Appendix A. Supplementary information

Appendix A.1. Weather pattern characteristics

Table A.2 summarizes the distinctive characteristics of each of the 30 Met Office weather patterns used throughout this article, including anomalies in wind speed, snowfall, and temperature for each observed season.

Appendix A.2. Breakdown of weather-induced power system failures from 2010 to 2019 in the UK by season

Figs. A.5–A.8 provide a breakdown of weather-induced power system failures per season ($\overline{F}_s$ values listed in Table 1). F_{xws} values are shown as a function of the direct failure cause x and daily weather pattern w when they occurred.

Appendix A.3. Long-term probability of occurrence of a weather pattern given the weather pattern in the previous day in spring, summer, and fall

Analogously to Fig. 1, Figs. A.9–A.11 show the probability of occurrence of next-day weather patterns in spring, summer, and fall based on [26].

Appendix A.4. Supplementary discussion on the frequency of weather-induced power system failures by weather pattern and season in spring, summer, and fall

Appendix A.4.1. Great Britain

This section provides supplementary information to Section 2.2.1, by investigating the top three causes of power system failures in spring, summer, and fall. Trends in power outages caused by lightning strikes, wind and gale, and solar heat are investigated in summer, whereas trends in power outages caused by wind and gale, lightning strikes, and snow and ice are investigated in spring and fall. The 2-dimensional histograms in Figs. A.12–A.14 (charts on the left) show the frequency of occurrence of a given weather pattern up to 2 weeks ahead of the occurrence of a weather-induced power outage.

In Fig. A.12(a), the main trends in power outages induced by wind and gale relate to weather patterns 4, 8, 23 and 30 (all westerly types), as nearly a third of outages occurred during these weather patterns. In turn, Fig. A.12(b) shows that nearly a quarter of power outages induced by lightning strikes occurred during or the day after weather pattern numbers 6 (high pressure extension over the UK) and 7 (cyclonic south-westerly). In Fig. A.12(c),

Table A.2: Distinctive UK characteristics for the set of 30 Met Office weather patterns based on ERA5 (1981 - 2020). In the intensity columns, ”low” roughly corresponds to a lower intensity than average under this weather pattern, ”moderate” roughly corresponds to a slightly higher intensity than average under this weather pattern and ”high” roughly corresponds to a significantly higher intensity than average under this weather pattern. In the season columns, 1 stands for winter, 2 for spring, 3 for summer, and 4 for fall.

#	Wind speed		Rainfall		Snowfall		Temperature	
	Intensity	Season	Intensity	Season	Intensity	Season	Intensity	Season
1	Low	all	Moderate	all	Moderate	1	Mild	all
2	Low	all	Moderate	1	Low	all	Warm	2, 4
3	Low	all	Low	all	Low	all	Warm	1, 2, 4
4	Moderate	all	Low	all	Low	all	Warm	1
5	Low	all	Moderate	2–4	Low	all	Cold	1
6	Low	all	Low	all	Low	all	Cold	1
7	Low	all	High	all	Low	all	Warm	2
8	Moderate	2–4	High	all	Moderate	1	Cold	3
9	Low	all	Low	all	Moderate	1, 4	Warm	2
10	Low	all	Low	all	Low	all	Mild	all
11	Low	all	High	all	High	1	Cold	1, 3
12	Low	all	Low	all	Low	all	Warm	3
13	Moderate	all	Low	all	Low	all	Cold	3
14	Moderate	all	High	3	Moderate	2	Cold	2, 3
15	Moderate	all	Low	all	Moderate	4	Warm	3
16	Low	all	Low	all	Moderate	4	Cold/Warm	1/3
17	Low	all	Low	all	Low	all	Cold/Warm	1, 4/3
18	Low	all	Low	all	Moderate	2	Mild	all
19	Moderate	2–4	High	2, 3	High	1, 2, 4	Cold	all
20	High	all	High	1, 2, 4	Low	all	Warm/Cold	1/2–4
21	Moderate	all	High	all	Low	all	Warm/Cold	1/3
22	Low	all	High	all	Low	all	Cold/Warm	1/3
23	High	all	Low	all	Low	all	Warm/Cold	1/2, 4
24	Low	all	High	all	Moderate	1, 2	Cold	all
25	Low	all	Low	all	Low	all	Cold	all
26	High	all	High	1, 2, 4	Moderate	1, 2, 4	Cold	2–4
27	Moderate	2	Low	all	High	1, 2, 4	Cold	all
28	Moderate	2	High	1, 3, 4	High	1, 2, 4	Cold	all
29	Moderate	2–4	High	all	Moderate	1, 2, 4	Cold	2, 4
30	High	all	High	1, 2, 4	Moderate	2, 4	Warm/Cold	1/2–4

the main trends in power outages induced by snow and ice relate to weather patterns 14, 19 and 24 (all northerly types) and 28 (southerly tracking low undercutting a cold pool over the UK), as almost all outages during or a few days after these weather patterns in spring.

In Fig. A.13(a), the main trends in power outages caused by lightning strikes relate to weather patterns 5 and 16 (both with a southerly flow over the UK), as nearly a third of outages occurred during or the day after these weather patterns. In Fig. A.13(b), the main trends in power outages induced by wind and gale relate to weather patterns 20 and 21 (both cyclonic westerly or south-westerly types), as nearly a third of outages occurred during weather pattern 20 and a few days after weather pattern 21. In turn, Fig. A.13(c) shows that over 50% of power outages induced by solar heat occurred during or a few days after weather pattern numbers 3 (anticyclonic south-westerly), 5 (unbiased southerly), 6 (high pressure extension over the UK), 7 (cyclonic south-westerly) and 22 (very cyclonic southerly) in summer.

In Fig. A.14(a), the main trends in power outages induced by wind and gale relate to weather patterns 14 (cyclonic northerly), 20 (cyclonic westerly), 21 (cyclonic south-westerly), 26 (very cyclonic north-westerly) and 30 (very cyclonic westerly), as over 50% of outages occurred during these weather patterns. Likewise, Fig. A.14(b) shows that over 50% of outages caused by lightning strikes occurred during or the day after weather pattern numbers 23 (unbiased westerly) and 26 (very cyclonic north-westerly). In Fig. A.14(c), the main trend in power outages induced by snow and ice relates to weather pattern 14 (cyclonic northerly), as over a third of occurrences were a few days after this weather pattern in fall.

Appendix A.4.2. Northeast of England

In this section, the top three causes of power system failures investigated in Section Appendix A.4.1 for each season are further analyzed in the Northeast of England with fault data collected between 2004 and 2021. The 2-dimensional histograms in Figs. A.15–A.17 (charts on the left) show the corresponding frequency of occurrence of a given weather pattern up to 2 weeks ahead of the occurrence of a weather-induced power outage.

In Fig. A.15(a), the main trends in power outages induced by wind and gale relate to weather patterns 13 (anticyclonic north-westerly), 20 (cyclonic westerly), 21 (cyclonic south-westerly), 23 (unbiased westerly), 24 (cyclonic northerly) and 30 (very cyclonic westerly), as over 50% of outages occurred during these weather patterns. These trends partly match those shown in

Fig. A.12(a), as weather patterns 23 and 30 are also among the most significant ones. In turn, Fig. A.15(b) shows that nearly a quarter of power outages induced by lightning strikes occurred during or the day after weather pattern numbers 7 (cyclonic south-westerly) and 9 (weak high pressure centred over the UK). Again, these trends partly match those shown in Fig. A.12(b), as weather pattern 7 represents the main contribution in both cases. In Fig. A.15(c), the main trends in power outages induced by snow and ice relate to weather patterns 14 (cyclonic northerly), 19 (unbiased northerly), 27 (anticyclonic easterly) and 28 (southerly tracking low undercutting a cold pool over the UK), as over 50% of outages occurred during or a few days after these weather patterns in spring. Again, these results partly match those shown in Fig. A.12(c), as weather patterns 14, 19 and 28 are also among the most significant ones.

In Fig. A.16(a), the main trends in power outages caused by lightning strikes relate to weather patterns 1 (unbiased north-westerly), 5 (unbiased southerly), 7 (cyclonic south-westerly), 8 (cyclonic westerly) and 11 (low centred over the UK), as almost 50% of outages occurred during or the day after these weather patterns. These results partly agree with those shown in Fig. A.13(a), as weather pattern 5 is among the main contributions and weather patterns 1, 7, 8 and 11 are also related to a significant number of outages. In Fig. A.16(b), the main trends in power outages induced by wind and gale are not as strong as in Fig. A.13(b), but weather pattern 20 (cyclonic westerly) is among the main contributors. Notably, roughly the same number of outages shown in Fig. A.16(b) (over 50% of total) occurred during weather patterns 1 (unbiased north-westerly), 2 (cyclonic south-westerly), 5 (unbiased southerly), 7 (cyclonic south-westerly), 8 (cyclonic westerly), 20 (cyclonic westerly) and 26 (very cyclonic south-westerly). In turn, Fig. A.16(c) shows that almost all outages induced by solar heat occurred during or a few days after weather pattern numbers 3 (anticyclonic south-westerly), 5 (unbiased southerly), 6 (high-pressure extension towards the UK) and 17 (anticyclonic southerly or south-easterly) in summer. These results partly agree with those shown in Fig. A.13(c), as weather pattern numbers 3, 5, and 6 are also among the main trends a few days before outages induced by solar heat in summer.

In Fig. A.17(a), the main trends in power outages induced by wind and gale relate to weather patterns 13 (anticyclonic north-westerly), 15 (unbiased south-westerly), 20 (cyclonic westerly), 23 (unbiased westerly), 26 (very cyclonic north-westerly) and 30 (very cyclonic westerly), as over 50% of outages occurred during these weather patterns. These results mostly agree with those shown in Fig. A.14(a), as some the main trends relate to weather patterns 20, 26 and 30 and some of the secondary trends relate to weather patterns 13 and 15. In turn, Fig. A.17(b) shows that nearly a quarter of outages caused by lightning strikes occurred during or the day after weather pattern numbers 19 (unbiased northerly) and 29 (very cyclonic south or south-westerly). These trends differ from those shown in Fig. A.14(b), which relate weather pattern numbers 23 (unbiased westerly) and 26 (very cyclonic south-westerly) to the majority of outages caused by lightning strikes. In Fig. A.17(c), the main trends in power outages induced by snow and ice relate to weather patterns 19 (unbiased northerly) and 27 (anticyclonic easterly), as nearly 50% of occurrences happened during or a few days after them in fall. It is noteworthy that these trends correspond to secondary trends in Fig. A.14(c). Likewise, the main trend relating power outages induced by snow and ice in fall to weather pattern 14 (cyclonic northerly) in Fig. A.14(c) corresponds to a secondary trend in Fig. A.17(c).

Appendix A.4.3. Southern Scotland

In this section, the top three causes of power system failures investigated in Section Appendix A.4.1 for each season are further analyzed in Southern Scotland with fault data collected between 2017 and 2022. The 2-dimensional histograms in Figs. A.18–A.20 (charts on the left) show the corresponding frequency of occurrence of a given weather pattern up to 2 weeks ahead of the occurrence of a weather-induced power outage.

In Fig. A.18(a), the main trends in power outages induced by wind and gale relate to weather patterns 1 (unbiased north-westerly), 2 (cyclonic south-westerly), 8 (cyclonic westerly) and 13 (anticyclonic north-westerly), as roughly a quarter of outages occurred during these weather patterns. These trends partly match those shown in Fig. A.12(a), as weather pattern 8 is also among the strongest contributions. In turn, Fig. A.18(b) shows that nearly a quarter of power outages induced by lightning strikes occurred during or the day after weather pattern numbers 2 (cyclonic south-westerly) and 6 (high pressure extension towards the UK). These results partly agree with those shown in Fig. A.12(b), as weather pattern 6 is among the strongest contributions in both cases. In Fig. A.18(c), all the 4 outages caused by snow and ice in spring relate to weather patterns 28 (southerly tracking low undercutting a cold pool over the UK) and 29 (very cyclonic south or south-westerly), as they occurred during or a few days after these weather patterns. Again, these results partly match those shown in Fig. A.12(c), as weather pattern number 28 is among the most significant ones.

In Fig. A.19(a), the main trends in power outages caused by lightning strikes relate to weather patterns 1 (unbiased north-westerly) and 5 (unbiased southerly), 7 (cyclonic south-westerly), 8 (cyclonic westerly) and 11 (low centred over the UK), as roughly a quarter of outages occurred during these weather patterns. These results partly agree with those shown in Fig. A.13(a), as weather pattern 5 is among the main contributions and weather pattern 1 is related to a significant number of outages. In Fig. A.19(b), the main trends in power outages induced by wind and gale are related to weather patterns 1 (unbiased north-westerly), 2 (cyclonic south-westerly), 3 (anticyclonic westerly), 8 (cyclonic westerly) and 13 (anticyclonic north-westerly), as roughly 50% of outages occurred during these weather patterns. These weather patterns represent slightly less than a fifth of occurrences in Fig. A.13(b) and are not among the main trends in Great Britain. In turn, Fig. A.19(c) shows that over a third of outages induced by solar heat occurred during or a few days after weather pattern numbers 3 (anticyclonic westerly), 6 (high pressure extension towards the UK) and 12 (unbiased south-westerly) in summer. These results partly agree with those shown in Fig. A.13(c), as weather pattern numbers 3 and 6 are also among the main trends a few days ahead of an outage induced by solar heat in summer.

In Fig. A.20(a), the main trends in power outages induced by wind and gale relate to weather patterns 13 (anticyclonic north-westerly), 14 (cyclonic northerly), 15 (unbiased south-westerly), 21 (cyclonic south-westerly) and 22 (cyclonic southerly), as over a third of outages occurred during these weather patterns. These results partly agree with those shown in Fig. A.14(a), as weather patterns 14 and 21 are among the main trends in Great Britain. In turn, Fig. A.20(b) shows that half the outages caused by lightning strikes occurred during weather pattern numbers 7 (cyclonic south-westerly), 8 (cyclonic westerly), 13 (anticyclonic north-westerly), 14 (cyclonic northerly) and 26 (very cyclonic north-westerly). These trends partly agree with those shown in Fig. A.14(b), as weather pattern number 26 is also related to a significant number of outages caused by lightning strikes. In Fig. A.20(c), 3 out of 7 power outages induced by snow and ice occurred a few days after weather pattern 26 in fall. This results is clearly different from those shown in Fig. A.14(c), but similar to the results obtained for power outages induced by snow and ice in Southern Scotland in winter, as shown in Fig. 4(c).

Appendix A.5. Supplementary discussion on the analysis of trends in power outages and weather pattern transitions in spring, summer, and fall

In this section, the main trends associated with the weather-induced power outages described in Section Appendix A.4 are further evaluated in relation to the most likely proceeding weather pattern transitions. The Sankey diagrams in Figs. A.12–A.20 (charts on the right) show the breakdown of weather pattern transitions associated with the most common causes of weather-induced power outages. Analogously to Section 2.3, only the overall trends associated with weather-induced power outages in Great Britain are further investigated in this section, given the similarities between the results shown in Sections Appendix A.4.1–Appendix A.4.3 and the larger sample size of fault incidents available from Section Appendix A.4.1.

In spring, the main trends in power outages induced by wind and gale (Fig. A.12(a)) are represented by the next-day weather transitions 8→8 (a persisting cyclonic westerly type), 4→23 (a transition between two unbiased westerly types over the UK, whereby the transitioned type has stronger winds), and 30→30 (a persisting very cyclonic westerly type). As in winter, there is a focus on cyclonic westerly types, but these tend to have weaker areas of low pressure driving them. In turn, the main trends in power outages induced by lightning strikes (Fig. A.12(b)) are represented by the next-day weather transitions 6→6 (a persisting high pressure extension over the UK) and 7→7 (a persisting cyclonic south-westerly type). This represents a contrast in types, with weather pattern 6 likely representing lighting associated with convective outbreaks and meso-scale features, and weather pattern 7 likely reflecting lightning associated with larger-scale systems). For power outages induced by snow and ice (Fig. A.12(c)), the main trends are represented by the next-day weather transitions 19→19 (persisting unbiased northerly type), 28→16 (representing a Scandinavian high pressure system establishing its influence over the UK), 24→14 (representing transitions between two cyclonic northerly types), and 24→24 (a persisting cyclonic northerly type) a few days ahead of an outage.

In summer, the main trends in power outages induced by lightning strikes (Fig. A.13(a)) are represented by the next-day weather transitions 5→5 (a persisting unbiased southerly flow over the UK) and 16→16 (another persisting southerly flow over the UK, but with more of a high-pressure influence). In turn, the main trend in power outages induced by wind and gale (Fig. A.13(b)) is represented by the next-day weather transition 21→20 (a transitioning cyclonic south-westerly to westerly type). For power outages induced by solar heat (Fig. A.13(c)), the main trends are represented by the next-day weather transitions 3→3 (a persisting settled westerly or south-westerly type), 3→5 (a transition between a settled westerly or south-westerly type and a high-pressure dominating southerly type) , 5→5 (a persistence of the high-pressure dominating southerly type), 6→6 (a persistence of high pressure extending over the UK), 7→7 (a persisting cyclonic south-westerly type), and 22→22 (another persisting cyclonic south-westerly type) a few days ahead of an outage.

In fall, the main trends in power outages induced by wind and gale (Fig. A.14(a)) are represented by the next-day weather transitions 13→14 (a transitioning anticyclonic to cyclonic north-westerly), 20→20 (a persisting cyclonic westerly), 21→21 (a persisting cyclonic south-westerly), 22→21 (a transition between a cyclonic southerly and south-westerly), 20→26 (a transition between a cyclonic westerly and north-westerly), 26→26 (a persistence of a cyclonic north-westerly), 30→26 (a transition between a very cyclonic westerly and north-westerly), and 30→30 (a persisting very cyclonic westerly type). In turn, the main trends in power outages induced by lightning strikes (Fig. A.14(b)) are represented by the next-day weather transitions 23→26 (a transition between a windy unbiased westerly type and a windy, very cyclonic westerly type) and 15→23 (a transition between a windy unbiased south-westerly type and a windy, unbiased westerly type). For power outages induced by snow and ice (Fig. A.14(c)), the main trends are represented by the next-day weather transitions 14→14 (a persisting cyclonic northerly type), 14→30 (a transitioning cyclonic northerly to very cyclonic westerly type), 19→19 (a persisting unbiased northerly type), 19→27 (a transitioning northerly to easterly type), 27→27 (a persisting easterly type), and 30→24 (a transitioning very cyclonic westerly to cyclonic northerly type) a few days ahead of an outage.

By comparing these main trends associated with weather-induced power outages with the weather pattern transition matrices shown in Section 2.1 (Fig. 1) and Section Appendix A.3 (Figs. A.9–A.11), it can be noticed that they are mostly representative in a long-term horizon. Notably, all the main trends in weather-induced power outages in winter and summer also represent main transitions (dark blue background and red text) or secondary trends (dark blue background and white text) in the long-term weather pattern transition matrices. Although this is mostly true for trends in weather-induced power outages in spring and fall, there are few exceptions which represent minor trends (light blue background plus white or black text) in the long-term weather pattern transition matrices: 28→16, 24→14, and 4→23 in spring plus 14→30 and 19→27 in fall. Note that these less likely weather pattern transitions are mostly related to power outages caused by snow and ice in these seasons, which suggests that the sample size of those fault incidents might be inadequate (i.e., too small).

Appendix A.6. Supplementary discussion on the expected effects of weather pattern transitions on weather-induced power system failures in spring, summer, and fall

This section provides a discussion on the expected effects of weather pattern transitions on weather-induced power system failures described in Section Appendix A.4. In the next paragraphs, the main trends in weather-induced power outages and weather pattern transitions identified in Section Appendix A.5 are compared against the distinctive characteristics listed in Table A.2 for each representative weather pattern and weather phenomenon in spring, summer, and fall.

In spring, weather patterns 4, 8, 23, and 30 are characterized by moderate to high wind speeds, whereas weather patterns 8 and 30 present high precipitation volumes and weather patterns 23 and 30 are colder than average. Therefore, it is expected that they are among the main trends in power outages caused by wind and gale in spring. In the trends associated with outages induced by lightning strikes, it can be noticed that weather pattern 7 is wetter and warmer than average in spring, whereas weather pattern 6 is relatively mild. In turn, weather patterns 14, 19, 24, and 28 are characterized by moderate to high snowfall and are colder than average, whereas weather patterns 14, 19, and 28 are also characterized by moderate to high wind speeds and weather patterns 19 and 24 also present high precipitation volumes in spring. Therefore, these weather patterns are expected to be among the main trends in power outages caused by snow and ice in spring.

In the trends associated with outages induced by lightning strikes in summer, note that weather pattern 5 is wetter than average, whereas weather pattern 16 warmer than average. In turn, weather patterns 20 and 21 associated with power outages caused by wind and gale present moderate to high wind speeds and are colder than average in summer. In the trends associated with outages induced by solar heat, it can be noticed that weather patterns 3, 5, 6 and 7 are relatively mild in terms of average temperatures in summer, whereas weather pattern 22 is warmer than average. Thereby, the trends obtained for power outages induced by distinct weather phenomena in summer fairly meet the expected effects.

In fall, weather patterns 13, 14, 20, 21, 26, and 30 are characterized by moderate to high wind speeds, whereas weather patterns 20, 21, 26, and 30 are wetter than average and weather patterns 20, 26, and 30 are colder than average. Therefore, these weather patterns are expected to represent the main trends in power outages caused by wind and gale in fall. In turn, weather pattern 26 presents high precipitation volumes, unlike weather patterns 15 and 23 present associated with outages induced by lightning strikes. In the trends associated with outages induced by snow and ice in fall, it can be noticed that weather patterns 19, 27 and 30 are characterized by moderate to high snowfall, whereas weather patterns 19, 24, 27, and 30 are colder than average. Unsurprisingly, these weather patterns are among the main trends in power outages caused by snow and ice in fall.

The fact that some relatively mild weather patterns are among the main trends in power outages caused by snow and ice in spring and fall (e.g. 4 and 16 in spring, 14 in fall) suggests that impacts occurred during extreme versions of those weather patterns (i.e., associated with colder than average temperatures, heavier than average snowfalls and/or wet snow events). Therefore, effects of weather pattern transitions on weather-induced power system failures are better explained when the main trends in weather-induced power outages also represent main trends in the long-term weather pattern transition matrices.

Of particular note is that in Table 1, lightning strikes are in the top three causes of power outages in all seasons. This is despite the fact that using lightning observations over Europe, [37] show that the lightning flash density for the UK is significantly lower than over much of continental Europe. In Scotland especially, lightning flash densities are lower than 0.1 flashes km^{-2} year^{-1} yet our results in Fig. 4 and Figs. A.18–A.20 show that lightning strikes cause a significant number of outages in Southern Scotland, especially associated with weather pattern 26 in winter. Similarly, a combined dataset of thunder days by [38] show that most parts of the UK have less than 15 days of thunderstorms per year, yet our analysis in Table 1 shows that it is a significant cause of network faults. This would suggest that multiple faults due to lightning occur on the network on the same day.

Appendix A.7. Validation against past power outages induced by extreme weather events

In this section, the methodology is validated against past power outages caused by extreme weather events, considering the occurrences described in [39] from 2000 to 2022. Relevant occurrences with impacts on power grids are listed in Table A.3, where columns indicate: the start date of an extreme weather event, attributed causes of power outages, weather pattern number sequence up to 2 weeks ahead of the start date, and whether the weather pattern trends are consistent with those obtained for the corresponding season and weather phenomena in Section 2.3. Consistency between weather pattern trends is derived based on the occurrence of at least one expected transition within the observed types a few days ahead of an outage. For power outages induced by lightning strikes or wind and gale, consistency is verified in the previous day; for power outages induced by solar heat or snow and ice, consistency is verified up to 5 days ahead of an outage to account for accumulated effects. In the fourth column, Y and N stand for yes and no, whereas the letters in parenthesis correspond to the region in which trends were evaluated: GB (overall), Northeast of England and/or Southern Scotland (if appropriate).

Table A.3: Past power outages induced by extreme weather events in the UK from 2000 to 2022.

Start date	Causes	Sequence of weather patterns day 0 → day 14	Consistent trends(Y/N)?
30-Oct-2000	wind and gale	30–30–21–21–8–26–4–10–12–12–5–15–15–15	Y(GB)
07-Jul-2004	wind and gale, lightning strikes	6–6–13–4–4–8–8–2–12–3–2–22–7–8	N(GB)
07-Jan-2005	wind and gale	20–20–23–23–23–23–23–23–23–15–26–20–10–20	Y(GB), Y(NE)
11-Jan-2005	wind and gale	20–20–20–20–20–20–23–23–23–23–23–23–23–15	Y(GB), Y(SS)
10-Mar-2008	wind and gale	30–30–30–20–23–13–13–14–26–26–20–23–26–26	Y(GB), Y(SS), Y(NE)
07-Jan-2010	snow and ice	19–19–19–27–27–27–19–19–28–28–28–28–28–28	Y(GB), Y(SS), Y(NE)

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Table A.3 – continued from previous page

Start date	Causes	Sequence of weather patterns day 0→day 14	Consistent trends(Y/N)?
21-Dec-2010	snow and ice	28–28–28–28–19–19–25–25–27–27–9–25–25–19	Y(GB), Y(SS), Y(NE)
26-Nov-2011	wind and gale	23–23–15–15–15–10–12–5–22–22–16–16–16–16	Y(GB), N(SS), Y(NE)
08-Dec-2011	wind and gale	4–26–26–26–26–26–20–20–20–20–15–23–23–23	Y(GB), N(SS), N(NE)
13-Jan-2012	wind and gale	25–13–18–18–18–10–13–13–26–26–26–20–20–20	N(GB), N(SS)
28-Oct-2013	wind and gale	26–30–30–7–7–30–29–22–22–22–28–7-7-7	Y(GB)
05-Dec-2013	wind and gale	14–13–18–18–25–13–13–25–18–18–25–25–25–19	Y(GB), N(SS), Y(NE)
18-Dec-2013	wind and gale	21–15–20–15–15–12–7–12–12–12–15–3–13–14	N(GB), N(SS), Y(NE)
23-Dec-2013	wind and gale	30–20–20–15–20–21–15–20–15–15–12–7–12–12	Y(GB), Y(SS)
12-Feb-2014	wind and gale	30–30–30–30–30–30–30–29–29–21–21–30–21–5	Y(GB), Y(SS), Y(NE)
26-Dec-2015	wind and gale	3–3–20–20–20–20–20–21–21–21–22–16–16–9	N(GB), N(SS), N(NE)
20-Nov-2016	wind and gale	9–6–6–6–19–11–24–30–26–26–20–23–18–18	N(GB)
16-Oct-2017	wind and gale	3–15–15–15–20–20–21–10–13–13–13–14–23–23	N(GB)
28-Feb-2018	snow and ice	12–6–15–20–21–21–20–26–20–10–20–10–13–6	N(GB), N(SS), N(NE)
14-Jun-2018	wind and gale	20–2–1–1–1–1–6–6–5–9–9–9–1–6	N(GB), N(SS), N(NE)
19-Sep-2018	wind and gale	21–21–21–2–3–4–10–23–23–15–2–5–5–6	Y(GB), N(SS), N(NE)
11-Oct-2018	wind and gale	22–22–21–20–10–1–13–10–13–13–13–13–23–13	N(GB)
15-Dec-2018	wind and gale, snow and ice	22–12–12–22–12–9–14–26–26–2–3–9–24–30	N(GB), Y(SS), N(NE)

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Table A.3 – continued from previous page

Start date	Causes	Sequence of weather patterns day 0→day 14	Consistent trends(Y/N)?
26-Apr-2019	wind and gale	2–21–29–29–29–2–18–17–12–16–16–16–16–16	N(GB)
02-Nov-2019	wind and gale	24–8–16–17–27–27–9–14–7–11–11–3–10–19	N(GB)
09-Dec-2019	wind and gale	26–26–20–26–20–20–15–18–25–9–9–24–24–29	Y(GB)
08-Feb-2020	wind and gale	20–15–12–18–13–4–8–30–30–30–30–30–30–21	N(GB), Y(SS), Y(NE)
19-Aug-2020	wind and gale	29–7–7–5–3–10–6–6–5–5–6–6–12–22	N(GB)
02-Oct-2020	wind and gale	11–11–2–2–10–5–19–14–24–8–8–4–10	N(GB)
25-Jul-2021	lightning strikes	2–2–5–3–3–9–9–6–6–10–10–10–1–1	Y(GB)
26-Nov-2021	wind and gale, snow and ice	14–13–25–25–25–25–13–23–23–23–10–18–12–16	Y(GB), N(SS), Y(NE)
29-Jan-2022	wind and gale	13–18–13–18–18–18–18–18–18–25–25–18–18–13	N(GB), N(SS), N(NE)
16-Feb-2022	wind and gale	30–20–26–8–15–18–13–23–23–23–26–23–26–4	Y(GB), Y(SS), Y(NE)
18-Feb-2022	wind and gale	26–26–30–20–26–8–15–18–13–23–23–23–26–23	Y(GB), Y(SS), Y(NE)
19-Jul-2022	solar heat	2–3–12–3–3–13–10–10–12–6–18–18–13–13	Y(GB), N(NE)
11-Dec-2022	snow and ice	19–19–28–28–28–28–27–19–28–27–25–27–27–27	Y(GB), N(SS), Y(NE)

It can be noticed in Table A.3 that nearly 50% of the power outages attributed to exceptional weather conditions occurred in winter, nearly three quarters occurred in the second half of the time horizon (i.e., after 2010), and over 80% were caused by wind and gale. Thereby, the ability to identify relevant trends in weather patterns which can be used to predict power outages caused by wind and gale and/or in winter is particularly important to improve grid preparedness.

The fourth column of Table A.3 shows that the weather pattern transitions of 20 out of 36 events (55.6%) are consistent with the main trends (Y) in Great Britain (GB). It also shows that 10 out of 22 events (45.5%) which led to power outages in Southern Scotland (SS) and that 13 out of 21 events (61.9%) which led to power outages in Northeast England (NE) are consistent with the main trends obtained at regional level. These results indicate that the relevant weather patterns and trends obtained in Great Britain are reliable, but regionally specific information is important for forecasting risks. The results also highlight that the observation of high-risk weather patterns / pattern transitions does not necessarily mean impacts on the energy network will be experienced, but instead can be used to flag a higher-risk period where mitigating action may be appropriate.

Acknowledgments

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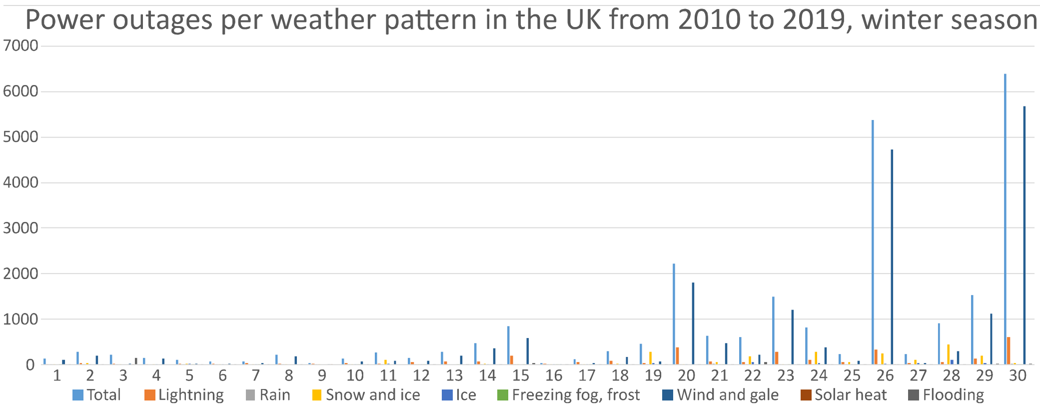


Figure A.5: Breakdown of weather-induced power system failures from 2010 to 2019 in the UK (y-axis) per weather pattern (x-axis) in winter.

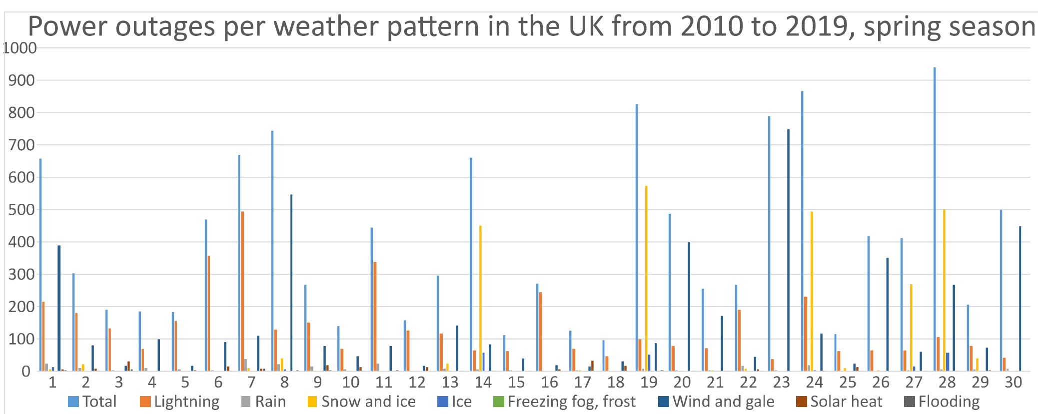


Figure A.6: Breakdown of weather-induced power system failures from 2010 to 2019 in the UK (y-axis) per weather pattern (x-axis) in spring.

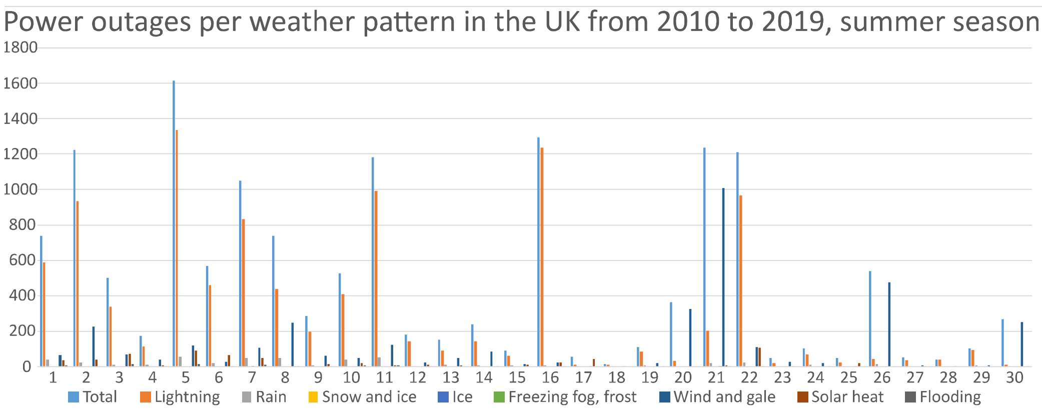


Figure A.7: Breakdown of weather-induced power system failures from 2010 to 2019 in the UK (y-axis) per weather pattern (x-axis) in summer.

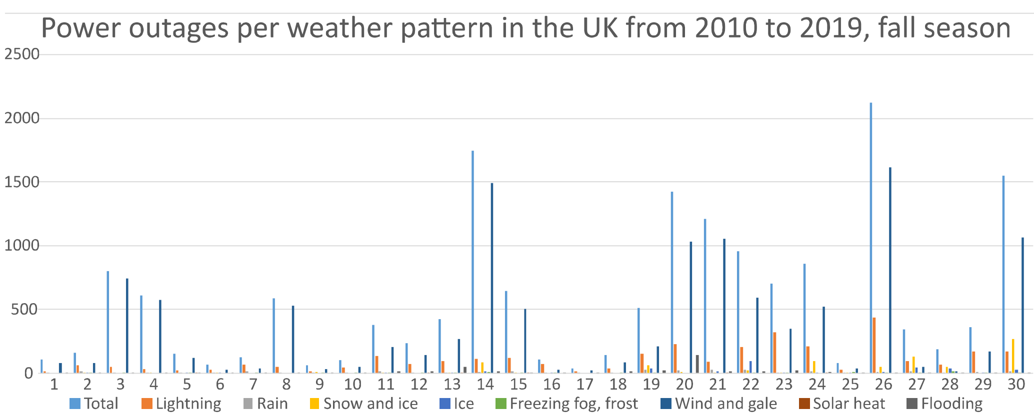


Figure A.8: Breakdown of weather-induced power system failures from 2010 to 2019 in the UK (y-axis) per weather pattern (x-axis) in fall.

		Weather Pattern next day																													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Weather Pattern	1	30.20	8.63	7.84	5.10	2.35	5.49	3.53	5.49	5.10	7.06	2.75	0.39	5.88	3.53	0.39	0.39	0.00	0.39	2.35	1.18	0.00	0.00	0.00	1.18	0.00	0.00	0.00	0.78	0.00	0.00
	2	2.35	27.84	3.53	5.49	5.10	0.78	5.10	7.45	0.00	3.92	3.53	4.31	0.00	0.00	5.10	0.39	0.00	0.00	0.39	5.10	12.55	2.35	0.39	0.00	0.00	0.78	0.00	0.39	1.96	1.18
	3	2.63	6.14	28.07	3.07	2.19	4.39	6.14	1.75	7.46	0.88	0.44	14.47	0.88	0.44	1.75	4.82	3.95	3.95	1.75	0.44	0.88	2.63	0.44	0.00	0.44	0.00	0.00	0.00	0.00	0.00
	4	7.20	3.79	11.36	29.17	0.00	0.38	3.79	7.20	1.52	5.30	0.00	1.52	5.30	4.17	4.55	0.00	0.00	0.00	0.00	2.65	1.89	0.00	3.03	1.14	0.00	5.30	0.00	0.00	0.00	0.76
	5	2.09	5.44	3.77	0.00	35.56	8.79	2.51	0.00	4.60	2.09	9.21	4.60	0.42	0.00	0.00	5.02	2.93	0.00	0.42	0.00	0.00	7.95	0.00	0.00	0.42	0.00	2.51	0.84	0.84	0.00
	6	3.67	1.98	2.54	0.00	7.91	42.09	0.28	0.56	5.65	7.91	0.56	3.39	4.24	0.00	0.85	0.56	5.37	3.39	1.98	0.28	0.00	0.28	0.00	0.00	5.08	0.00	1.41	0.00	0.00	0.00
	7	1.47	5.87	2.64	1.47	2.05	0.00	43.11	5.57	5.57	0.00	3.52	0.88	0.29	1.17	0.88	3.23	0.00	0.29	0.00	0.29	5.87	7.33	0.00	1.47	0.29	0.59	0.00	1.47	4.40	0.29
	8	6.50	6.14	0.72	10.11	0.00	0.00	8.66	35.38	0.36	0.72	3.97	0.00	0.36	3.25	0.36	0.36	0.36	0.00	0.00	1.08	5.42	0.36	0.72	5.42	0.72	4.33	0.00	0.00	1.81	2.89
	9	2.56	0.32	4.17	0.64	3.21	6.09	7.37	0.00	43.91	0.00	2.88	0.64	2.88	1.28	0.00	7.05	1.60	0.64	5.13	0.00	0.00	0.32	0.00	0.32	3.53	0.32	2.56	2.56	0.00	0.00
	10	5.99	4.87	3.37	4.49	1.12	5.62	0.00	0.37	0.75	30.71	0.75	3.00	6.74	1.87	8.24	0.00	0.00	6.74	0.37	4.49	0.00	0.37	8.99	0.00	0.00	0.37	0.00	0.00	0.37	0.37
	11	7.60	2.80	0.00	0.40	4.80	2.40	7.20	5.60	3.20	0.00	43.60	0.00	0.00	2.80	0.00	1.60	0.00	0.00	5.20	0.00	0.40	2.00	0.00	4.40	0.00	0.00	0.80	4.40	0.80	0.00
	12	0.00	6.20	6.20	0.41	9.09	3.72	0.83	0.00	0.00	6.61	0.00	35.12	0.00	0.00	11.98	2.89	7.02	4.55	0.00	0.41	1.65	1.65	1.24	0.00	0.00	0.00	0.00	0.41	0.00	0.00
	13	3.65	0.00	3.32	5.32	0.00	9.30	0.33	0.00	3.99	9.30	0.00	0.33	37.54	5.98	0.66	0.00	0.00	3.99	2.99	0.33	0.33	0.00	5.65	0.00	6.31	0.66	0.00	0.00	0.00	0.00
	14	10.65	0.00	0.93	3.70	0.00	0.46	4.63	2.31	4.17	2.31	2.31	0.00	13.43	40.74	0.46	0.00	0.00	0.00	5.56	0.00	0.00	0.00	0.00	3.24	0.00	4.17	0.00	0.00	0.46	0.46
	15	0.00	4.67	3.27	5.61	0.00	0.47	1.40	0.93	0.00	10.28	0.00	7.48	0.93	0.00	34.11	0.00	0.00	4.21	0.00	8.88	3.27	0.47	13.08	0.00	0.00	0.47	0.00	0.47	0.00	0.00
	16	0.00	0.51	0.51	0.00	6.57	2.02	3.54	0.00	5.56	0.00	2.02	10.10	0.00	0.51	0.00	43.94	5.56	0.00	0.51	0.00	0.00	10.61	0.00	0.00	0.51	0.00	4.55	3.03	0.00	0.00
	17	0.00	0.00	0.60	0.00	4.82	13.86	0.00	0.00	4.82	0.60	0.00	7.23	0.00	0.00	0.00	1.20	45.18	8.43	0.00	0.00	0.00	0.00	0.00	0.00	7.23	0.00	6.02	0.00	0.00	0.00
	18	0.00	0.60	5.36	0.00	0.00	4.76	0.60	0.00	1.79	8.93	0.00	2.98	8.93	0.00	4.76	0.60	8.33	38.10	0.00	0.60	0.00	0.00	6.55	0.00	7.14	0.00	0.00	0.00	0.00	0.00
	19	7.52	0.44	0.00	0.00	0.44	7.52	0.44	0.00	3.54	2.21	3.54	0.00	6.64	6.19	0.00	0.44	0.00	0.00	52.65	0.00	0.00	0.00	0.00	1.77	2.21	0.00	2.21	2.21	0.00	0.00
	20	0.00	1.17	0.00	8.19	0.00	0.00	0.58	3.51	0.00	1.75	0.00	0.00	0.00	0.00	4.09	0.00	0.00	0.00	0.00	40.94	5.26	0.00	11.70	0.00	0.00	15.79	0.00	0.00	0.00	7.02
	21	0.00	7.66	0.48	2.87	0.48	0.00	2.87	10.05	0.00	0.96	2.39	1.44	0.00	0.00	6.70	0.00	0.00	0.48	0.00	9.09	36.84	7.66	0.48	0.00	0.00	0.48	0.00	0.00	3.83	5.26
	22	0.00	5.41	0.00	0.00	8.56	0.00	7.21	0.90	0.45	0.00	2.70	6.76	0.00	0.00	1.35	7.66	0.00	0.00	0.00	0.45	6.76	42.34	0.45	0.00	0.00	0.00	0.00	3.60	5.41	0.00
	23	0.53	0.00	3.21	11.76	0.00	0.00	0.00	1.07	0.53	2.67	0.00	0.00	14.97	6.95	9.09	0.00	0.00	2.67	0.53	3.74	0.00	0.00	35.83	0.00	0.00	5.88	0.00	0.00	0.00	0.53
	24	5.93	0.74	0.00	0.74	0.74	0.00	7.41	13.33	0.00	0.00	11.85	0.00	0.00	8.15	0.00	0.74	0.00	0.74	3.70	0.00	0.00	0.74	0.00	37.04	0.00	0.74	0.00	1.48	5.93	0.00
	25	1.17	0.00	0.58	0.00	0.00	11.70	0.00	0.00	6.43	0.00	0.00	0.00	9.94	0.00	0.00	0.58	1.17	4.09	9.36	0.00	0.00	0.00	0.00	0.00	49.71	0.00	5.26	0.00	0.00	0.00
	26	0.78	0.00	0.00	17.05	0.00	0.00	0.00	6.98	0.00	3.10	0.78	0.00	5.43	14.73	0.78	0.00	0.00	0.78	0.00	6.98	0.78	0.00	2.33	6.98	0.00	27.13	0.00	0.00	0.78	4.65
	27	0.00	0.00	0.00	0.00	2.88	4.81	0.00	0.00	9.62	0.00	1.92	0.00	0.00	0.00	0.00	10.58	4.81	0.00	10.58	0.00	0.00	0.00	0.00	0.00	2.88	0.00	44.23	7.69	0.00	0.00
	28	0.00	0.00	0.00	0.00	0.00	0.66	4.61	0.00	3.29	0.00	8.55	0.00	0.00	0.00	0.00	3.95	0.00	0.00	0.66	0.00	0.00	6.58	0.00	6.58	0.00	0.00	2.63	55.26	7.24	0.00
	29	0.00	0.65	0.00	0.00	0.65	0.00	6.45	5.16	0.00	0.00	3.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	9.03	6.45	0.00	7.10	0.00	0.00	0.00	5.81	51.61	3.23
	30	0.00	1.06	0.00	2.13	0.00	0.00	0.00	13.83	0.00	0.00	1.06	0.00	0.00	1.06	0.00	0.00	0.00	0.00	0.00	3.19	7.45	0.00	1.06	6.38	0.00	11.70	0.00	0.00	4.26	46.81

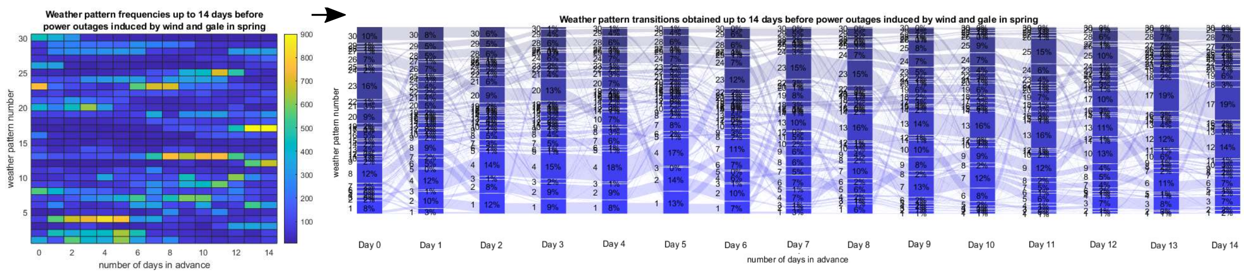
Figure A.9: Long-term probability of occurrence of a weather pattern (columns 1 to 30) given the weather pattern in the previous day (rows 1 to 30) in the UK in spring.

Weather Pattern	Weather Pattern next day																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	36.73	5.73	7.43	5.94	3.40	4.46	7.64	5.52	2.55	7.64	2.34	0.42	3.18	5.10	0.21	0.00	0.00	0.00	1.49	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	6.35	33.65	7.76	7.29	4.47	0.24	4.47	8.00	0.00	5.41	1.41	4.47	0.24	0.24	3.76	0.00	0.00	0.00	0.00	1.18	7.76	2.59	0.47	0.00	0.00	0.24	0.00	0.00	0.00	0.00
3	6.02	10.12	32.05	3.86	8.67	7.71	5.54	0.72	5.78	5.06	0.48	5.54	2.65	0.48	1.93	1.93	0.48	0.24	0.00	0.00	0.24	0.24	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	7.34	7.13	9.07	34.34	0.43	0.43	5.40	8.21	1.94	4.32	0.43	0.65	3.02	6.26	2.59	0.00	0.00	0.00	0.00	2.38	1.51	0.22	1.73	0.00	0.00	2.38	0.00	0.00	0.00	0.22
5	6.25	7.81	3.57	0.00	41.52	8.93	4.69	1.34	3.13	2.01	5.80	3.35	0.22	0.00	0.00	4.69	0.67	0.00	1.34	0.00	0.22	4.02	0.00	0.22	0.00	0.00	0.00	0.00	0.22	0.00
6	4.02	1.48	4.44	0.21	9.73	49.26	0.00	0.00	4.86	8.03	0.00	3.81	3.59	0.00	0.00	0.42	1.90	2.33	1.48	0.00	0.00	0.00	0.00	0.00	3.59	0.00	0.85	0.00	0.00	0.00
7	1.70	7.22	5.52	1.27	3.40	0.21	42.46	8.07	2.34	0.00	10.62	1.49	0.00	1.27	0.21	1.06	0.00	0.00	0.00	0.00	2.97	5.31	0.00	1.49	0.00	0.21	0.00	0.64	2.34	0.21
8	5.38	3.85	0.77	14.36	0.00	0.00	9.74	38.46	0.26	0.51	2.56	0.26	0.51	6.15	0.26	0.00	0.00	0.00	0.00	1.79	3.85	0.51	0.00	5.38	0.00	2.82	0.00	0.00	0.51	2.05
9	5.11	0.30	3.00	0.30	6.31	7.21	6.91	0.30	47.45	0.00	2.40	1.50	1.80	0.30	0.00	7.51	1.80	0.30	3.90	0.60	0.00	0.00	0.00	0.00	1.20	0.00	1.80	0.00	0.00	0.00
10	5.18	3.37	9.59	8.81	0.78	4.92	0.00	0.78	0.00	41.19	0.00	2.33	6.48	0.52	5.44	0.00	0.26	1.81	0.00	1.04	0.52	0.00	6.22	0.00	0.00	0.78	0.00	0.00	0.00	0.00
11	8.20	2.05	0.00	0.41	6.15	0.41	13.52	4.51	5.74	0.00	39.75	0.00	0.41	3.69	0.00	0.82	0.00	0.00	4.92	0.00	0.00	2.05	0.00	4.92	0.00	0.00	0.00	1.23	1.23	0.00
12	0.00	7.23	6.81	0.43	11.06	9.79	0.00	0.00	0.43	7.66	0.43	40.00	0.43	0.00	2.13	3.83	3.40	2.98	0.00	0.00	1.28	2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	6.46	0.00	6.08	5.32	0.38	8.37	0.38	0.00	7.98	11.41	0.00	0.38	41.44	4.94	0.00	0.00	0.38	1.90	1.52	0.00	0.38	0.00	0.00	0.00	2.66	0.00	0.00	0.00	0.00	0.00
14	18.22	0.47	0.00	13.08	0.00	0.93	5.14	3.27	3.74	1.87	0.00	0.00	13.55	32.71	0.00	0.00	0.00	0.00	3.74	0.00	0.00	0.00	0.47	0.93	0.00	1.87	0.00	0.00	0.00	0.00
15	0.00	10.26	7.69	11.11	0.00	0.00	1.71	0.85	0.00	8.55	0.00	9.40	1.71	0.00	23.93	0.00	0.00	1.71	0.00	11.11	5.98	0.85	5.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.56	1.12	0.00	19.10	1.12	3.37	0.56	3.93	0.00	0.56	5.62	0.00	0.00	0.00	48.88	1.69	0.00	0.00	0.00	0.00	6.74	0.00	0.00	0.00	0.00	3.93	2.81	0.00	0.00
17	0.00	0.00	2.82	0.00	8.45	15.49	0.00	0.00	1.41	0.00	0.00	5.63	1.41	0.00	0.00	9.86	40.85	5.63	0.00	0.00	0.00	0.00	0.00	0.00	7.04	0.00	1.41	0.00	0.00	0.00
18	0.00	1.64	13.11	0.00	0.00	13.11	0.00	1.64	3.28	8.20	0.00	4.92	8.20	0.00	3.28	0.00	1.64	32.79	0.00	0.00	0.00	0.00	0.00	0.00	8.20	0.00	0.00	0.00	0.00	0.00
19	12.61	0.00	0.00	0.00	2.52	7.56	0.84	0.00	9.24	0.84	5.88	0.00	3.36	4.20	0.00	0.84	0.00	0.00	45.38	0.00	0.00	0.00	0.00	1.68	4.20	0.00	0.00	0.84	0.00	0.00
20	0.00	3.61	0.00	32.53	0.00	0.00	0.00	7.23	0.00	1.20	0.00	0.00	1.20	0.00	8.43	0.00	0.00	0.00	0.00	24.10	4.82	0.00	3.61	0.00	0.00	10.84	0.00	0.00	0.00	2.41
21	0.00	12.64	0.55	4.40	0.00	0.55	2.20	12.64	0.00	1.10	0.55	1.65	0.00	0.00	6.59	0.00	0.00	0.00	0.00	7.69	39.56	3.30	0.00	0.00	0.00	0.00	0.00	0.00	2.20	4.40
22	0.67	8.00	0.67	0.67	11.33	0.67	10.67	2.00	0.67	0.00	3.33	3.33	0.00	0.00	1.33	6.67	0.00	0.00	0.00	0.00	8.00	40.00	0.00	0.00	0.00	0.00	0.00	1.33	0.67	0.00
23	0.00	0.00	5.08	22.03	0.00	3.39	0.00	1.69	0.00	6.78	0.00	1.69	22.03	5.08	1.69	0.00	0.00	3.39	0.00	5.08	0.00	0.00	22.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	6.90	0.00	0.00	2.30	0.00	0.00	9.20	16.09	0.00	0.00	6.90	0.00	0.00	13.79	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	33.33	0.00	4.60	0.00	2.30	1.15	2.30
25	1.14	0.00	0.00	0.00	0.00	15.91	0.00	0.00	12.50	0.00	0.00	0.00	5.68	1.14	0.00	1.14	7.95	2.27	5.68	0.00	0.00	0.00	0.00	0.00	45.45	0.00	1.14	0.00	0.00	0.00
26	0.00	0.00	0.00	28.36	0.00	0.00	2.99	7.46	0.00	2.99	0.00	0.00	0.00	17.91	0.00	0.00	2.99	0.00	0.00	4.48	0.00	0.00	0.00	4.48	0.00	25.37	0.00	0.00	0.00	2.99
27	0.00	0.00	3.33	0.00	3.33	10.00	0.00	0.00	13.33	0.00	3.33	0.00	0.00	0.00	0.00	3.33	0.00	0.00	3.33	0.00	0.00	0.00	0.00	0.00	13.33	0.00	40.00	6.67	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.06	0.00	0.00	6.06	0.00	9.09	0.00	0.00	0.00	48.48	3.03	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	4.35	15.22	0.00	0.00	2.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.04	2.17	0.00	13.04	0.00	0.00	0.00	0.00	47.83	2.17
30	0.00	0.00	0.00	4.88	0.00	0.00	0.00	19.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44	7.32	0.00	0.00	4.88	0.00	17.07	0.00	0.00	2.44	41.46

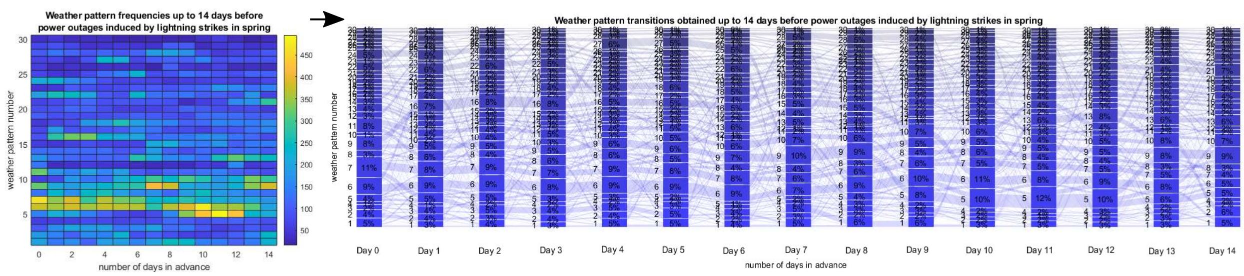
Figure A.10: Long-term probability of occurrence of a weather pattern (columns 1 to 30) given the weather pattern in the previous day (rows 1 to 30) in the UK in summer.

Weather Pattern	Weather Pattern next day: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	16.09	10.34	1.15	1.15	3.45	5.75	2.30	6.90	3.45	18.39	2.30	4.60	2.30	4.60	1.15	0.00	1.15	0.00	4.60	1.15	0.00	2.30	0.00	2.30	1.15	2.30	0.00	0.00	0.00	1.15
2	2.70	18.24	2.70	2.70	2.70	0.00	0.68	6.08	0.00	4.05	8.78	4.73	0.00	0.00	11.49	0.00	0.00	0.00	0.00	4.73	20.27	5.41	0.68	0.00	0.00	1.35	0.00	0.68	0.00	2.03
3	3.23	1.61	19.35	2.42	2.42	2.42	5.65	0.00	8.06	1.61	0.00	12.90	2.42	4.84	8.87	7.26	4.03	4.03	1.61	1.61	1.61	2.42	0.00	0.00	0.81	0.81	0.00	0.00	0.00	0.00
4	3.08	3.08	6.15	21.54	0.00	0.00	9.23	6.92	3.08	2.31	2.31	1.54	6.15	5.38	3.85	0.00	0.00	1.54	0.77	4.62	5.38	0.77	4.62	0.00	0.00	4.62	0.00	0.00	0.00	3.08
5	1.37	2.74	0.00	0.68	32.88	8.90	2.05	0.00	1.37	2.05	6.85	10.96	0.00	0.00	0.00	6.85	2.74	0.00	3.42	0.00	2.05	11.64	0.00	0.00	0.00	0.00	2.05	0.68	0.68	0.00
6	1.59	1.06	3.17	0.53	6.88	27.51	0.53	0.00	3.17	13.23	0.00	10.05	7.41	0.00	1.06	3.17	5.29	7.94	0.53	0.53	0.00	0.00	0.53	0.00	4.76	0.00	1.06	0.00	0.00	0.00
7	0.00	1.57	0.00	5.51	1.57	0.00	19.69	3.94	4.72	0.00	6.30	3.94	0.00	3.94	2.36	3.94	0.00	0.00	0.00	1.57	9.45	17.32	0.79	1.57	0.00	0.79	0.00	3.94	4.72	2.36
8	2.11	7.75	0.00	7.75	0.00	0.70	6.34	19.72	0.00	2.11	6.34	0.00	0.70	6.34	0.70	0.00	0.00	0.00	2.82	1.41	8.45	1.41	0.00	9.86	0.00	5.63	0.00	0.00	6.34	3.52
9	1.28	0.64	3.85	0.00	5.77	4.49	1.92	0.00	28.85	0.64	3.21	3.85	0.64	2.56	0.00	10.90	7.69	1.28	3.85	0.00	0.00	1.28	0.00	0.00	6.41	0.00	8.97	1.92	0.00	0.00
10	0.48	4.35	3.38	3.86	0.48	3.86	0.00	1.45	0.00	21.74	0.48	1.93	11.59	0.48	11.11	0.48	1.93	6.76	0.00	6.28	0.48	0.00	14.49	0.48	1.93	1.45	0.00	0.00	0.00	0.48
11	3.36	4.03	0.67	0.67	5.37	0.67	6.04	4.03	1.34	0.67	30.87	0.00	0.00	2.01	0.00	0.67	0.00	0.00	13.42	0.67	2.01	4.70	0.00	8.72	0.00	0.00	2.01	3.36	4.70	0.00
12	1.12	6.32	4.83	0.00	1.49	1.49	1.49	0.00	0.74	4.09	0.00	33.83	0.37	0.00	14.50	2.97	7.81	8.18	0.00	2.60	1.86	4.09	1.12	0.37	0.00	0.00	0.37	0.00	0.37	0.00
13	2.80	0.62	1.86	2.48	0.62	5.90	0.62	0.00	3.11	7.45	0.00	1.55	34.16	6.83	1.24	0.62	0.31	4.66	4.66	0.93	0.00	0.00	8.70	0.00	9.32	1.24	0.31	0.00	0.00	0.00
14	3.69	0.41	2.46	0.82	0.41	2.05	2.05	4.51	8.20	4.10	0.82	0.00	15.98	28.69	0.00	0.00	0.00	0.00	13.11	0.41	0.00	0.00	1.23	5.33	2.05	2.05	0.41	0.82	0.00	0.41
15	0.00	3.14	2.79	2.44	0.70	0.35	0.35	1.39	0.35	9.06	0.00	5.23	0.00	0.35	29.97	0.00	0.00	4.88	0.00	14.29	5.92	1.39	16.03	0.00	0.00	0.70	0.00	0.00	0.00	0.70
16	0.00	0.84	0.00	0.42	5.86	0.84	3.35	0.00	2.51	0.00	0.84	10.04	0.00	0.00	0.84	46.44	7.95	0.42	0.00	0.00	0.00	12.55	0.00	0.00	0.00	0.00	5.44	1.67	0.00	0.00
17	0.00	0.37	1.86	0.00	1.49	2.97	0.00	0.00	1.86	0.37	0.00	7.43	0.37	0.00	0.74	5.95	52.04	8.55	0.00	0.00	0.00	0.00	0.00	0.00	8.55	0.00	7.06	0.37	0.00	0.00
18	0.00	0.00	3.59	1.20	0.40	2.39	0.00	0.00	2.39	2.39	0.00	5.18	11.55	0.80	7.17	1.20	7.57	37.45	0.00	0.00	0.40	0.40	8.37	0.00	7.17	0.00	0.40	0.00	0.00	0.00
19	4.98	0.77	0.38	0.00	3.83	9.20	0.00	0.38	1.92	1.92	3.83	0.38	8.05	5.75	0.38	0.00	0.00	0.00	42.91	0.00	0.00	0.38	0.00	1.15	6.51	0.00	3.83	3.07	0.38	0.00
20	0.00	0.00	1.77	5.31	0.00	0.00	0.44	0.88	0.00	0.88	0.44	1.33	0.44	0.88	7.96	0.00	0.00	0.00	0.00	34.07	4.87	0.00	11.95	1.33	0.00	18.14	0.44	0.00	0.00	8.85
21	0.00	5.65	0.71	1.06	0.35	0.00	1.77	4.95	0.35	0.00	0.35	0.71	0.00	0.00	7.77	0.35	0.00	0.00	0.00	9.89	38.87	4.24	0.00	0.00	0.00	1.41	0.00	0.00	6.71	14.84
22	0.39	5.45	0.00	0.00	4.28	0.00	4.28	0.78	0.00	0.00	3.50	5.06	0.00	0.00	1.17	7.00	0.78	0.00	0.39	0.39	14.01	39.30	0.00	0.00	0.00	0.00	0.78	3.50	8.95	0.00
23	0.00	0.39	3.88	4.65	0.00	0.00	0.39	1.55	0.39	1.94	0.39	0.00	18.22	10.47	8.91	0.00	0.00	5.04	0.00	4.26	0.00	0.00	32.17	0.00	0.39	6.59	0.00	0.00	0.00	0.39
24	4.44	1.33	0.00	0.44	0.44	0.00	2.22	5.33	0.89	0.44	6.22	0.00	0.00	13.78	0.00	0.89	0.00	0.00	9.78	0.44	0.44	0.44	0.00	41.33	0.00	1.78	0.00	1.78	4.89	2.67
25	0.00	0.00	0.00	0.00	0.39	8.14	0.00	0.00	4.65	1.55	0.00	0.39	4.26	0.00	0.00	0.39	6.98	12.02	5.43	0.00	0.39	0.00	0.39	0.00	50.00	0.00	5.04	0.00	0.00	0.00
26	0.46	0.00	0.91	6.39	0.00	0.46	1.83	4.11	0.00	1.83	0.00	0.00	4.11	15.53	1.83	0.00	0.00	0.00	0.00	5.48	0.46	0.00	2.74	8.22	0.00	37.44	0.00	0.00	0.00	8.22
27	0.00	0.00	0.00	0.00	1.37	3.20	0.00	0.00	2.28	0.46	0.00	0.91	0.00	0.00	0.46	10.96	5.48	0.46	4.11	0.00	0.00	1.37	0.00	0.00	4.57	0.00	59.82	4.11	0.46	0.00
28	0.00	0.66	0.00	0.00	0.66	0.66	0.00	0.00	1.99	0.00	3.31	0.00	0.00	0.00	0.00	2.65	0.00	0.00	5.96	0.00	0.66	7.95	0.00	3.31	0.00	0.66	3.31	58.94	9.27	0.00
29	0.00	0.45	0.45	0.00	0.00	0.00	1.81	2.71	0.00	0.00	2.26	0.00	0.00	0.45	0.45	0.00	0.00	0.00	0.90	0.00	5.43	7.24	0.00	11.76	0.00	0.00	0.00	4.52	52.04	9.50
30	0.00	0.44	0.00	0.44	0.00	0.00	2.22	4.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.44	0.00	0.00	4.00	6.67	0.44	0.00	13.78	0.00	16.44	0.00	0.00	6.22	43.56

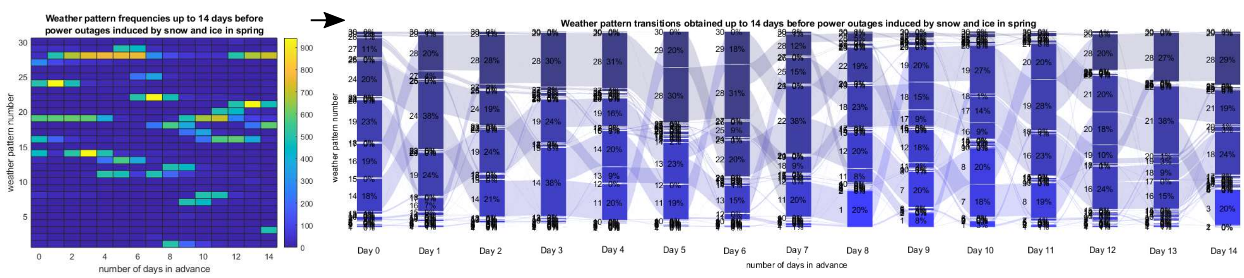
Figure A.11: Long-term probability of occurrence of a weather pattern (columns 1 to 30) given the weather pattern in the previous day (rows 1 to 30) in the UK in fall.



(a) Top 1 spring: wind and gale

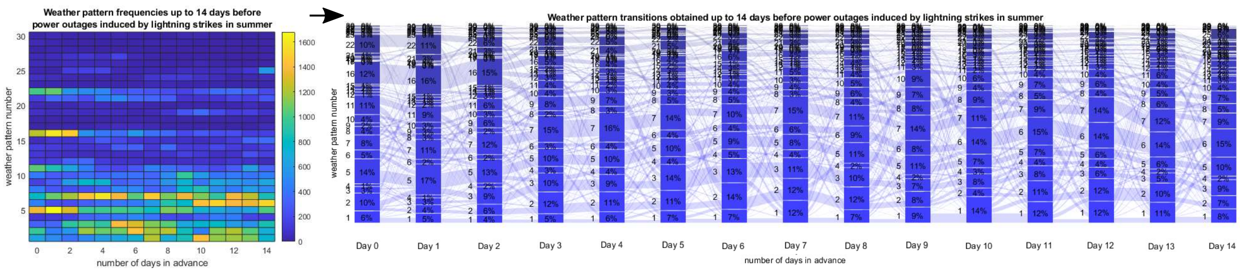


(b) Top 2 spring: lightning strikes

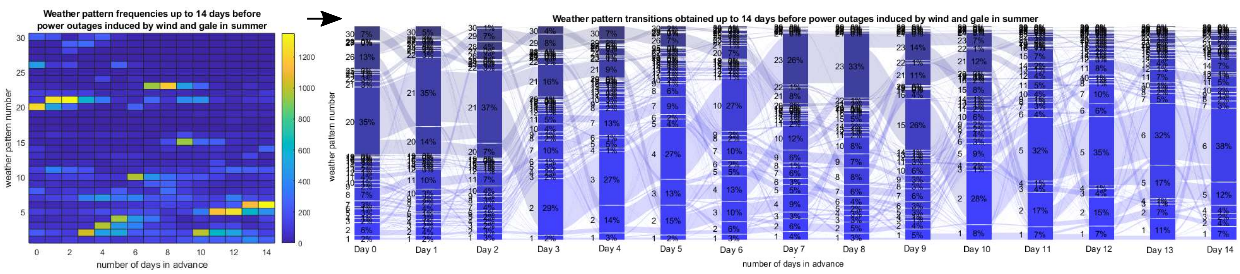


(c) Top 3 spring: snow and ice

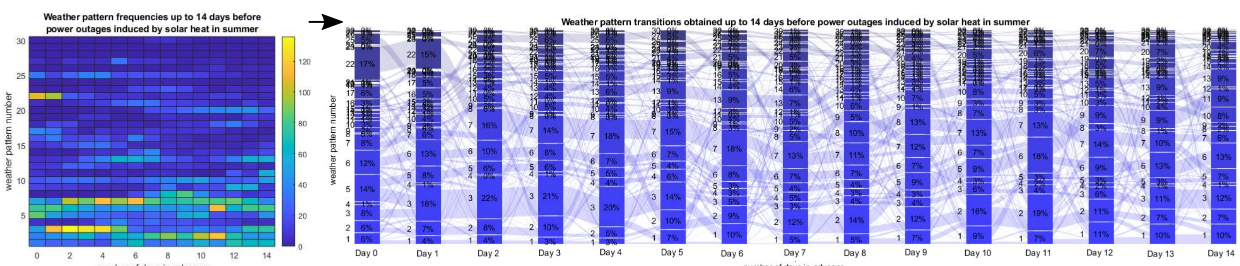
Figure A.12: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in spring in the UK from 2010 to 2019.



(a) Top 1 summer: lightning strikes

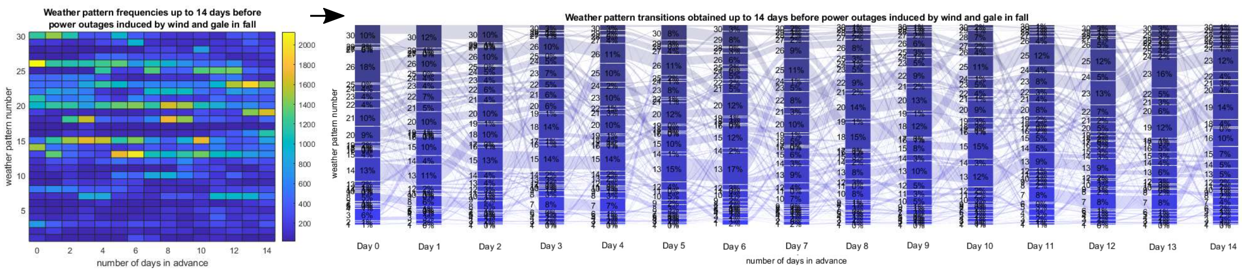


(b) Top 2 summer: wind and gale

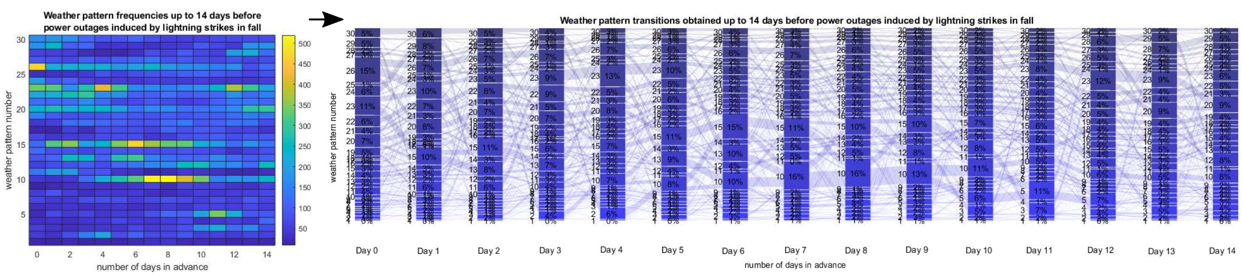


(c) Top 3 summer: solar heat

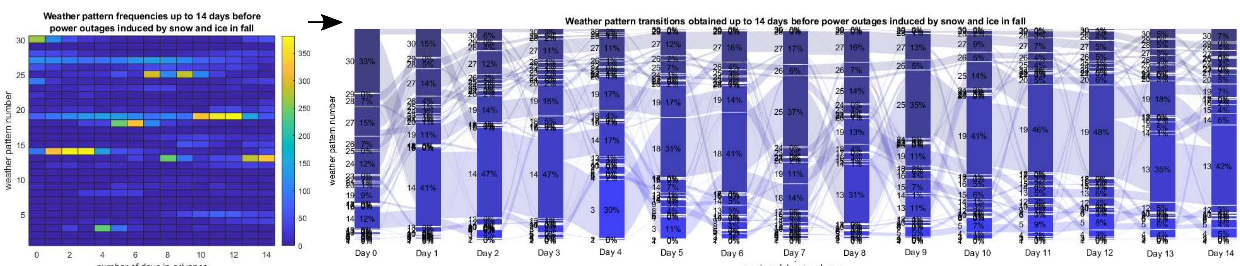
Figure A.13: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in summer in the UK from 2010 to 2019.



(a) Top 1 fall: wind and gale

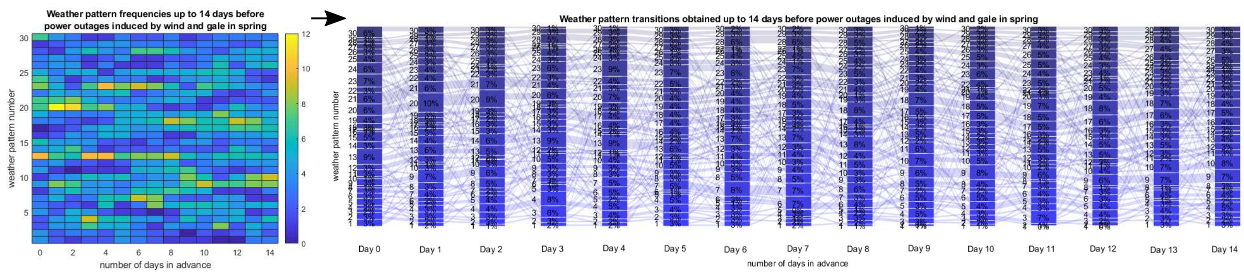


(b) Top 2 fall: lightning strikes

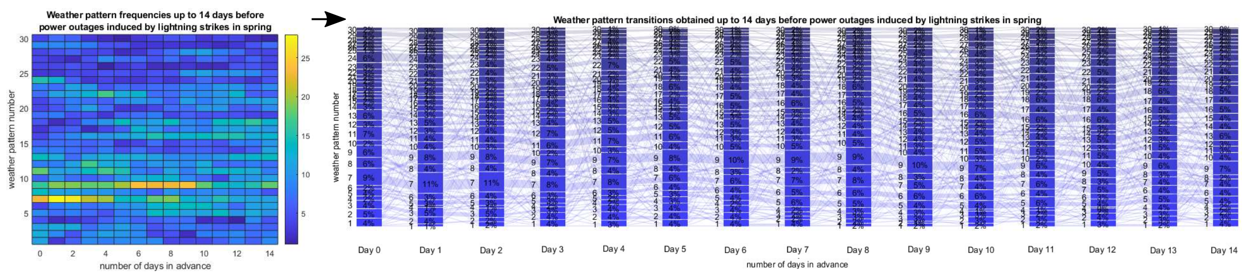


(c) Top 3 fall: snow and ice

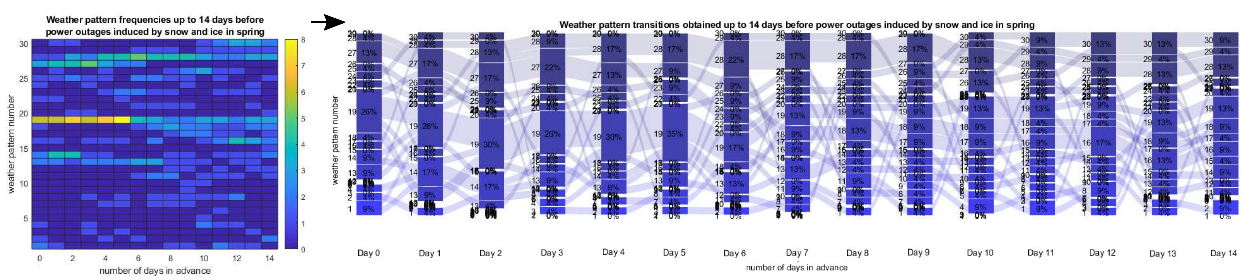
Figure A.14: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in fall in the UK from 2010 to 2019.



(a) Top 1 spring: wind and gale

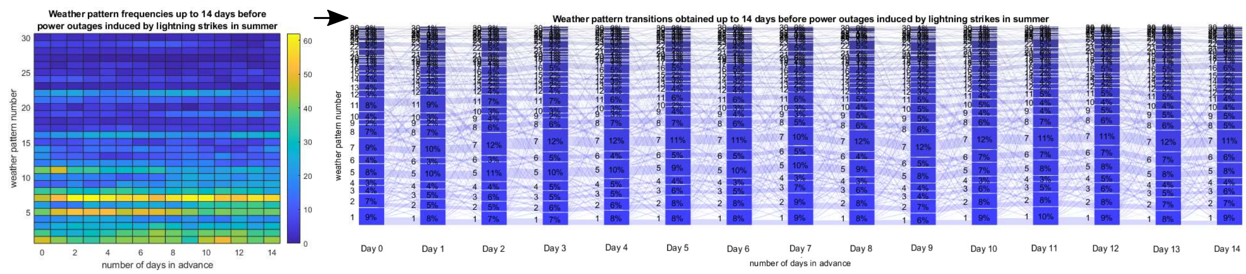


(b) Top 2 spring: lightning strikes

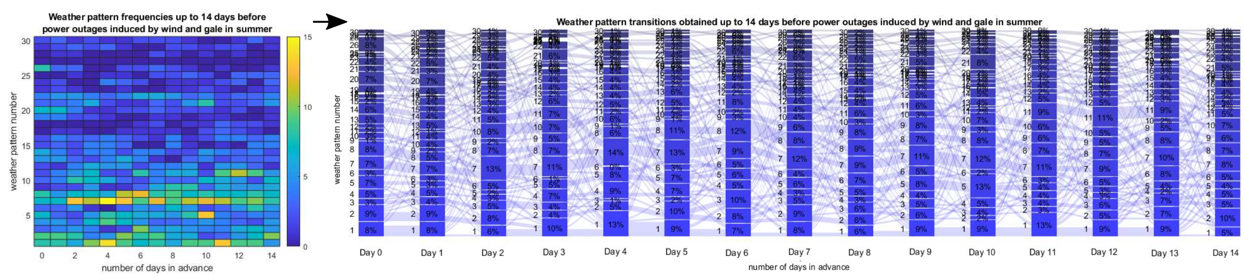


(c) Top 3 spring: snow and ice

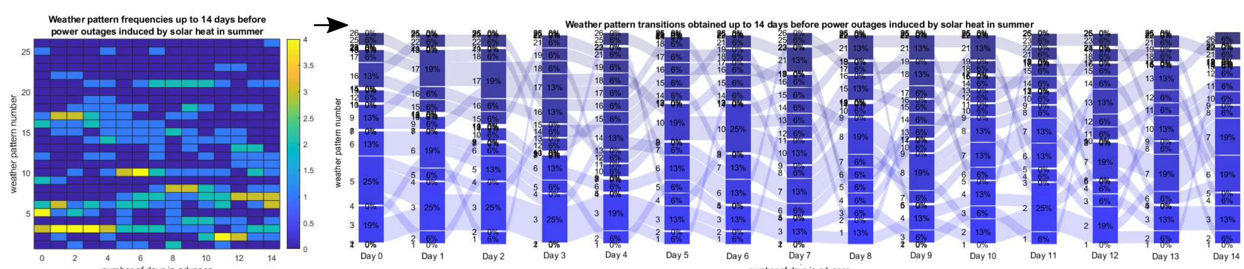
Figure A.15: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in spring obtained with data from Northeast England from 2004 to 2021.



(a) Top 1 summer: lightning strikes

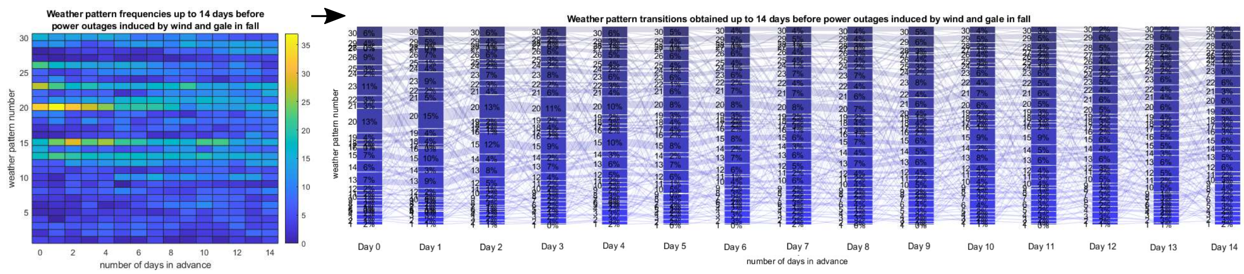


(b) Top 2 summer: wind and gale

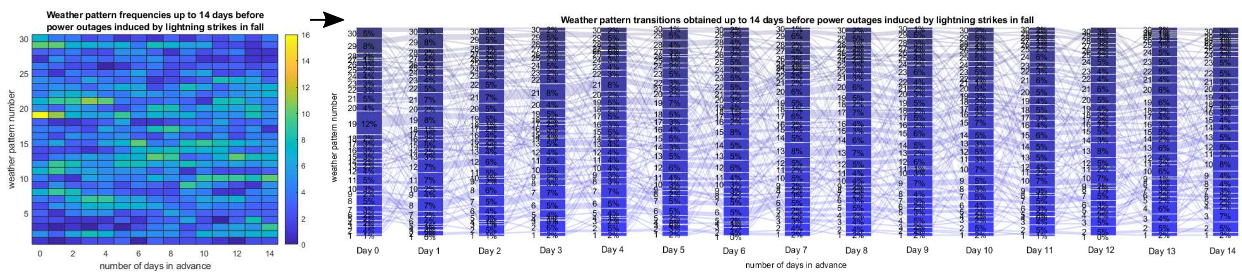


(c) Top 3 summer: solar heat

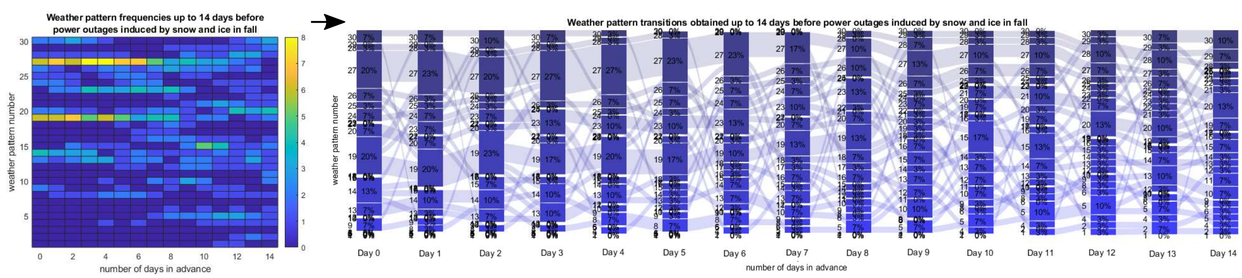
Figure A.16: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in summer obtained with data from Northeast England from 2004 to 2021.



(a) Top 1 fall: wind and gale

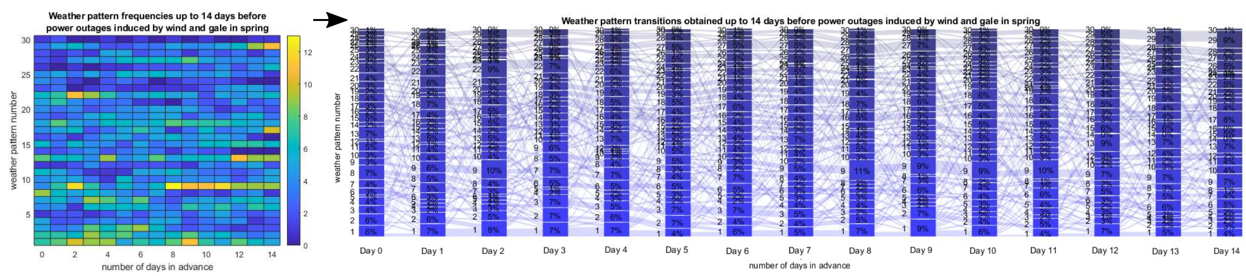


(b) Top 2 fall: lightning strikes

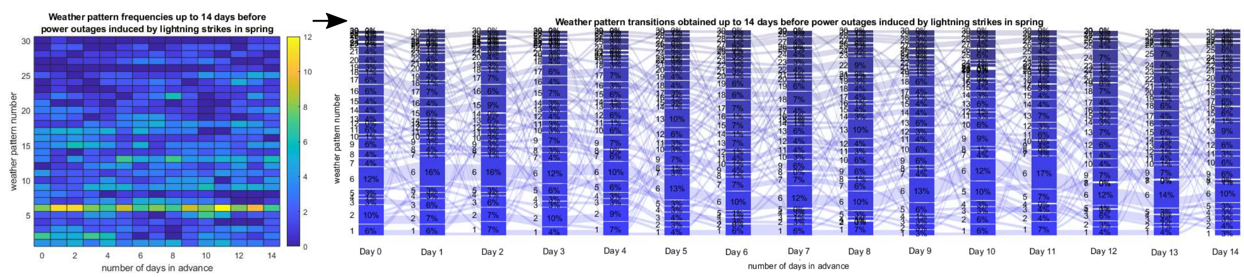


(c) Top 3 fall: snow and ice

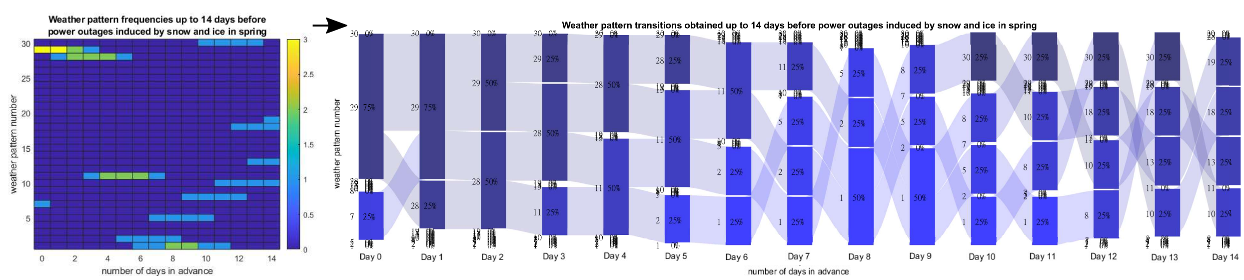
Figure A.17: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in fall obtained with data from Northeast England from 2004 to 2021.



(a) Top 1 spring: wind and gale

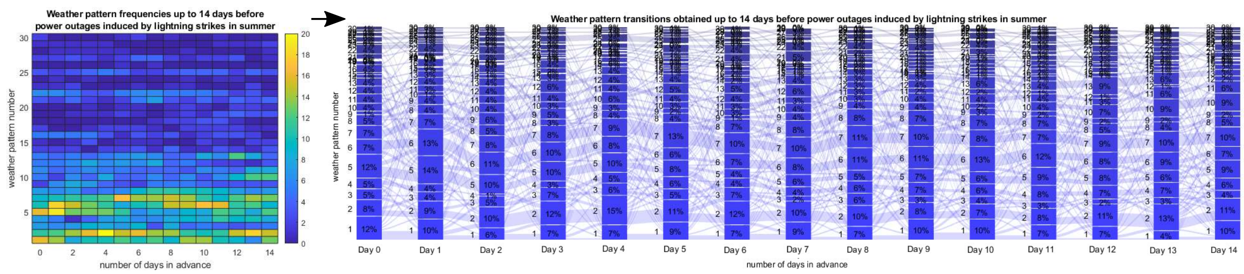


(b) Top 2 spring: lightning strikes

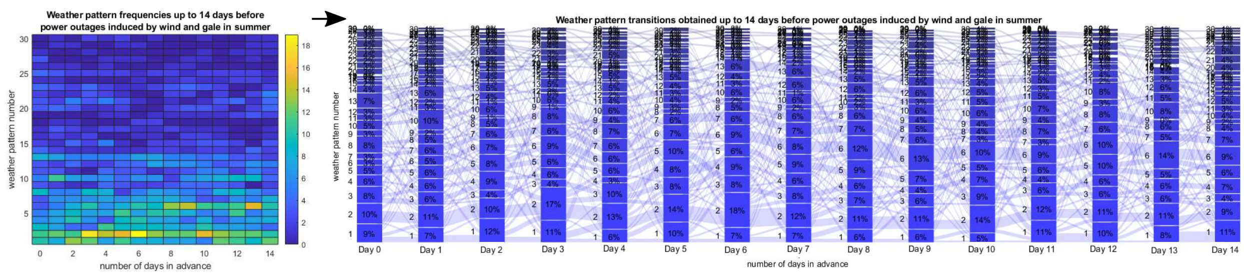


(c) Top 3 spring: snow and ice

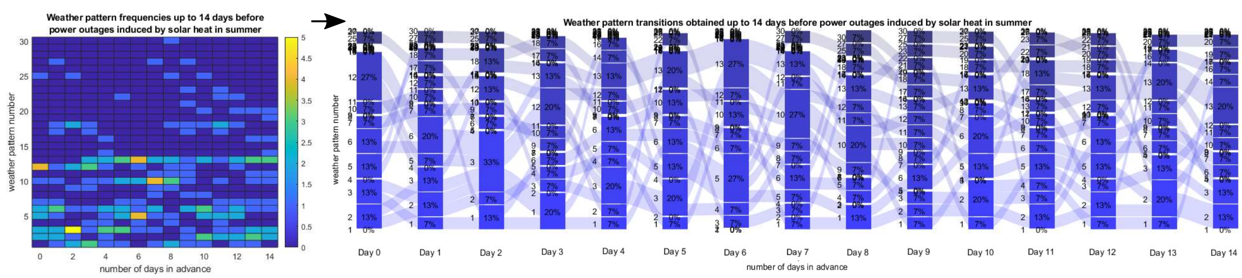
Figure A.18: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in spring obtained with data from Southern Scotland from 2017 to 2022.



(a) Top 1 summer: lightning strikes

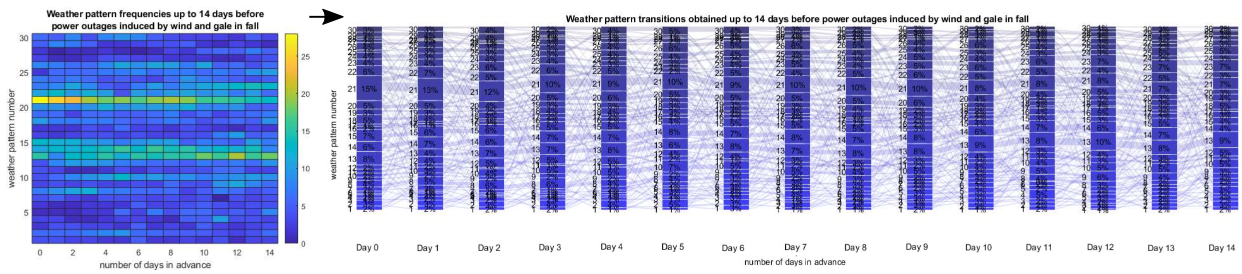


(b) Top 2 summer: wind and gale

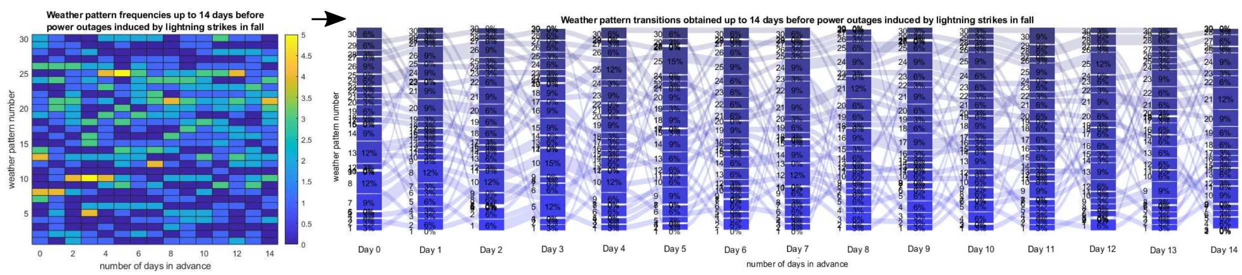


(c) Top 3 summer: solar heat

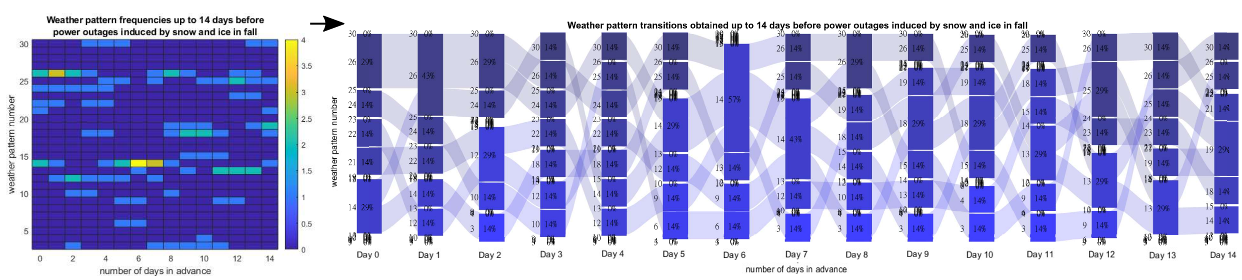
Figure A.19: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in summer obtained with data from Southern Scotland from 2017 to 2022.



(a) Top 1 fall: wind and gale



(b) Top 2 fall: lightning strikes



(c) Top 3 fall: snow and ice

Figure A.20: Frequency of occurrence of weather patterns (on the left) and weather pattern transitions (on the right) up to 2 weeks ahead of the three most common causes of weather-induced power outages in fall obtained with data from Southern Scotland from 2017 to 2022.