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)

- $\Delta P=0-30$ GW
- Often matches peak demand

**multi-day variability** (days – weeks)

- $\Delta P=10-40$ GW
- Strong ramps
- Long lasting
- Irregular occurrence

**seasonal variability** (months)

- $\Delta P=10-50$ GW
- Regular seasonal anti-correlation of wind and solar power

Storage and flexible demand

Large-scale storage not available currently!

Co-deployment of wind and solar PV

www.raonline.ch
Scope of the study

short-range variability (hours – days)

multi-day variability (days – weeks)

seasonal variability (months)

• $\Delta P=0-30$ GW
• often matches peak demand
• strong ramps
• longlasting
• irregular occurrence
• $\Delta P=10-50$ GW
• regular seasonal anti-correlation of wind and solar power

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

• Country-aggregated wind and solar PV capacity factors $CF$
• Hourly data based on calibrated Renewables.Ninja (1985-2016)

Pfenninger et al. (2016), doi: 10.1016/j.energy.2016.08.060
Staffell et al. (2016), doi: 10.1016/j.energy.2016.08.068
Modulation of 100 m wind by weather regimes

- Atlantic trough (AT, 13.1%)
- Zonal regime (ZO, 13.8%)
- Scand. Trough (ScTr, 11.3%)

- Atlantic trough (AR, 9.7%)
- Eu. Blocking (EuBL, 10.9%)
- Sc. Blocking (ScBL, 6.5%)
- Greenland Bl. (GL, 11.7%)

- 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

Europe

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
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.
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

Current

- solid
  - Atlantic trough
  - Zonal Regime
  - Scandinavian trough
  - No regime
  - All winter days

- dashed
  - Atlantic ridge
  - European blocking
  - Scandinavian blocking
  - Greenland blocking
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|                                           |

Current

2030 Planned
Future variability

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

- **Solid**
  - Atlantic trough
  - Zonal Regime
  - Scandinavian trough
  - No regime
  - All winter days

- **Dashed**
  - Atlantic ridge
  - European blocking
  - Scandinavian blocking
  - Greenland blocking
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/](https://www.renewables.ninja/)

Blog: [https://christiangrams.wordpress.com/balancing-europes-wind-power/](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 potential

Bars for each country of 

\( \Delta CF \): 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

AT: 44 GW (+10 GW)

EuBL: 22 GW (-12 GW)

Volatility of 22 GW (65%)