Severity of variable renewably energy droughts in Europe

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Overview

Renewable energy is one pivotal element in the decarbonization of our energy systems. With a limited potential of firm renewable energy in many regions, variable renewable energy sources (VRE) are the main technologies contributing to the transition. VRE availability depends on prevailing weather conditions, posing integration challenges: During a period with high VRE availability, surplus energy needs to be integrated into the system to serve demand at another place or later in time. In periods of VRE shortage, flexibility options need to serve demand with stored or shifted surplus energy. Notably, long-lasting stretches of low VRE availability of varying severity, frequency, duration, and spatial coverage (VRE droughts) challenge the security of supply. Simultaneity with high-demand phases exacerbates this system stress. Due to the variable spatio-temporal extent of weather events, VRE droughts are not limited to a specific region or country but vary largely across time and space. This paper evaluates VRE droughts in terms of severity, duration, timing, and simultaneity. Initially focusing on Germany, VRE droughts are investigated in the European context to account for the VRE balancing across regions.

Methods

Two definitions apply to VRE droughts (Ohlendorf & Schill, 2020). First, droughts as periods of consecutive hours with a VRE availability constantly below a certain threshold (CBT). VRE availability of a region is measured as an availability factor that represents the theoretical VRE generation potential (MWh) normalized by the installed VRE generation capacity (MW). Second, droughts as periods of consecutive hours with a moving average of VRE availability below a certain threshold (mean below threshold – MBT). The CBT notion identifies VRE drought periods in the narrow sense regardless of the VRE availability in adjacent periods. The MBT approach finds droughts in a wider sense by accounting for longer stretches of low VRE availability on average, with allows for short instances of VRE availability above a threshold and may include multiple periods of CBT droughts. This is especially relevant for identifying the need for long-term storage, e.g., based on hydrogen. Contrasting results from these two approaches reveals insights on the different temporal scales of required system flexibility, for instance, by different types of storage (short-, medium-, and long-term).

Additionally, there are two options to count VRE droughts: First, a *drought window* denotes a period of consecutive availability factors with a fixed duration, qualified either according to the CBT or MBT notion. Windows are counted for increasing window size, starting with a few hours up to multiple months. This method identifies ‘slices’ of flexibility need that the system needs to provide for all relevant time scales. Second, a *drought event* is a period of consecutive availability factors with variable duration. The algorithm counts in descending order from the longest event potentially lasting multiple months down to events lasting only a few hours. Consequently, each qualified CBT or MBT event is counted only once. Results reveal the number of drought events with a minimum duration that the system needs to balance. These two counting algorithms address the shortcomings of previous work on VRE droughts and improve the robustness of the results.

Results

Initially, droughts of single VRE are analyzed to explore the characteristics of droughts each VRE technology faces. Then, as the availability of wind and solar power balance each other across time and space, drought periods of all VRE generation technologies combined are explored. Finally, to account for simultaneity with demand peaks, system energy deficits are identified by examining residual load time series (Ruhnau & Qvist, 2022). Different indicators measure the severity of VRE drought periods (Ohlendorf & Schill, 2020) below different availability factor thresholds. The frequency of drought periods per duration (event or window lasting a certain number of hours) averaged over all years reflects the expected number of droughts occurring per year for a given drought duration (Figure 1). The return period is measured as the reciprocal of the expected number of droughts per year and indicated the probability of droughts for the renewable energy system.

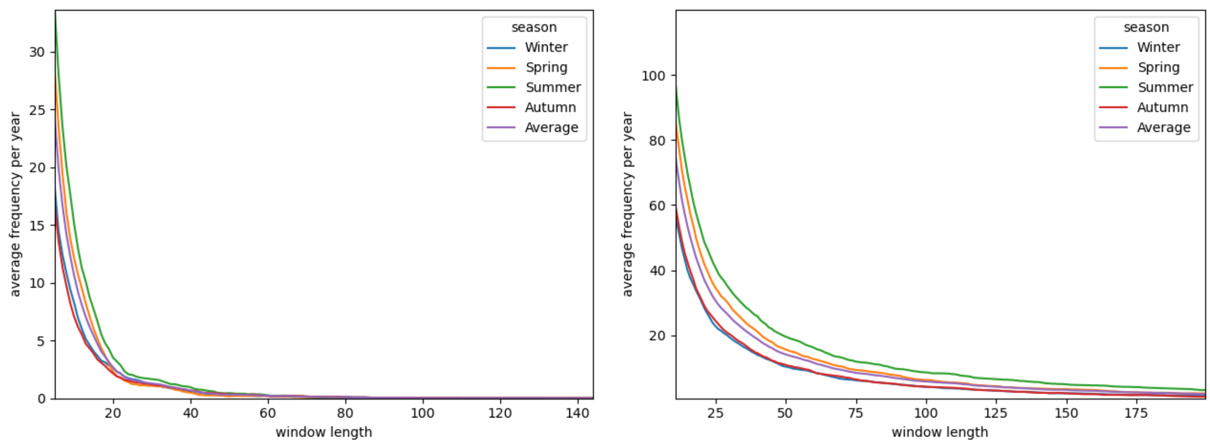

Figure 1: Average frequency of MBT drought windows for increasing window durations of onshore wind in Germany for a threshold of 0.02 (left) and 0.10 (right). Low-wind windows are more frequent in spring and summer than in autumn and winter.

Conclusions

Insights allow for a distinct assessment of the relevance of energy droughts concerning VRE technologies individually and in terms of simultaneity for the transition of our energy systems, both in the German and European context (Raynaud et al., 2018; Kaspar et al., 2019).

References

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