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Meteorological Drivers of European Power System Stress

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ABSTRACT

A fast decarbonisation of intensity frameworks is in progress to restrict ozone harming substance discharges and meet carbon-decrease targets. Sustainable power is a critical fixing to meet these objectives; in any case, it is significant that public force frameworks actually keep up energy security with expanding levels of inexhaustible infiltration. The working capability of inexhaustible age on occasion of pinnacle interest (a crucial time for power framework stress) isn't surely known. This investigation hence utilizes a multidecadal dataset of public interest, wind power, and sun oriented force age to recognize the meteorological conditions when pinnacle request happens and the commitment of renewables during these occasions. Wintertime European pinnacle power request occasions are related with high climatic weight over Russia and Scandinavia and are joined by below the norm air temperatures and normal breeze speeds across Europe. When considering power request boundaries net of sustainable force creation, the related meteorological conditions are appeared to change. There is impressive spatial fluctuation in the dates of public pinnacle request occasions and the measure of inexhaustible age present. Development in sustainable age can possibly diminish top requests. Nonetheless, these effects are additionally not uniform with a lot bigger decreases in top interest found in Spain than in focal Europe. The reanalysis-determined energy models have permitted late pinnacle request occasions to be placed into a drawn out setting.

INTRODUCTION

In order to meet the carbon-reduction targets, such as those outlined within the Paris Agreement, a rapid decarbonisation of national energy systems is required [1]. There has been a large global uptake of renewable generation (i.e., wind power, solar power, and hydropower) in recent years [2]. However, renewable power generation is weather-dependent and therefore has variability over a range of temporal scales. For efficient operation (i.e., avoiding costly disruption and maintaining security of supply) of a power system with high penetrations of renewable generation, an understanding of the weather-driven variability and the meteorological conditions which result in power system stress is required. Of the conditions which cause system stress, a particular challenge is peak demand, which is the hour/day of the year when there is a largest demand for electricity (i.e., times which lead to high power system costs and problems with energy security).

Electricity demand is dependent on temperature and wind chill (for heating and cooling) and illumination (for lighting) [3–6]. In most central and northern European countries, peak electrical loads occur in winter, at darkness peak (e.g., the UK [6–8]; Scandinavia [9]; and Germany [4, 9]). However, in southern European countries, peak demand can be seen in summer (e.g., Greece [10, 11]; Spain [9]; and Italy [9, 10, 12]) due to increased demand for air conditioning.

The ability of renewable generation to provide a contribution to peak demand is sometimes described in the literature as the capacity credit. This is defined as the contribution that a generator makes to system adequacy, usually related to a defined reliability target [13]. In countries with a winter peak, there is no guarantee that wind power will be available at times of peak demand, although some positive correlation has been shown between times of high demand and wind power generation [14, 15]. Several studies have investigated the potential for the availability of wind generation at peak demand, with the term “low wind, cold snap” being common in the literature to describe times of potential concern for winter peaking energy systems [16]. A comprehensive review of the literature showed that there is a large variation in estimations of the capacity credit of wind power in the UK, with a range from 5–30% in the required increase reserve requirements if 20% of energy generation is renewable [16]. Although there are a wide range of estimates between studies, there is a general consensus that, as the penetration of wind and solar power increases, the capacity credit decreases, and beyond a 20% penetration level, the value of capacity credit declines [16].

One limiting factor in the ability to understand the contribution of renewable generation at times of peak demand is the length of consistent observational demand and wind power records. To address this, meteorological reanalysis data have been harnessed to create synthetic multidecadal records of demand and renewable generation (e.g., [7, 17–22]). Using reanalysis data, Brayshaw et al. [18] and Thornton et al. [15] showed there are a number of possible weather conditions present during times of UK peak demand, resulting in variable levels of wind generation.

Solar power has the potential to contribute to summer peak demands due to its favourable correlation with temperature [23, 24]. This has been demonstrated in Italy [9] and Greece [25], but it could become increasingly important in future years due to the increasing uptake of air conditioning for summer cooling [4, 10, 26].

The weather conditions present at times of peak demand are dependent on the definition of peak demand (i.e., whether the renewable generation contribution is included within the load). Bloomfield et al. [27] showed that if you compare the weather conditions present during times of peak demand and peak demand-net-wind (i.e., assuming all available wind generation is dispatched), then a shift in the weather condition causing the largest system stress (i.e., the largest requirements for conventional generation) is seen from the high pressure to the north of the UK (resulting in very cold temperatures and moderate winds), to the high pressure centred over the UK (resulting in very cold temperatures and very low winds). This is also seen in [28] across Western Europe.

Although work has clearly been completed in this field, the consequences of current- and future-installed renewable generation at times of most critical power system stress are not well understood. The aim of this study is therefore to identify the conditions which lead to peak demand across the whole of Europe and a set of case study countries. A secondary aim is to quantify how these events are affected by the introduction of renewables. Knowledge of these meteorological conditions is useful for future power system design and can help transmission system operators highlight conditions of the largest potential system risk.

METHODS

The following subsections describe the methods of creating daily-mean national demand, wind power generation, and solar power generation from the ERA5 reanalysis [29]. Further details on the methods and extensive model validation are provided by Bloomfield et al. [17], and all data used in this study can be downloaded in https://researchdata.reading.ac.uk/227/. In this study, we have chosen to focus on the European total peak load and a selection of three case study countries chosen, for their geographic diversity and range of meteorological conditions experienced throughout Europe.

Demand Model
Wind Power Model
Solar Power Model
Peak Load Classification

RESULTS

The renewable generation responses are highly varying across the top 10 peak demand events, suggesting that relatively subtle changes in large-scale meteorology can result in quite different renewable generation anomalies. Some points of note are that Spain has positive wind generation anomalies (suggesting the ability to provide aid) in all UK peak demand events (although we note Spain also has negative solar generation anomalies in all these events). The UK does not, however, always have the positive wind energy anomalies during the Spanish peak demand events (sometimes with large negative anomalies seen). This analysis highlights the complexity of the relationships between neighbouring countries' generation at times of system peak, and that just increasing the level of interconnection across Europe does not provide a solution to managing system stress.

DISCUSSION AND CONCLUSIONS

This study has used a modelled 39-year dataset of country-level demand and wind power and solar power generation to investigate the weather conditions which are present at times of peak loa,d and how this may change with increases in installed renewable generation. The focus of this work is both the European total demand and a set of representative case study countries.

At a European scale, peak demand events are found to be driven by large high-pressure systems, extending westwards from Russia towards Scandinavia. These meteorological conditions result in cold and relatively clear conditions over Europe, with the cold temperatures resulting in peak demands. A change in the synoptic conditions is seen if peak demand-net-renewables (i.e., assuming all renewable generation is contributing to meet system peak) rather than peak demand. A relocation of the area of high pressure results in cold and still conditions over Europe, resulting in very low wind power production. The largest changes are seen between no renewables, and the present day installed levels suggesting that although future weather conditions at times of peak load may still change, the changes are likely to be less substantial to those presented here.

At present, Europe does not have a fully interconnected power system, and it is therefore important to consider the times of largest power system stress at an individual country level. The meteorological drivers of peak demand are found to vary from country to country, with different events contribution to times of extreme system stress. These results emphasise the differing nature of responses across Europe at times of peak demand. Some large events are found to be in common between central European countries and the European total, but localised regions of cold/warm air can result in peak demand events which do not impact the whole of Europe simultaneously. Detailed analysis into the wind and solar energy anomalies at times of peak demand highlights that the renewable response is complex, with a wide range of possible generation across neighbouring countries. This has shown that diversifying the level of interconnection across Europe is not a solution to managing system stress.

The use of the 39-year dataset allows for individual events to be placed in a long-term context. This study has put events which have caused significant stress on the power systems of multiple European countries into a long-term context. This information can allow for more robust power system planning.

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