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Compound winter low-wind and cold events impacting the French electricity system: observed evolution and role of large-scale circulation

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Figure S1 shows an increasing and non-linear relationship between ERA5 100-m wind speed averaged over France against the ERA5 wind capacity factor index at the daily scale. This increasing and non-linear relationship is expected as the power output of a wind turbine grows non-linearly with the wind speed at its hub height, provided that the wind speed is within the turbine's operational range (Mathews, 2006). This figure also shows that low wind days (scatters below the red dotted line in Figure S1, see section 2.5) are mainly associated with days with rather low mean wind speeds at 100m in France. These events are therefore referred to as low wind days in the main text.

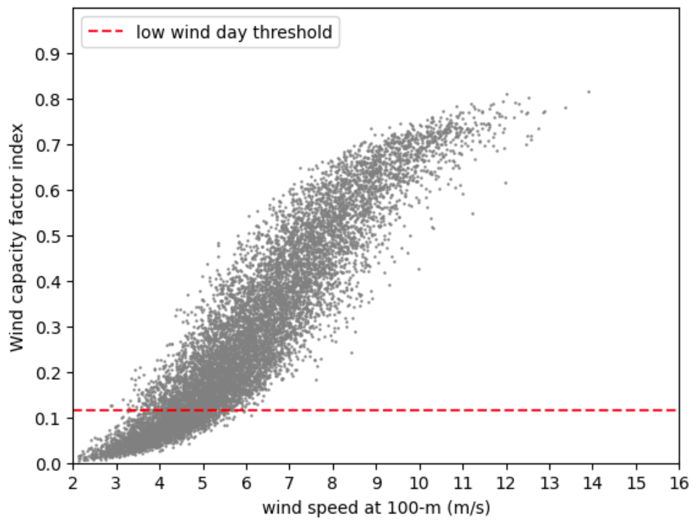

Figure S1: Wind capacity factor index (Y-axis) against 100-m wind speed wind averaged over France (X-axis) as calculated with ERA5 for each day of the 1950-2022 period.

Sensitivity of compound events to their definition

In this section, the sensitivity of compound events properties to the thresholds applied to the wind capacity factor and temperature indices is discussed. In this study, compound events are defined based on a more extreme threshold for the temperature index (i.e., 5th quantile, or 0°C in ERA5) compared to the wind capacity factor index (i.e., 23th quantile, or 0.11 in ERA5). Here, two alternative definitions are used and compared with the main definition. The first one tests a more extreme threshold for the wind capacity factor index (i.e., 5th quantile, or 0.045 in ERA5) compared to the temperature index (i.e., 23th quantile, or 3.6°C in ERA5). The second one tests identical thresholds for both indices to define compound events (i.e., 10th quantile for both indices, or 0.065 and 1.5 °C in ERA5, respectively).

Overall, we find that the climatological characteristics of compound events remain generally similar between these different definitions, with a comparable number of compound events that are similarly distributed across the extended winter months and have similar durations (Figure S2).

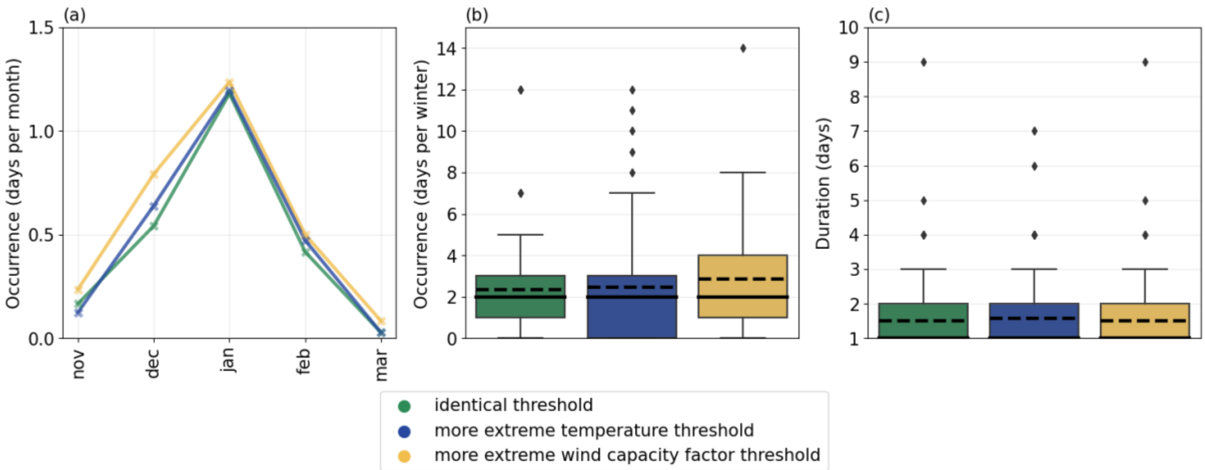

Figure S2: (a) Monthly mean number of compound low wind and cold events;(b) distributions of the number of compound events per winter; (c) distribution of the duration (in days) of compound events in winter over the 1951-2022 period in ERA5. Colors refer to the different definition tested for the identification of compound low wind and cold events: (green) identical thresholds for both the temperature and wind capacity factor indices, (blue) more extreme threshold for the temperature index compared to the wind capacity index as used in the main text (5th vs 23rd percentile, respectively), and (yellow) more extreme threshold for the wind capacity factor index compared to the temperature index (5th vs 23rd percentile, respectively). The solid line and the dashed line in the boxplots in (b) and (c) show the median and the average, respectively.

Further exploring the sensitivity to the definition on the observed evolution, we find that, while compound events defined with a more extreme temperature threshold significantly decrease during the 1951-2022 period in ERA5 (p=0.02, Figure 5 and Table 1 of the main text), the other two definitions of compound events tested here do not exhibit a significant trend over this period (p=0.38 and p=0.28, respectively; Table S2). For these two alternative definitions, the absence of trend might result from the lower influence of cold days and the higher influence of low wind days in the interannual evolution of compound events (Table S1), as cold days exhibit a significant decrease while low wind days exhibit an absence of trend (Table S2).

Pearson correlation Compound event definition	r(low wind days, compound events)	r(cold days, compound events)
More extreme temperature threshold	0.20	0.85
Identical threshold	0.40	0.67
More extreme wind capacity factor threshold	0.51	0.41

Table S1: Values of the Pearson correlation coefficient between the interannual evolution of low wind days and compound events (first column) and cold days and compound events (second column) for each compound event definition (per raw) over the 1950-2022 period, in ERA5.

Long-term trend Compound event definition	Low wind days	Cold days	Compound events
More extreme temperature threshold	-0.08 (0.59)	-0.72 (0.02)	-0.19 (0.02)
Identical threshold	-0.38 (0.27)	-1.5 (0.00)	0.0 (0.28)
More extreme wind capacity factor threshold	-0.28 (0.16)	-2.5 (0.00)	0.0 (0.38)

Table S2: Trend (slope in days/decade) and associated p-value in the number of compound low wind and cold events, cold days, and low wind days for each compound event definition over the 1950-2022 period in ERA5. The slope is calculated using the Theil-Sen estimator and the p-value with the Mann-Kendall test. Significant trends (p-value < 0.05) are highlighted with a grey shaded cell.

We then investigate the average large-scale circulation pattern associated with the different definitions of compound events. Overall, we find that the three definitions lead to similar features: strong positive mean sea-level pressure anomalies over the British Isles and relatively less intense negative anomalies centered over the Azores (Figure S3b). The location of the positive sea-level pressure anomalies over the British Isles slightly varies according to compound event definition. We then investigate whether these average differences are linked with differences in weather type frequencies (see section 2.6 and 3.2). For that, we project compound events onto the low wind day weather types used in section 2.6., which is made possible by the fact that compound events, as they are defined, are included in the subset of low wind days. The weather type WT3 is the most frequent for all compound event definitions, despite a lower frequency in compound events defined with identical and more extreme wind thresholds (Figure S3c).

Overall, this sensitivity analysis shows that setting a more extreme threshold on either the wind capacity factor or the temperature index in the definition of compound events has limited impacts on the characteristics of compound events over the 1951-2022 period, except for the observed evolution and trend estimate.

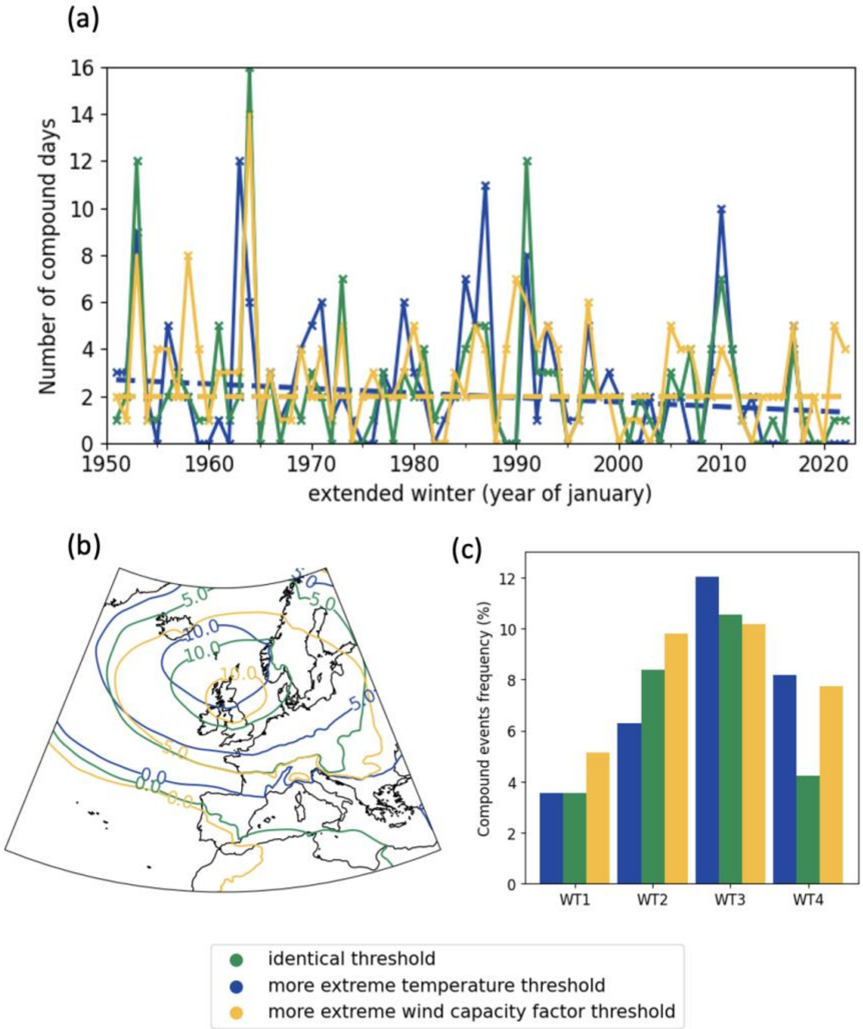

Figure S3: (a) Interannual evolution of the number of compound events per winter, with dashed lines showing the linear trend (calculated with the Theil-Sen estimator), (b) composite of sea-level pressure, with solid contours corresponding to positive anomalies, (c) frequency of compound events for each weather type (in % of weather type size). Colors correspond to the different definitions of compound events tested: (green) identical thresholds for both the temperature and wind capacity factor indices, (blue) more extreme threshold for the temperature index compared to the wind capacity index as used in the main text (5th vs 23rd percentile, respectively), and (yellow) more extreme threshold for the wind capacity factor index compared to the temperature index (5th vs 23rd percentile, respectively).

References

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