Supplementary Information

**Net Zero Without the Gridlock through Peer-to-Peer Coordinated Flexibility**

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**This PDF file includes:**

Supplementary Text and Tables S1 to S8

**Supplementary Text:**

The data corresponding to Figures 2-6 are provided in Tables S1-S8. The data for Figure 2 is found in Table S1, the data for Figure 3 is in Tables S2-S3, the data for Figure 4 is in Table S4, the data for Figure 5 is in Table S5, and the data for Figure 6 is spread across Tables S6-S8. It is noteworthy that due to space limitations, only data from 50 networks is displayed in Tables S6-S7.

**Table S1. Total electrical demand and DER capacities within UK LVDNs.**

|  |  |  |
| --- | --- | --- |
| Category | Year | Values (GW) |
| PV capacity | 2020 | 4.1 |
| 2030 | 13.0 |
| 2040 | 26.6 |
| 2050 | 40.7 |
| Electrical peak demand | 2020 | 18.6 |
| 2030 | 23.5 |
| 2040 | 38.8 |
| 2050 | 38.4 |
| BS capacity | 2020 | 0.03 |
| 2030 | 0.9 |
| 2040 | 3.6 |
| 2050 | 8.4 |
| Shiftable peak demand | 2020 | 0.04 |
| 2030 | 1.0 |
| 2040 | 2.9 |
| 2050 | 3.2 |

**Table S2. Various electrical demand and DER capacities within UK LVDNs under LW and CT pathways.**

|  |  |  |  |
| --- | --- | --- | --- |
| Category | | LW pathway | CT pathway |
| Shiftable peak demand (GW) | | 3.2 | 3.8 |
| BS capacity (GW) | | 8.4 | 7.2 |
| PV capacity (GW) | | 40.7 | 40.7 |
| Electrical peak demands (GW) | Heating | 20.9 | 27.2 |
| EV charging | 8.0 | 10.4 |
| Others | 9.5 | 12.2 |

**Table S3. UK LVDNs’ per-household PV capacity and average initial loading level in different regions.**

|  |  |  |
| --- | --- | --- |
| Region | Per-household PV capacity (kW) | Average initial loading level |
| South West | 3.2 | 67% |
| South East & London | 1.2 | 61% |
| Midlands & East England | 1.2 | 64% |
| North England | 1.4 | 57% |
| Scotland | 1.6 | 54% |
| Wales | 2.4 | 58% |
| Northern Ireland | 1.2 | 55% |

**Table S4. UK LVDNs’ per-household PV capacity and average initial loading level in different regions.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Cases | Annual maximum substation flow (kVA) | | | | | |
| 2020 | No Flex | Lower bound | 128 | Upper bound | 137 | Average value | 132 |
| No P2P | Lower bound | 125 | Upper bound | 137 | Average value | 131 |
| Full P2P | Lower bound | 124 | Upper bound | 136 | Average value | 129 |
| 2025 | No Flex | Lower bound | 128 | Upper bound | 139 | Average value | 132 |
| No P2P | Lower bound | 125 | Upper bound | 137 | Average value | 131 |
| Full P2P | Lower bound | 120 | Upper bound | 131 | Average value | 126 |
| 2030 | No Flex | Lower bound | 163 | Upper bound | 183 | Average value | 170 |
| No P2P | Lower bound | 141 | Upper bound | 159 | Average value | 148 |
| Full P2P | Lower bound | 125 | Upper bound | 141 | Average value | 133 |
| 2035 | No Flex | Lower bound | 214 | Upper bound | 244 | Average value | 232 |
| No P2P | Lower bound | 172 | Upper bound | 190 | Average value | 182 |
| Full P2P | Lower bound | 148 | Upper bound | 161 | Average value | 155 |
| 2040 | No Flex | Lower bound | 277 | Upper bound | 294 | Average value | 287 |
| No P2P | Lower bound | 225 | Upper bound | 254 | Average value | 242 |
| Full P2P | Lower bound | 188 | Upper bound | 214 | Average value | 199 |
| 2045 | No Flex | Lower bound | 274 | Upper bound | 304 | Average value | 290 |
| No P2P | Lower bound | 248 | Upper bound | 279 | Average value | 264 |
| Full P2P | Lower bound | 197 | Upper bound | 222 | Average value | 211 |
| 2050 | No Flex | Lower bound | 271 | Upper bound | 303 | Average value | 282 |
| No P2P | Lower bound | 215 | Upper bound | 267 | Average value | 247 |
| Full P2P | Lower bound | 182 | Upper bound | 217 | Average value | 202 |

**Table S5. Future loading levels in 2050 in various UK regions under LW scenario for Full P2P and No P2P case.**

|  |  |  |
| --- | --- | --- |
| Region | No P2P | Full P2P |
| South West | 220% | 149% |
| South East & London | 123% | 94% |
| Midlands & East England | 129% | 99% |
| North England | 112% | 89% |
| Scotland | 109% | 85% |
| Wales | 138% | 86% |
| Northern Ireland | 112% | 93% |

**Table S6. Maximum line flow (kVA) of No P2P case at different line depth and in various networks under the LW scenario in 2050.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Line depth  Networks | 1 | 4 | 7 | 10 | 13 | 16 | 19 | 22 |
| Network 1 | 28.5 | 20.0 | 13.9 | 10.6 | 7.7 | 5.9 | 3.5 | 3.3 |
| Network 2 | 31.8 | 25.3 | 18.2 | 13.0 | 10.1 | 8.1 | 6.5 | 5.6 |
| Network 3 | 28.4 | 20.6 | 14.2 | 10.9 | 8.3 | 6.8 | 4.1 | 2.3 |
| Network 4 | 28.2 | 20.9 | 14.5 | 11.2 | 8.3 | 6.0 | 3.9 | 3.2 |
| Network 5 | 28.8 | 21.7 | 15.4 | 11.7 | 8.5 | 6.8 | 4.8 | 4.2 |
| Network 6 | 29.4 | 20.9 | 13.9 | 10.4 | 7.9 | 6.0 | 3.6 | 2.6 |
| Network 7 | 27.9 | 20.0 | 14.1 | 11.4 | 8.2 | 5.9 | 3.6 | 3.4 |
| Network 8 | 27.1 | 20.1 | 14.5 | 11.0 | 8.0 | 6.8 | 4.2 | 3.4 |
| Network 9 | 27.9 | 20.0 | 13.7 | 10.4 | 7.6 | 6.3 | 4.2 | 3.8 |
| Network 10 | 27.1 | 19.7 | 13.6 | 10.3 | 7.7 | 6.3 | 4.9 | 5.4 |
| Network 11 | 27.9 | 22.2 | 16.5 | 10.9 | 8.8 | 8.2 | 6.7 | 6.4 |
| Network 12 | 32.8 | 25.9 | 18.6 | 13.3 | 10.6 | 8.4 | 6.9 | 5.9 |
| Network 13 | 28.9 | 22.9 | 16.4 | 10.8 | 8.3 | 7.2 | 6.9 | 8.0 |
| Network 14 | 28.0 | 22.4 | 16.8 | 11.1 | 8.9 | 8.6 | 7.3 | 7.0 |
| Network 15 | 27.7 | 22.3 | 16.1 | 10.4 | 8.2 | 8.0 | 6.9 | 7.1 |
| Network 16 | 29.0 | 23.0 | 16.8 | 11.0 | 8.7 | 7.7 | 6.4 | 6.6 |
| Network 17 | 28.7 | 22.9 | 17.2 | 11.3 | 9.1 | 8.6 | 6.5 | 5.7 |
| Network 18 | 29.1 | 22.9 | 16.4 | 10.8 | 8.9 | 8.7 | 7.5 | 6.7 |
| Network 19 | 27.8 | 22.0 | 16.0 | 10.7 | 8.3 | 7.4 | 6.1 | 6.2 |
| Network 20 | 31.0 | 24.6 | 17.4 | 11.1 | 9.0 | 8.1 | 5.9 | 6.0 |
| Network 21 | 26.8 | 23.4 | 16.7 | 11.9 | 10.8 | 8.1 | 5.4 | 4.3 |
| Network 22 | 33.8 | 26.5 | 19.0 | 13.6 | 11.0 | 8.7 | 7.2 | 6.2 |
| Network 23 | 27.1 | 22.3 | 14.3 | 9.9 | 9.4 | 7.4 | 5.3 | 4.2 |
| Network 24 | 25.9 | 22.0 | 14.8 | 10.0 | 9.1 | 7.3 | 5.3 | 3.6 |
| Network 25 | 26.0 | 22.3 | 15.0 | 10.4 | 9.7 | 7.7 | 5.6 | 3.7 |
| Network 26 | 25.6 | 22.7 | 15.8 | 10.8 | 10.7 | 8.6 | 6.2 | 4.1 |
| Network 27 | 26.8 | 22.8 | 15.7 | 11.0 | 9.8 | 8.1 | 5.8 | 3.6 |
| Network 28 | 26.7 | 23.2 | 15.0 | 10.5 | 10.4 | 8.2 | 5.9 | 4.4 |
| Network 29 | 29.2 | 25.3 | 17.1 | 11.1 | 9.9 | 7.9 | 5.5 | 3.7 |
| Network 30 | 25.4 | 21.9 | 14.8 | 10.5 | 10.1 | 8.5 | 6.2 | 4.3 |
| Network 31 | 28.3 | 22.8 | 15.9 | 14.0 | 11.2 | 8.9 | 7.7 | 6.7 |
| Network 32 | 29.8 | 23.7 | 16.4 | 15.3 | 12.6 | 9.8 | 8.2 | 7.4 |
| Network 33 | 27.8 | 20.9 | 13.0 | 11.3 | 8.8 | 7.5 | 7.1 | 6.6 |
| Network 34 | 30.4 | 23.9 | 15.7 | 13.8 | 10.5 | 8.7 | 7.5 | 6.3 |
| Network 35 | 30.3 | 23.2 | 14.6 | 12.3 | 9.6 | 7.9 | 7.0 | 6.6 |
| Network 36 | 28.8 | 22.8 | 15.4 | 13.3 | 10.3 | 8.4 | 7.6 | 6.7 |
| Network 37 | 28.6 | 22.6 | 15.3 | 14.0 | 11.6 | 9.5 | 8.0 | 6.6 |
| Network 38 | 28.5 | 22.6 | 15.1 | 13.4 | 10.5 | 8.8 | 7.8 | 7.1 |
| Network 39 | 29.1 | 22.9 | 14.1 | 12.0 | 9.8 | 8.7 | 8.0 | 6.2 |
| Network 40 | 29.1 | 23.0 | 15.2 | 13.1 | 10.3 | 8.8 | 8.0 | 7.2 |
| Network 41 | 32.9 | 26.8 | 19.6 | 13.8 | 9.7 | 7.1 | 4.6 | 4.7 |
| Network 42 | 33.0 | 25.5 | 18.5 | 13.4 | 9.2 | 6.6 | 4.8 | 5.5 |
| Network 43 | 33.8 | 26.8 | 19.6 | 14.1 | 9.7 | 7.0 | 4.8 | 4.5 |
| Network 44 | 32.5 | 25.3 | 17.9 | 12.7 | 9.0 | 6.5 | 4.7 | 5.0 |
| Network 45 | 32.2 | 25.8 | 18.4 | 12.7 | 8.9 | 6.6 | 4.3 | 4.0 |
| Network 46 | 29.5 | 22.8 | 16.5 | 12.2 | 9.2 | 7.1 | 4.9 | 4.2 |
| Network 47 | 34.5 | 27.4 | 19.6 | 14.0 | 9.8 | 7.0 | 5.2 | 5.6 |
| Network 48 | 32.3 | 26.1 | 19.3 | 13.7 | 9.4 | 6.9 | 4.8 | 5.6 |
| Network 49 | 35.6 | 28.1 | 20.6 | 14.5 | 10.1 | 7.5 | 5.0 | 4.3 |
| Network 50 | 34.3 | 26.6 | 19.7 | 14.4 | 10.1 | 7.4 | 5.1 | 4.4 |

**Table S7. Maximum line flow (kVA) of Full P2P case at different line depth and in various networks under the LW scenario in 2050.**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Line depth  Networks | 1 | 4 | 7 | 10 | 13 | 16 | 19 | 22 |
| Network 1 | 34.8 | 25.9 | 17.9 | 14.2 | 9.9 | 7.4 | 4.5 | 3.3 |
| Network 2 | 40.2 | 32.0 | 23.1 | 16.4 | 12.8 | 10.2 | 8.2 | 7.1 |
| Network 3 | 35.8 | 26.5 | 18.1 | 14.1 | 9.8 | 8.1 | 5.1 | 4.5 |
| Network 4 | 35.1 | 26.4 | 18.4 | 14.7 | 10.1 | 7.6 | 4.8 | 3.4 |
| Network 5 | 35.0 | 26.3 | 18.1 | 13.9 | 10.0 | 8.1 | 4.8 | 3.2 |
| Network 6 | 35.4 | 26.0 | 17.7 | 14.1 | 9.8 | 7.4 | 4.7 | 3.7 |
| Network 7 | 36.0 | 26.7 | 18.7 | 14.6 | 10.0 | 7.7 | 4.9 | 3.7 |
| Network 8 | 35.2 | 26.3 | 17.9 | 13.9 | 9.6 | 7.5 | 4.8 | 3.5 |
| Network 9 | 35.6 | 26.1 | 17.5 | 13.7 | 9.6 | 7.8 | 4.9 | 3.7 |
| Network 10 | 35.4 | 26.4 | 17.6 | 13.4 | 9.6 | 7.6 | 4.6 | 3.8 |
| Network 11 | 37.1 | 30.3 | 21.1 | 13.3 | 11.5 | 10.3 | 8.7 | 8.6 |
| Network 12 | 41.5 | 32.8 | 23.6 | 16.8 | 13.4 | 10.6 | 8.7 | 7.5 |
| Network 13 | 37.1 | 30.1 | 21.6 | 13.7 | 11.3 | 9.8 | 7.9 | 8.5 |
| Network 14 | 38.1 | 30.6 | 21.8 | 14.1 | 12.0 | 10.2 | 8.1 | 7.2 |
| Network 15 | 37.7 | 30.6 | 22.0 | 14.1 | 11.8 | 10.4 | 8.5 | 8.2 |
| Network 16 | 38.2 | 31.1 | 22.3 | 14.1 | 11.7 | 10.3 | 8.6 | 8.0 |
| Network 17 | 37.5 | 29.8 | 21.0 | 13.5 | 11.5 | 10.3 | 8.1 | 7.8 |
| Network 18 | 38.4 | 30.8 | 21.8 | 14.0 | 11.8 | 10.3 | 8.1 | 7.9 |
| Network 19 | 37.7 | 30.5 | 22.0 | 13.9 | 11.4 | 10.1 | 8.3 | 8.1 |
| Network 20 | 37.1 | 30.3 | 21.9 | 14.1 | 11.6 | 10.3 | 9.4 | 9.7 |
| Network 21 | 36.7 | 31.9 | 20.6 | 13.5 | 12.4 | 10.0 | 7.1 | 4.7 |
| Network 22 | 42.8 | 33.5 | 24.0 | 17.2 | 13.9 | 11.0 | 9.1 | 7.8 |
| Network 23 | 36.3 | 31.1 | 20.5 | 13.8 | 12.7 | 9.8 | 6.8 | 4.7 |
| Network 24 | 35.4 | 30.2 | 19.8 | 13.2 | 12.2 | 10.1 | 7.3 | 4.7 |
| Network 25 | 35.7 | 30.7 | 20.0 | 13.6 | 13.1 | 10.8 | 7.4 | 4.6 |
| Network 26 | 35.6 | 30.9 | 19.9 | 13.0 | 11.8 | 9.5 | 7.0 | 4.9 |
| Network 27 | 36.4 | 31.3 | 20.6 | 14.2 | 13.2 | 9.8 | 6.7 | 4.9 |
| Network 28 | 36.0 | 31.0 | 20.1 | 13.5 | 12.8 | 10.5 | 7.4 | 4.7 |
| Network 29 | 36.8 | 31.1 | 20.0 | 13.5 | 12.3 | 9.7 | 7.0 | 4.9 |
| Network 30 | 36.7 | 32.1 | 21.1 | 14.0 | 12.7 | 10.7 | 8.0 | 5.2 |
| Network 31 | 36.5 | 29.1 | 19.4 | 17.4 | 14.2 | 11.4 | 10.6 | 8.9 |
| Network 32 | 37.5 | 29.4 | 19.1 | 17.3 | 14.5 | 11.5 | 10.1 | 7.9 |
| Network 33 | 37.9 | 30.2 | 19.7 | 17.6 | 14.7 | 11.6 | 10.0 | 9.3 |
| Network 34 | 37.5 | 29.7 | 19.5 | 17.5 | 14.3 | 11.1 | 9.9 | 8.4 |
| Network 35 | 38.9 | 30.5 | 19.3 | 17.2 | 14.2 | 10.7 | 9.4 | 8.1 |
| Network 36 | 37.6 | 29.6 | 19.3 | 17.3 | 14.3 | 11.7 | 11.2 | 9.2 |
| Network 37 | 37.4 | 29.4 | 18.8 | 16.7 | 13.9 | 11.2 | 10.0 | 8.0 |
| Network 38 | 37.7 | 29.1 | 18.7 | 16.6 | 14.0 | 11.4 | 10.3 | 8.8 |
| Network 39 | 38.2 | 30.1 | 19.6 | 17.6 | 14.3 | 11.0 | 9.7 | 8.3 |
| Network 40 | 38.4 | 30.3 | 19.7 | 18.0 | 15.1 | 11.6 | 9.9 | 8.2 |
| Network 41 | 43.8 | 34.7 | 24.6 | 16.7 | 11.3 | 8.5 | 5.7 | 4.9 |
| Network 42 | 43.3 | 34.3 | 25.5 | 18.1 | 12.0 | 8.7 | 6.2 | 5.9 |
| Network 43 | 43.2 | 34.3 | 25.3 | 17.6 | 12.2 | 9.0 | 6.0 | 5.5 |
| Network 44 | 44.6 | 34.8 | 24.7 | 16.7 | 11.5 | 8.7 | 6.1 | 6.2 |
| Network 45 | 43.7 | 34.4 | 25.3 | 17.4 | 11.6 | 8.4 | 5.5 | 4.9 |
| Network 46 | 44.3 | 34.1 | 24.5 | 16.9 | 11.4 | 8.7 | 6.1 | 6.0 |
| Network 47 | 43.3 | 34.4 | 25.5 | 18.0 | 12.1 | 8.7 | 6.4 | 6.8 |
| Network 48 | 43.1 | 34.0 | 24.7 | 17.1 | 11.6 | 8.7 | 6.4 | 5.9 |
| Network 49 | 43.5 | 34.0 | 24.8 | 17.5 | 11.9 | 8.4 | 5.6 | 5.4 |
| Network 50 | 44.0 | 34.5 | 25.1 | 17.5 | 11.8 | 8.6 | 6.3 | 7.2 |

**Table S8. Maximum line flow reduction (kVA) of Full P2P case compared to No P2P case at different line depth and percentile rank under the LW scenario in 2050.**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Line depth  Percentile rank | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| 5% | 0.7 | 0.6 | 0.4 | 0.3 | 0.2 | 0.1 | 0.1 | 0 | 0 | 0 | 0 |
| 10% | 1.4 | 1.2 | 0.9 | 0.8 | 0.5 | 0.3 | 0.1 | 0 | 0 | 0 | 0 |
| 15% | 2.2 | 1.8 | 1.5 | 1.2 | 0.8 | 0.4 | 0.2 | 0 | 0 | 0 | 0 |
| 20% | 2.6 | 2.1 | 1.7 | 1.4 | 0.9 | 0.5 | 0.2 | 0 | 0 | 0 | 0 |
| 25% | 2.4 | 1.9 | 1.5 | 1.2 | 0.8 | 0.3 | 0.1 | 0 | 0 | 0 | 0 |
| 30% | 1.8 | 1.5 | 1.2 | 0.9 | 0.5 | 0.2 | 0 | 0 | 0 | 0 | 0 |
| 35% | 1.1 | 0.9 | 0.7 | 0.5 | 0.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40% | 0.5 | 0.4 | 0.3 | 0.3 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45% | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 50% | 0.7 | 0.5 | 0.4 | 0.3 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 55% | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 60% | 1.3 | 1 | 0.8 | 0.7 | 0.4 | 0.2 | 0 | 0 | 0 | 0 | 0 |
| 65% | 1.1 | 1 | 0.8 | 0.6 | 0.4 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 70% | 1.1 | 0.9 | 0.7 | 0.6 | 0.3 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| 75% | 1.1 | 0.9 | 0.7 | 0.6 | 0.4 | 0.2 | 0.1 | 0 | 0 | 0 | 0 |
| 80% | 1.2 | 1.1 | 1 | 0.8 | 0.6 | 0.4 | 0.3 | 0.1 | 0.1 | 0 | 0 |
| 85% | 2.5 | 2.2 | 2 | 1.7 | 1.3 | 1 | 0.7 | 0.5 | 0.4 | 0.3 | 0.3 |
| 90% | 5.5 | 5 | 4.4 | 3.8 | 2.9 | 2.2 | 1.7 | 1.3 | 0.9 | 0.7 | 0.7 |
| 95% | 12.3 | 10.7 | 9.2 | 8 | 6.1 | 4.3 | 3.1 | 2.1 | 1.4 | 1.2 | 1 |
| 100% | 14.7 | 12.7 | 10.8 | 9.3 | 7.1 | 5.2 | 3.7 | 2.2 | 1.4 | 1 | 0.7 |