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

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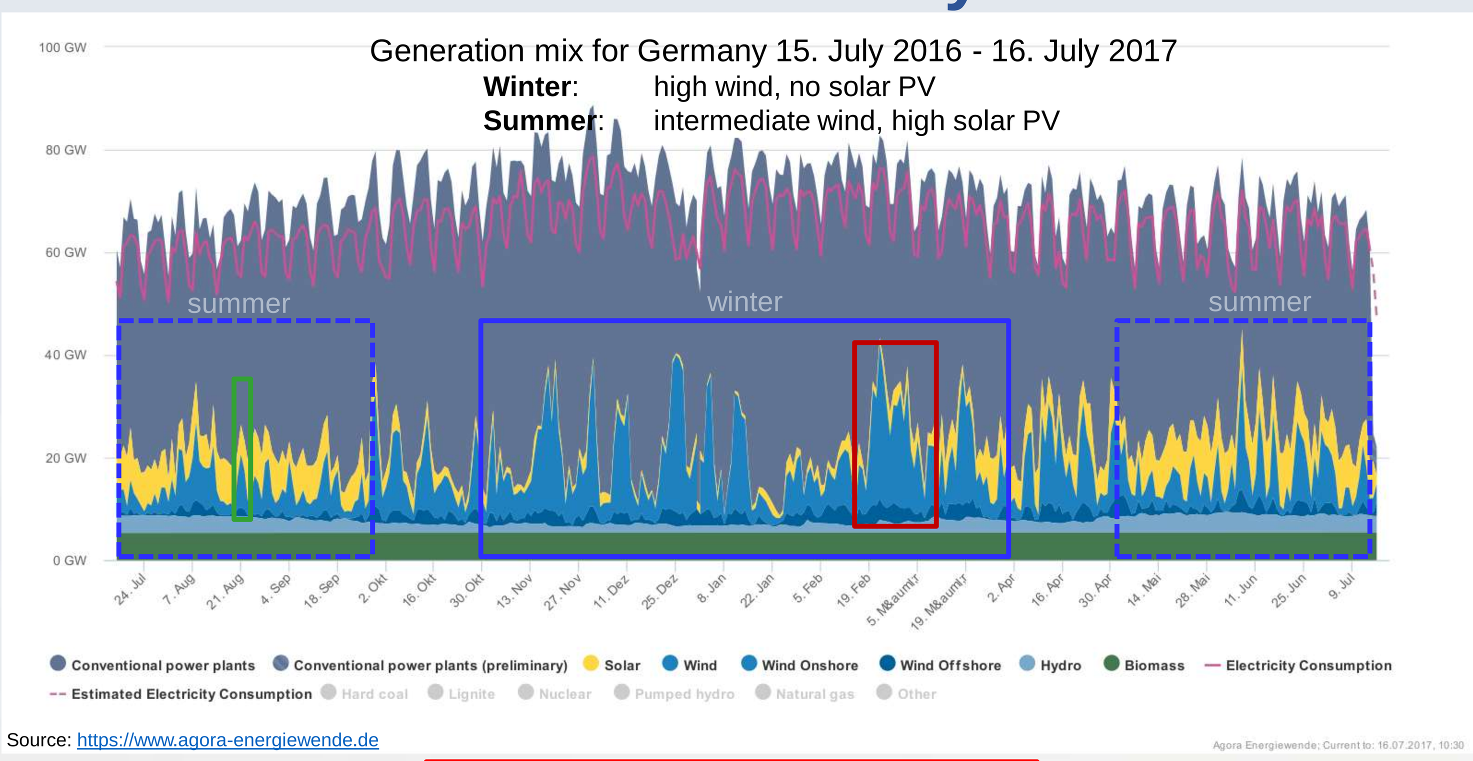
doi:10.1038/nclimate3338

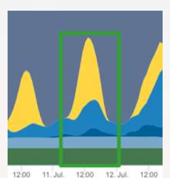
Blog: https://christiangrams.wordpress.com/balancing-europes-wind-power/

1. Weather induced variability of Renewables



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

short-range variability (hours – days)

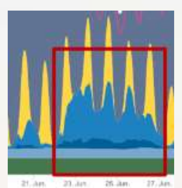


- ΔP=0-30 GW
- often matches peak demand

- Diurnal cycle
- local clouds
- thunderstorms

Storage and flexible demand

multi-day variability (days – weeks)



- ΔP=10-50 GW
- strong ramps
- long-lasting
- irregular occurrence

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

?

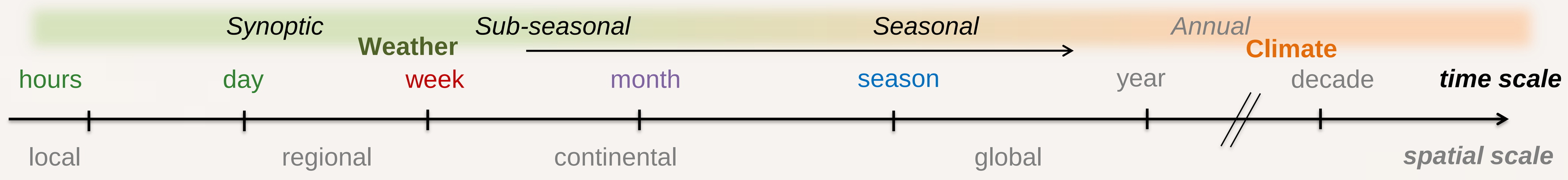
Large-scale storage not available!

seasonal variability (months)

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

- seasonal cycle

Co-deployment of wind and solar PV

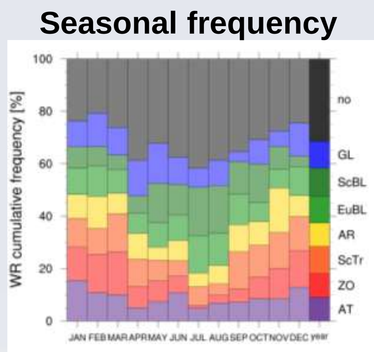


2. Weather regimes and power modelling

Weather Regimes

- year-round Atlantic-European weather regimes
- Six-hourly data based on ERA-Interim (1979-2016)
- EOF analysis and k-means clustering of 5d low pass-filtered 500hPa geopotential height anomalies
- Normalization to account for seasonality

Seasonal frequency



- **Cyclonic regimes**:
  - Atlantic trough
  - Zonal Regime
  - Scandinavian trough
- **Blocked regimes**:
  - Atlantic ridge
  - European blocking
  - Scandinavian blocking
  - Greenland blocking

Renewables.Ninja

https://www.renewables.ninja/

- hourly (1985-2016) country-aggregated capacity factors (CF) for wind and solar PV
- Sophisticated modelling of wind fleet and solar PV installations
- Calibration and bias-correction based on monitored power output

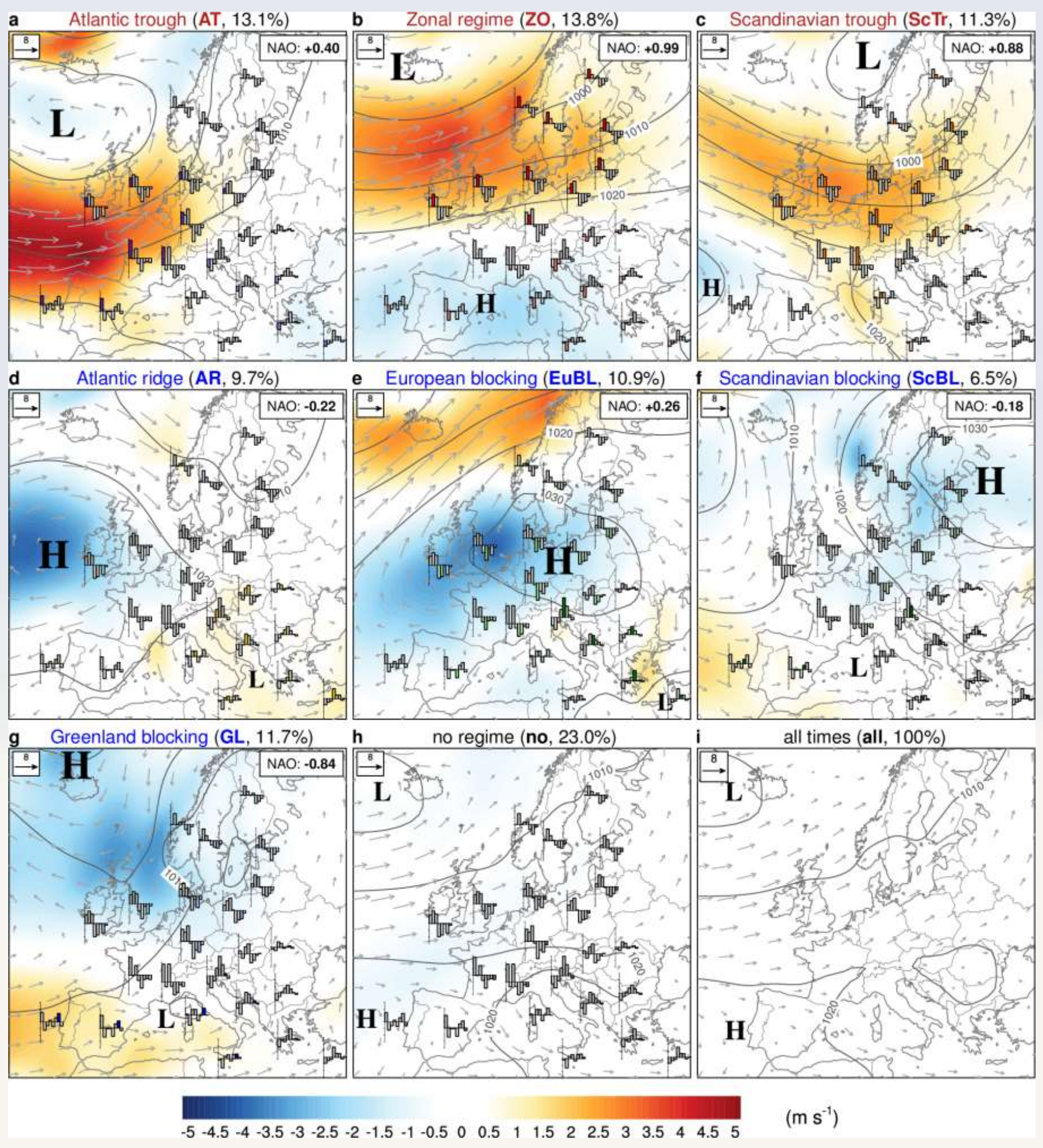
→ Best available historic power output data

IC installed capacity in GW
P power output in GW
CF = *P* / *IC* capacity factor

$$\Delta CF = (CF_{wr} - CF_{season})/CF_{season}$$

Relative Change in power output potential

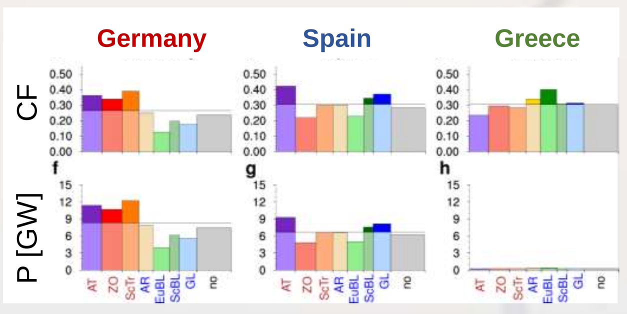
100m wind anomalies during different weather regimes in winter



100m wind speed anomaly wrt. winter (DJF) mean (shading in m s⁻¹), 100m winter mean wind vectors (length scale in m s⁻¹ upper left corner), winter mean pressure at mean sea level (contours every 10hPa), mean NAO index (upper right corner)

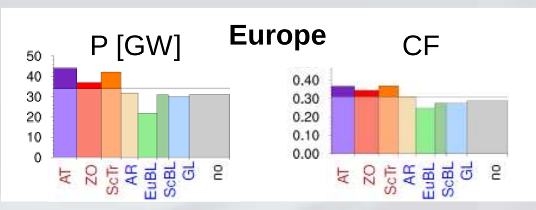
3. Modulation of wind power potential

- ***Wind power potential*** varies by up to ± 50% for individual countries depending on weather regimes
- Different climatological regions:
  - **North Sea:** surplus during cyclonic regime, strong reduction during blocked regimes
  - **Balkans:** surplus during blocked regimes
  - **Western Mediterranean:** mixed
- Conditions in Europe correlate with North Sea as this is the largest region

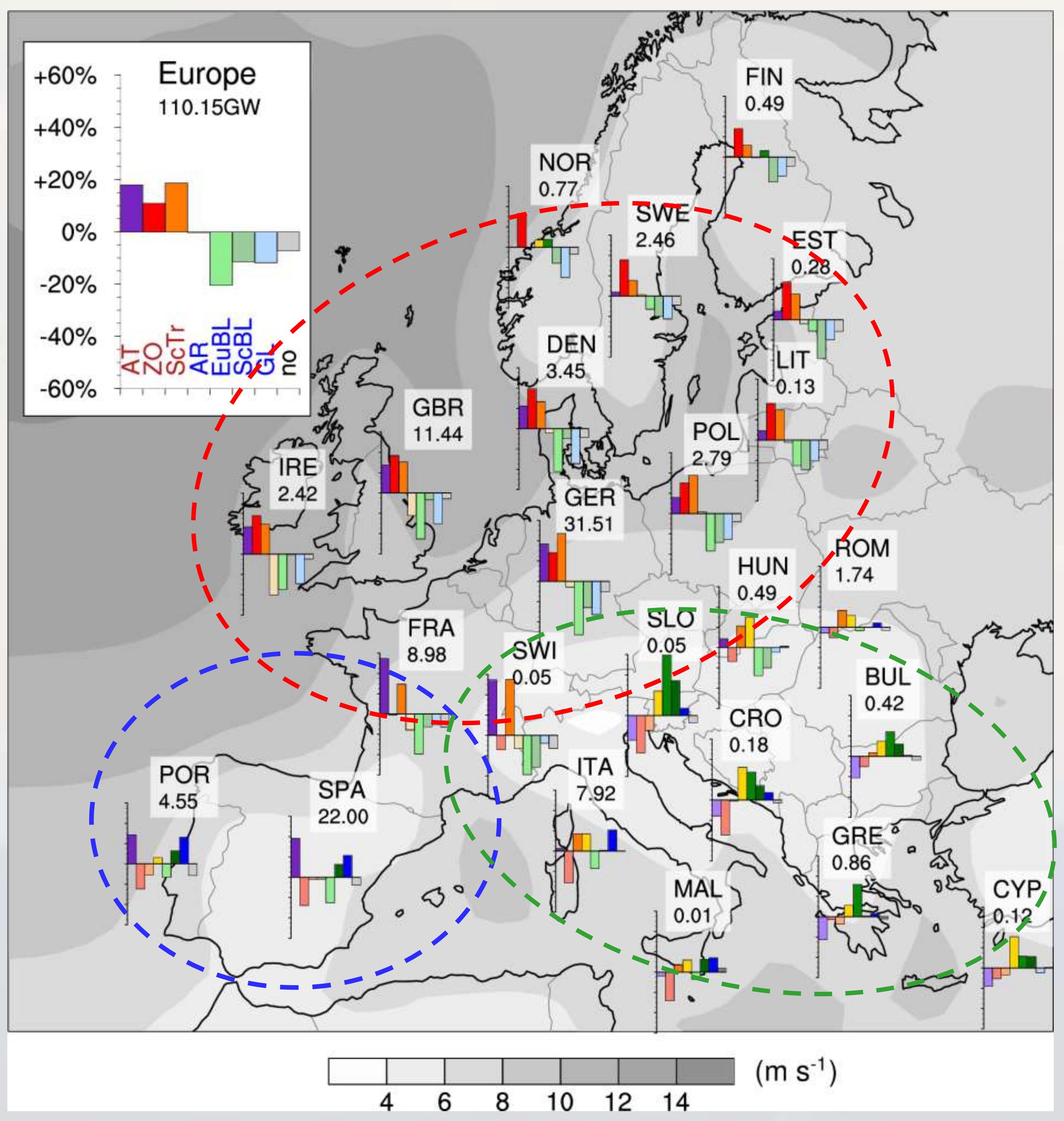


Country-specific mean capacity factors CF [0-1] and mean wind electricity generation [GW] for winter days in different regimes

- Actual European wind electricity dominated by North Sea due to bulk of installed capacity
- Wind power potential in Balkans is not exploited

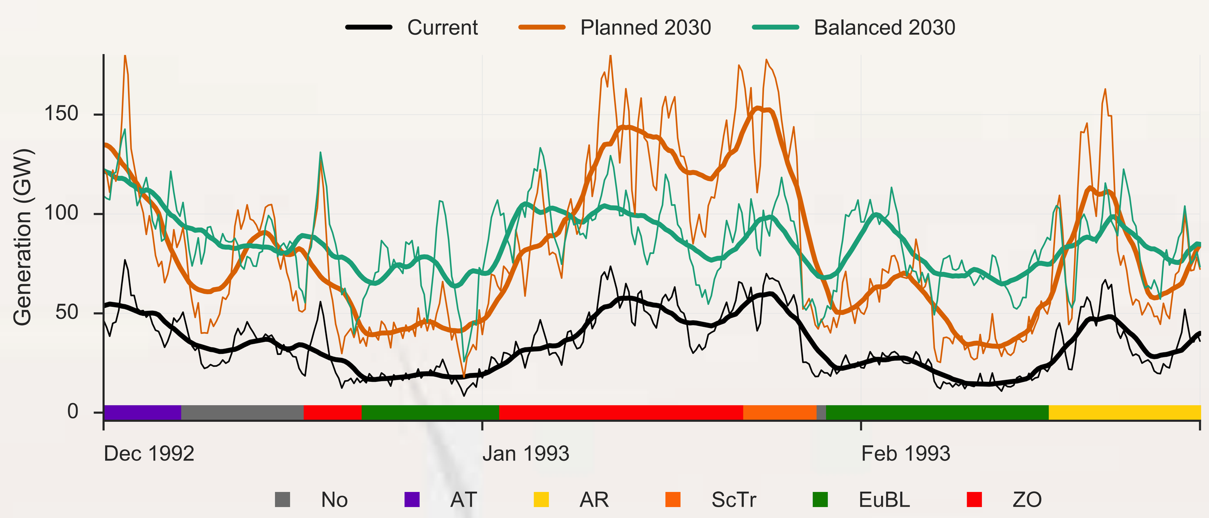


Weather regime-dependent change in wind electricity generation



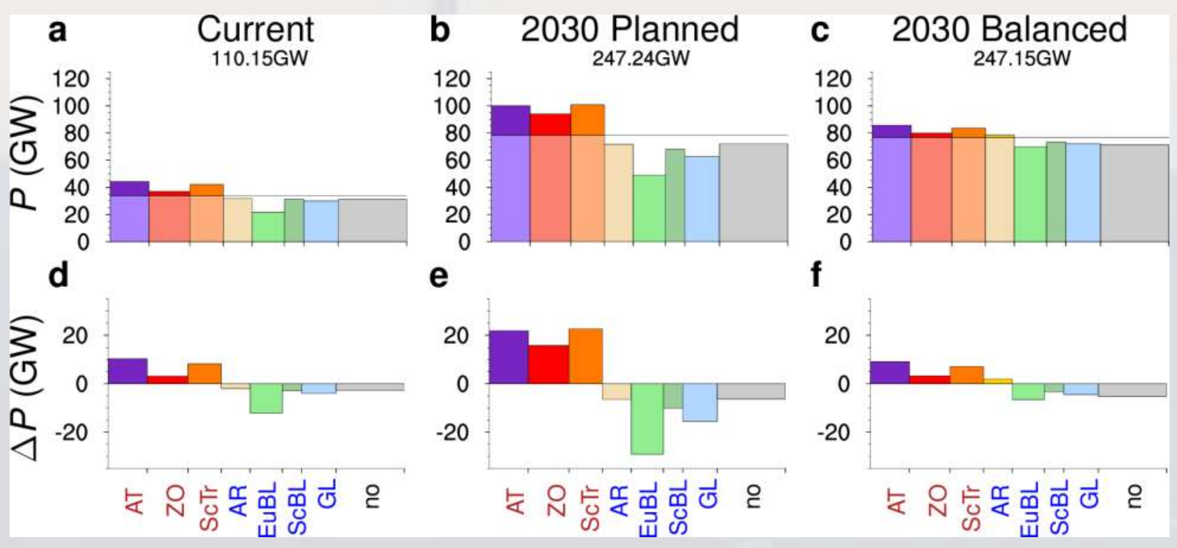
Country-specific change of CF during cyclonic (red labels) and blocked regimes (blue labels) shown as percent deviation from winter mean CF. Barplot label indicate ISO country code and installed capacity (in GW) as of 2015. Grey shading indicates winter mean 100m wind speed (in m s⁻¹)

4. Future scenarios



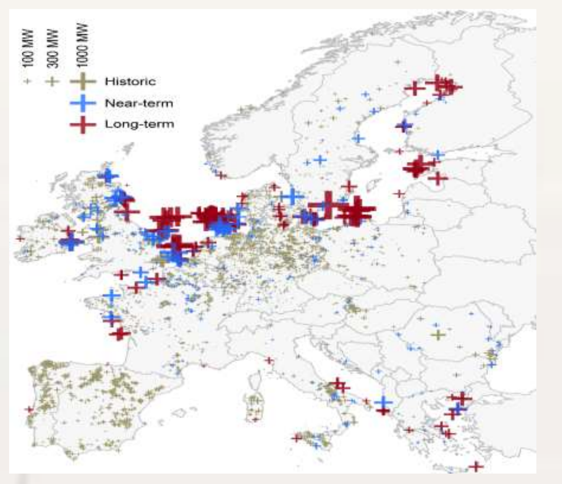
European wind electricity generation (6-hourly thin, 5d running mean thick) with weather conditions as of winter 1992/93

- Bias of IC towards North Sea region imposes high volatility to European wind power output
- Ramps of about 30 GW during regime transitions (e.g. end of Jan 1993) aggravate to 100 GW with current planning of 137 GW new IC in North Sea region
- Alternate balanced would yield same winter mean output at much reduced volatility



Wind electricity generation (in GW) for Europe for different scenarios and weather regime-dependent absolute change (in GW) in wind electricity generation.

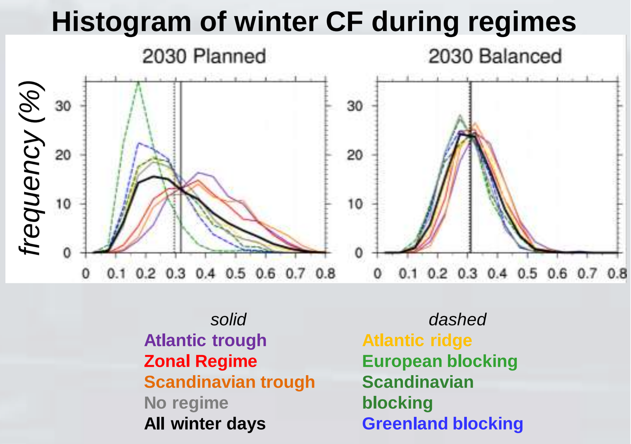
Installed wind farms



Installed wind capacity in Europe as of 2015 (green), planned by 2025 (blue) and by 2030 (red)

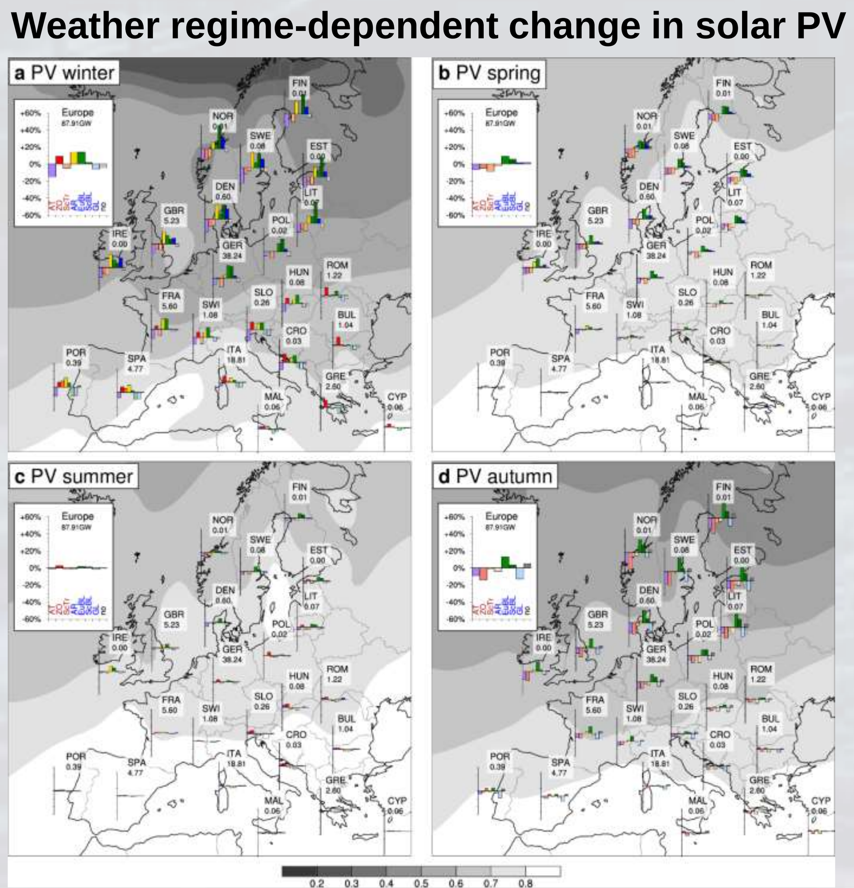
- Bulk of existant IC (110 GW) in North Sea and Iberia
- **Future deployment**
  +137 GW in North Sea region
- **Alternate balanced scenario**
  +30 GW in Iberia
  +67 GW in the Balkans
  +40 GW in Northern Europe

Histogram of winter CF during regimes



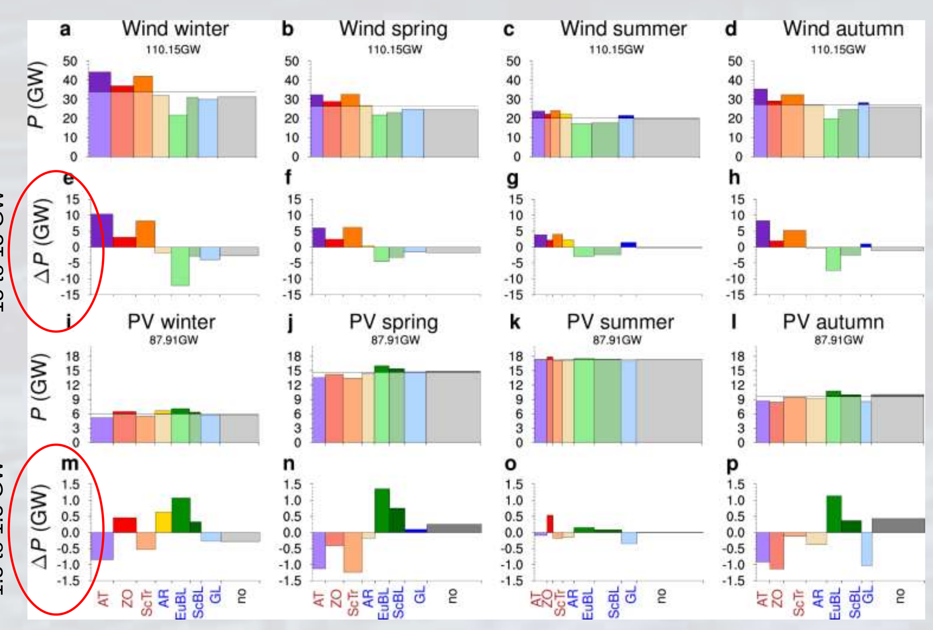
5. Modulation of wind and solar PV all seasons

Weather regime-dependent change in solar PV



Country-specific change of CF for solar PV during cyclonic (red labels) and blocked regimes (blue labels) shown as percent deviation from seasonal mean CF. Barplot label indicate ISO country code and solar PV IC (in GW) as of 2015. Grey shading indicates seasonal mean fraction of maximal insolation

European wind and solar PV power output



- Strongest weather regime-dependent variability in winter, but CF very low due to reduced insolation
- Current variability of *P* for solar PV is 10x smaller than for wind in winter and most other seasons
- Co-deployment can not balance multi-day variability induced by weather regimes. Only suitable for balancing seasonal variability

6. Conclusions

- Multi-day variability in wind power output governed by weather regimes
- Unbalanced deployment in North Sea region causes very high-volatility of Europe-wide wind electricity generation
- Future deployment aggravates volatility but alternate strategies could stabilise wind power
- European collaboration needed

Citing from Grams et al. (2017): "This study provides a deeper meteorological understanding of multi-day volatility in European wind power output. Atlantic-European weather regimes cause important wind electricity surpluses and deficits in European sub-regions lasting several days to weeks, which are more difficult to address than local short-term fluctuations. Peripheral regions of Europe in Northern Scandinavia, Iberia, and the Balkans exhibit a high potential for enhanced wind electricity generation during severe lulls in the North Sea region. In addition, these lulls come along with prevailing cold conditions and therefore high demand[24]. An interconnected European power system combined with future deployment in peripheral regions could therefore be a strategic response to the multi-day volatility challenge and grid management needs imposed by the effects of weather regimes. Moreover, this meteorological understanding might help to better exploit sub-seasonal weather forecasts in the energy sector. Solar PV could have a local balancing effect, but only if large-scale investment increases its capacity tenfold. Our results show that a profound understanding of continent-scale weather regimes can substantially improve wind power supply irrespective of how the rest of the European power system develops."

References

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FNSNF Fonds national suisse Schweizerischer Nationalfonds Fondo nazionale svizzero Swiss National Science Foundation

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Background photo: Bernhard Mühr www.wolkenatlas.de

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