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Identifying weather stress events from power system optimisation outputs

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The climate crisis and cost reductions in key technologies like solar, wind, and batteries are pushing an ambitious transition of power systems to renewables. This shift towards intermittent generation deepens the impact of weather and climate on the energy sector and can introduce new risks if not accounted for properly. Furthermore, as the ramifications of climate change are only to become even more noticeable, extreme events are expected to increase both in frequency and intensity. This in itself may lead to additional stress on renewable power systems, and recent research in energy meteorology relates these extreme weather events to so-called compound weather events, which are caused by more than one variable or component at the same time. However, compound events, their characteristics, and their risk for energy systems design are not yet well understood.

In this work, we use outputs of a power system model to identify what meteorological drivers lead to difficult periods and stress in the European electricity system. For this we couple energy modelling and meteorology in an iterative process that can connect weather insights from a synoptic scale to features of a highly resolved representation of the European electricity network. We use the open energy system model PyPSA-Eur with four decades of reanalysis weather data to find cost-minimal solutions for a fully decarbonised European power system. Dual variables of these optima are used to identify difficult weather periods, understood as periods that drive system design and total cost. This use of dual variables of the optima - as opposed to studying weather data in isolation - allows for a more accurate identification of difficult periods, tailored to the energy system at hand. We then characterise the underlying weather conditions during those periods and assess their effects on the power system and energy variables. Due to the level of integration, some of these spread across the entire continent, whereas other phenomena remain local; they can be of varied intensity and persist on different time scales.

Bringing an enhanced understanding of which weather events are difficult for energy systems, this approach can help to find obstacles for a transition to a fully renewable European power network, and inform how certain risks can be avoided or resilience strengthened.