Dunkelflaute and long-term electric energy shortage events in Europe

Yvonne Scholz1, Lueder von Bremen1, Gerald Lohmann1, Wenxuan Hu1, Marion Schroeder-Homscheidt2
1German Aerospace Center (DLR), Institute of Networked Energy Systems, Oldenburg, Germany
yvonne.scholz@dlr.de

In central Europe, slowly moving low-pressure systems in winter can cause prolonged periods of low wind and solar power generation with simultaneously increased demand for electricity for heating. Information about such electric energy shortage events is important for long term planning of storage capacities and other flexibility options in energy supply systems with high shares of variable renewable energy (VRE) sources. Furthermore, multi-annual remaining residual loads may cause additional needs of VRE generators.

We use the TYNDP Distributed Energy1 scenario and 30 years of ERA5 reanalysis data2 to investigate shortage events of different duration that, given the installed capacities from the scenario, would have happened in Europe between 1990 and 2020. The information helps assessing the amount of energy required for balancing or generator extension. We also identify the calendar dates when the events would have occurred. The identified most critical calendar periods can be used as input to specify the set-up of further energy systems analysis studies.

### References
2. ERA5 Copernicus Climate Change Service (C3S) (2023): ERA5 hourly data on single levels from 1990 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 10.24381/cds.adbb2d47 (accessed in July 2021)

### Acknowledgement
EnDat module input data sets and data handling were updated within the Sesame Seed project, which was funded by the German Federal Ministry for Economic Affairs and Climate Action. The updated model version was used to generate the presented results. The results contain modified Copernicus Climate Change Service information 2020. Neither the European Commission nor ECMWF is responsible for any use that may be made of the Copernicus information or data it contains.

### Key take aways and outlook
- Energy shortage events of one day to several years duration can be important for energy system modelling.
- The residual load and with it the energy demand can be elevated by up to 246 % compared to the mean residual demand in a 14 day period, by up to 29% in one year and 5% in ten years.
- If a year with average residual load is chosen for energy systems modelling, the long term storage requirement can therefore be underestimated.
- The identified time periods and the corresponding VRE and demand time series can be used in energy system models for further investigation.
- The identified time periods may also be chosen or used to generate synthetic weather years that reflect extremes of residual load for energy systems modelling.

### Figures
1. Plotting distributions of residual load anomalies with different rolling average windows = durations
2. Focusing on the maxima and considering the resulting additional energy demand
3. Maximum residual load anomaly events (Europe, 1990 - 2020)
4. Maximum one day rolling average of residual load anomaly: 298 GW ± 35% of mean residual load
   - 180-day rolling average: distinct seasonal pattern with winter peaks
   - One-Year (365-day) rolling average can be above the mean residual load for more than one year in a row

### Methods
- Power generation time series with EnDat3 (Energy Data Analysis Tool)
- Residual load: daily power demand minus daily VRE power generation
- Residual load anomalies: residual load minus mean residual load
- Rolling averages of residual load anomalies with different durations:
  - Dunkelflaute: several days
  - Seasonal electric energy shortages: one to several months
  - Long term electric energy shortages: one to several years

### Data
- ERA5 reanalysis data2: SSRD, T_2M, U_100M, V100M
- European supply scenario based on TYNDP Distributed Energy1
  - Interpolated year 2035
  - Capacity: 646 GW PV, 667 GW Wind onshore, 206 GW Wind offshore
  - Power demand: 4365 TWh/a
- ENTSO-E energy demand data4

### Results
- Mean load: 410 GW
- Mean residual load: 84 GW
- 79.5 % VRE
- 20.5 % non-VRE

### Notes
- Averaging a "classical Dunkelflaute" period of 14 days leads to variations of the residual load anomalies between 207 GW and -144 GW ± 246 % and -171 % of mean residual load
- Less than 4 years averaging is associated with maximum residual load anomaly values of more than 10 % of medium residual load
- 10 year residual load anomaly is still up to +5 % of mean residual load

### Further Reading
- Dunkelflaute: several days
- Seasonal electric energy shortages: one to several months
- Long term electric energy shortages: one to several years

- References
  2. ERA5 Copernicus Climate Change Service (C3S) (2023): ERA5 hourly data on single levels from 1990 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). 10.24381/cds.adbb2d47 (accessed in July 2021)
  3. ENTSO-E energy demand data downloaded from https://transparency.entsoe.eu/load, accessed in October 2022