UiO : Department of Mathematics
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Identifying weather stress events from power system optimisation outputs

Joint work with Koen van Greevenbroek and Hannah Bloomfield

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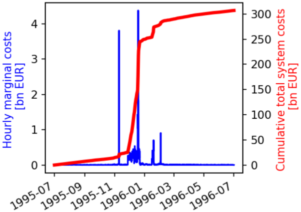
Research questions

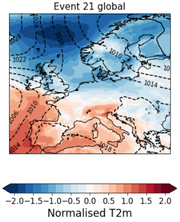
- Can power system models tell us what kind of weather systems lead to difficult periods?
- In which way were these weather events difficult for power systems?

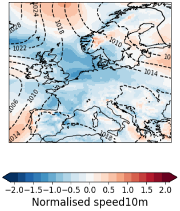
Approach

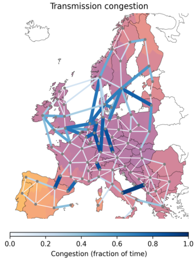
Iterative process between model outputs (PyPSA-Eur, 181/90 nodes, hourly resolution) and meteorological insights

1. Single-year optimisations (July - June, 1980 - 2020) with filtering for extreme periods.
2. Meteorological classification (all based on ERA5 reanalysis [1]).
3. Investigation of relevant energy system variables.









Clustering of weather

- Events have common features: European-wide impact, low wind speeds and low temperatures
- Almost all extreme events happen between November and March.
  - Additionally seek out the most extreme events in the summer month (less severe).
- Events have different lengths (from several hours up to 2 weeks).
- We can sort them into four winter and three summer categories:
  1. High pressure over North-East (Winter)
  2. High pressure over Central Europe (Winter)
  3. High pressure over GB (Winter)
  4. Multiple features over Europe (Winter)
  5. High pressure over West/GB (Transition/Summer)
  6. Warm Central Europe (Summer)
  7. Warm Southern Europe (Summer)

Longer vs. shorter effects

- Annual system costs are mostly driven by a few difficult periods.
- Annual NAO index (previously identified as indicator for compound events [2, 3, 4, 5]) does not correlate with annual system costs.

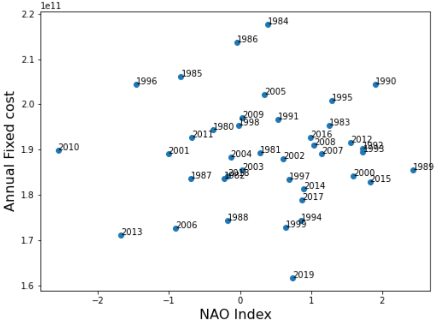


Figure: NAO index vs. total system costs

Identification of key components

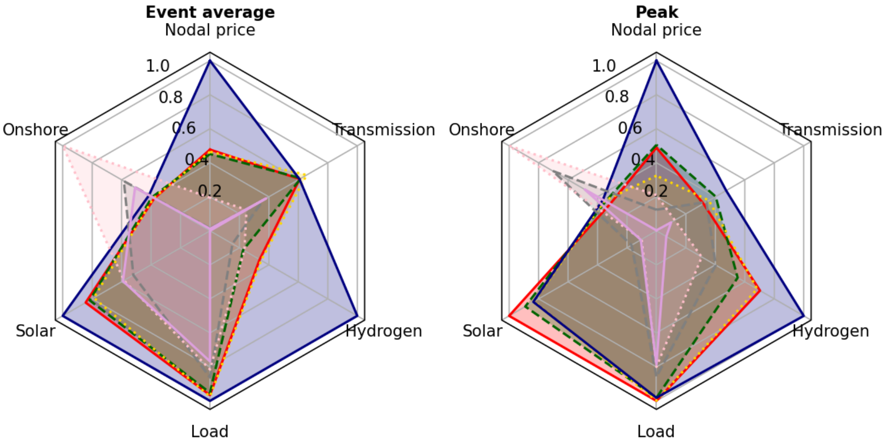
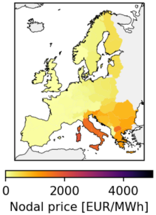
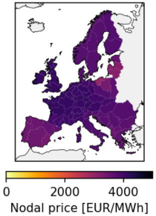


Figure: Normalised indicators of event averages (1 being most difficult)

Questions and outlook

- What about more localised events? For example:





- Is difficulty more driven by magnitude or duration?
- How to use this for seasonal forecasting?

References I

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ERA5 hourly data on single levels from 1959 to present, 2021.
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The influence of weather regimes on European renewable energy production and demand, 2019.
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Variability in North Sea wind energy and the potential for prolonged winter wind drought, 2023.
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References II

Tedesco, P. et al.
Gaussian copula modeling of extreme cold and weak-wind events over Europe conditioned on winter weather regimes
https://doi.org/10.1088/1748-9326/acb6aa

Mockert, F. et al.
Meteorological conditions during Dunkelflauten in Germany: Characteristics, the role of weather regimes and impacts on demand
https://doi.org/10.48550/arXiv.2212.04870

Thank you for your attention! Any questions?

Feel free to catch me (aleksgro@math.uio.no) or Koen van Greevenbroek here.

Identification of extreme events

1. Consider the dual variables $\eta_{n,t}$ to

$$\text{dem}_{n,t} \leq \text{supply}_{n,t} \text{ for a node } n \text{ at time } t.$$

2. For $T \leq 2$ weeks and a cost threshold C an event starting at time t_0 is considered "extreme" if

$$\sum_{n} \sum_{t=t_0}^{t_0+T} \eta_{n,t} \geq C.$$

- We select a cost threshold of $C = 100$ billion EUR and found 32 events.
- For summer events (between April and September) we selected a much lower threshold of $C = 3.5$ billion EUR and found 12 events.

Focus on inputs vs. outputs

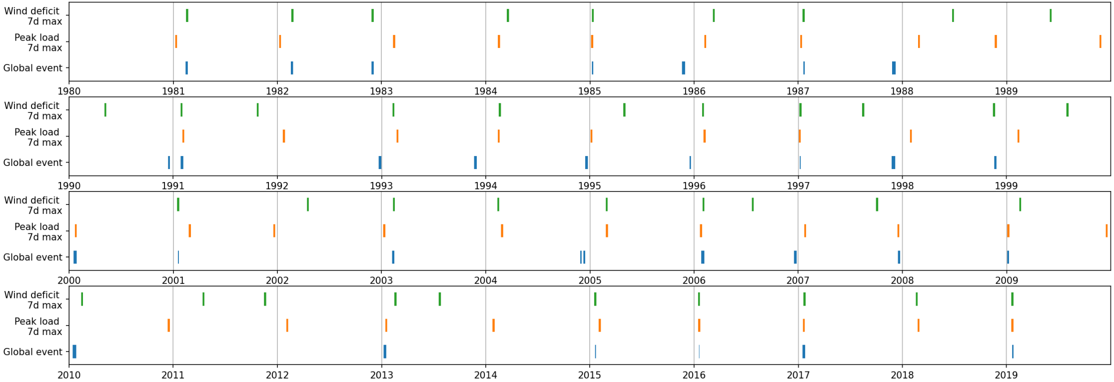


Figure: Extreme periods (for each year $\max_t \sum_{i=0}^{168} \text{dem}_{t-i}^{\text{eur}}$, $\max_t \sum_{i=0}^{168} [\text{dem}_{t-i}^{\text{eur}} - \text{gen}_{t-i}^{\text{onwind}}]$) vs. our approach

Meteorological composites (Winter events)

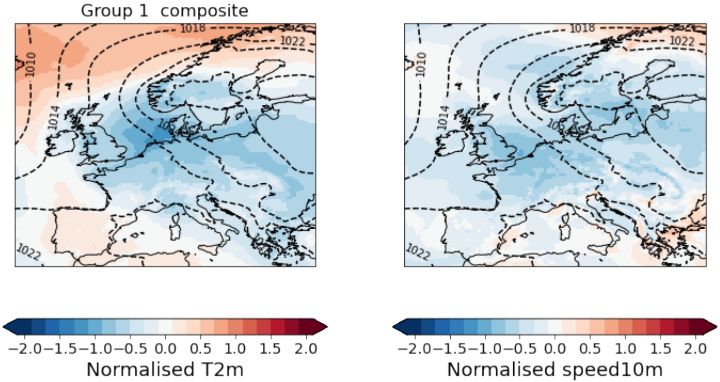


Figure: High pressure over North-East

Meteorological composites (Winter events)

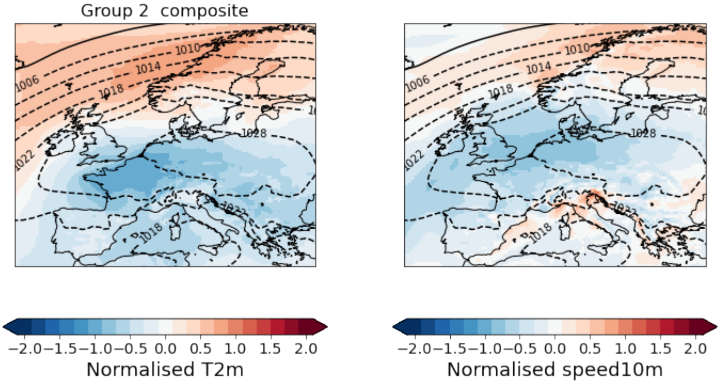


Figure: High pressure over Central Europe, strong pressure gradient to the North

Meteorological composites (Winter events)

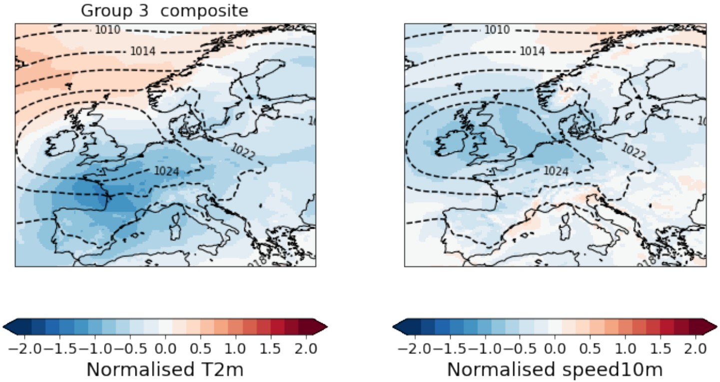
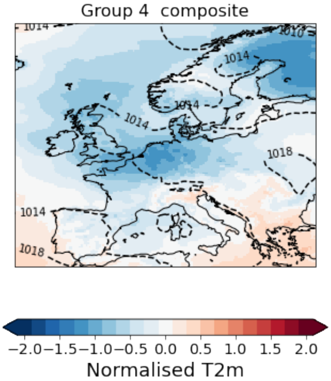


Figure: High pressure over GB, cold Central/North/East

Meteorological composites (Winter events)



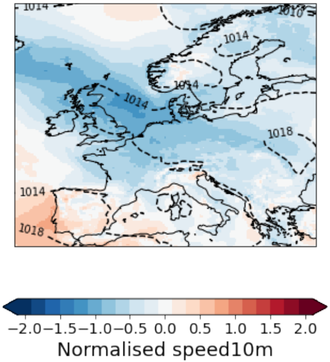


Figure: Multiple weather features (often over the Atlantic + Northern Europe)

Meteorological composites (Summer events)

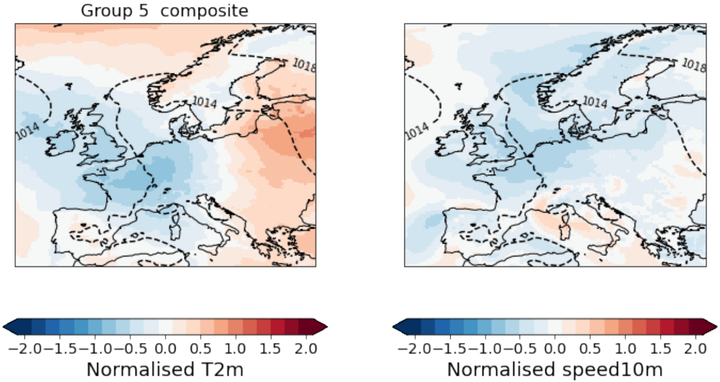


Figure: High pressure over West/GB, driven by cold weather — transition season extremes

Meteorological composites (Summer events)

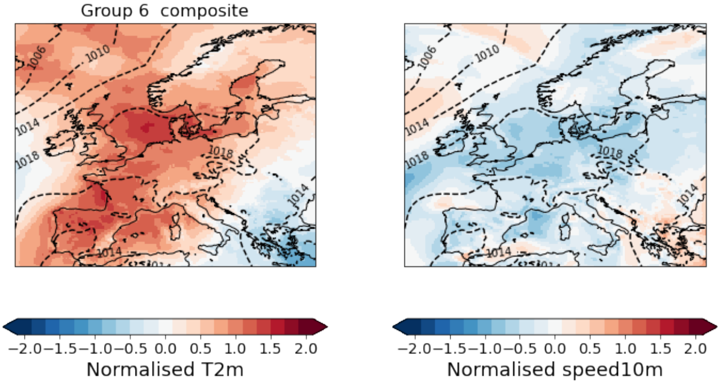


Figure: Warm Central to Northern Europe, low wind over North Sea

Meteorological composites (Summer events)

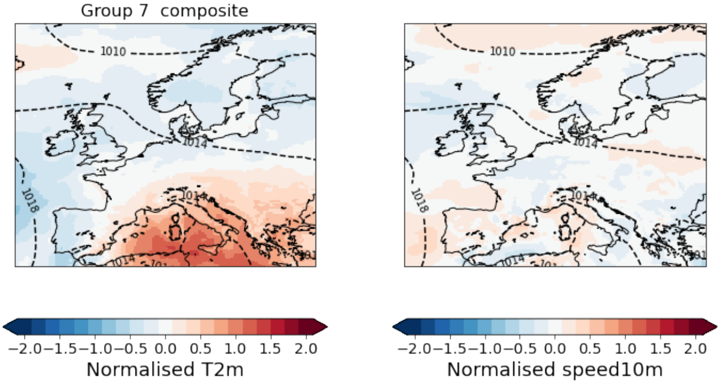


Figure: Warm South, cold and low wind in other regions