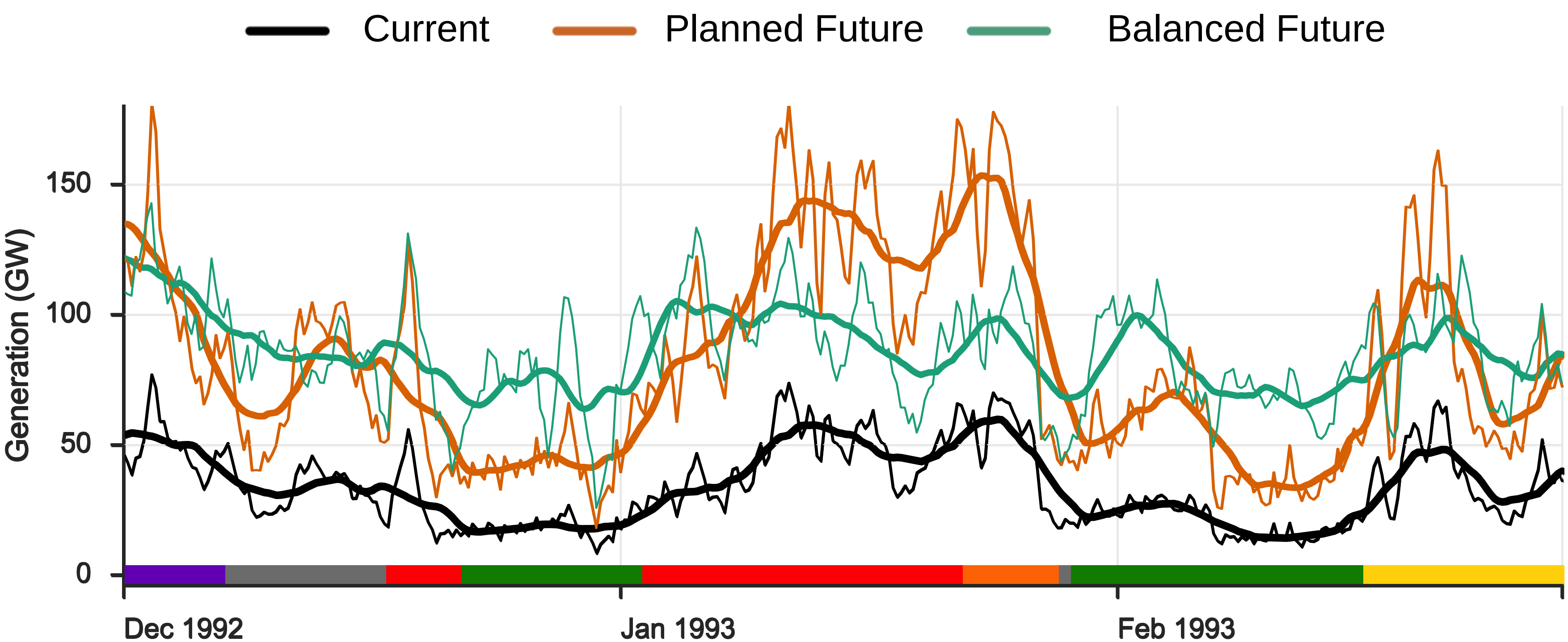
- Heavy bias towards Northwestern Europe

Future deployment



- Predominant offshore deployment in North and Baltic Seas
- Slow new deployment in Spain

Example Winter 1992/93



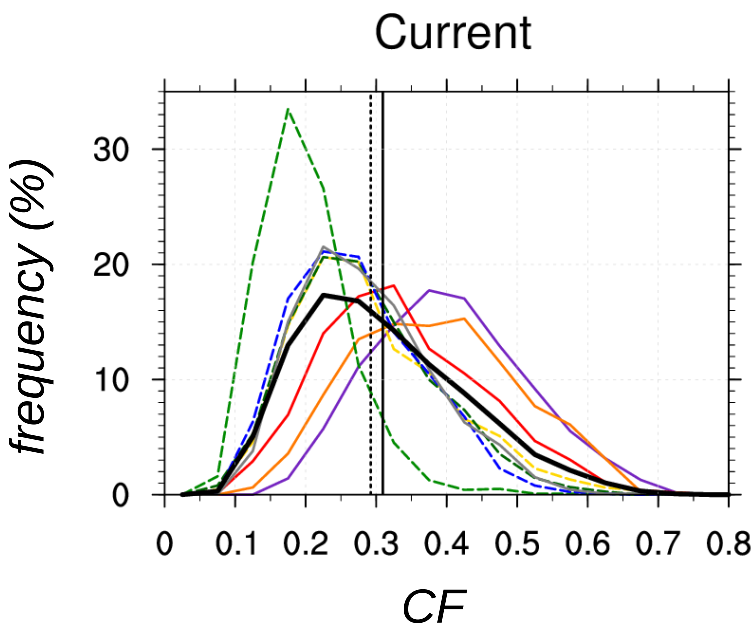
→ Multi-day variability in European wind power output could be balanced through spatial deployment informed by weather regimes

Grams, C.M., et al. (2017), [doi:10.1038/nclimate3338](https://doi.org/10.1038/nclimate3338).
Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/

Future variability

- Histogram of 6-hourly *CF (=P/IC)* for Europe
- Actual Europe-wide power output / Europe-wide installed capacity

solid	*dashed*
Atlantic trough	**Atlantic ridge**
Zonal Regime	**European blocking**
Scandinavian trough	**Scandinavian blocking**
No regime	**Greenland blocking**
All winter days	



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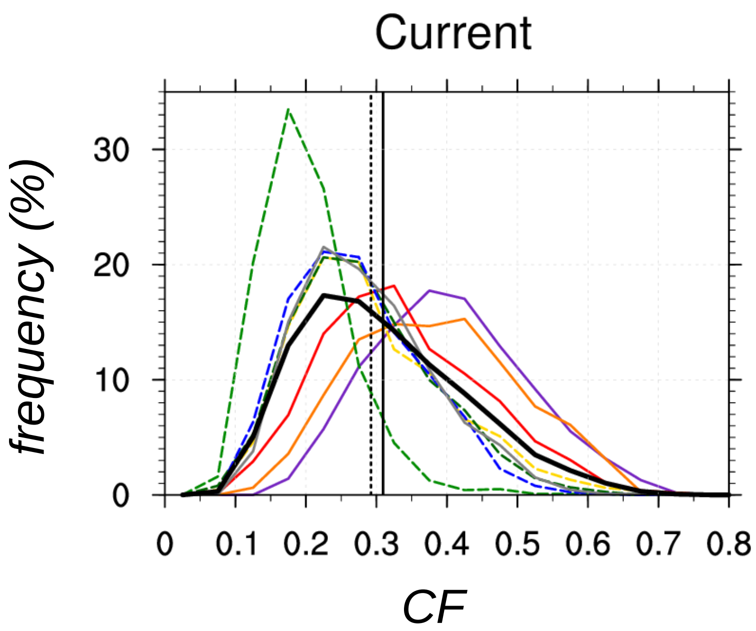

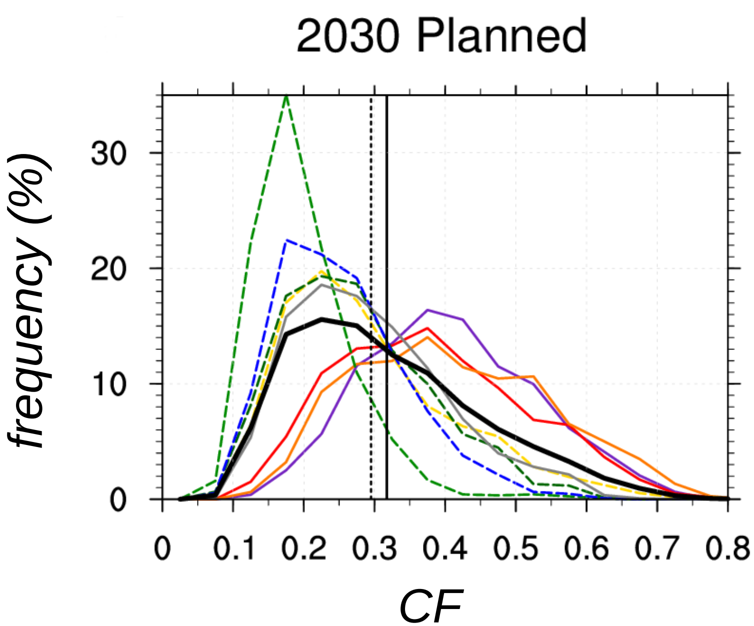

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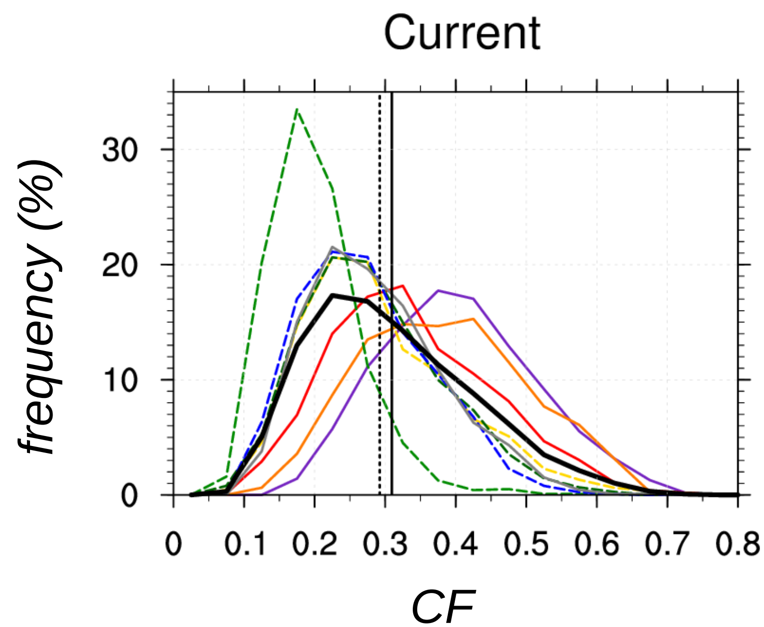
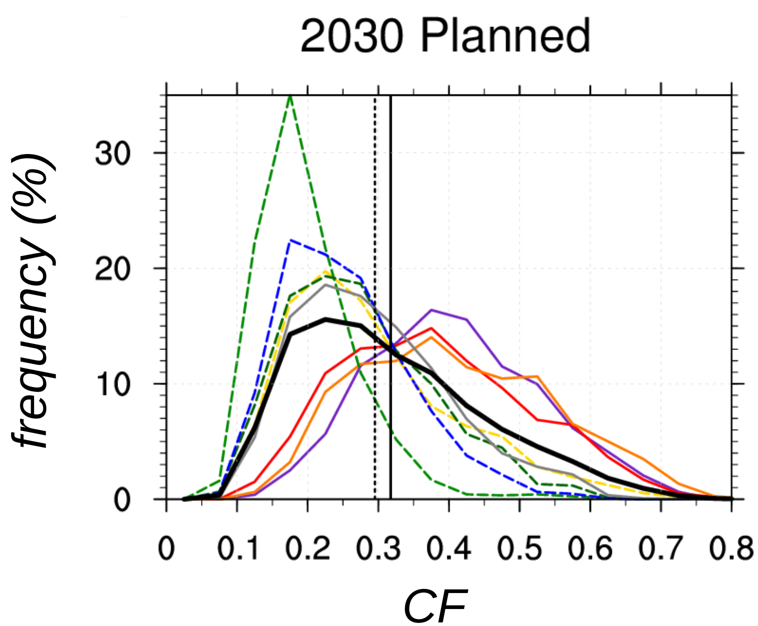
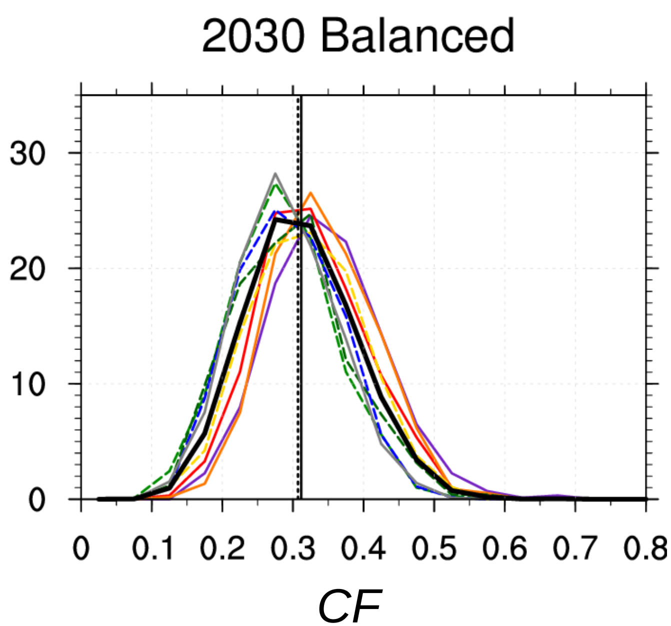
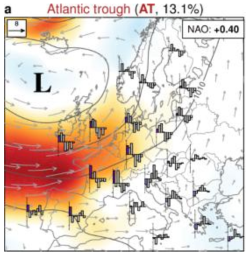


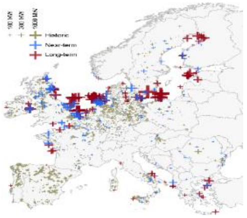




Conclusions

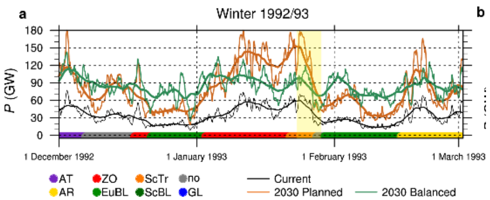
- Multi-day variability in country-aggregated wind power output governed by weather regimes





- Unbalanced deployment in North Sea region causes very high-volatility of Europe-wide wind electricity

- Future deployment makes volatility worse, but alternate strategies could stabilise wind power
- European collaboration needed



References

Grams, C.M., R. Beerli, S. Pfenninger, I. Staffell, and H. Wernli (2017). Balancing Europe's wind power output through spatial deployment informed by weather regimes, *Nature Climate Change*, **7**, 557–562, doi:10.1038/nclimate3338

Pfenninger, S., and I. Staffell, 2016: Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. *Energy*, **114**, 1251–1265, doi:10.1016/j.energy.2016.08.060.

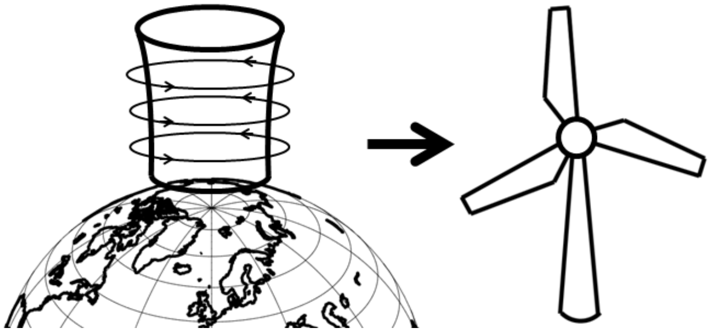
Staffell, I., and S. Pfenninger, 2016: Using bias-corrected reanalysis to simulate current and future wind power output. *Energy*, **114**, 1224–1239, doi:10.1016/j.energy.2016.08.068.

Data: https://www.renewables.ninja/

Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/

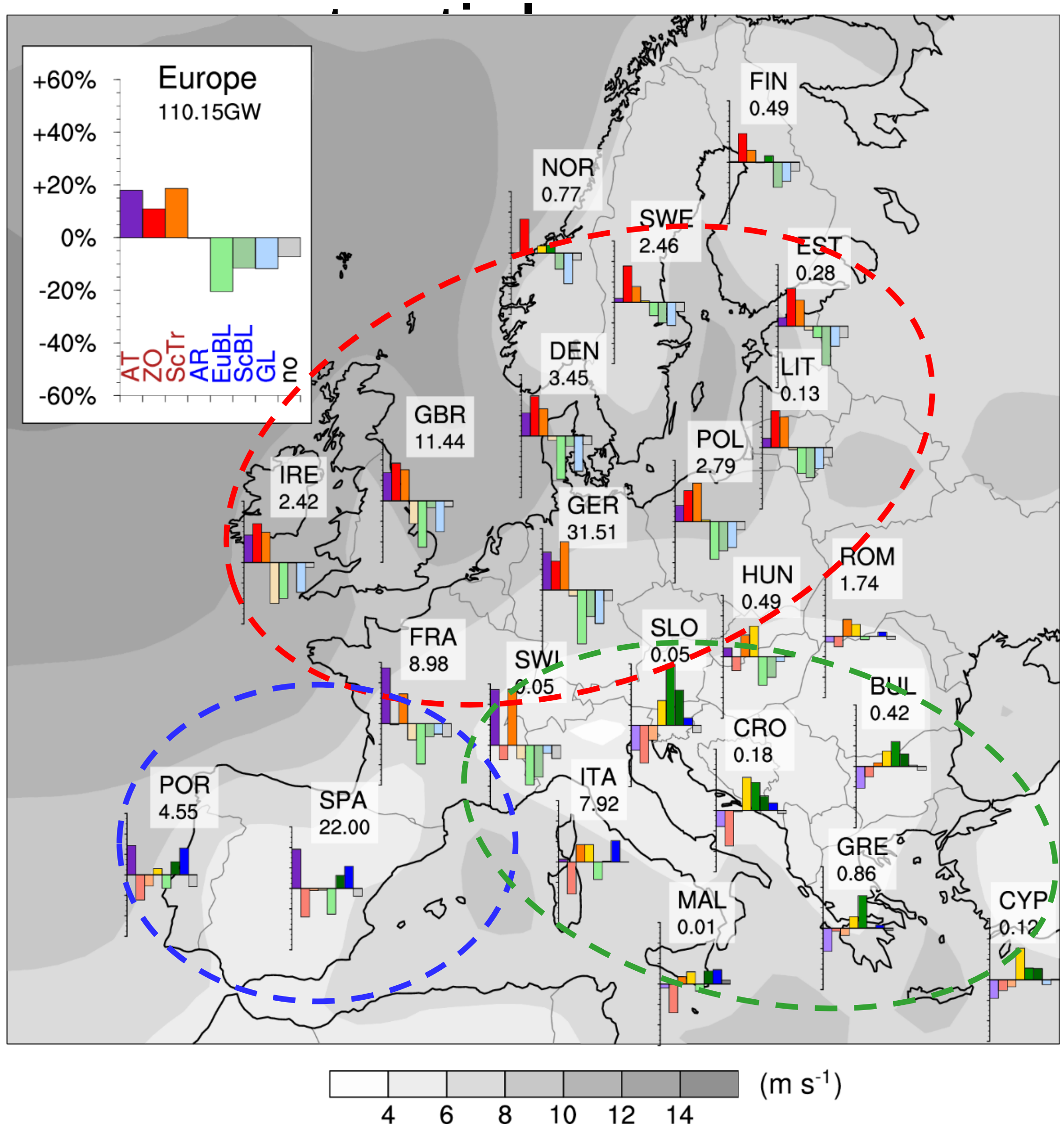
Outlook

- In a second paper which combines reanalysis data and renewables.ninja we showed that for two of the seven weather regimes there exists predictability of wind power on monthly time scales, when there are strong anomalies in the stratosphere



Beerli, R., H. Wernli and C. Grams (2017). Does the lower stratosphere provide predictability for month-ahead wind electricity generation in Europe? Quarterly Journal of the Royal Meteorological Society, doi:10.1002/qj.3158

Appendix: Modulation of wind power



Bars for each country of

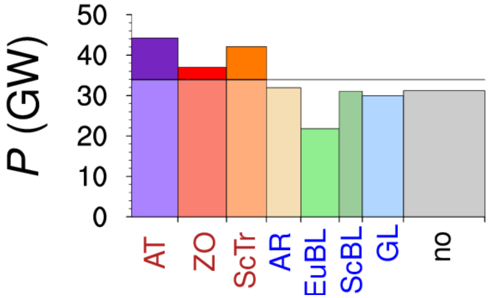
ΔCF : wind power output change from winter mean

numbers: country's *IC* in GW (as of end 2014)

grey shading: DJF mean 100m wind

Appendix Maximum Over-/Under-production

Europe



Winter mean: 34 GW

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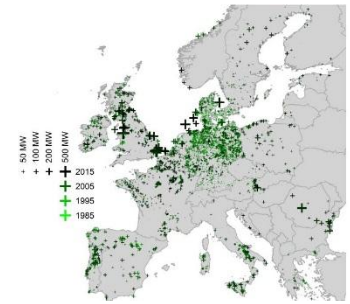
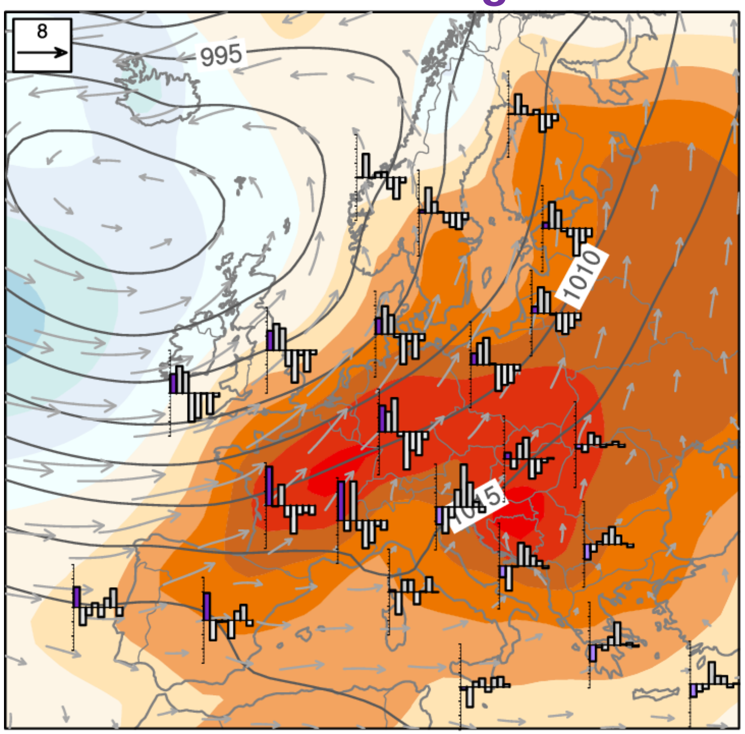
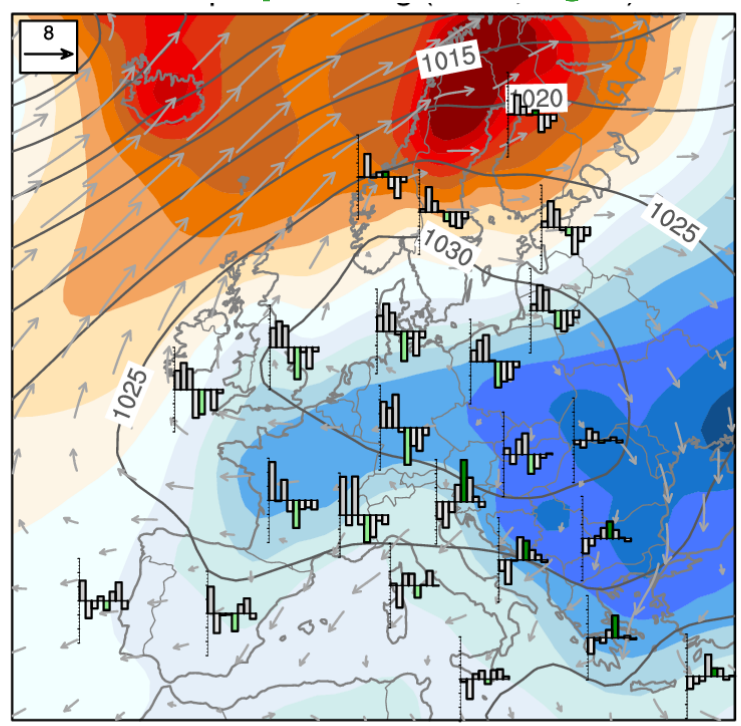
Volatility of 22 GW (65%)



Atlantic trough



European Blocking



Temperature 2 m