Peak EV Charging Demand on the Strategic Road Network

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Climate Change Committee

SYSTRA

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Executive Summary

This report has been commissioned by the Climate Change Committee (CCC) in order to understand the following:

1. How peak traffic flow on the Strategic Road Network (SRN) matches that of peak EV charging demand; and
2. The anticipated infrastructure for en route charging to meet demand through to 2050

The report builds on the tools and assumptions developed as part of the 'Plugging the Gap'[1] study undertaken for the Climate Change Committee (CCC).

We explore the relationship between peak charging demand and peak traffic flows on the SRN by selecting 29 routes across Great Britain and obtaining traffic counts (available online from National Highways and Traffic Scotland) and Zapmap charging data. A comparison is made between the top 5% peak flow days and top 5% peak demand days to ascertain if there is alignment in the current network and fleet composition (2022).

The busiest days for traffic flows were Fridays, with the majority of routes sharing similar days, bank holiday weekends account for three of the top 10. Charging demand did not have the same profile and was spread more across the week, although still with a general focus around the weekend. The results of this analysis therefore found no noticeable correlation between these peak demand and peak traffic days currently. The days when en route charging is at a peak may be reflective of days when people are choosing to take longer journeys but this is not necessarily the days when traffic flows are highest.

As EV uptake increases there may be a slight convergence towards peak days aligning however this will remain dependent on the trip type/lengths people decide to take and how they choose to charge. For example, lots of shorter trips will contribute to greater traffic demand but unlikely to need to charge en route.

Traffic flow and charger information was used to update the En Route Charging Optimisation (ERCO) tool in order to assess the en route charging infrastructure needs from a base year of 2022 through to 2050. A number of scenarios were tested including Do Nothing, Carbon Optimisation, Developer Optimisation and Driver Optimisation.

Carbon Optimisation is the core scenario used within this analysis as it considers what the charging network needs in order to reduce 'lost' demand and keep waiting times to an acceptable level without commercial return limitations. The outputs have been analysed to consider the number of additional chargers, the capital costs required and the geographical areas of intervention.

1 https://www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/

Using the peak flow uplifts identified between 2022 Typical Day and Median Peak demand the results concluded that:

- For a Typical Day the model identified a total of **1,633** rapid chargers on the SRN were required and **1,647** for the Median Peak in 2022 (compared to current 1,755 figure provided by Zapmap). By 2035 this figure increases by **1.5x** for a Typical Day and **1.7x** for the Median Peak to **2,432** and **2,755** respectively, a difference of 12% between the demand profiles. By the last year modelled, 2050, this was **1.7x (2,796)** and **2x (3,368)** respectively, a difference which has increased to 20%.
- For the upper quartile peak demand the difference in required chargers from a Typical Day is even more significant, **18%** in 2035 and **29%** in 2050.
- The anticipated capital costs to achieve this are:
    - **2035: £67.5M** for Typical Day and **£94.7M** for Median Peak demand (40% increase in costs)
    - **2050: £100.6M** for Typical Day and **£146.6M** for Median Peak demand (31% increase in costs)
- The majority of additional chargers, and where pressures on the network appear greatest, are around the Midlands and Yorkshire.

A failure to address the needs for en route charging would have an impact on the uptake in EVs in the short term due to issues around growing charge anxiety which by association wouldn't tackle carbon emissions through 'lost' demand. This could equate to **63%** of lost demand in 2035 on a Typical Day in a Do Nothing scenario and **74%** in 2050. A Do Nothing approach (also similar to Developer Optimisation) would result in an additional **1.1million kg** of carbon due to lost demand by 2035 and **2million kg** by 2050, for the modelled day, compared to Carbon Optimisation.

These results also show that the optimal network for typical levels of demand will not be sufficient to meet demand peaks. Instead, additional chargers need to be planned to cater for peak demand, otherwise our modelling shows that by 2035 waiting times exceed that of the acceptable 12 minute limit and by 2040 a fifth of demand could be lost on these peak days. This could equate to an additional **410,000kg** of carbon in 2040 compared to the optimal network for the peak.

Terminology

Term/Abbreviation	Description
AADT	Annual Average Daily Traffic - total annual traffic divided by 365, representing traffic levels of a 'Typical Day' at a specific location – may change over time and will have been affected by Covid restrictions in 2020, 2021 and 2022
ERCO	En route Charging Optimisation
High Days & Holidays	Public holidays &/or other 'special' days in the year when journey patterns are likely to differ significantly from normal – these may vary by region and might or might not generate higher traffic volumes &/or higher demand for en route EV charging on some or all routes
Peak Car Flow Days	Top 5% days when the volume of car traffic is significantly higher than average along a route (aggregated count site data) – i.e. similar to Peak Traffic Flow Days, but excluding non-car-based vehicle types
Peak Demand	The demand for en route charging on a given route, averaged over the agreed set of Peak Demand Days.
Peak Demand Days	A small subset of days when the demand for en route charging on a given route is significantly higher than average – in this report they are the top 5% – the actual dates of these days may differ by route and they may or may not coincide with days with higher-than-average traffic flows on those routes
Peak Traffic Flow Days	Days when total traffic flows are significantly higher than average along a route (aggregated count site data) – in this report they are defined as the top 5%
SRN	Strategic Road Network
Typical Demand	The demand for EV Charging on a Typical Day (i.e. where traffic levels are close to the Annual Average Daily Traffic (AADT) levels
Traffic Flows	Traffic count data obtained from National Highways and Traffic Scotland web based portals
Typical Traffic Days	Days when the traffic at a given location, route or region is close to the AADT and with a typical trip length distribution and journey purpose split

1 | Introduction

SYSTRA Ltd. have been commissioned to undertake this study on behalf of the Climate Change Committee (CCC) to assess the peak EV charging demand on the Strategic Road Network (SRN) and how it relates to peak traffic flows. The En Route Charging Optimisation tool (ERCO), as developed by the CCC, has been used in this report to scenario test:

- Typical demand through to 2035
- How the typical network copes with anticipated peak demand
- Infrastructure updates required and associated costs to meet demand

The UK is legally bound by the Climate Change Act to achieve Net Zero emissions by 2050 and the CCC is tasked with:

- Providing independent advice to government on setting and meeting carbon budgets;
- Preparing for climate change; and
- Monitoring progress in reducing emissions and achieving Carbon Budgets.

The transport sector is a key target area for reducing emissions, as this is relatively more straightforward and less costly than sectors such industry and agriculture. Transport related emissions must reduce close to zero in order to reach the Net Zero target by 2050. In 2019 greenhouse gas emissions attributed to road transport accounted for 31% of all emissions in the UK, the greatest contributor of all National Communication (NC) sectors[2]. As a result, ultra-low emission vehicles (ULEVs) will play a key role in delivering emission reductions and therefore the charging infrastructure will need to be in place to facilitate an uptake in EVs.

The number of EVs on the road network in the UK increased by 60% from Q4 2021 to the Q4 2022, where the number of battery electric vehicles on UK roads had hit over 690,000[3]. This figure is expected to continue increasing as we approach the ban on the sale of new petrol and diesel vehicles in 2030. Whilst battery technology is also improving there will continue to be pressures on the charging network for some time. An appropriate number of en route charging will be necessary to combat the ongoing 'charge anxiety' which has been a blocker to EV uptake[4]. En route charging generally refers to rapid (22-99kW) and ultra-rapid (100kW+) found on major roads to facilitate longer trips.

2 https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2021

3 DfT VEH0132

4 https://forecourttrader.co.uk/latest-news/charging-anxiety-has-replaced-range-anxiety-for-ev-drivers-as-new-report-says-charge-point-reliability-is-key/668644.article

Recent media coverage has focused on queues forming whilst accessing rapid charging devices, particularly on busy road traffic days. It has also identified how the ‘growing number of EVs on the road network is significantly outpacing installation of public charge points’[5].

Figure 1. **Electric car infrastructure creaks under demand (The Times, 31st May 2023)**

TRANSPORT

Electric car infrastructure creaks under demand

Study finds areas with one public charging point for every 85 vehicles

In May 2023, the RAC reported, in response to a government policy paper ‘Taking charge: the electric vehicle infrastructure strategy’[6], that the Government was not likely to meet the target of having six or more rapid or ultra-rapid EV chargers at every motorway service area in England by the end of 2023[7]. Using data available on Zapmap, the RAC found that there are an average of 3.4 rapid or ultra-rapid chargers at motorway service stations and currently there are only six services in England with more than 12 devices.

Whilst it is useful to have targets such as these, this report aims to consider how the charging need is distributed across the year and also across the country. A focus on the average chargers per vehicle, per region, ignores the transient nature of travel across regions and where there may be particular hotspots on the network. These media reports are also generally focused on all charging provision, including slower long-term parking solutions whereas this report focuses on the need for en route only. Use of the ERCO tool can help identify how the network copes with a Typical Day, peak day and what infrastructure is anticipated into the future following the CCC’s balanced pathway growth in EV assumption, as identified in their Sixth Carbon Budget[8]. By reporting on the investment required it also guides policy makers on how to balance the need of peak demand with that of the cost and therefore return on investment.

5 https://www.thetimes.co.uk/article/electric-car-vehicle-charging-points-uk-2023-nbx8rh0tz

6 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1065576/taking-charge-the-electric-vehicle-infrastructure-strategy.pdf

7 https://www.rac.co.uk/drive/news/motoring-news/government-not-on-track-to-hit-motorway-services-ev-charger-target-by-end-o/

8 https://www.theccc.org.uk/publication/sixth-carbon-budget/

2 | Strategic Road network Route selection

2.1 Ensuring Geographical Coverage

A total of 29 routes along the SRN have been selected as part of this project. The approach to route selection considered the following characteristics:

- Geographical coverage across mainland Great Britain
- Intercity journeys
- Access to ports
- Access to holiday destinations

The variation in characteristics was chosen to highlight how peak flows and charging may vary depending on journey purpose and time of year. Limitations in the availability of some data resulted in slight changes to the initial approach, as outlined in the section below.

2.2 Route Selection Limitations

In order to undertake this work there were two key dependencies to updating the ERCO tool:

- Traffic Flow Data
- Charging Session Data

The availability of this data had implications on the selection of SRN routes and geographical coverage across Great Britain. Traffic flow data was required from count sites along the SRN to understand peak traffic flow and update the Origin-Destination matrix within the tool. Charging sessions help to identify the peak charging days and also ensure charges per device were calibrated to the correct baseline.

The associated highway authorities in the nation states that make up Great Britain collect and report traffic flows differently. England and Scotland have online portals and APIs available to download the required data from count sites along roads managed by Highways England (WebTris) and Traffic Scotland (Drakewell) respectively. This data was easily accessible for use within the project, more information on these datasets are outlined in Appendix A.

Wales traffic flow data is not made available through online portals, emails were sent to trunkroadtrafficdata@traffic-wales.com to request required flows. As no response was received the decision was taken to not include Wales in this analysis due to lack of data. To capture traffic entering and leaving Wales, three routes were directed towards various points in the Wales, these include routes 9 (South Wales), 13 (Mid-Wales) and 17 (North Wales).

To understand peak demand, electric vehicle charging sessions were obtained from Zapmap (**section 4.1**). Charging data was supplied with the restriction that sufficient operators must be present along a route to prevent the identification of any single provider's sessions.

Initially, 30 SRN routes were selected and the Zapmap charger locations attributed to them which identified one route in northern Scotland as not meeting the supplier number threshold. This route was then merged with a connecting route to form Route 28 (see **section 2.3**) to create a total of 29 routes for this report.

2.3 Final Routes

A total of 29 routes have been selected for this analysis matching the criteria set above and that Zapmap were able to provide charging data for. A list of these routes is provided in **Appendix A**, along with the start/end points and route length (**Table 25**).

The routes have been visualised on the maps below (**Figure 2**) to show their geographical extent, with good north-south and east-west coverage in England (**Figure 4**) and Scotland (**Figure 3**) including some cross border routes. On the maps below, routes 4, 7 and 19 have been offset for visualisation purposes only, as they overlap with some sections of other routes.

Routes passing through London have not been considered as part of this analysis due to the nature of longer distance routes avoiding the built up area, these are directed around the M25. Some routes have a start/end point using the SRN radiating from Greater London, these include the A1(M), A3, A12, M1, M2, M4, M11, M23 and M40 which accounts for demand to/from London.

Figure 2. 29 SRN Routes Analysed

Figure 3. SRN Routes - Scotland

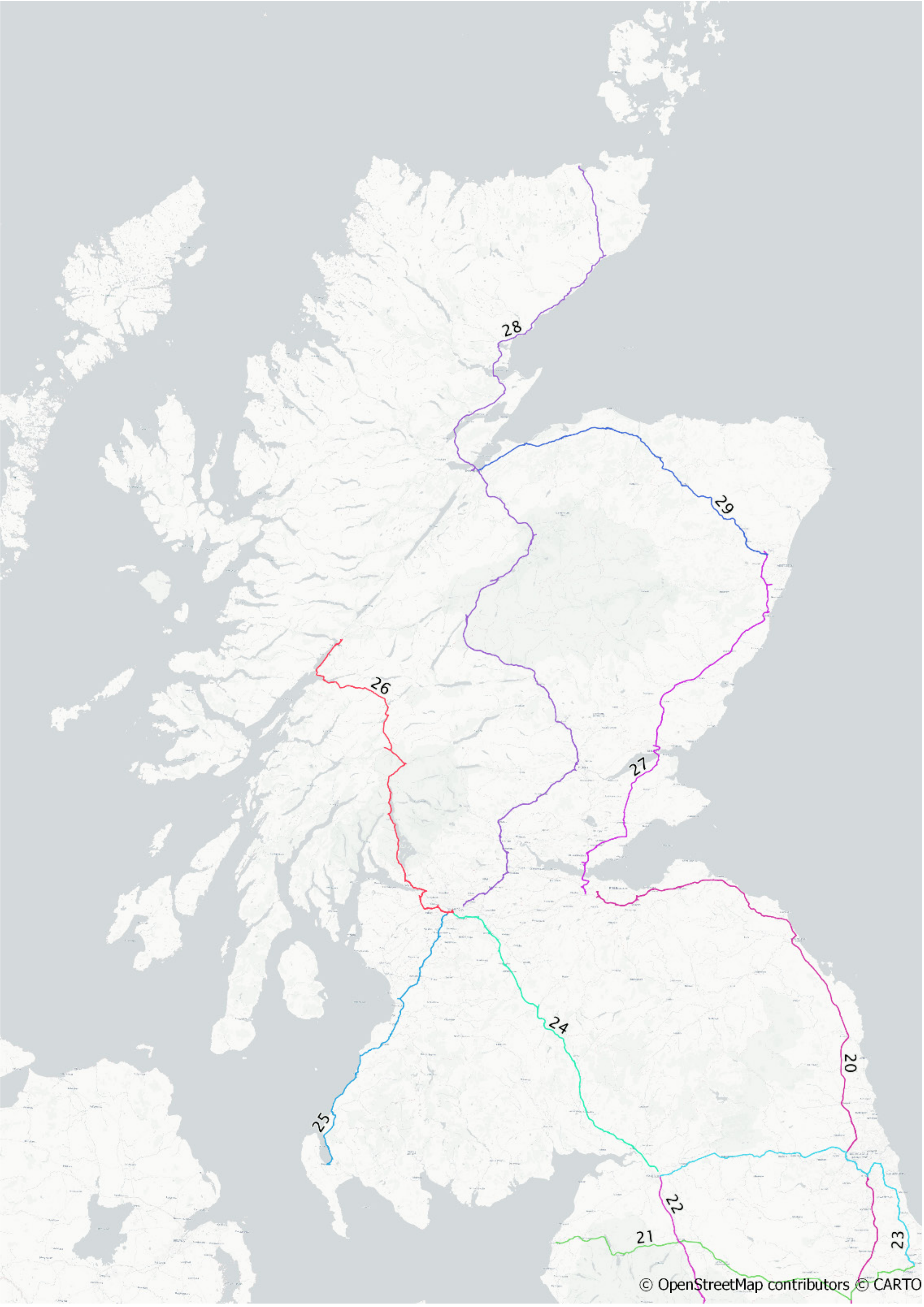


Figure 4. SRN Routes - England

3 | Traffic Flows

3.1 Sources and Extraction Approach

Traffic flows on the SRN are available in England from the online WebTris portal and from Scotland through the Drakewell system.

Count site locations were selected along the 29 routes as candidates for export prior to further data quality checks. Filters were applied to these sites to:

- Ensure data quality of at least 90% for all sites
- Avoid junctions and exits/slips
- Ensure bi-directional data was available (England sites report single direction)

Sites that met the criteria above were considered as part of the whole route representation. Given the length of the routes, the median of the sites selected for each route has been used for the total of any given day.

Data has been collected for every day in 2019 and 2022 to check the relationship between pre and post covid demand. **Table 1** shows the difference between 2019 and 2022 yearly flows per route, a positive percentage indicating 2022 recorded higher flows than 2019. Two routes, 27 and 29, did not have suitable data availability in 2019 for this comparison. These comparisons consider all traffic flows recording (including goods vehicles, PHVs, buses etc.), it is also possible to extract counts for cars only and these are considered later in this report for peak car flow days.

Network wide difference (for 27 routes where data is available) is -3.49% in 2022 relative to 2019. The variance by month does not track the anticipated increase in activity as covid restrictions were lifted in 2022. For example, January 2022 was +6.4% on 2019 whereas July and December 2022 were -5.6% and -5.9% respectively.

These checks were conducted to ensure satisfaction with flow levels in 2022 as being representative of a typical network, the overall network difference is small enough to be satisfied. Therefore, data for 2022 has been used in this project, with some data patching where gaps exist, more detail on count data collection and processing methodology can be found in Appendix A.

Table 1. Flow Difference (%) by Route, 2022 v 2019

Route	Yearly Flow Difference 2022 v 2019	Route	Yearly Flow Difference 2022 v 2019
1	5.10%	16	-1.20%
2	-0.07%	17	-6.65%
3	-6.21%	18	-4.13%
4	-5.36%	19	-4.72%
5	-3.00%	20	-2.82%
6	-2.35%	21	3.79%
7	-5.39%	22	-1.26%
8	-6.97%	23	-8.45%
9	-9.98%	24	10.74%
10	-11.75%	25	-3.04%
11	4.09%	26	-0.31%
12	-5.74%	27	No 2019 data
13	-6.54%	28	0.47%
14	-4.55%	29	No 2019 data
15	-7.82%	**Total**	**-3.49%**

3.2 Traffic Flow Statistics

Traffic flow statistics have been calculated for all routes in order to:

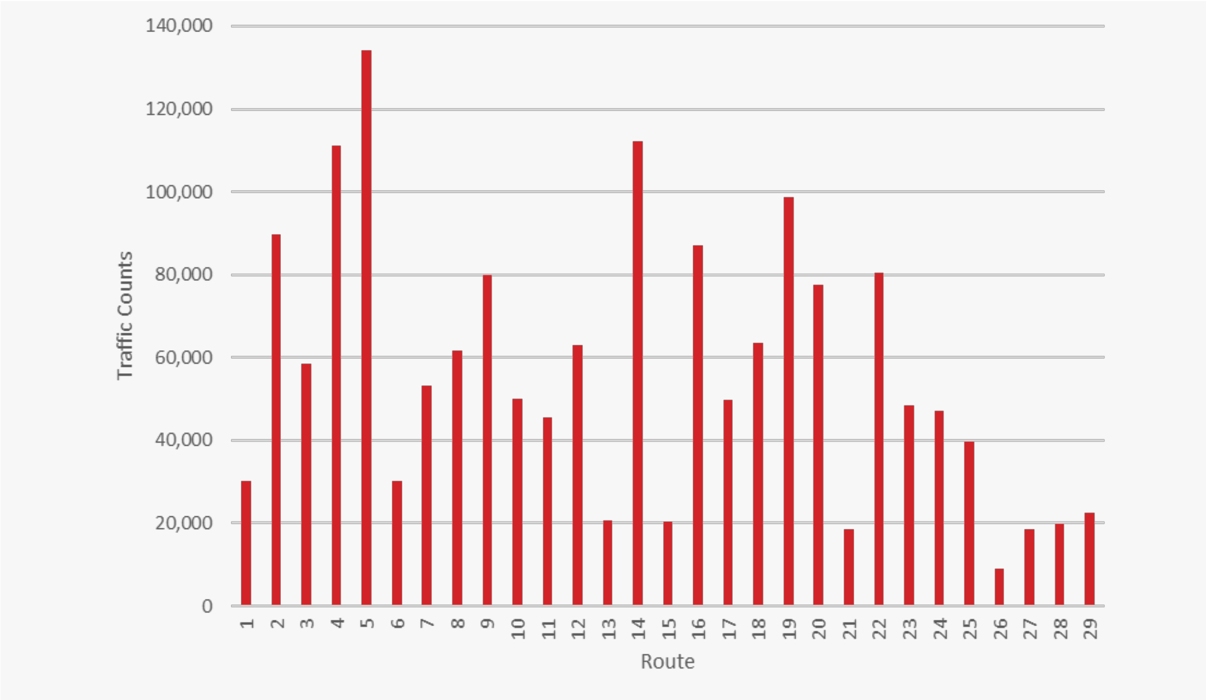
- Identify the different flows between routes
- Generate typical and peak flow days for the ERCO model
- Compare between peak traffic flow and typical traffic days
- Compare between peak traffic flow and peak demand days

All statistics are aggregated to route level by taking the median of all sites along the route, this has the implication of some variance across count sites e.g. peak flow days along a route may not necessarily be the peak flow day at an individual site on that route but are intended to be reflective of the route as a whole.

Typical Traffic Days

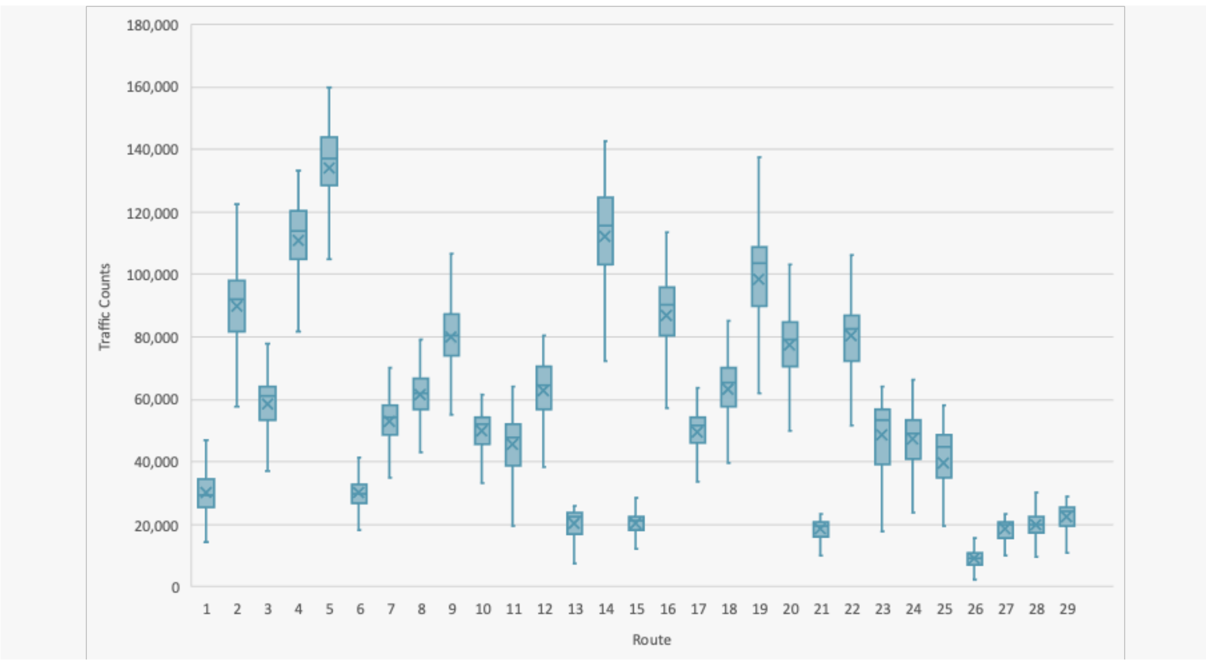
The bi-directional Average Annual Daily Traffic (AADT), for all modes, has been calculated for each of the routes. This is also used by the ERCO tool to obtain a Typical Traffic Day, in which the flows for that day are close to the AADT (**section 4.3**). The AADT for each route is shown in the **Figure 5**, the range of AADT for the 29 routes is between **9,114** (route 26) and **134,270** (route 5) and the median is **48,509** (route 23). These are unsurprising results given the nature of the routes, 26 is generally a tourist focused route between Glasgow and Fort William and routes with greatest AADT are on the major motorway network, pass around London and access Dover (route 5).

Figure 5. Average Annual Daily Traffic, Bi-Directional by Route Number, 2022



Whilst the AADT gives the typical flow, the nature of the road network and the routes present interesting ranges between the maximum and minimum flows recorded. **Figure 6** below shows the maximum, minimum, median and interquartile range of the bi-directional flows across 2022 for each route. The mean (AADT) is denoted with a cross on the chart also. The greatest ranges can be found on the longest routes due to their large geographical spread and therefore influenced by a number of local, regional and national factors more so than some of the shorter routes.

Figure 6. Range of Traffic Flows by Route Number, 2022



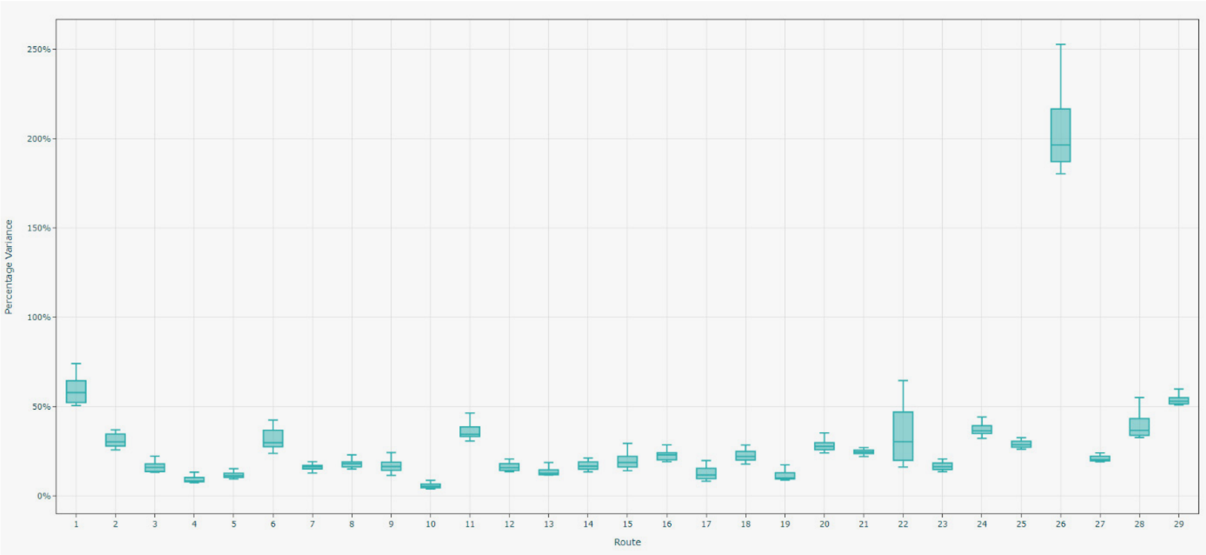
Peak Traffic Flow Days

Peak traffic flow days are identified for each route as the 5% of days with greatest traffic flow across 2022. Peaks for some routes vary more widely than others, both within the top 5% of days ('the peaks') but also relative to the AADT. **Table 2** shows the percentage difference between the peak values and the AADT by considering the highest peak, lowest peak and average difference from the AADT for the top 5% flow days.

Table 2. Maximum, Minimum and Average Difference of Peak Flows compared to AADT by Route, 2022

Route	Max Difference	Min Difference	Average Difference
1	74%	51%	59%
2	37%	26%	31%
3	24%	13%	17%
4	13%	7%	9%
5	15%	9%	12%
6	42%	24%	31%
7	25%	13%	17%
8	43%	15%	20%
9	24%	11%	17%
10	9%	4%	6%
11	46%	31%	36%
12	21%	13%	16%
13	19%	12%	14%
14	21%	13%	17%
15	29%	14%	19%
16	29%	19%	23%
17	20%	8%	12%
18	108%	18%	27%
19	32%	9%	12%
20	38%	24%	29%
21	30%	22%	25%
22	116%	16%	39%
23	21%	13%	17%
24	44%	32%	37%
25	40%	26%	29%
26	253%	180%	206%
27	27%	19%	21%
28	55%	33%	39%
29	61%	51%	54%

Figure 7. Range of Variance of Peak Flows compared to AADT, 2022



The range in variance from AADT (**Figure 7**) across the peak days is small for some routes indicating a similar peak profile for the top 5% of days. Example routes include routes 4, 5, 10 21 and 27. For other routes the difference within the peaks is significant such as routes 22 and 26 with over 100 percentage points difference between max and min yet route 22 average variance is similar to other routes indicating some outliers at each end. More information on the distribution of peak flows by route has been provided in the supplementary interactive .html document.

Example flow distribution for route 5 and route 26 are shown in **Figure 8** and **Figure 9** respectively. These two routes have been taken as examples to emphasise how different route characteristics impact flow distribution across the year. Route 5 crosses the Midlands eventually ending in Dover, flow along this route is generally flat and predictable across the year with a shoulder evident at the Christmas and New Year period. Route 26 is influenced by tourist travel and so has an element of seasonality with a clear peak in the summer, including two very high peak days the 4th June 2022 (bank holiday weekend) and 13th August 2022.

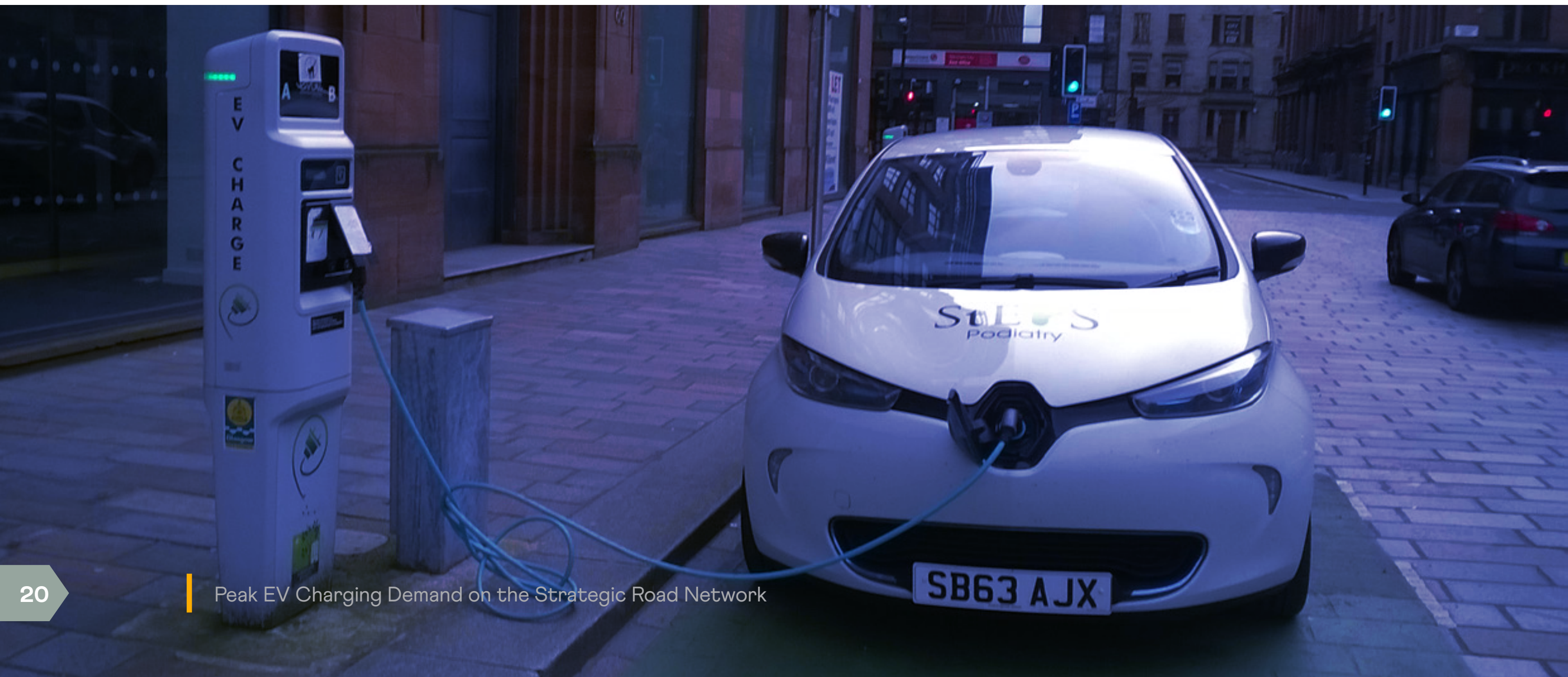


Figure 8. Daily Traffic Flows, Route 5, 2022

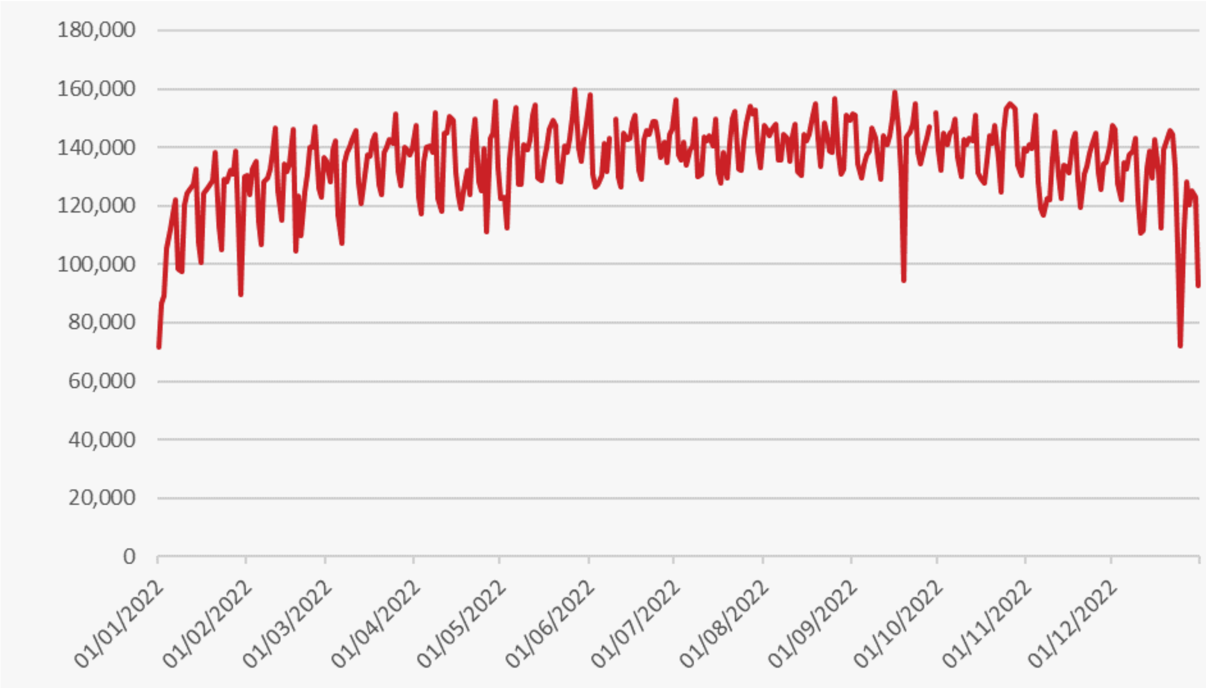
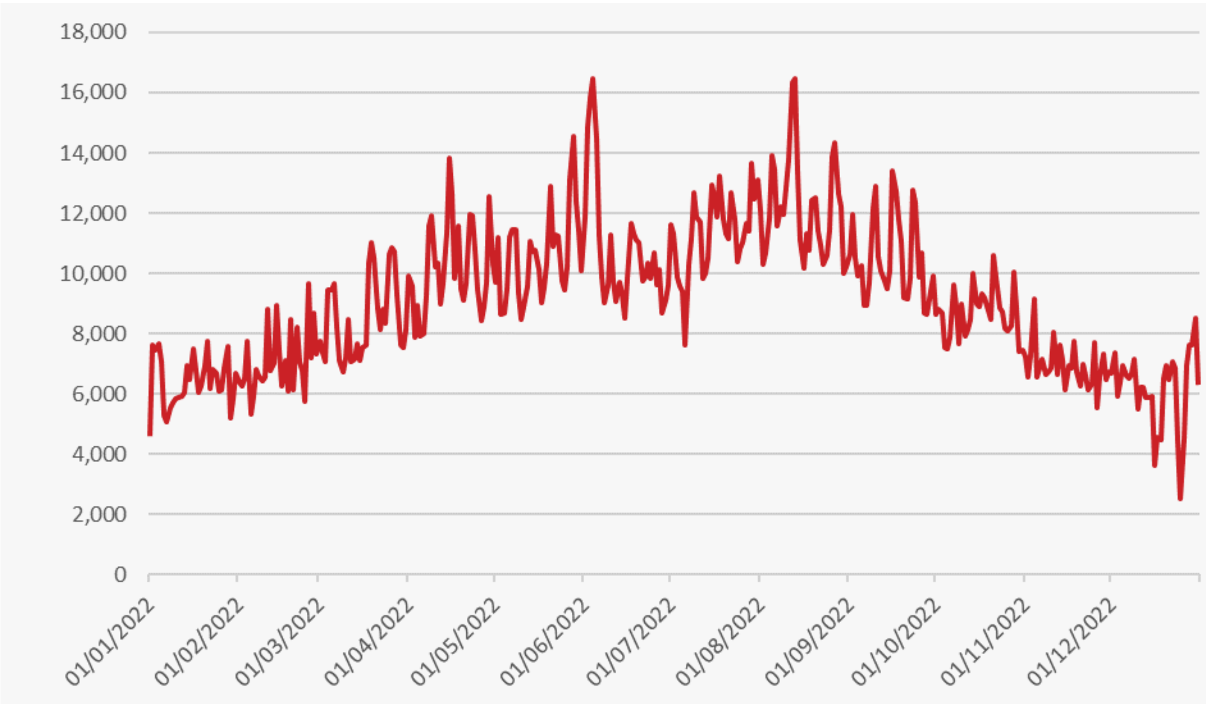


Figure 9. Daily Traffic Flows, Route 26, 2022



Not all peak flow dates are the same for each of the routes, this is an anticipated outcome due to the variety in route characteristics as outlined in **section 2.1**. A total of 120 days within 2022 account for a peak flow day of at least one route and 59 of those account for two or more routes. For comparison, if all routes had the same peak days this would equate to 19 days within the year (5%).

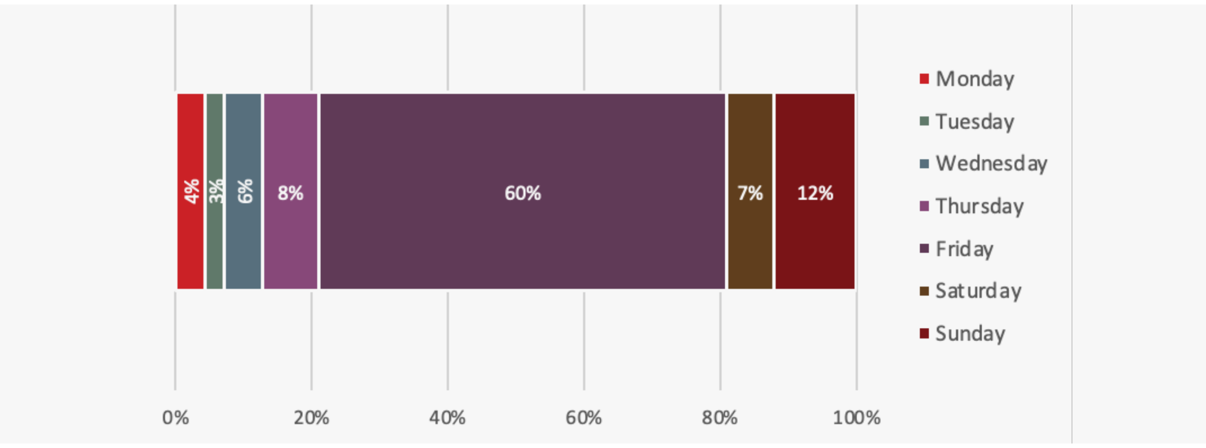
Table 3 shows the top 10 dates in 2022 where there were overlaps between routes and their top 5% traffic flow days. 26th August was a peak flow day for 25 of the 29 routes and is also the Friday of a bank holiday weekend, as was 27th May which features in 24 routes.

Peak flow days are not evenly distributed throughout the week, all dates in **Table 3** are Fridays and Fridays accounted for 60% of the peak flow days along the routes in 2022, as shown in **Figure 10**.

Table 3. Top 10 Peak Flow Days by Route Tally, All Traffic, 2022

Date	Day	Peak Count	Bank Holiday Weekend?
26/08/2022	Friday	25	Yes
27/05/2022	Friday	24	Yes
19/08/2022	Friday	24	No
29/07/2022	Friday	23	No
01/07/2022	Friday	20	No
12/08/2022	Friday	20	No
16/09/2022	Friday	19	Yes
24/06/2022	Friday	18	No
02/09/2022	Friday	18	No
23/09/2022	Friday	18	No

Figure 10. Peak Flow Days Profile, 2022



Peak flows are used to determine the uplift within the model, given the range in peaks for some of the routes there will be three definitions of peak used. These are to be defined as the **median, upper quartile** and **lower quartile** of the top 5% of days. This is to ensure there is a sensible representation of what is meant by a peak day and therefore testing the network on a range of scenarios.

Peak Car Flow Days

The preceding analysis considers all traffic flows, however, as the flow sources break down the counts by mode it allows for analysis of just the peak car flow days. The EV market share is dominated by cars, in Q3 2022 they accounted for 93% of the total EV licensed road using vehicles in Great Britain (93% in England, 95% in Scotland and 92% in Wales)[9].

9 DfT VEH1103 https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables. EVs classified as Plug in Hybrid (electric & Diesel), Battery Electric and Range Extended Electric.

Peak car flow days have been identified in order to compare peak demand with peak traffic flows to account for the significant proportion of en route charging vehicles expected to be cars. A comparison between the peak demand days and the peak flow days is summarised in **section 4.3**.

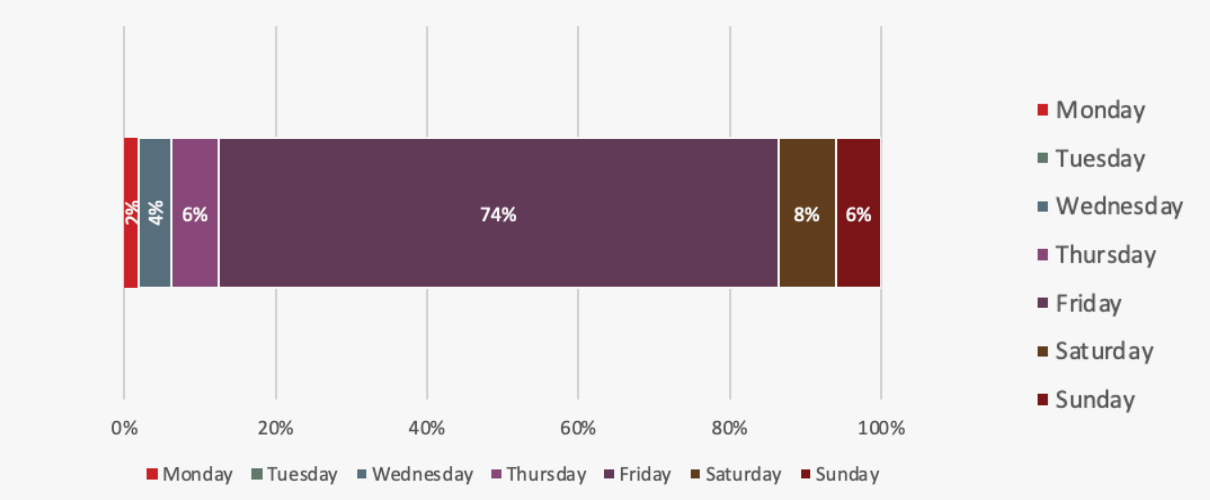
A repeat analysis into the top 10 peak flows that overlap multiple routes has been undertaken for car traffic only, **Table 4**. As with all traffic, all top 10 days where peak days overlap are Fridays, the majority of the dates are duplicate of those in **Table 2**. The top day again, is the 26th August 2022 which was a summer bank holiday weekend and was the peak for 27 of the 29 routes. Route 4 and 19 do not feature in this peak day, route 4 is somewhat surprising given its connection to Brighton, an expected bank holiday destination.

Table 4. Top 10 Peak Flow Days by Route Tally, Car Only, 2022

Date	Day	Peak Count	Bank Holiday Weekend?
26/08/2022	Friday	27	Yes
19/08/2022	Friday	25	No
29/07/2022	Friday	25	No
05/08/2022	Friday	23	No
12/08/2022	Friday	22	No
27/05/2022	Friday	22	Yes
24/06/2022	Friday	22	No
01/07/2022	Friday	22	No
02/09/2022	Friday	19	No
16/09/2022	Friday	17	Yes

As with all traffic flows, the distribution of peak car days is not even across the week, Fridays accounted for an even greater proportion than for all traffic, 74% of the peak days across the routes, and no days were Tuesdays.

Figure 11. Peak Car Flow Days Profile, 2022



4 | Charging Sessions

4.1 Zapmap Data

Demand for charging has been derived from data provided by Zapmap[10] (ZM), who provide a mapping service for users to identify charge locations. ZM has a direct connection via an API to charge point operators in order to obtain utilisation status which is updated every 5 minutes. At the time of this report, ZM had utilisation data for around 70% of connected charge points.

The data obtained from ZM included:

- Location of charge sites for joining to routes (more info in Appendix A)
- Total charge sessions per day per route in 2022
- Charge sessions are from Rapid/Ultra-Rapid chargers only (22kW+) as these are most applicable to en route charging
- Number of charger sites per route

As mentioned in previous sections, charging data was supplied with the restriction that sufficient operators must be present along a route to prevent the identification of any single provider's sessions. This was overcome by combining two routes in Scotland where the criteria wasn't met and resulted in the final figure of 29 routes.

The charging data has been used to derive the typical demand for charging and also the peak demand in order to compare to AADT and peak traffic flow days.

4.2 Charging Demand Statistics

Charging Demand statistics have been calculated for all routes in order to:

- Identify range of charging demand
- Identify growth in charge device availability
- Identify peak charge demand days
- Calculate charge sessions per device to calibrate the ERCO tool
- Compare between peak traffic flow and peak demand days

All statistics are aggregated totals by route as provided by Zapmap, there are no individual charging site statistics due to the commercial sensitivity limitations mentioned in **section 4.1**.

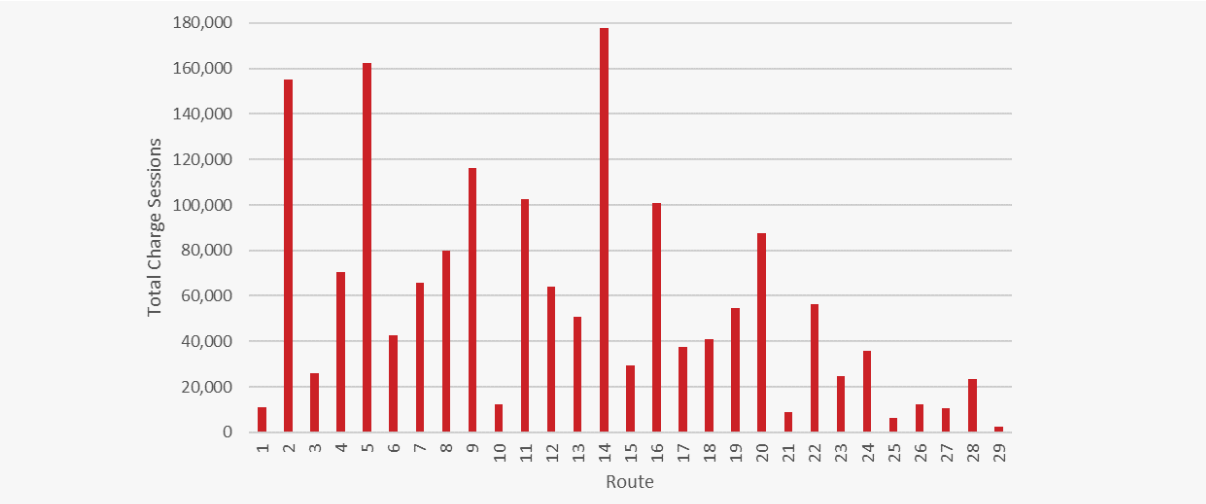
10 https://www.zap-map.com/

Summary of Charging Demand

Summary statistics have been included here for reference but there are more detailed results and comparison with peak flows for each route in the supplementary interactive .html document.

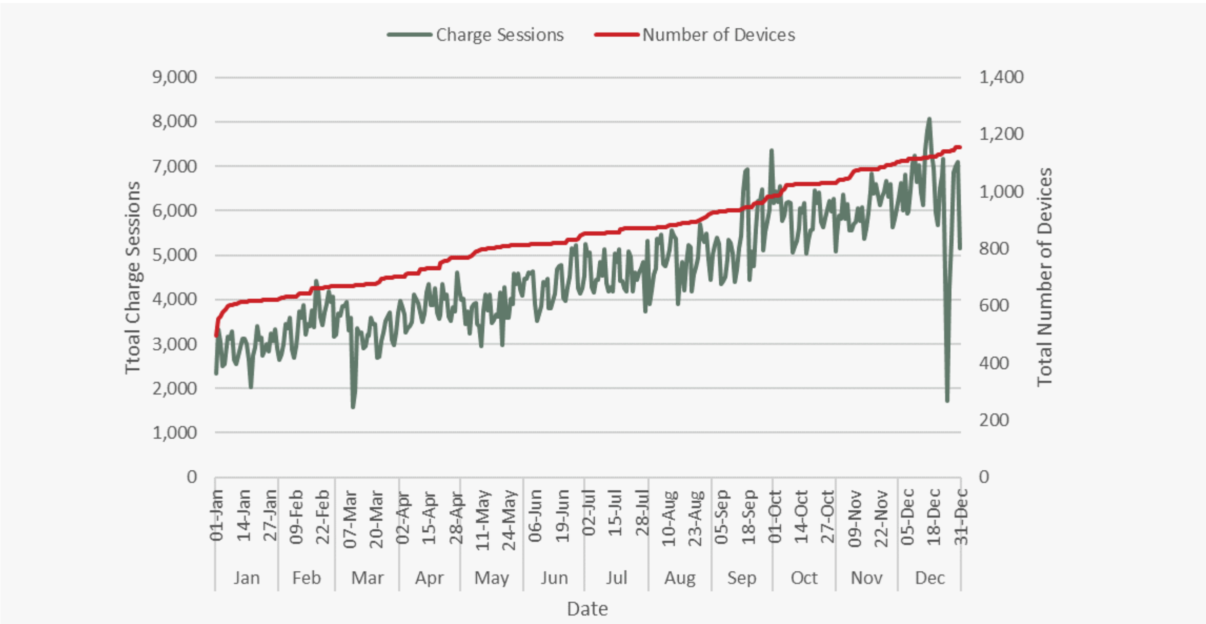
In 2022 the data provided from ZM indicated over **1.6 million** charging session across the 29 routes. Total charge sessions by route range from **177,855** (route 14) to **2,367** (route 29) and a median of **42,719** (route 6), totals by route are shown in **Figure 12**.

Figure 12. Total Yearly Charge Sessions by Route, 2022



Across 2022 the number of EVs within the national fleet increased by around 60% (**section 1**) The number of charge devices available increased to meet this demand, the number of devices across the 29 routes increased by **85%** across 2022 as shown in **Figure 13**.

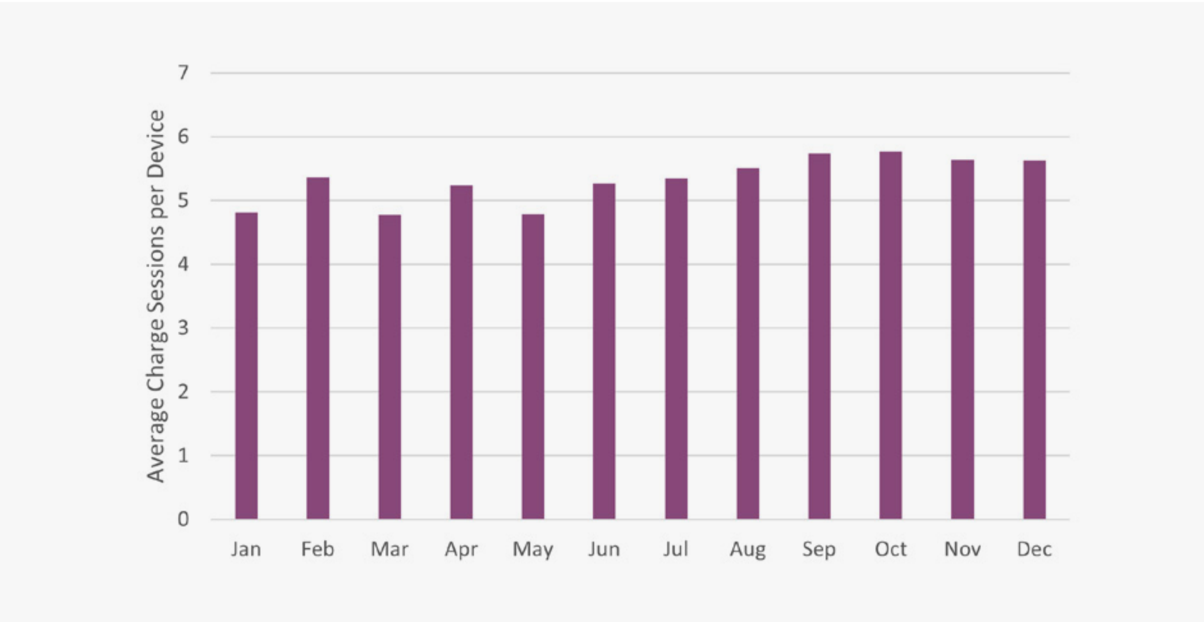
Figure 13. Total Number of Charge Sessions and Devices for 29 Routes, 2022



The number of devices is expected to track the increasing number of EVs at this stage of EV adoption through a standard supply meeting demand assumption and commercial viability considerations. It is clear in **Figure 13** that the increase in charging sessions tracks that of the increase in charge device availability. There are two dips in charge sessions, on 9th March (due to data feed problems) and 25th December (an anticipated drop in demand on Christmas day).

By using the number of devices per route, the charge sessions have been normalised to account for the increase across the year and the charge per device measure is used. This has flattened the charge sessions trend to more clearly identify peaks across the year, see **Figure 14** for the all route monthly average values. The gradient of the trend line for the number of charge sessions without normalisation is 10.43 yet when normalised the charge session per device is brought down to 0.0027 which is a very slight increase across the year. Therefore there is confidence that this normalising approach has flattened the trend.

Figure 14. Monthly Average Charge Sessions per Device for all 29 Routes, 2022

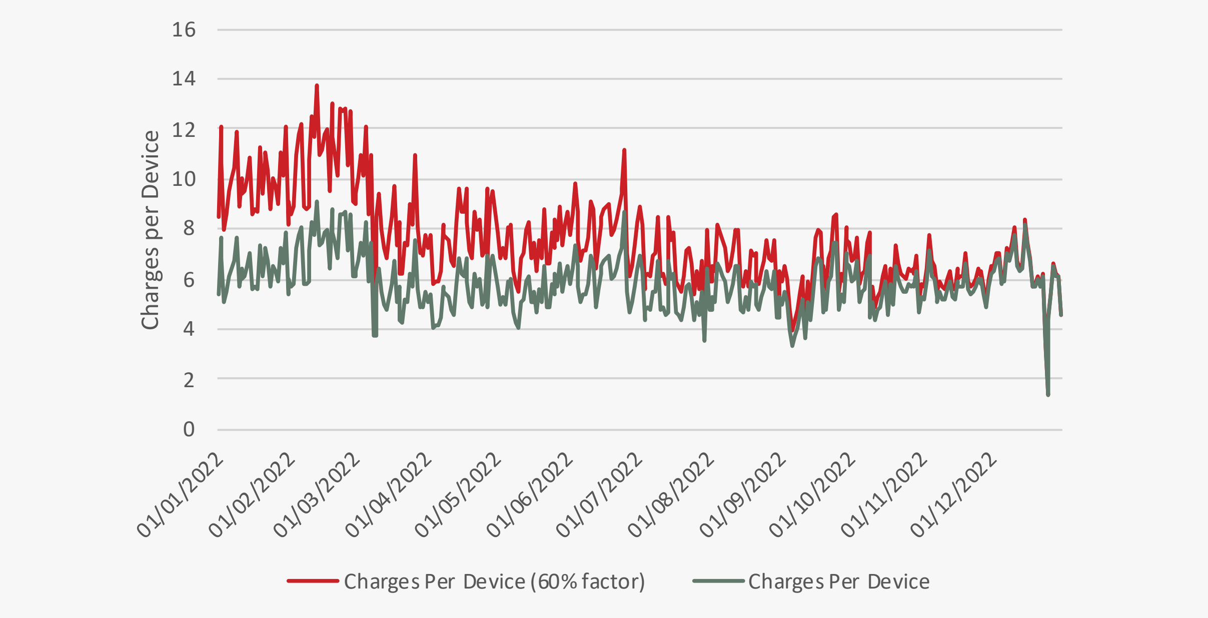


To check other normalisation approaches, a factor was considered to account for the increase in EVs. To test this, a factor of 60% increase on 1st January, reducing to 0% at the end of the year was applied to charging sessions (assuming a linear growth in EVs). The result was a skewed trendline sloping downward from the beginning of the year, indicating an overestimate of charging sessions.

Figure 15 shows an example for route 7 where the growth in EV factors is applies and causes a significant upward skew at the beginning of the year. When the factor isn't applied the trend is generally flatter with more obvious peak days.

As a result, and with the consideration that suppliers generally meet demand, the decision was taken to continue to use the charge sessions per device, without increasing EVs uplift factor, as a normalised indicator of typical and peak demand.

Figure 15. Charges per Device, Route 7, 60% growth in EV factor applied



Peak Demand Days

Peak demand days, like that for peak traffic flow days, are defined as the top 5% days for charging demand and have been calculated for each route. This is necessary to compare the peak demand to peak flow and identify where there is alignment and, more often than not, different peak days.

The peak demand day for all routes combined was 16th December 2022, **8057** charge sessions were recorded followed by **7801** on 15th December 2022 and **7364** on 14th December 2022. These dates coincide with long trips in the weekend before Christmas but there is still the potential skew of the number of devices and EVs increasing towards the end of the year, the prevalence of the upward trend is highlighted in **Figure 13**.

The average peak demand per route is shown in **Figure 16** which takes into account the increase in charger availability. These represent the average of the top 5% days of charge demand along each route and do not necessarily represent the same day range.

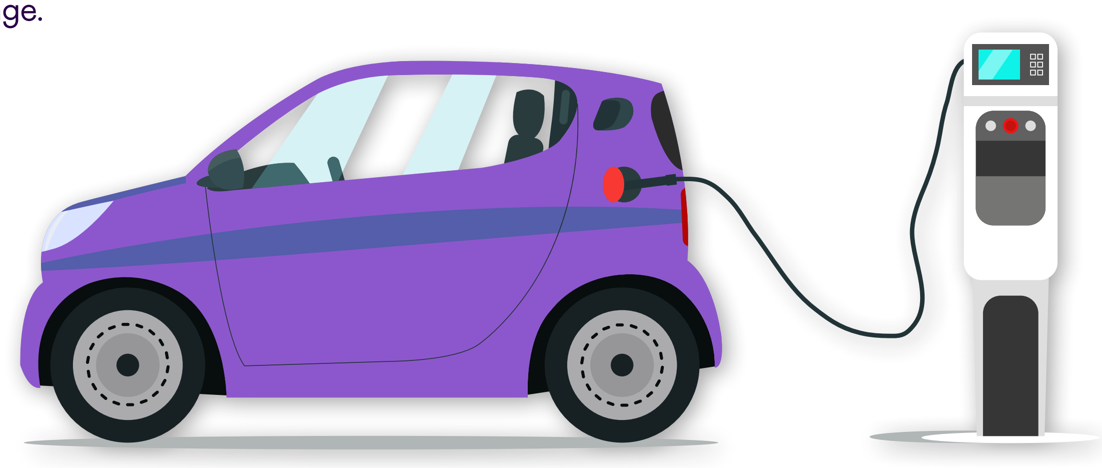
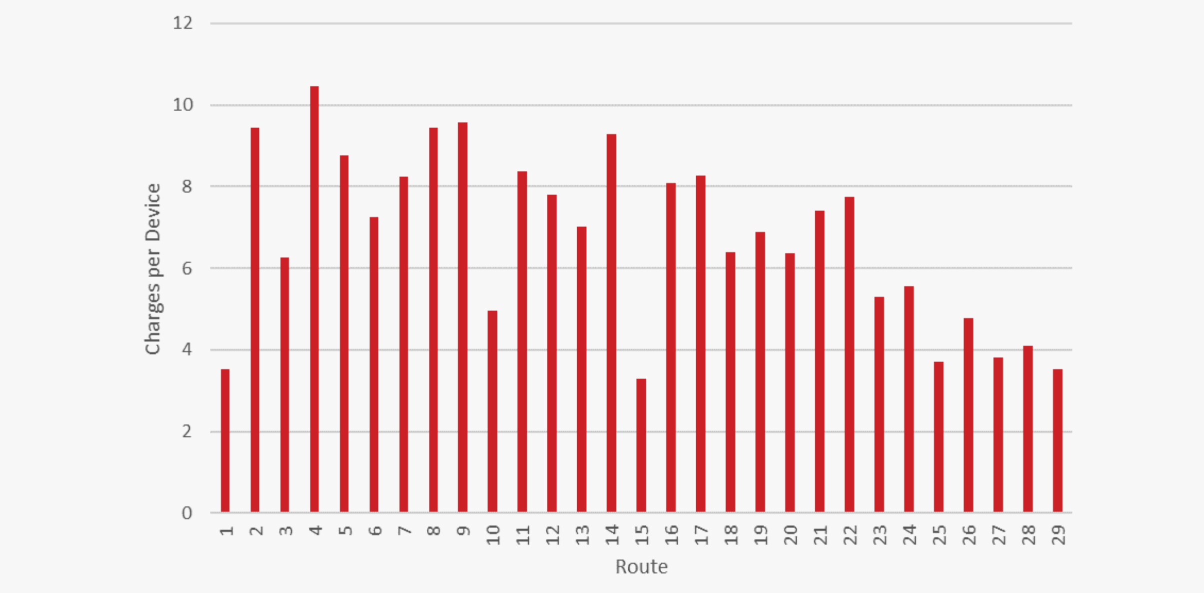


Figure 16. Average Peak Demand (Charges per Device) by Route, 2022



A total of 170 days within the year contain peak demand days for at least one route, of which 102 are for peak days for two or more route. The top 10 peak demand days where multiple routes share the date are shown in **Table 5**. As with peak demand totals, 16th December is again at the top of the table with 65% of routes having this date within their top 5% of demand. This is Friday before the run up to Christmas which is likely to be a significant factor here.

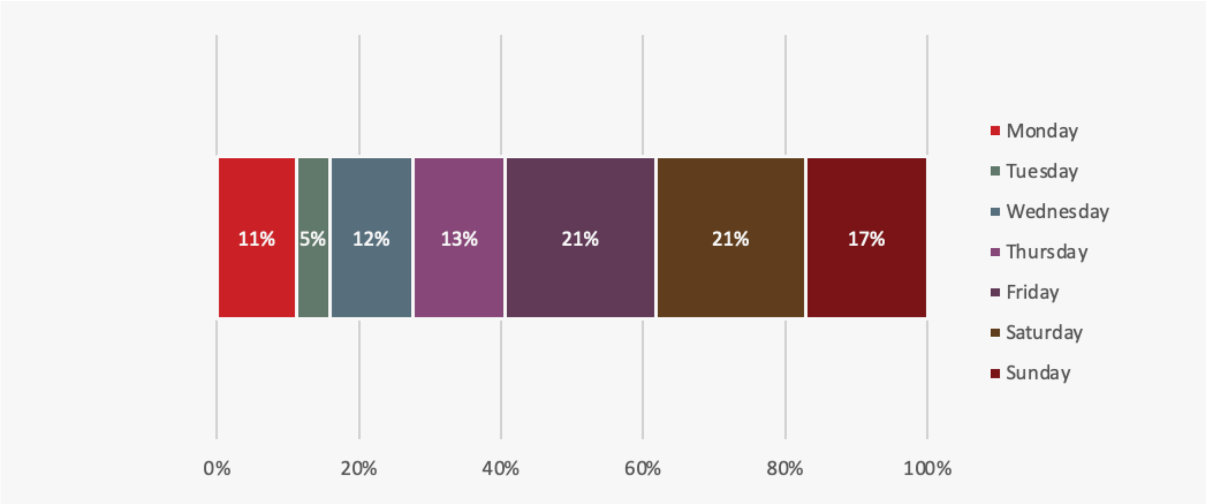
Additional dates in September have also appeared in multiple routes, 17th and 18th September being the weekend prior to the Bank Holiday Monday for the State Funeral of Queen Elizabeth II. The most frequent days are still skewed towards the end of the year, even with normalisation.

Peak demand day distribution is slightly more evenly distributed than peak traffic flows (**Figure 10**) however the weekend still accounts for 59% of peak demand days with Friday and Saturday both accounting for 21% of the peak demand days each (**Figure 17**).

Table 5. Top 10 Peak Demand Days by Route Tally

Date	Day	No. Routes	Bank Holiday Weekend?
16/12/2022	Friday	19	No
30/09/2022	Friday	17	No
15/12/2022	Thursday	15	No
17/09/2022	Saturday	14	Yes
14/12/2022	Wednesday	13	No
18/09/2022	Sunday	12	Yes
09/12/2022	Friday	12	No
17/12/2022	Saturday	11	No
04/10/2022	Tuesday	10	No
23/12/2022	Friday	10	Yes

Figure 17. Peak Demand Days Profile, 2022



4.3 Peak Charging v Peak Flows

One outcome of this project has been to evaluate to what extent peak demand days and peak traffic flow days align. This tests the hypothesis that there is a correlation between the peak demand and the peak flow days. This hypothesis is based on the assumption that EVs have the same journey purposes as current non-EVs in the network today.

Using the traffic flow data and charging data outlined in the previous sections we have compared the peak days to see where they align and if there is some evidence to suggest peak days and peak charging demand on the SRN occur on the same day.

A comparison of peak flow days and peak demand days has been made for each of the routes to see if there are any outliers (**Table 6**). The comparison has been made for all traffic but also the car only flows given the significance of cars in the EV market. Routes 2 and 6 have the greatest number of matches (7 out of 19), eight routes have no match with car demand and six with only one day.

In order to understand these result we can look at the distribution of peak flow days (**Figure 11**), which fall mostly on Fridays but are spread across the week for peak demand (**Figure 17**). This indicates that we are unlikely to find a consistent match between demand and flows.

Table 6. Number of peak days per route which are the same for demand and flows, all vehicles, 2022

Route	Peak day matches, all traffic (out of 19)	Peak day matches, car only (out of 19)
1	5	5
2	7	6
3	1	2
4	0	1
5	2	2
6	6	7
7	0	0
8	0	1
9	2	3
10	1	0
11	0	0
12	0	0
13	2	2
14	1	1
15	1	2
16	1	1
17	0	4
18	0	0
19	0	1
20	4	4
21	2	2
22	2	6
23	1	2
24	3	4
25	0	0
26	0	0
27	0	1
28	1	0
29	1	2

Journey purpose may have something to do with the difference in distribution. The EV market is still in its early stages and coupled with the charge anxiety mentioned in **section 1**, there may be a reluctancy to take longer trips with an EV. For multi-car households this may result in an EV being used as a 'run around' vehicle and a non-EV for longer journeys.

For those who do use their EV for a long journey there is also the consideration that, although this report is looking at the need for en route charging and the data is focused on the SRN, there will be those who charge the night before a potentially medium to long journey. These trips will be part of the peak flows but won't necessarily be caught in the peak demand if their vehicle has the range to complete the journey.

We do not have dedicated origin-destination flow information in this analysis, so all journeys along the routes are considered which will include shorter ones. However, given the peak flows tend to fall on a Friday/weekend it is sensible to assume that these are generally longer trips to visit friends/family or leisure purposes. This peak flow trend creates some grounding for the hypothesis but the charging results do not support it.

For more detail, the accompanying .html dashboard shows the peak demand and peak flow days on a graph for each of the routes.

5 | En route Charging Optimisation Tool

5.1 Tool Summary

The En Route Charging Optimisation (ERCO) Tool was initially developed to investigate en route charging demand as part of the Plugging the Gap study for the Climate Change Committee[11]. Based in Excel, the tool considers the vehicle trips across Great Britain, and how these relate to current and potential future locations of EV charging devices on the strategic road network.

Route demand between zones was estimated using a gravity model, calibrated to match long-distance trip rates derived from National Travel Survey data. The model zones have been defined based on the 39 Nomenclature of Territorial Units for Statistics level 2 (NUTS2), disaggregated where necessary to consider large population centres (i.e. large cities) separately, and merged in places of high population density (e.g. London) where trip origins could be considered to be similar. There are a total of 50 zones in the model.

The model allocates demand to charging locations based on the range capabilities of the EV fleet and the distances between each Origin and Destination zone (O-D) pair, and using a logit-based generalised cost location choice model. The generalised cost of using a location takes into account the diversion time needed to call at that location while travelling between the O and D zones, the expected waiting time, the charging time, and the (monetary) cost of charging at that location.

Once demand is allocated, the model can describe the performance of the network in terms of certain key metrics. These include the number of daily charge events served (in total nationally, and on average per device), the expected wait time for users, the average service time for users, and the amount of demand which is 'lost' (i.e. trips carried out in fossil fuel vehicles because there is insufficient EV charging capacity).

The model produces the following outputs for the scenarios that are tested:

- Number of chargers to be added
- Total number of chargers
- Number of charge events per day
- Average daily charge events per charger
- Expected waiting time (mins)
- Mean service time per vehicle (mins) – the time for a vehicle to charge

11 https://www.theccc.org.uk/publication/plugging-gap-assessment-future-demand-britains-electric-vehicle-public-charging-network/

- Lost demand (total) – either by not having access to a charge device or no appropriate route found with charging availability
- Lost demand (%)
- Estimated Capital Costs

Results are also split by charger type (1,2,3) which, for the purposes in the model, are assumed to be Rapid 1 (43kW), Rapid 2 (150kW) and Rapid 3 (350kw). These charger types were introduced in 2010, 2016 and 2020 and the ability of a car to use these is assumed to depend on year of manufacture, the majority of electric vehicles in the model are able to use all three.

Following evaluation of the existing network, the model will move on to the Optimisation phase where the installation of additional charging devices will be recommended according to a set of user-defined criteria.

Lost demand is a measure of two factors. The first is that associated with the model being unable to find a suitable charging location on a given route, accounting for vehicle range and a driver's range anxiety. The other is demand lost due to availability/waiting times at chargers, it is this demand loss which is of greatest focus in this analysis. This lost demand indicates where the network cannot accommodate the charge needs within waiting time bounds.

The user can choose one or many criteria, including to minimise the lost trips, maximise developer revenue, or minimise driver costs and/or time spent. The possible stopping criteria for the optimisation are when a user-specified minimum service time (national average) or minimum wait time (nationally, or by zone) is achieved, when a user-specified budget limit is reached, or when no further improvements can be found by the algorithm.

5.2 Assumptions and Calibration Approach

A version of the model was obtained from CCC and updated accordingly to match current economic assumptions, matrices based on traffic flows and the charging sessions present in the Zapmap data.

Assumptions

The following section outlines the assumptions and alterations to the model which were made to derive the results of this report.

Values and prices from TAG Databook have been updated to 2022 prices (from 2016 values).

Tariff values updated for inflation:

- Electricity component of CPI, Dec 2016 = 127.7 (note: 2010 = index 100)
- Electricity component of CPI, Dec 2022 = 304.9 (note: 2010 = index 100)
- Inflation estimated as 304.9/127.2 = 2.388

Baseline O-D matrix from original model has been unaltered, a comparison test with the uplift matrix provided by the CCC has been undertaken and a summary is provided in **section 6.5**.

Peak Day uplift percentage calculated for Median and Upper & Lower Quartiles of peak day flows (as outlined in **section 3.2**). Spreadsheet functionality expanded to allow this to be applied to O-D matrix. The process to get the uplift percentage is outlined in **Appendix B**.

EVs by year and zone updated for Balanced Pathway forecast; 2022 DfT figures on BEV/ULEV/Car ownership used as starting point for zone-by-zone forecast.

Range bucket profile extended to 2050, assuming all new EVs 2030 onwards are 450km+.

Charge locations were not changed, it is assumed that those identified previously as likely candidates are taken up by the increase in charging devices since the model was last run.

The charge point installation costs were left unchanged from the previous version of the model. Correspondingly, the budget step set for the optimisation phase of the model remained at £500,000, and the overall maximum budget for the optimisation phase remained set at £100,000,000. Note that this maximum budget is used as one of the stopping criteria for the model, allowing the model run to be terminated if no solution meeting the other specified criteria (e.g. wait time, lost demand, etc.) can be found within a reasonable running time.

Any model runs which terminate due to reaching the maximum budget are referred to in the results as having 'not converged'. Non-converged results should be treated as lower bounds to the true results – for example, the true total cost in that case would be at least the cost found, the number of chargers required would be at least the number given in the results, and so on.

Calibration

Calibration of the model needed to consider the new demand figures from Zapmap. The data showed the number of charge events at a subset of the locations, and indicated a total of 1688 devices on the SRN by the end of 2022.

There were only 457 devices in the model from the 2016 iteration, so this required updating in order to obtain the average number of daily charge events per device which is necessary to compare locations.

Optimisation process was run with 2022 Typical Day demand, objective to minimise carbon, to reach a solution which matched the number of charge events per device. This solution had 1612 chargers in total, which is consistent with the mid-year 2022 number of devices provided by Zapmap.

6 | Scenario Testing & Results

6.1 Modelled Periods

The model has been run for a base year of 2022 then at five year steps from 2025 to 2050. Each year has been run independently and for the various demand and optimisation scenarios outlined below, they have not been interpolated for intermediate years.

The standard modelled day is 12 hours, arrivals are spread evenly over this period. The model is set up to represent and average (or peak in this instance) hour or day, each of which are considered independent.

6.2 Scenarios

The model is run for five demand scenarios:

- **Typical Day demand**: the baseline demand matrix for the model, designed to represent trips which take place on an average day of the year.
- **Median Peak demand**: an uplift is applied to the demand matrix to match the peak demand from the routes. As the peak is represented by the top 5% days, the median of these is taken.
- **Upper Quartile Peak demand (P75)**: the upper quartile of peak demand day sites along the route is taken as the uplift for demand matrix.
- **Lower Quartile Peak demand (P25)**: the lower quartile of peak demand day sites along the route is taken as the uplift for the demand matrix.
- **CCC Matrix demand**: as a comparison test, the matrix defined by CCC which applies an additional uplift in future years was also used for a limited number of model runs to compare with the Typical Day and Median Peak demand scenarios.

The model was run for of the following optimisation scenarios:

- **Do nothing**: the performance of the existing network (as obtained from the calibration process) is assessed against the various future year demand scenarios.
- **Carbon Optimisation**: the model seeks to add additional devices which will reduce the amount of demand deemed to be 'lost' on the network, i.e. journeys which are carried out in petrol or diesel vehicles because there is a shortage of suitable charging locations.
- **Developer Optimisation**: the model seeks to add additional devices which will maximise the net revenue for developers. This scenario can be considered a representation of how the (commercial) market will develop if left to its own devices.

- **Drivers Optimisation**: the model seeks to add additional devices which will maximise the benefit for drivers (and their passengers) in terms of total time and total costs, combined into a 'generalised cost' by applying a monetary value to driver time. As these measures can always be improved, even fractionally, by the addition of another device, this optimisation scheme is run with defined stopping criteria. Two distinct sets of stopping criteria are used, namely:
  - Stop the optimisation when the average queuing time for all charge events in the network is as low as the base level average service time, and no one zone has a wait time of more than 10 minutes;
  - Stop the optimisation when the average service time across all charge events in the network is within 25% of the 'theoretical optimum' service time, i.e. the time which could be achieved if all vehicles requiring a charge were able to access the fastest compatible device.

In each of the optimisation scenarios there are two iterations of the peak demand scenarios which determine the starting point for the number of chargers available. These are:

- **Applied to Typical Day Solution**: The peak demand matrix is applied, but the number of devices remains as optimised for the Typical Day demand. This gives an indication of how the network would cope with infrastructure to cope for a Typical Day.
- **Starting from Typical Day Solution**: The optimisation is run to obtain the ideal network for the peak day demand. The network found for the Typical Day is used as the model's starting point, giving a result of the additional charging infrastructure required for the peak demand scenario.

The results in the main body of this report will focus on **Do Nothing** and the **Carbon Optimisation Scenarios**. The results from this optimisation approach are therefore an indication of what the SRN network needs rather than what is deemed commercially viable by developers.

Results for all optimisation scenarios are provided in an accompanying .html document for interactive chart viewing.

6.3 Do Nothing Results

The Do Nothing scenario focuses on the performance of the existing network and there is no additional infrastructure provided. It is used to set a benchmark against other scenarios and compare the impacts of no further investment despite increasing demand.

Due to the nature of this optimisation scenario, there are **no additional chargers** and **no associated capital cost** regardless of demand scenario.

In this scenario, lost demand at locations increases from **1%** using Typical Day demand and 2% for peak demand to **63%** and **69%** respectively in 2035 and **74%** and **79%** by 2050. Waiting times also increase from less than 1 minute to over 12 minutes in the peak by 2050.

Charge Events

The number of charge events and also the charger events per charger increases in the first step up to 2025 and then begins to fall through to 2050. The results of which are shown in **Table 7**.

As this is the do nothing scenario there are no additional chargers so we can expect the two metrics to follow the same trend. There are a combination of competing factors at play here:

- Range of vehicle increase which reduces demand as some trips will no longer need a charge
- Larger batteries to facilitate improved range have longer charging times (with the current charger types) and therefore fewer charge events can be served in a day
- An increase in EVs on the road which pushes up demand for existing trips

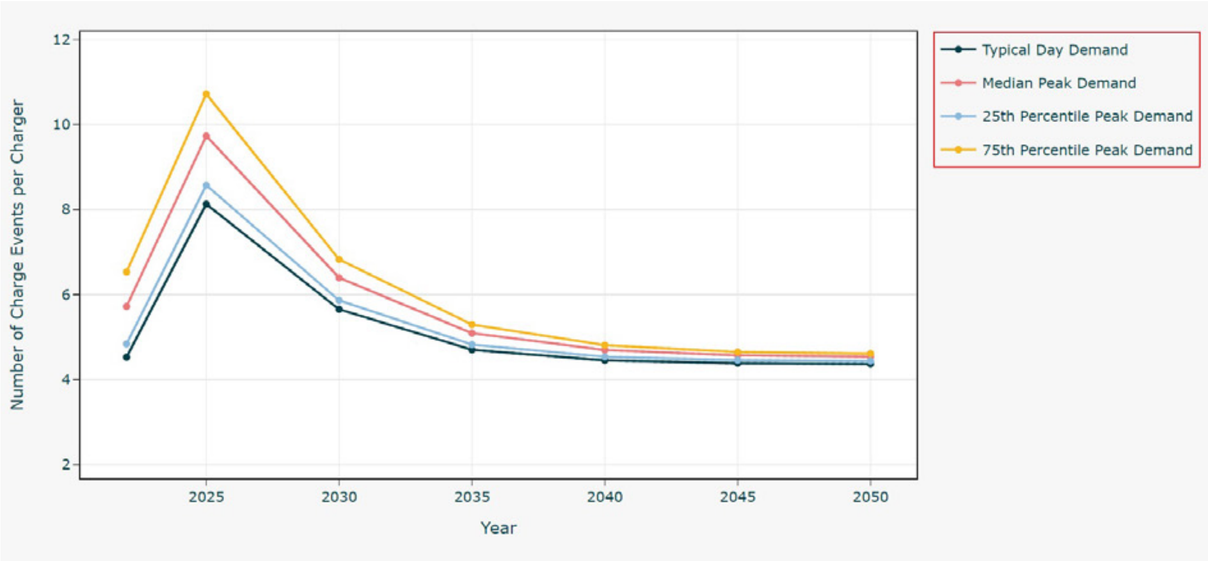
Comparing the Typical Day to the Median Peak, the number of charge events per day is around 20% higher in the peak for 2025 but this begins to drop to around 4% more than the Typical Day in 2050, denoting a convergence of the peak. As 74% of Typical Day demand is lost by 2050 in a Do Nothing scenario it also indicates that charging infrastructure would be used much as it is today and not cater for the future increases in demand.

Table 7. Total Charge Events & Events per Device by Modelled Year and Demand Scenario (Do Nothing)

	Number of charge events per day				Avg daily charge events per device			
Year	Typical day	Median peak	P25	P75	Typical day	Median peak	P25	P75
2022	7,297	9,222	7,800	10,531	4.53	5.72	4.84	6.53
2025	13,109	15,692	13,825	17,289	8.13	9.73	8.58	10.73
2030	9,114	10,311	9,452	11,010	5.65	6.40	5.86	6.83
2035	7,579	8,209	7,777	8,536	4.70	5.09	4.82	5.30
2040	7,176	7,572	7,312	7,753	4.45	4.70	4.54	4.81
2045	7,063	7,369	7,185	7,497	4.38	4.57	4.46	4.65
2050	7,038	7,318	7,152	7,435	4.37	4.54	4.44	4.61

The average number of charge events for each modelled year and demand scenario is shown in **Figure 18**. By the 2045 forecast the total number of charges per has levelled off, along with the charge events per device (around 4.5).

Figure 18. Average Daily Charge Events per Device (Do Nothing)



Although the number of charge events across the network averaged out at around 4.5 the distribution across Great Britain isn't even with some areas exceeding this. The distribution of average daily charge events per charger are shown in **Figure 19** and **Figure 20**. Lower number of charge events per charger are in the South East of England with the greatest around Nottinghamshire and Derbyshire, as well as up the North East of England including Yorkshire and Durham.

Figure 19. Average Charge Events per Charger by Model Zone for Do Nothing, Typical Day Demand, 2035

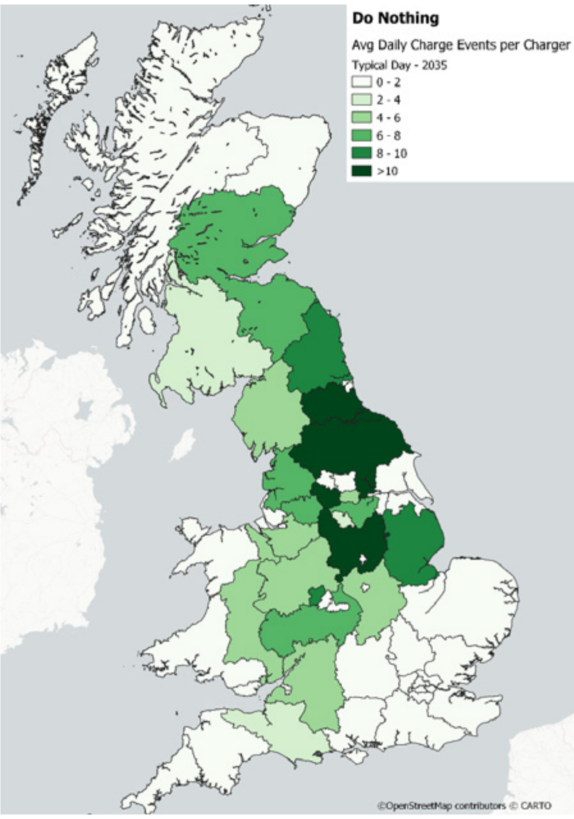
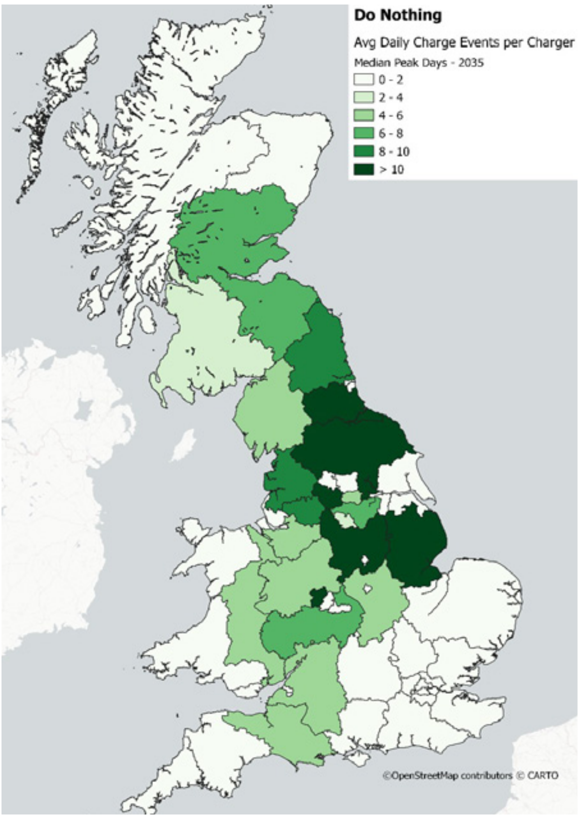


Figure 20. Average Charge Events per Charger by Model Zone for Do Nothing, Median Peak Demand, 2035



Waiting and Service Times

Waiting and mean service times increase for each of the modelled years, this is unsurprising given the increase in EVs yet no change to the number of charging devices available.

In this Do Nothing scenario, the average wait time in mins for the Typical Day increases from just under a minute in 2022 to 9 minutes in 2035 and over 11 minutes by 2050 (**Table 8**). This value surpasses 12 minutes by 2045, the acceptable wait time limit, when peak demand is used. As this is an average, it can be expected that some users will experience wait times considerably above this or choose not to travel by EV resulting in lost demand.

Table 8. Expected Waiting Time & Mean Service Time per Vehicle by Modelled Year and Demand Scenario (Do Nothing)

Year	Expected waiting time (mins)				Mean service time per veh (mins)			
	Typical day	Median peak	P25	P75	Typical day	Median peak	P25	P75
2022	0.824	0.881	0.836	0.921	26	26	26	25
2025	4.221	5.423	4.706	5.980	29	29	29	28
2030	7.215	7.673	7.380	7.954	37	37	37	36
2035	9.358	9.865	9.542	10.099	42	42	42	42
2040	10.576	11.427	10.874	11.736	44	45	45	45
2045	11.156	12.068	11.538	12.316	45	46	46	46
2050	11.304	12.194	11.688	12.471	46	46	46	46

Values for the median peak results are generally much closer to the upper quartile demand (P75). Whilst wait times are similar across all demand scenarios in 2022 they diverge in 2025 by over 1 minute between the Typical Day and median peak. There is some convergence by 2035 to about 0.5 min difference before the gap widens again in 2050. This is demonstrated in **Figure 21**.

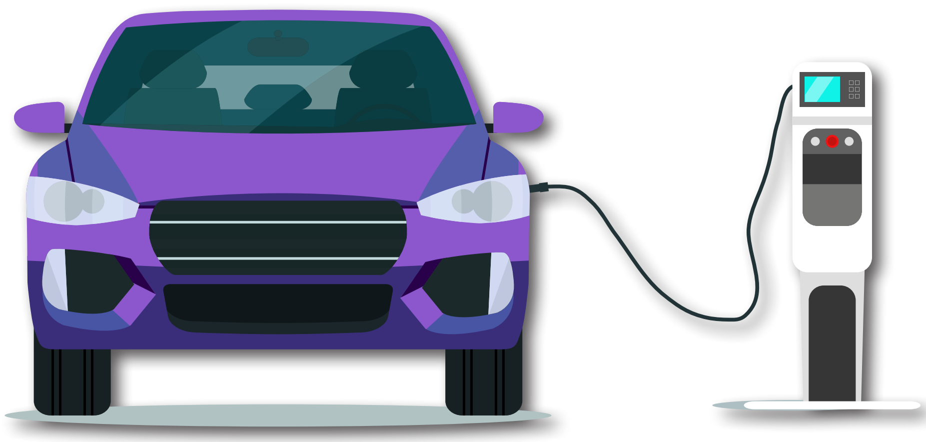
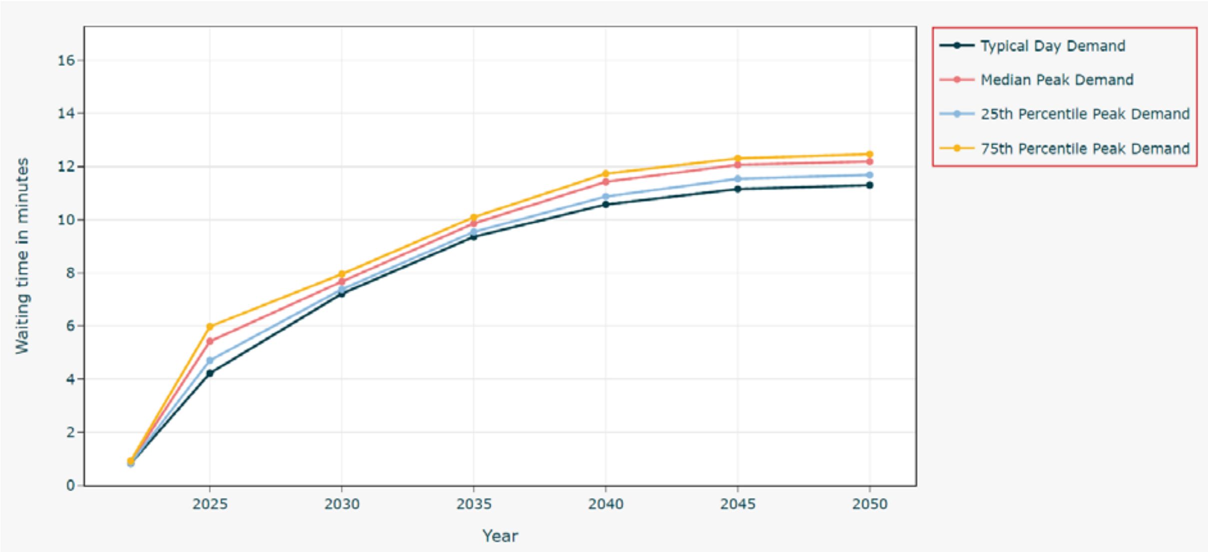


Figure 21. Average Waiting Time (Do Nothing)



Average wait times are highest in areas where the charge events per charger are also high, particularly around West Yorkshire, the North East of England and southern Scotland. In these areas average wait times are over 12 minutes in both Typical Day (**Figure 22**) and peak demand (**Figure 23**) scenarios by 2035 which exceeds the acceptable wait limit.

Figure 22. Overall Expected Waiting Time by Model Zone for Do Nothing, Typical Day Demand, 2035

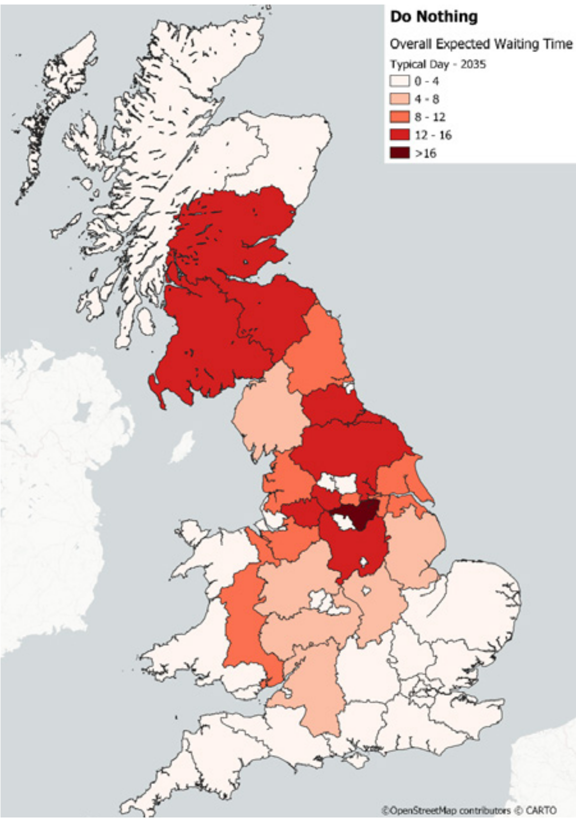
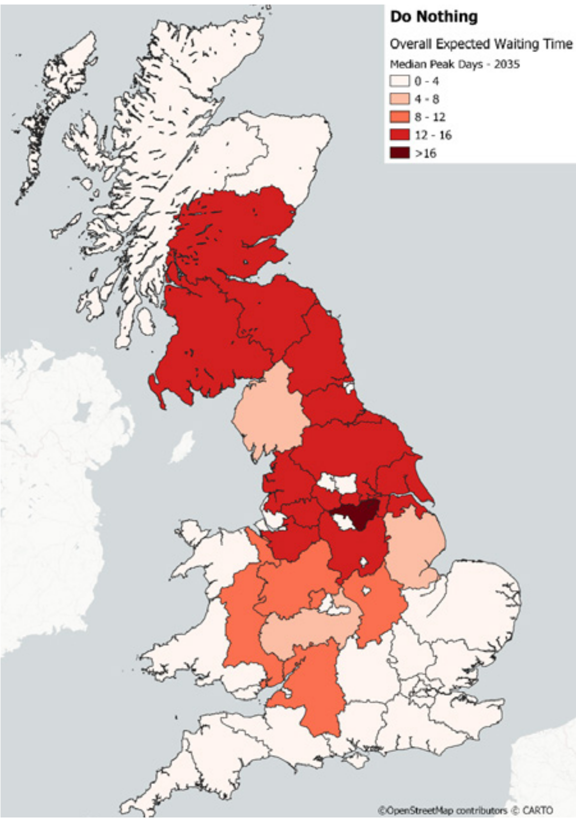
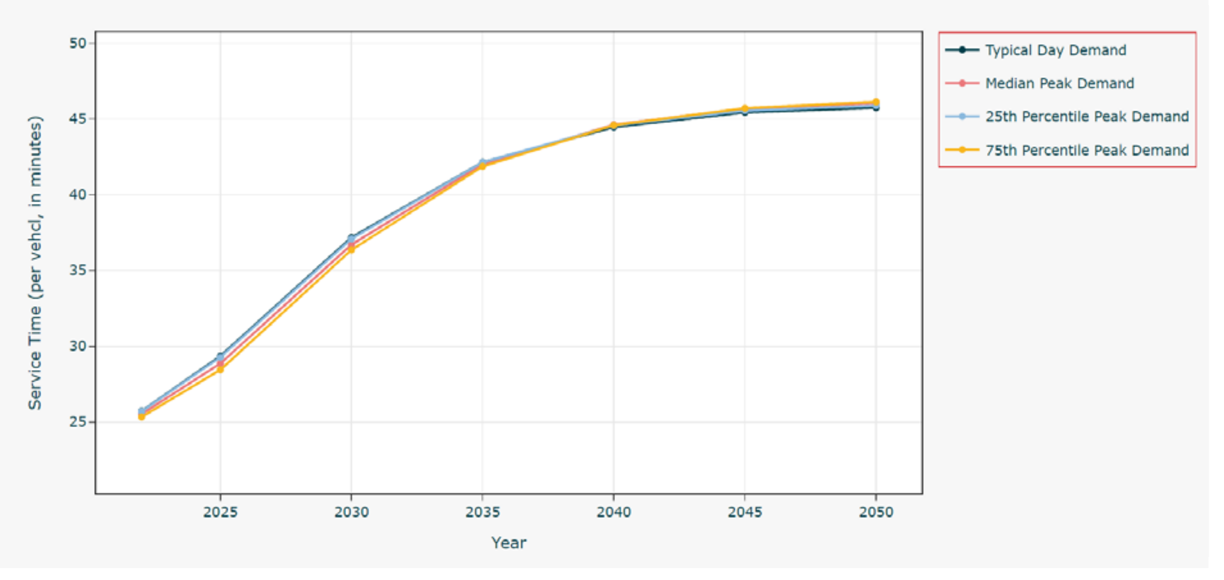


Figure 23. Overall Expected Waiting Time by Model Zone for Do Nothing, Median Peak Demand, 2035



The mean service time increases in each of the 5 year time bands, as with waiting time this is an anticipated result due to constant charge device availability. The mean service remains roughly the same for all demand scenarios (**Figure 24**) The mean service time increases in each of the 5 year time bands, as with waiting time this is an anticipated result due to constant charge device availability. The mean service remains roughly the same for all demand scenarios.

Figure 24. Average Service Time per Vehicle (Do Nothing)



Lost Demand

Lost demand, both in raw km terms and as a percentage of total demand, increased with each 5 year step. These results are to be expected as there is no increase in charger supply to meet demand, lost demand percentage is summarised in **Table 9**.

Table 9. Lost Demand: Percentage of Daily Vehicle km by Modelled Year and Demand Scenario (Do Nothing)

Year	Lost demand (total)			
	Typical day	Median peak	P25	P75
2022	15%	16%	15%	16%
2025	21%	28%	23%	32%
2030	50%	58%	53%	61%
2035	68%	73%	69%	75%
2040	74%	79%	76%	81%
2045	76%	80%	77%	82%
2050	76%	81%	77%	83%

In 2022, the modelled base year, lost demand contributes to over **19,300kg** of carbon emissions on a Typical Day and **26,000kg** in the Median Peak. This indicates that the current en route charging network is already proving to be a limit to those wishing to use EVs for longer trips. By 2035 lost demand carbon emissions increase to over **1.2million kg** on a Typical Day and over **2million kg** with Median Peak demand.

The rate of increase in lost km is greater than that of lost percentage which begins to plateau by 2040, as shown in **Figure 25** and **Figure 26**. The growth trend in lost % across the demand scenarios is much the same, the gap in raw km lost increases between a Typical Day and the peaks. In 2035 the lost km gap between Median Peak and Typical day is around **2.8million** km compared to **4.2million** in 2050.

Figure 25. Lost Demand: Percentage of Daily Vehicle km (Do Nothing)

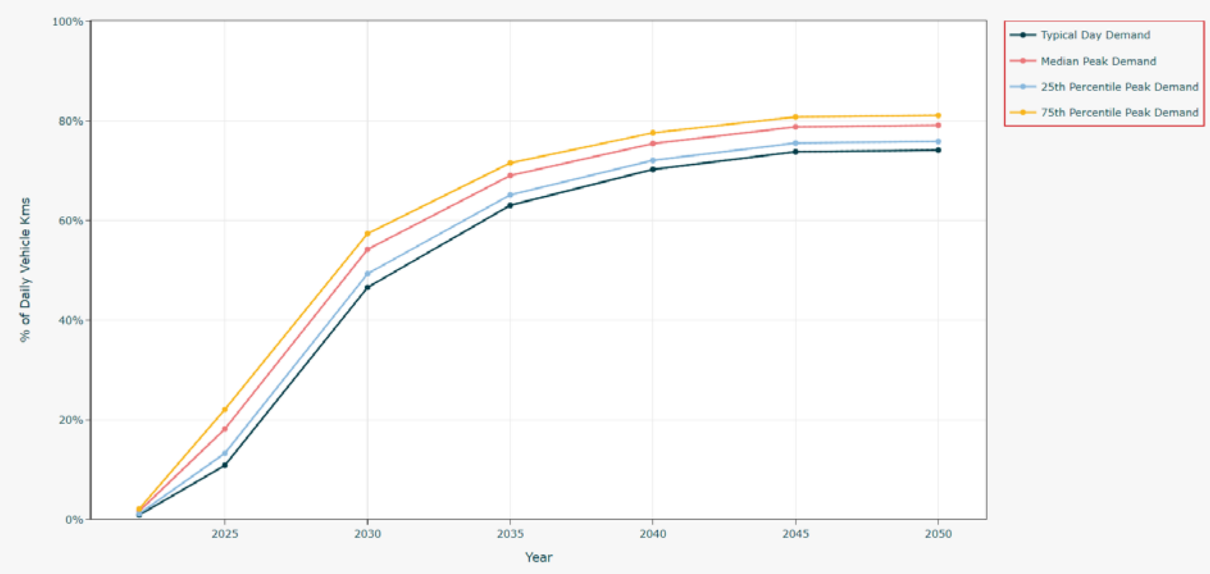
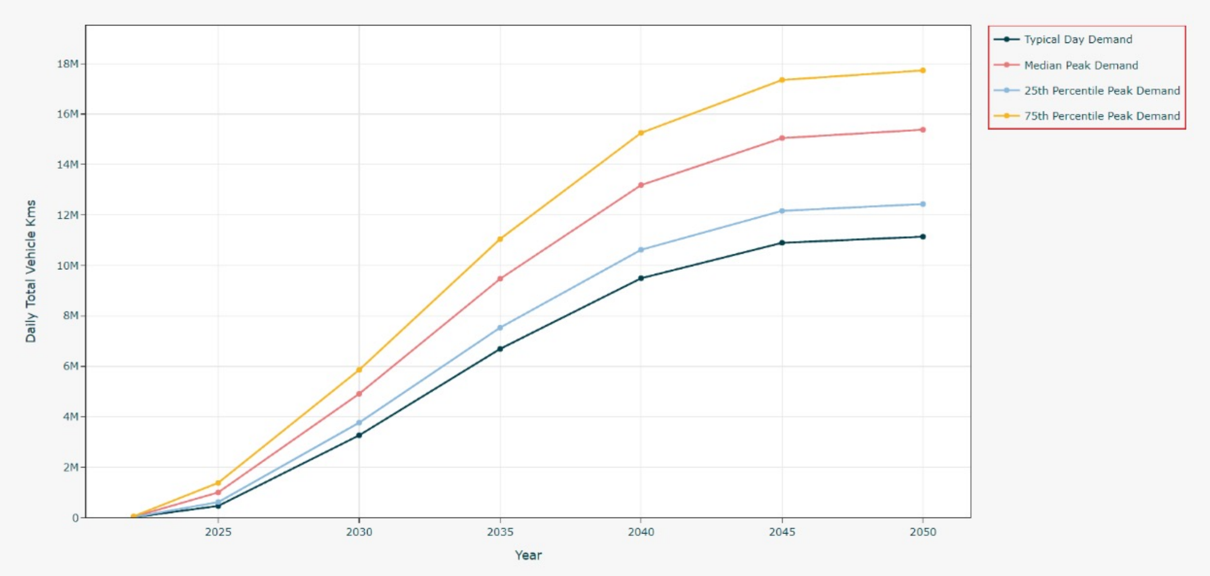


Figure 26. Lost Demand: Daily Vehicle km (Do Nothing)



6.4 Carbon Optimisation Results

The Carbon Optimisation scenario is the core scenario for analysis in this report as it identifies, more than the others, what is needed by the SRN to meet the demand, charging targets and aim to remain within the £100M budget constraint (as outlined in **section 5.2**).

Number of Chargers

In the Carbon Optimisation scenario the model adds devices to the network in order to try and reduce the demand that is lost. It can therefore be expected that the number of chargers increases each modelled year in order to accommodate increasing EVs in the fleet.

Table 10 shows the number of chargers to be added to the network within this optimisation scenario. For the Typical Day scenario this is the figure added to the 1609 starting number, for the peak scenarios this is the number added to the Typical Day and is reflected in the 'number of chargers (inc. added)' column.

The model has identified, for a Typical Day, the number of chargers needed by 2035 is **1.5x** from the base year (2022) and **1.7x** by 2050. Accounting for Median Peak demand would require an increase of **1.7x** by 2035 and **2x** by 2050.

By 2050 the number of chargers identified is almost **2,800** for Typical Day and over **3,300** for Median Peak. These figures are almost three times those in the 'Plugging the Gap' study and is a reflection of the growth in EVs since that research took place and more ambitious growth projections.

Table 10. Number of Chargers Added and Total Chargers by Modelled Year and Demand Scenario (Carbon Optimisation)

	Number of chargers to be added				Number of chargers (inc added)			
Year	Typical Day	Median Peak	P25	P75	Typical Day	Median Peak	P25	P75
2022	21	14	3	26	1,633	1,647	1,636	1,659
2025	125	98	32	158	1,737	1,835	1,769	1,895
2030	440	206	65	322	2,052	2,258	2,117	2,374
2035	820	323	101	501	2,432	2,755	2,533	2,933
2040	1119	417	135	638	2,731	3,148	2,866	3,369
2045	1191	534	226	773	2,803	3,337	3,029	3,576
2050	1184	572	262	819	2,796	3,368	3,058	3,615

As expected, the total number of chargers increases each year, along with an increase in rate of the number of chargers added. Initially the model increases charger devices by **6%** for Typical Day and **11%** for Median peak between 2022 and 2025. This then increases to **18%** and **23%** from 2025 to 2030, the rate is similar for the next two five year modelled periods before dropping to **1%** increase from 2045 to 2050.

If we consider the difference in total chargers required in each of the peaks, relative to a typical day, the percentage uplifts are (P25/Median/P75) **3%/10%/16%** in 2035 and in 2050 this uplift has increased to **9%/20%/29%**. By 2050 the number of additional chargers required to cater for demand above that of the Typical day could be as much as an additional fifth for the Median Peak.

Geographical distribution of additional chargers required is shown in **Figure 27**, for the Typical Day solution, the median peak has the same distribution just with greater number required (**Figure 28**).

Figure 27. Number of Additional Chargers, Carbon Optimisation for Typical Demand Scenario

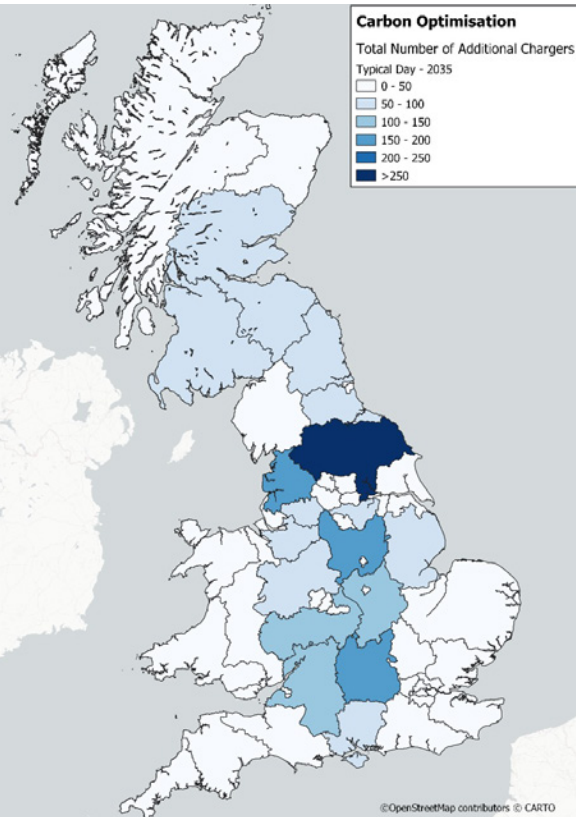
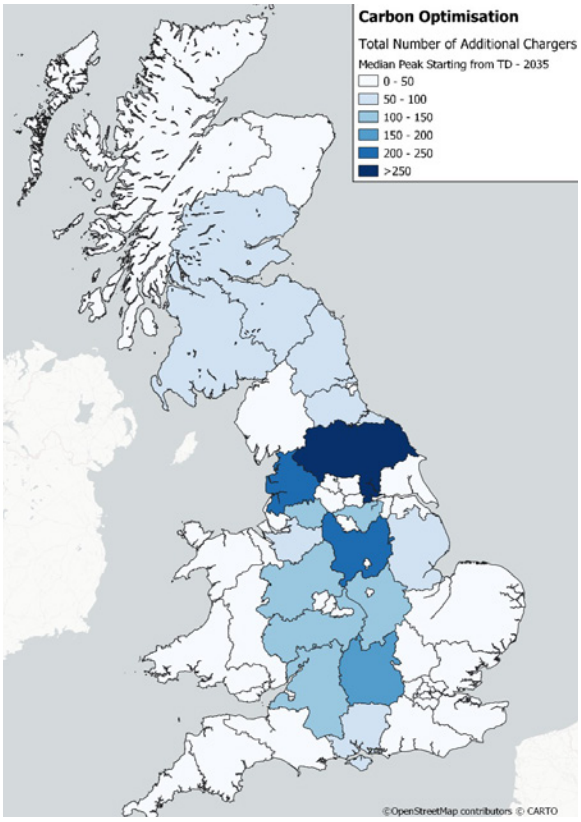
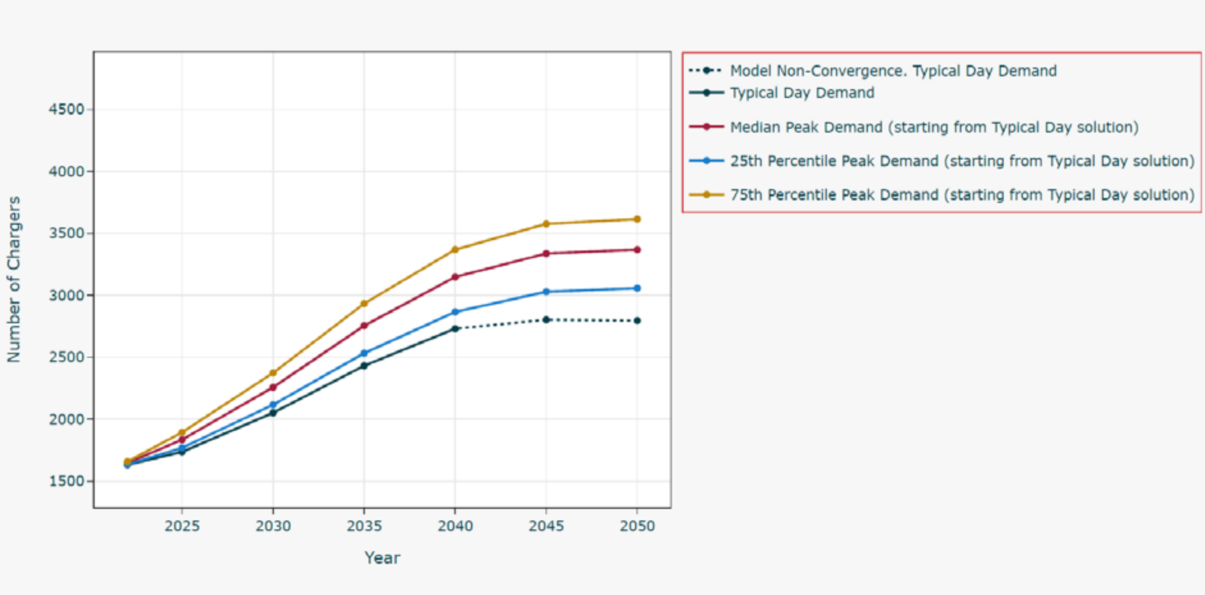


Figure 28. Number of Additional Chargers, Carbon Optimisation for Median Peak Demand Scenario



Greatest demand for additional chargers is in Yorkshire, but other areas along a central spine of the country show a need for intensification. The model does not identify a need for as many additional chargers in South East England. A focus in the middle of the country is likely to be a reflection of vehicle ranges and this area being a mid-point for longer distance en route charging. Although the South West region is expected to have longer leisure journeys the flow volumes are lower relative to the central region of the country and therefore the model has sought to optimise around this central point.The additional charger distribution across the demand scenarios is also as expected, the Typical Day with the fewest and the upper quartile peak with the most added (**Figure 29**). The results show that in order to meet peak demand the network would need to scale up much more substantially and quickly than to meet the Typical day demand. By 2035 the additional chargers required to meet Median Peak demand is 11% on Typical Day demand, by 2050 this gap has widened to 14%.

Figure 29. Total Number of Chargers by Modelled Year and Demand Scenario (Carbon Optimisation)



Charge Events

As this scenario seeks to optimise the use of the network through the addition of chargers there are more opportunities to charge compared to the do nothing. **Table 11** shows that the number of charge events increases for each of the modelled years in all demand scenarios.

By 2035 the number of charge events in a Typical Day is **19,718** which is 160% greater than the number in the Do Nothing scenario, this is accommodated by **820** additional chargers (**Table 10**) which is a 49% increase in chargers. By 2050 there are **26,238** charge events compared to **7,038** in Do Nothing, as demand is lost in that scenario this represents a 273% increase in charge events accommodated by an additional **1,184** chargers (74% increase).

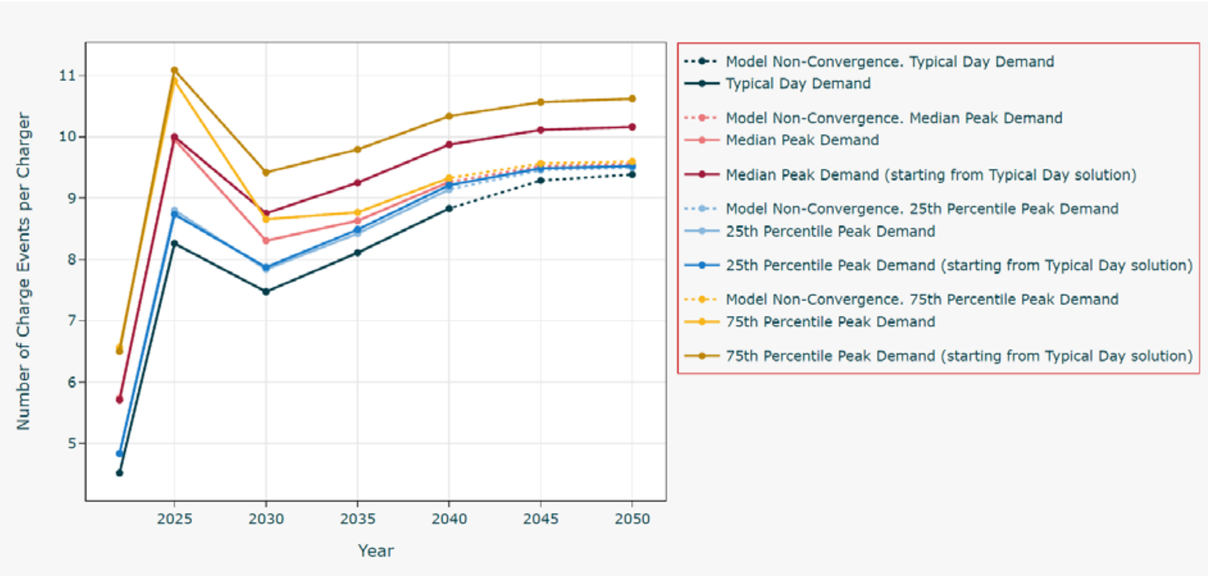
Table 11. Total Charge Events & Events per Device by Modelled Year and Demand Scenario (Carbon Optimisation)

	Number of charge events per day				Avg daily charge events per device			
Year	Typical Day	Median Peak	P25	P75	Typical Day	Median Peak	P25	P75
2022	7,380	9,400	7,907	10,787	4.52	5.71	4.83	6.50
2025	14,346	18,349	15,450	21,008	8.26	10.00	8.73	11.09
2030	15,334	19,761	16,667	22,357	7.47	8.75	7.87	9.42
2035	19,718	25,483	21,494	28,718	8.11	9.25	8.49	9.79
2040	24,114	31,073	26,391	34,816	8.83	9.87	9.21	10.33
2045	26,027	33,738	28,727	37,773	9.29	10.11	9.48	10.56
2050	26,238	34,212	29,115	38,387	9.38	10.16	9.52	10.62

As with the Do Nothing scenario (**Figure 18**) the number of charge events continues to increase as the model optimises for the increased demand and lost demand is limited through the addition of chargers. The average daily charge events is over double those in the Do Nothing scenario from 2025 onwards and settles at around 9 to 10 charge events per charger, again a reflection of demand being accommodated in this scenario by additional chargers.

Figure 30 shows how the number of charge events per device peaks, then drops slightly in 2030 before rising and levelling as the model aims to accommodate the charging demand, unlike the Do Nothing scenario. The lines for 'applied to Typical Day solution' (see **section 6.2**) are generally lower than those 'starting from Typical Day solution' as the former limits the number of chargers to the Typical Day solution. This limits supply and then increases the amount of lost demand (see below) which is reflected in lower charger utilisation. Dashed lines denote where the model has failed to converge due to limitations mentioned in **section 5**.

Figure 30. Average Daily Charge Events per Device (Carbon Optimisation)



As with the Do Nothing scenario, the greatest number of charge events per charger is focused around Derbyshire, Nottinghamshire, Yorkshire and Durham (**Figure 31** and **Figure 32**). 10 zones in the model average over 10 charging events per charger. The Greater Manchester region has also appeared as an area of high charge events per charger. Greatest number of events per charger, both for Typical Day demand and Median Peak demand, follows the significant motorways of the M5, M6 and M1 in England as well as up M90/A9 in Scotland.

Figure 31. Average Charge Events per Charger by Model Zone for Carbon Optimisation, Typical Day, 2035

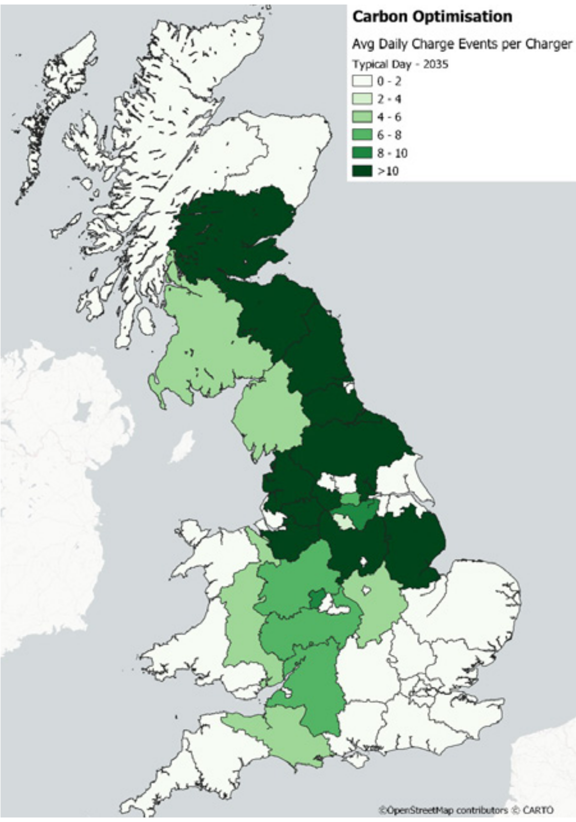
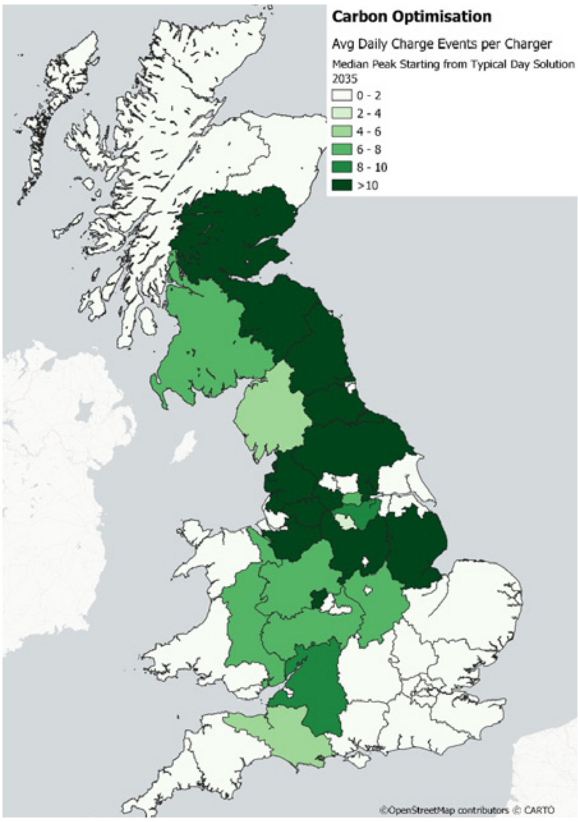


Figure 32. Average Charge Events per Charger by Model Zone for Carbon Optimisation, Median Peak, 2035



Waiting and Service Times

Waiting time results for all years remains within the 12 minute acceptable wait time limit when the model is permitted to add devices on top of the Typical Day (**Table 12**). When the number of devices is limited to the Typical Day demand optimisation then the wait time exceeds that of the acceptable limit by 2035 in the peaks and continues to increase (**Figure 33**). The wait time on a Typical Day is kept below 10 minutes for most modelled years however as more chargers are made available and therefore demand is retained there is some deterioration in wait time in later years relative to the Do Nothing scenario.

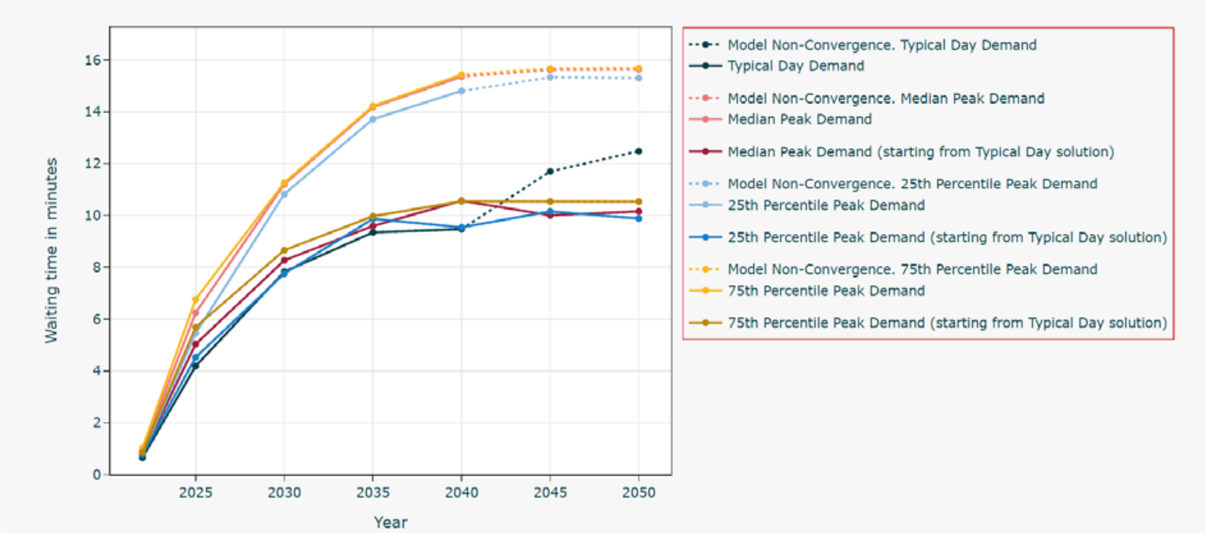
When the model is permitted to add additional charging devices ('Starting from Typical Day') the wait times between the Typical Day and the Median Peak are insignificantly different. This would indicate that providing a charge network for peak demand the wait time experience for Median Peak would be similar to a Typical Day when there are no additional chargers. By association, the expected waiting time for a Typical Day in this solution would decrease compared to the 'Applied to Typical Day' solution as more chargers are made available and therefore would bring the waiting times near the 12 minute limit below 10 minutes (2045 and 2050). This is an additional benefit of planning the network to cater for peak demand.

Table 12. Expected Waiting Time per Vehicle, Applied to Typical Day & Starting from Typical Day by Modelled Year and Demand Scenario (Carbon Optimisation)

Year	Expected Waiting time - applied to TD (mins)				Expected Waiting time - starting from TD (mins)		
	Typical Day	Median Peak	P25	P75	Median Peak	P25	P75
2022	0.656	0.933	0.790	1.028	0.798	0.770	0.858
2025	4.187	6.245	5.461	6.760	5.035	4.527	5.686
2030	7.826	11.200	10.820	11.263	8.264	7.752	8.655
2035	9.346	14.173	13.715	14.217	9.594	9.871	9.966
2040	9.471	15.353	14.799	15.431	10.563	9.541	10.545
2045	11.696	15.619	15.326	15.671	10.003	10.151	10.537
2050	12.478	15.633	15.298	15.688	10.153	9.881	10.534

The average wait time for the Typical Day demand and the peak scenarios (starting from Typical Day) plateau at just around 10 minutes from 2040 onwards yet, unlike Do Nothing, the model is still catering for an increase in charge events (**Table 11**) by providing more chargers (**Table 10**). Note the non-convergence of Typical day demand indicates an uptick in wait time that would be expected to also plateau if convergence was achieved.

Figure 33. Average Waiting Time (Carbon Optimisation)



Average times are generally reduced across the country in the Carbon Optimisation scenario. However, there are some hotspots in both Typical Day (**Figure 34**) and Median Peak demand (**Figure 35**) that surpass the 12 minute acceptable limit, these are south western region of Scotland, South Yorkshire and around Durham.

Figure 34. Overall Expected Waiting Time by Model Zone for Carbon Optimisation, Typical Day Demand, 2035

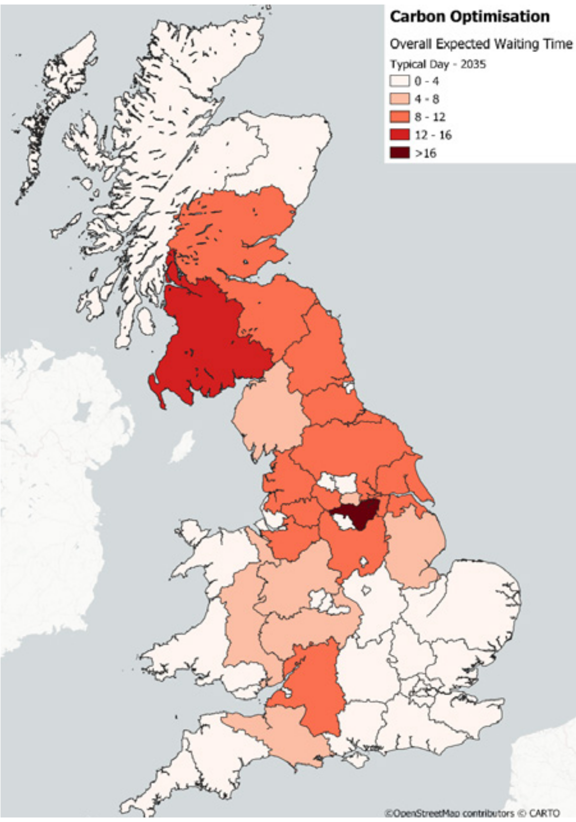
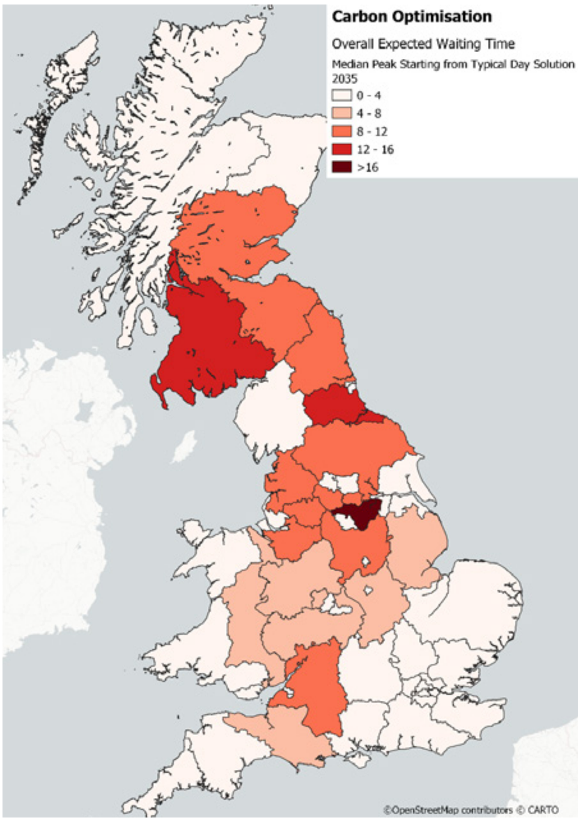
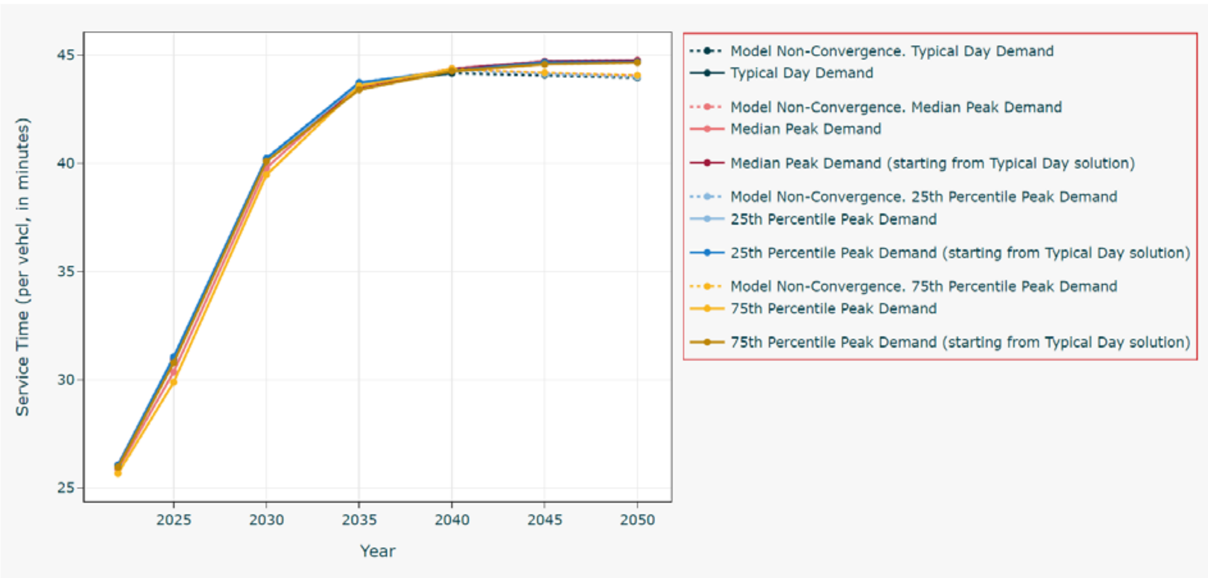


Figure 35. Overall Expected Waiting Time by Model Zone for Carbon Optimisation, Median Peak, 2035



A graph of the mean service time has been included to confirm the relative consistency between this scenario and the Do Nothing. Mean service time is dependent on charge time for vehicles and therefore doesn't change significantly between demand or optimisation scenarios (**Figure 36**).

Figure 36. Average Service Time per Vehicle (Carbon Optimisation)



Lost Demand

The nature of the Carbon Optimisation scenario limits the lost demand across all the demand scenarios. It is most effective when additional charge devices are permitted on top of those for the Typical Day but both approaches are still significantly better than the Do Nothing scenario.

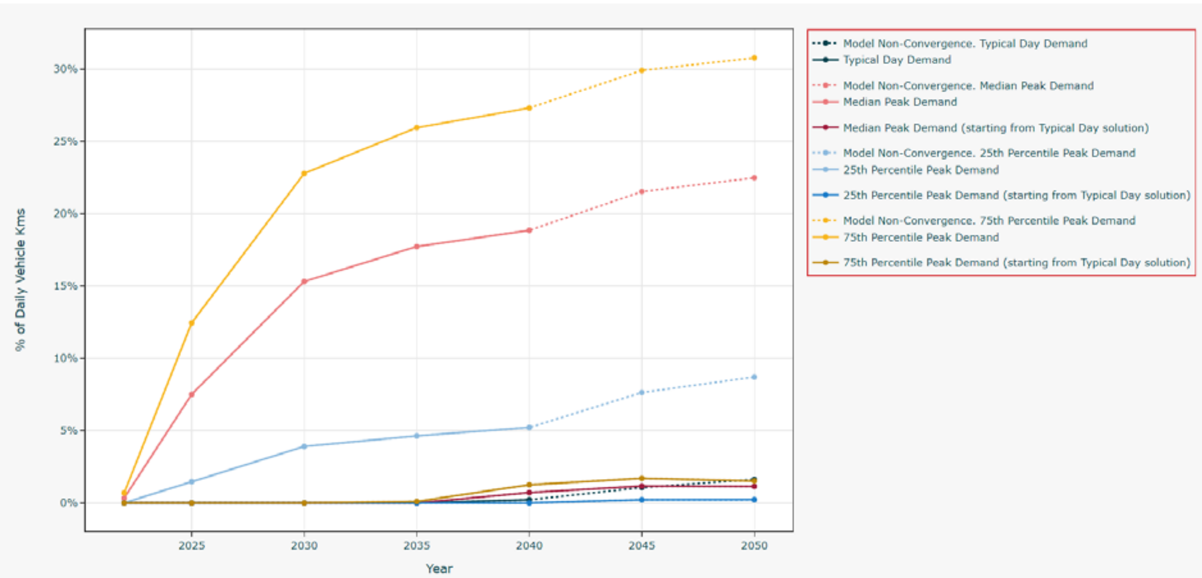
Lost demand is mitigated significantly when additional chargers beyond the Typical Day solution are applied. It is only by 2040 that lost demand (at locations) begins to be observed in the peaks (**Table 13**) yet for the Typical Day solution lost demand occurs much sooner and by 2040 a fifth of demand is lost in the Median Peak.

Table 13. Lost Demand, Percentage of Daily Vehicle km, Applied to Typical Day & Starting from Typical Day by Modelled Year and Demand Scenario (Carbon Optimisation)

	Lost demand - applied to TD				Lost demand - starting from TD		
Year	Typical Day	Median Peak	P25	P75	Median Peak	P25	P75
2022	0%	0%	0%	1%	0%	0%	0%
2025	0%	8%	1%	12%	0%	0%	0%
2030	0%	15%	4%	23%	0%	0%	0%
2035	0%	18%	5%	26%	0%	0%	0%
2040	0%	19%	5%	27%	1%	0%	1%
2045	1%	22%	8%	30%	1%	0%	2%
2050	2%	22%	9%	31%	1%	0%	2%

Lost demand between the demand scenarios is also reduced (**Figure 37**) relative to the Do Nothing scenario (**Figure 25**). By 2035 lost demand for the Median Peak is 0% when starting from Typical Day, 18% applied to Typical Day, yet 72% for Do Nothing. So, even catering just for a Typical Day has significant savings on lost demand.

Figure 37. Lost Demand: Percentage of Daily Vehicle km (Carbon Optimisation)



Lost demand, measured in kilometres, is significantly less than in the Do Nothing scenario (**Figure 38**). Carbon emissions associated with the lost demand in the Median Peak reduce to nearly zero compared to the Do Nothing scenario (**Table 14**). By 2035 the saving is over **1.1million kg** (96%) and almost **2million kg** by 2050 (97%), within the 12 hr modelled period.

Figure 38. Lost Demand: Daily Vehicle km (Carbon Optimisation)

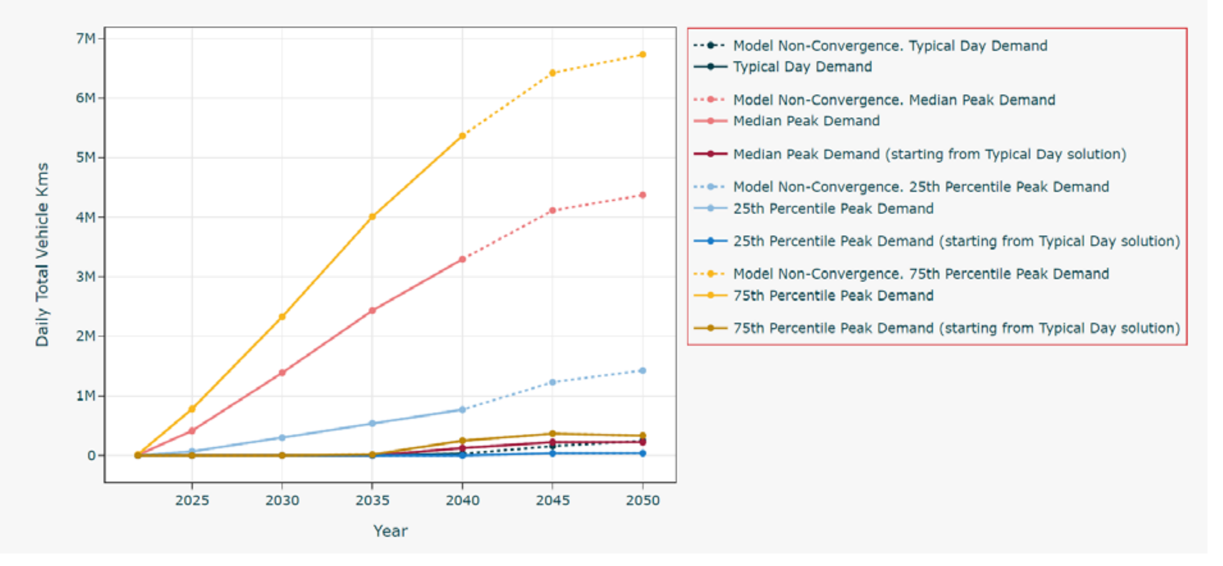


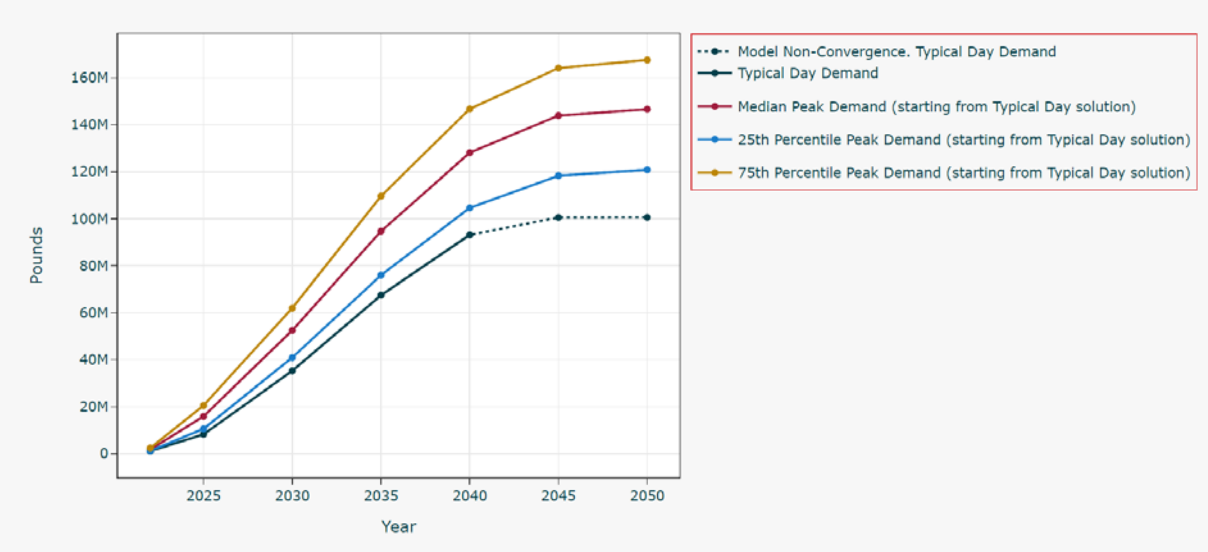
Table 14. Carbon emissions associated with lost demand by modelled year for Do Nothing and Carbon Optimisation scenarios (Median Peak)

Year	Carbon (kg)			Saving as % of Do Nothing
	Do Nothing	Carbon Optimisation	Saving	
2022	26,027	23,330	2,697	10%
2025	117,990	32,385	85,605	73%
2030	534,199	16,265	517,935	97%
2035	121,7889	49,906	1,167,983	96%
2040	1,766,934	76,205	1,690,730	96%
2045	1,989,921	52,492	1,937,429	97%
2050	2,041,728	52,965	1,988,763	97%

Capital Costs

Figure 39 shows the capital costs required to install chargers from the current network level. This considers the costs of obtaining the Typical Day and then the additional costs to meet the peak demand and keep waiting times within the appropriate limits as mentioned above. The dashed line for Typical Day denotes how for these later years the model did not converge as the £100M stop was reached, for the peak scenarios the limit is £100 for Typical Day and £100M for peak and therefore the ceiling is £200M.

Figure 39. Total Capital Costs from Existing Network (Carbon Optimisation)



The rate of increase in costs is higher in the first few modelled year scenarios, the relative difference then levelling off towards 2050. Towards the middle of the century EVs in the fleet are expected to be the majority of the network and the number of charge events remains about the same. As each model year has been run independently for this scenario, although the investment is increasing it can be different in each zone (can increase or decrease) each model year. So whilst future years appear to require diminishing additional investment they may be targeted in different zones.

It is anticipated that by 2035 in order to meet Typical Day demand the capital costs would amount to **£67.5M** and **£94.7M** to meet the Median Peak demand (**Table 16**), an increase of 40% in costs.

It is shown in **Figure 37** that the difference in lost demand between the Median Peak when applied to Typical Day solution and the Median Peak when additional chargers can be added is around 15-22%% from 2030 onwards. The capital cost difference to make up for this lost demand is however around 48% in 2030, 40% in 2035 and 46% in 2050.

These results would indicate a recapturing of around 1% of lost demand to an additional 2-3% of capital costs assuming the typical demand investment was accounted for.

If we consider this in expected waiting time terms, the 12 minute limit is breached for the Median Peak when applied to the Typical Day solution from 2035 onwards. Allowing the model to add additional chargers bring this down to 10 minutes, a saving of 4 minutes in 2035 and over 5 minutes by 2050.

These results would indicate that a reduction in expected waiting time by 1 minute would require an additional 12% of capital costs on the Typical Day solution in 2035 and 9% for 2050.

6.5 CCC Uplift Matrix Results

The baseline O-D matrix remain unaltered in this analysis, however an uplifted matrix had also been supplied by CCC. For completeness we have run the tool with the CCC uplift matrix for comparison purposes. The previous sections should be considered most relevant when informing recommendations. The uplift matrix has a factor applied to all O-D pairs that is even across all. The matrix tests how demand may increase given the anticipated reduction in EV ownership and use costs.

The test runs have been conducted for the Do Nothing and Carbon Optimisation scenarios with the Typical Day and median peak demand tested.

The additional demand in the matrix (**Table 15**) has implications on the model finding the appropriate number of chargers to match demand. To accommodate for the Median Peak the model has identified 10% more chargers to meet demand by 2035 relative to the un-modified matrix and 101% by 2050.

Table 15. Additional Demand requiring at least one charge in CCC Matrix relative to Original Baseline

Year	Additional Demand
2022	0%
2025	5%
2030	9%
2035	13%
2040	17%
2045	21%
2050	25%

The additional chargers have a capital cost associated with them, **Table 16** shows the output capital costs for a Typical Day and Median Peak with the original O-D matrix and the uplift. As with the original matrix, the Typical day reaches the £100M limit in later years and therefore no difference is observed. Despite this, In 2035 the capital costs increase by **£32M** (18%) and **£15M** (16%) for Typical Day and Median Peak respectively. In 2050 this difference increases significantly to account for the Median Peak increasing by **£40M** (27%) for the Median Peak relative to the original O-D matrix.

Table 16. Capital Costs for Original Matrix and CCC Uplift Matrix by Modelled Year and Demand Scenario

Year	Original Matrix		CCC Uplift Matrix		Difference	
	Typical Day	Median Peak	Typical Day	Median Peak	Typical Day	Median Peak
2022	£1,104,000	£1,790,000	£1,104,000	£1,790,000	0%	0%
2025	£8,288,000	£15,898,000	£9,694,000	£17,550,000	17%	10%
2030	£35,264,000	£52,480,000	£40,208,000	£59,436,000	14%	13%
2035	£67,456,000	£94,674,000	£79,476,000	£109,660,000	18%	16%
2040	£93,096,000	£128,088,000	£100,628,000	£152,280,000	8%	19%
2045	£100,572,000	£143,868,000	£100,608,000	£176,648,000	0%	23%
2050	£100,604,000	£146,590,000	£100,646,000	£186,776,000	0%	27%

The lost demand, as a percentage, is a few percentage points greater in 2040 to 2050 compared to the original matrix, for the Carbon Optimisation scenario (**Table 13**). The increase in costs reflects the model trying to keep lost demand down however the 17-25% increase in demand in the uplift matrix results in a slightly greater proportion being lost.

6.6 Additional Scenarios

As mentioned in **section 6.2**, two additional optimisation scenarios have been tested with Typical Day and Median Peak demand. The results are presented in the accompanying charts attachment. A summary of the results is presented here, however these are not the focus results of this report.

Developer Optimisation

It is not deemed commercially viable to add additional en route chargers until 2045 in which only 1 charger is added for the Typical Day solution and then 34 in 2050. Only 8 additional chargers are provided for the Median Peak.

It should be noted that through this modelling the assumed Balanced Pathway rates of EV uptake are applied without being impacted by external factors such as charge device availability, It can therefore be said that in this scenario the providers are guaranteed demand so may not see it worth investing. In reality, demand would likely drop if charging availability was not there and therefore revenues would also drop. It is perhaps more realistic to consider that there would be some continuation of suppliers meeting some of the demand as has been the case in 2022 (**Figure 13**).

This still provides insight that the private sector is unlikely to fulfil the demand requirements and if EV uptake was to remain as it does in the balanced pathway there is little commercial incentive to do so. In particular, it is unlikely that the private-sector investment alone will cater for the uplift in charging provision that we have seen to be necessary to cater for peak demand days. Therefore public-sector investment or other incentive/policy lever is likely to be required to meet the expansion the network has been shown to require in the Carbon Optimisation scenario.

As few chargers are added the results are similar to Do Nothing.

Driver Optimisation

The most chargers are added to this scenario as the focus is on reducing the waiting and service time for drivers within the limits outlined in **section 6.2**. In 2035 there are 1,105 added and 1,157 in 2050 for the Typical Day.

By 2035 there are 3,667 chargers on the network for the Median Peak, compared to 2,717 for the Typical day (an uplift of 34%). However, in this scenario the model struggled to converge due to the stopping limits that are applied. In this case a desire to add as many chargers as possible (which in an ideal world would be one charger per car) results in capital costs becoming prohibitive and hitting the funding ceiling that has been set.

Due to the failure to converge these results are less conclusive than other scenarios. The results are denoted with a dashed line in the accompanying charts to signal non-convergence.

7 | Summary and Conclusions

7.1 Summary

This report has considered the future en route charging infrastructure requirements along the Strategic Road Network (SRN) in Great Britain through to 2025. This work was commissioned by the Climate Change Committee (CCC).

29 routes were selected across the UK to represent a variety of journey destinations and lengths across the SRN. These routes have been used for the basis of extracting the traffic flow data and also acquiring charge session and rapid/ultra-rapid charge locations from Zapmap.

We have used the En Route Charging Optimisation Tool (ERCO), developed for the 2018 'Plugging the Gap' study which allocated demand to charging location based on the range capabilities of the EV fleet and the distance between origin and destination pairs. The results give an indication of the anticipated capital costs to meet charging demand and keep wait times within 12 minute acceptable limits.

Data has been analysed for 2022 and was used to update the ERCO model assumptions and demand matrix as well as to test the question as to whether peak flow demand occurs alongside peak en route charging on the SRN.

The model uses various approaches for optimisation, the core scenario for this report is that of Carbon Optimisation, which adds additional charge points to the network where possible in order to reduce demand losses. It is a reflection of what is needed on the network and not a commercial consideration. Results are also compared to a Do Nothing scenario.

Various demand scenarios have been tested which cover:

- **Typical Day:** demand on a typical flow day
- **Median peak demand:** median of top 5% traffic flow days
- **Upper & Lower quartile peak demand:** upper quartile and lower quartile of top 5% traffic flow days

7.2 Uncertainties and Sensitivities

Charging sessions data and the number of chargers available has been obtained for 2022, yet the number of EVs increased across the year also. The utilisation figures are impacted by the increase in EVs however the assumption is made that the number of chargers increases in step to accommodate the increase in EVs.

Detailed origin and destination data has not be obtained for this analysis and therefore assumptions remain the same as the baseline O-D matrix provided as part of the model. Flow uplifts are applied to all journey using the routes selected and this would include both shorter and longer trips within the model.

Whilst it is important to have a variety of route lengths they can be impacted in different ways by national and regional events, both planned and unplanned, including spikes and troughs in flows. Longer routes have the ability to absorb these fluctuations however some of the smaller routes may be more greatly impacted. We have not investigated any significant road works or events that may have impacted flows and this is part of the reason why multiple count sites and the median were taken.

EV range assumptions will also have an impact on results and reduce or increase the need for en route charging. It has been assumed here that all new EVs from 2030 onwards have a range of 450km+ but this could change following any technological breakthroughs in battery technology. Alternatively, if technological development is slower, ensuring there is public confidence in charging infrastructure could still play a role in reducing charging anxiety and more confidence in using lower range vehicles.

The way in which people have access to charging will also have an impact, as at-home or on-street parking becomes more prevalent people may have greater opportunity to charge before undertaking a journey. However, there will still be significant numbers who will not have access to that at home facility due to the nature of their accommodation.

The funding cap of £100M will also mean that some of the scenarios are limited in the number of chargers they can add. Varying this would indeed vary the number of chargers available, this would be more noticeable in the Driver Optimisation scenario as the other scenarios tested were still able to converge within the budget constraint.

7.3 Key Results and Conclusions

Traffic flow data and charging data were compared for each of the routes across 2022, the peak days were selected as the top 5% days in each year.

Analysis found that peak flow days tend to occur on a Friday and around bank holidays, yet there was no such trend for charging events which were spread more evenly across other days, although still with a focus at the weekend. As a result there was no significant trend found between the peak flow days and the peak demand days.

As more EVs enter the fleet there is the potential that peak demand and peak charge days begin to converge. However, busier days could be made of a number of shorter trips whilst en route charging is saved for longer journey. As this report has shown it is not necessarily a given conclusion.

Key results from the modelling are presented for the Carbon Optimisation scenario as a way of maximising utilisation and reduction in carbon emissions.

Starting from a base year (2022) we found that:

- For a Typical Day **1,633** rapid chargers were required on the SRN and **1,647** for the Median Peak in 2022. By 2035 this figure increases by **1.5x** for a Typical Day and **1.7x** for the Median Peak to **2,432** and **2,755** respectively, a difference of 12% between the demand profiles. By the last year modelled, 2050, this was **1.7x (2,796)** and **2x (3,368)** respectively, a difference which has increased to 20%.
- For the upper quartile peak demand the difference in required chargers from a Typical Day is even more significant, **18%** in 2035 and **29%** in 2050.
- The anticipated capital costs to achieve this are:
  - **2035: £67.5M** for Typical Day and **£94.7M** for Median Peak demand (40% increase in costs)
  - **2050: £100.6M** for Typical Day and **£146.6M** for Median Peak demand (31% increase in costs)
- Overall over **2,700** en route chargers are needed along the SRN by 2035 and over **3,300** by 2050 in order to provide a good level of service during peak demand.
- If only Typical Day demand is catered for then over **2,400** chargers are needed by 2035 and around **2,800** by 2050. However, this would lead to excessive wait times and demand being lost on peak days.
- Optimising the network to meet peak demand results in a carbon saving of **1.1million kg** in 2035 and **2million kg** in 2050 compared to a Do Nothing scenario.
- There is a need to accommodate more charging in the central spine of the country, reflecting the north/south movements, particularly around Nottingham and Derbyshire and along key motorway corridors such as the M1, M5 and M6.

Investment required is significant, financial support will be needed in order to meet the charger requirements into the future. The results from the Developer Optimisation scenario indicated it is unlikely that the private sector will invest in the provision of en route chargers beyond the level needed to ensure growth in EVs which will restrict the uptake of EVs and their potential market. Focus from the private sector is likely to be on those with greatest return which may not be the optimal solution for addressing en route charging needs, reducing waiting times and charge anxiety. There will therefore need to be investment support or other policy mechanisms from Government to ensure the network meets the anticipated demand in the right areas.

There will be a need to actively monitor the provision of en route charging as the EV fleet composition, range capabilities and journey purposes change. There will need to be considerations on whether the Typical Day or the peak demand should be accommodated for through permanent infrastructure or whether flexibility is needed around the country at different times in the year. Results from this report indicate that the central region of the country should be an initial area of focus to increase en route charging infrastructure.

Appendix A | Data Summary Note

Introduction

Purpose of this note is to provide a clear description and associated metadata for the data collected as part of the Peak EV Charging Demand on the SRN project (the project). It will cover:

- Data source
- Brief Description
- Purpose within the project
- Processes to obtain and clean the data
- Limitations

An additional .html document has also been provided to map out the location and high level information on the data used in the project.

Data Summary

Below lists the input data used within this project alongside a brief description, they include open source data available (traffic counts) and commercial data obtained as part of this project (Zapmap). Each data source has a dedicated section later in this report.

Dataset	Licence type	Source	Brief description
Traffic Counts – England	Open	National Highways Webtris	Continuous daily count data available through API on Webtris
Traffic Counts – Scotland	Open	Traffic Scotland NTDS Portal	
Rapid/Ultra-Rapid Charging Locations	Proprietary	Zapmap	Charging locations within the Zapmap database
Rapid/Ultra-Rapid Daily Charging Sessions	Proprietary	Zapmap	Charging sessions for 29 routes along the SRN. Reported daily over 2022.

Traffic Counts – England

Source

Data was extracted from WebTris[12] via an application programming interface (API).

12 http://webtris.nationalhighways.co.uk/

Description

For each selected site, the monthly report was collected. This contains the total volume of vehicles per day in a given date range. Data was collected for the years 2019 and 2022. See **Table 17**.

Table 17. Attribute Table for England Traffic Count Data

Field	Additional information
DayNumber	Day number (1 to 31)
DayName	Day Name
FlowValue	Total daily traffic volume
LargeVehiclePercentage	Percentage of traffic volume that corresponds to large vehicles.
Month	Month
SiteId	Unique site id
Date	Date
Direction	Direction

Data quality and locations for each site was also extracted in a csv file whose fields are as indicated in **Table 18**.

Table 18. England Site Information

Field	Additional information
SiteID	Unique site id
Name	Day Name
Status	Active or Inactive
Description	Site short name
longitude	longitude
latitude	latitude
year	Year
Direction	Direction
Overall_quality	Percentage of days with data availability in a given year

Purpose

Traffic count data will be used to get the peak days profile for each of the selected routes.

Processing

1. Location information and status was extracted for each site available in WebTris was extracted. Sites with "Active" status were selected as a first step.
2. Site locations were mapped and a 0.5mile buffer applied around each of the proposed SRN routes.
3. A many to one join was applied between the WebTris sites and the route buffer which allows for one site location to be attributed to multiple routes when they overlap.

4 For this subset of sites, the overall data quality was extracted for years 2019 and 2022. This metric indicated the percentage of days within a given date range for which data is available.

5 The sites were then filtered by data quality, so that all the chosen sites have at least 90% of data availability (an exception was made for the sites in Route 1 due to poor data availability; the threshold used in this case was 80%). See **Table 26** for further detail.

6 A filter was applied to pick sites that are not on the exits of a road.

7 A filter was made to select sites in the main road.

8 A filter was applied to select sites for which there is another site in the opposite direction and this is no more than 0.15 km far from the first one. The reason for this is that each site records traffic volumes for a single direction. In order to extract a balanced sample of traffic data, both directions are needed for each location.

9 Finally, a manual inspection was made to refine the selection and remove sites near junctions.

The total number of sites for which data was collected for each route is shown in **Table 19**.

Table 19. Total Number of WebTris sites selected per Route

Route	2019	2022	Route	2019	2022
1	21	19	**13**	20	20
2	28	28	**14**	116	115
3	28	28	**15**	12	12
4	40	40	**16**	18	18
5	105	105	**17**	17	17
6	8	8	**18**	50	50
7	12	12	**19**	26	26
8	8	8	**20**	60	60
9	78	78	**21**	12	8
10	8	6	**22**	10	10
11	10	10	**23**	12	10
12	22	22			

Limitations

For some routes and given the poor data availability, the sites selected are mainly concentrated at the beginning/end of the route. This is case for Route 10, Route 11 and Route 21. An effort was made to find pairs of sites, one for each direction, where data availability was acceptable for at least one of the years 2019 or 2022. Therefore, data was collected for these additional sites only for 2019.

Traffic Counts – Scotland

Source

Data was collected from Scotland's National Traffic Data System provided through Drakewell.[13]

Description

For each selected site, the Multi-Day Class by Direction report was collected. This comes in a csv file that contains classified traffic volumes per direction, day and hour. See **Table 20**.

Table 20. Attribute Table Scotland Traffic Data

Field	Additional information
Date	Date
Time	Hour
Direction	Direction
Vehicle class	This attribute varies per site, and therefore a reclassification was made to combine vehicles classes.
Total	Total volume
Site_ID	Unique site id
Site_Name	Site short name

Data availability and locations for each site was also extracted in a csv file whose fields are as indicated in **Table 21**.

Table 21. Attribute Table Scotland Sites Data

Field	Additional information
Site ID	Site ID
Site Name	Site short name
Description	Site description
Year	Year
Monthly total volumes	Total volumes
Node	Node type (Live or Historic)
Speed Limit	Speed limit in miles per hour
Orientation	Orientation (North, South, South-East, etc)
Latitude	Latitude
Longitude	Longitude

13 https://ts.drakewell.com/c2.asp

Purpose

Traffic count data will be used to get the peak days profile for each of the selected routes.

Processing

1. Using the Drakewell map interface, a filter was applied to visualise sites for which data availability in 2019 was of at least 300 days out of 365 and class and direction information is available.
2. Location information and monthly total volumes was extracted for each site in the filtered map using the multi-node report option.
3. Site locations were mapped and a 0.5mile buffer applied around each of the proposed SRN routes.
4. A many to one join was applied between the Scotland sites and the route buffer which allows for one site location to be attributed to multiple routes when they overlap.
5. Manually, 3 to 5 sites were selected per each route avoiding sites near junctions, road exits and urban areas; and making sure that the Multi-Day Class by Direction report was available for years 2019 and 2022. Each site records traffic counts for both directions.
6. Using the Drakewell Tabular interface, the Multi-Day Class by Direction report was extracted as an .xlsx file. An extraction was made to cover the entire year, since this is the maximum date range that can be downloaded for that report format. Data was also extracted for years 2020 and 2021 where available. The total number of sites for which data was collected is shown in **Table 22**. The data availability for each individual site is reported in **Table 27** (see Appendix, **Data Quality**).
7. The xlsx files were compiled and vehicle classifications were combined as indicated in **Table 23**.
8. Unusual zero flows or extremely low flows were identified. The method to detect these outliers was based on the mean and the standard deviation of the yearly distribution of vehicle flows per site, direction, day and hour of the day. If a value was 3 times of standard deviations away from the mean, that data point is identified as an outlier. The average of the percentage of data that do not required patching, i.e., the data quality per site, is shown in **Table 28** (see Appendix, **Data Quality**).
9. The data was patched by replacing the outliers with the appropriate average flow. For weekdays, the average of other neutral weekdays – typically Tuesday, Thursday, Wednesday - of the same week was used. For weekend flows, the average of other weekends in the same month was used.
10. Finally, data was summarised to get total volumes per day and vehicle class for each site. An example of the comparison of total volumes before and after patching is illustrated in **Figure 40** (see Appendix, **Data Quality**).

Table 22. Total Number of Scotland sites selected

Route	2019	2020	2021	2022
20	2	2	3	3
24	3	3	3	3
25	3	2	2	3
26	1	2	2	2
27	1	1	1	3
28	2	2	4	8
29	1	4	4	4

Table 23. Vehicle Classification

Type	Class
Invalid	Class_0
Mcl	Class_1
Car	Class_2
Car+T	Class_2
HVan	Class_3
LGV	Class_3
Rigid	Class_4
R+T	Class_4
Artic	Class_4
Bus	Class_4
MBus	Class_4
Coach	Class_4
HGVs	Class_4
R2X	Class_4
R3X	Class_4
R4X	Class_4
R2+T1/2	Class_4
R2+T3	Class_4
R3+T2	Class_4
R3+T3	Class_4
A2+T1	Class_4
A2+T2	Class_4
A3+T1	Class_4
A3+T2	Class_4
A2+T3	Class_4
A3+T3	Class_4
7+Axle	Class_4
UC	Class_4
Short	Class_2
Medium	Class_3
Long	Class_4

Limitations

It was not possible to automate the extraction process since there is no API to get data from Scotland's National Traffic Data System. Therefore, data of fewer sites was collected. Additionally, as explained in 0, where no data was available for an entire day, it was not possible to reconstruct the traffic flow distribution.

Rapid/Ultra-Rapid Charging Locations

Source

Extracts purchased from Zapmap[14]

Description

Type: .csv list of locations with latitude and longitude attributes, see **Table 24**.

Rapid and Ultra-Rapid charge locations have been extracted by Zapmap, this shows charge locations by network provider for all locations within the Zapmap database. This includes sites additional to the SRN which is the main area of focus for this project.

- Rapid: 25-99kW
- Ultra-rapid: 100kW+

Table 24. Attribute table for Zapmap site locations.

Field	Additional information
Pid	Unique Zapmap device ID
Locnum	Unique Zapmap location ID
Latitude	Geocode-lat
Longitude	Geocode-long
DateAdded	Date record added to ZM
ChargeDeviceName	Public device name
Connector count by type	Rapid/Ultra-Rapid
Networks	Device network(s)
LocationType	On-street, off-street, car park, etc.

Purpose

Charge locations provided as part of the SRN route selection phase in order for Zapmap to extract the session data along each of the routes. Zapmap require the route associated with each Pid and Locnum in order to extract session data for each route.

Processing

1. Site locations were mapped and a 0.5mile buffer applied around each of the proposed SRN routes (initially 30, down to 29 following Zapmap feedback – see 0).
2. A many to one join was applied between the charge sites and the route buffer which allows for one charge location to be attributed to multiple routes when they overlap.
3. An output spreadsheet was supplied to Zapmap with the routes attributed to the Pid and Locum of each site.

Limitations

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14 https://www.zap-map.com/

Rapid/Ultra-Rapid Charging Sessions

Source

Extracts purchased from Zapmap.

Description

Type: Excel data tables

Daily total number of sessions recorded on Zapmap and the total number of devices the sessions were recorded on for each of the SRN routes.

Purpose

To provide charging sessions for each day along the routes so a comparison can be made between peak charging demand and peak traffic demand.

Data on the number of allows for any trend in the increase in device availability to be factored into analysis. It is anticipated that more devices will be made available over the year.

Processing

1. Zapmap extract session data for each route using the data joining processes conducted by SYSTRA.
2. Session data is provided to SYSTRA for each of the routes.
3. Trend analysis to check rate of increase in charge sites.

Identify the top 5% busiest days for each route.

Limitations

1. Charging data was supplied with the restriction that sufficient operators must be present along a route to prevent the identification of any single provider's sessions and the session data then aggregated for each route. The process outlined in **section 4.3** was also used to determine the number of providers.
2. Licensed content cannot be places in the public domain or passed on to any other third party without agreement from Zapmap.

Route Selection

Table 25. Route Selection

Route	Road(s)	From	To
1	A30	Exeter	Penzance
2	M5/A38	Birmingham	Exeter/Plymouth
3	A3	London	Bournemouth
4	M11/M25/M23/A23	Cambridge	Brighton
5	M1/M25/M2	Nottingham	Dover
6	A303/A30	London (M25)	Exeter
7	A34/A31	Oxford	Bournemouth
8	A43/M40/A34	Northampton	Southampton
9	M4	London (M25)	South Wales
10	A12/A14	London (M25)	Felixstowe
11	A14	Felixstowe	Birmingham (partly M6)
12	A1(M)	London (M25)	Leeds
13	A5/M54	Milton Keynes	Mid-Wales
14	M1	London	Leeds
15	A47	Peterborough	Great Yarmouth
16	M6	Birmingham	Blackpool
17	M1/A628/M67/M60/M56/M53/A55	Sheffield	North Wales
18	M62/A64	Manchester	Scarborough
19	M62	Hull	Liverpool
20	A1	Leeds	Edinburgh
21	A66	Middlesborough	Workington
22	M6	Manchester	Carlisle
23	A69	Suderland	Carlisle
24	A74(M)	Glasgow	Carlisle
25	A77/M77	Glasgow	Stranraer
26	A8/A82	Glasgow	Fort William
27	M90/A90	Edinburgh	Aberdeen
28	M80/M9/A9	Glasgow	Thurso
29	A96	Aberdeen	Inverness

Data Quality

The average, minimum and maximum data quality for the selected sites for England Routes is shown in **Table 26**.

Table 26. Data Quality England Traffic Data

Route	2019 min Data Quality	2019 mean Data Quality	2019 max Data Quality	2022 Min Data Quality	2022 Mean Data Quality	2022 Max Data Quality
1	86	98.81	100	81	94.59	100
2	97	99.67	100	92	97.37	100
3	93	99.38	100	91	98.71	100
4	93	99.28	100	90	98.13	100
5	95	99.48	100	90	97.87	100
6	99	99.88	100	97	99.63	100
7	98	99.83	100	90	98.42	100
8	97	99.30	100	97	98.90	100
9	93	98.96	100	91	96.99	100
10	99	99.92	100	97	99.50	100
11	95	98.65	100	93	97.60	100
12	97	99.69	100	90	96.46	100
13	96	99.73	100	92	98.41	100
14	91	99.31	100	90	96.52	100
15	99	99.83	100	96	99.08	100
16	99	99.75	100	90	96.04	98
17	98	99.65	100	90	96.65	100
18	95	99.22	100	90	95.38	98
19	95	99.56	100	91	95.19	98
20	97	99.73	100	90	95.32	99
21	95	98.33	100	97	99.25	100
22	99	99.86	100	93	95.86	97
23	92	99.00	100	99	99.90	100

Data Availability for Scotland sites can be seen in **Table 27** below. Data availability refers to the number of days with some data available divided by the total number of days in a year.

Table 27. Data Availability for Scotland Sites

Route	site_name	Direction	2019 Data Availability	2020 Data Availability	2021 Data Availability	2022 Data Availability
20	JTC00031	N	0%	0%	0%	99%
20	JTC00031	S	0%	0%	0%	99%
20	JTC00130	N	99%	100%	0%	0%
20	JTC00130	S	99%	100%	0%	0%
20	JTC00422	N	99%	0%	99%	0%
20	JTC00422	S	99%	0%	99%	0%
20	JTC00462	N	0%	99%	100%	100%
20	JTC00462	S	0%	99%	100%	100%
20	JTC08407	N	0%	0%	99%	100%
20	JTC08407	S	0%	0%	99%	100%
24	ATC6_22N	N	99%	100%	100%	100%
24	ATC6_22S	S	99%	100%	100%	100%
24	ATC6_32N	N	99%	100%	100%	100%
24	ATC6_32S	S	99%	100%	100%	100%
24	JTC00242	N	99%	100%	100%	100%
24	JTC00242	S	99%	100%	100%	100%
25	CTC01014	N	99%	100%	100%	100%
25	CTC01015	S	99%	100%	100%	100%
25	JTC00111	N	99%	0%	0%	0%
25	JTC00111	S	99%	0%	0%	0%
25	JTC00112	N	0%	0%	0%	99%
25	JTC00112	S	0%	0%	0%	99%
25	JTC00364	N	99%	100%	100%	100%
25	JTC00364	S	99%	100%	100%	100%
26	JTC00535	N	99%	100%	100%	100%
26	JTC00535	S	99%	100%	100%	100%
26	JTC08223	N	0%	99%	100%	100%
26	JTC08223	S	0%	99%	100%	100%
27	123488	N	99%	99%	100%	100%
27	123488	S	99%	99%	100%	100%
27	JTC00063	N	0%	0%	0%	99%
27	JTC00063	S	0%	0%	0%	99%
27	JTC00564	N	0%	0%	0%	99%
27	JTC00564	S	0%	0%	0%	99%
28	118850	N	0%	0%	0%	84%
28	118850	S	0%	0%	0%	84%
28	ATC01012	N	0%	0%	0%	99%

Route	site_name	Direction	2019 Data Availability	2020 Data Availability	2021 Data Availability	2022 Data Availability
28	ATC01012	S	0%	0%	0%	99%
28	ATC01023	N	0%	0%	99%	99%
28	ATC01023	S	0%	0%	99%	99%
28	ATC01027	N	0%	0%	0%	99%
28	ATC01027	S	0%	0%	0%	99%
28	ATC01334	N	0%	0%	82%	100%
28	ATC01334	S	0%	0%	82%	100%
28	ATC03022	N	0%	99%	100%	100%
28	ATC03022	S	0%	99%	100%	100%
28	JTC00008	N	99%	0%	0%	0%
28	JTC00008	S	99%	0%	0%	0%
28	JTC00352	N	0%	0%	0%	99%
28	JTC00352	S	0%	0%	0%	99%
28	JTC00367	N	99%	100%	100%	100%
28	JTC00367	S	99%	100%	100%	100%
29	126400	E	99%	100%	100%	100%
29	126400	W	99%	100%	100%	100%
29	ATC02034	N	0%	99%	100%	100%
29	ATC02034	S	0%	99%	100%	100%
29	ATC02036	N	0%	99%	100%	100%
29	ATC02036	S	0%	99%	100%	100%
29	ATCNE014	E	0%	99%	100%	100%
29	ATCNE014	W	0%	99%	100%	100%

Average of data quality is shown in **Table 28**. Data quality for each single day is calculated as the number of time periods that do not need to be patch divided by the total number of time periods. Then, an average was taken to get a yearly figure.

Table 28. Average Data Quality for Scotland Sites

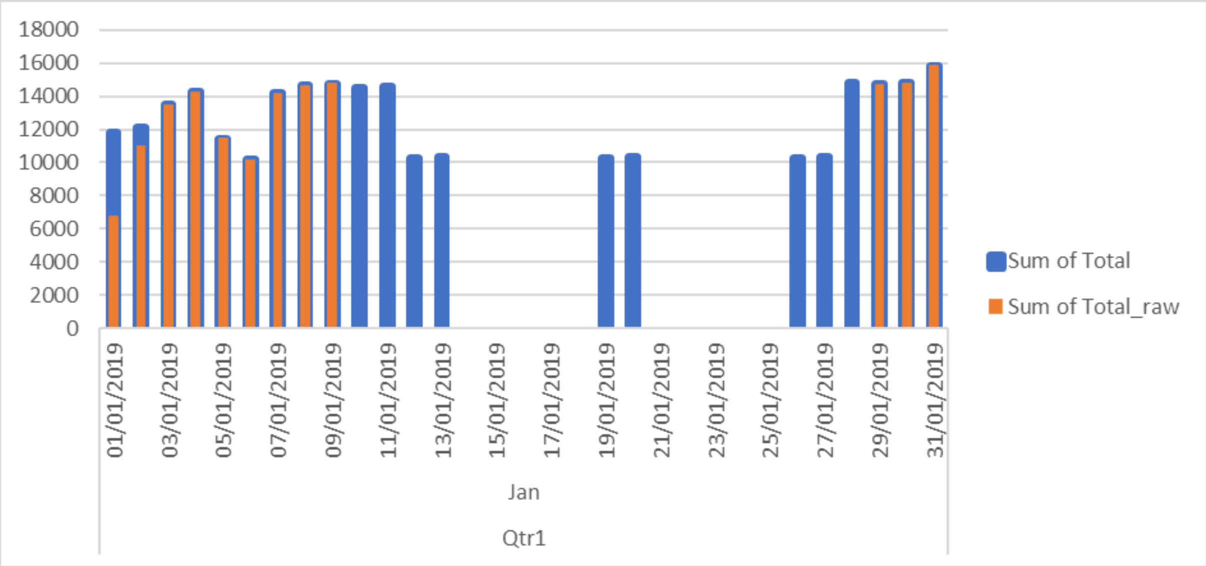
Route	site name	Direction	2022	2019	2020	2021
20	JTC00031	N	93%			
20	JTC00031	S	91%			
20	JTC00130	N		97%	100%	
20	JTC00130	S		98%	100%	
20	JTC00422	N		87%		70%
20	JTC00422	S		84%		99%
20	JTC00462	N	100%		100%	93%
20	JTC00462	S	100%		100%	92%
20	JTC08407	N	99%			100%
20	JTC08407	S	99%			44%
24	ATC6_22N	N	99%	99%	100%	100%
24	ATC6_22S	S	99%	99%	100%	100%
24	ATC6_32N	N	99%	99%	100%	100%
24	ATC6_32S	S	100%	99%	100%	100%
24	JTC00242	N	99%	97%	99%	100%
24	JTC00242	S	99%	97%	99%	100%
25	CTC01014	N	99%	99%	100%	99%
25	CTC01015	S	99%	99%	100%	99%
25	CTC01021	S			99%	
25	JTC00111	N		91%		
25	JTC00111	S		89%		
25	JTC00112	N	99%			
25	JTC00112	S	99%			
25	JTC00364	N	94%	99%	100%	100%
25	JTC00364	S	91%	99%	100%	100%
26	JTC00535	N	100%	99%	100%	100%
26	JTC00535	S	100%	99%	100%	100%
26	JTC08223	N	100%		100%	100%
26	JTC08223	S	100%		100%	100%
27	123488	N	99%	99%	100%	100%
27	123488	S	99%	99%	100%	100%
27	JTC00063	N	95%			
27	JTC00063	S	97%			
27	JTC00564	N	96%			
27	JTC00564	S	96%			
28	118850	N	99%			
28	118850	S	99%			
28	ATC01012	N	99%			
28	ATC01012	S	99%			
28	ATC01023	N	100%			100%
28	ATC01023	S	100%			100%
28	ATC01027	N	100%			
28	ATC01027	S	100%			

Route	site name	Direction	2022	2019	2020	2021
28	ATC01334	N	99%			100%
28	ATC01334	S	99%			100%
28	ATC03022	N	100%		100%	100%
28	ATC03022	S	100%		100%	100%
28	JTC00008	N		99%		
28	JTC00008	S		99%		
28	JTC00352	N	99%			
28	JTC00352	S	99%			
28	JTC00367	N	99%	100%	100%	100%
28	JTC00367	S	100%	100%	100%	100%
29	126400	E	99%	100%	100%	100%
29	126400	W	99%	99%	100%	100%
29	ATC02034	N	100%		100%	100%
29	ATC02034	S	99%		100%	100%
29	ATC02036	N	100%		100%	100%
29	ATC02036	S	100%		100%	100%
29	ATCNE014	E	99%		100%	100%
29	ATCNE014	W	99%		100%	100%

An example of the impact of the data patching is shown in the **Figure 40** below. Here, patching was undertaken for site JTC00111 of Route 25, for days that show partial data of unusual low flows. Where no data was available for an entire day, it is not possible to reconstruct the traffic flow distribution.

In the chart, “Total” refers to total vehicle counts after patching and “Total_raw”, before patching.

Figure 40. Example of data patching



Appendix B | Matrix Uplift Calculations

The baseline O-D matrix is based on all the possible vehicle travel demand patterns between 50 zones (1250 combinations for each direction, 2500 in total). The following approach was used to match this matrix to the observed traffic flows in the 29 routes.

Firstly, the population-weighted centroids were obtained for each zone using the 2020 population estimates by MSOA for England and by administrative area in Scotland.

Then, the 29 routes were merged into a single network, retaining directionality, and filling in any gaps so that the network is fully connected. For this, the tool "join multiple lines" in QGIS was used to merge multiple features of a line layer into one feature with a continuous line. This plugin puts the selected lines in a geographical logical order and direction.

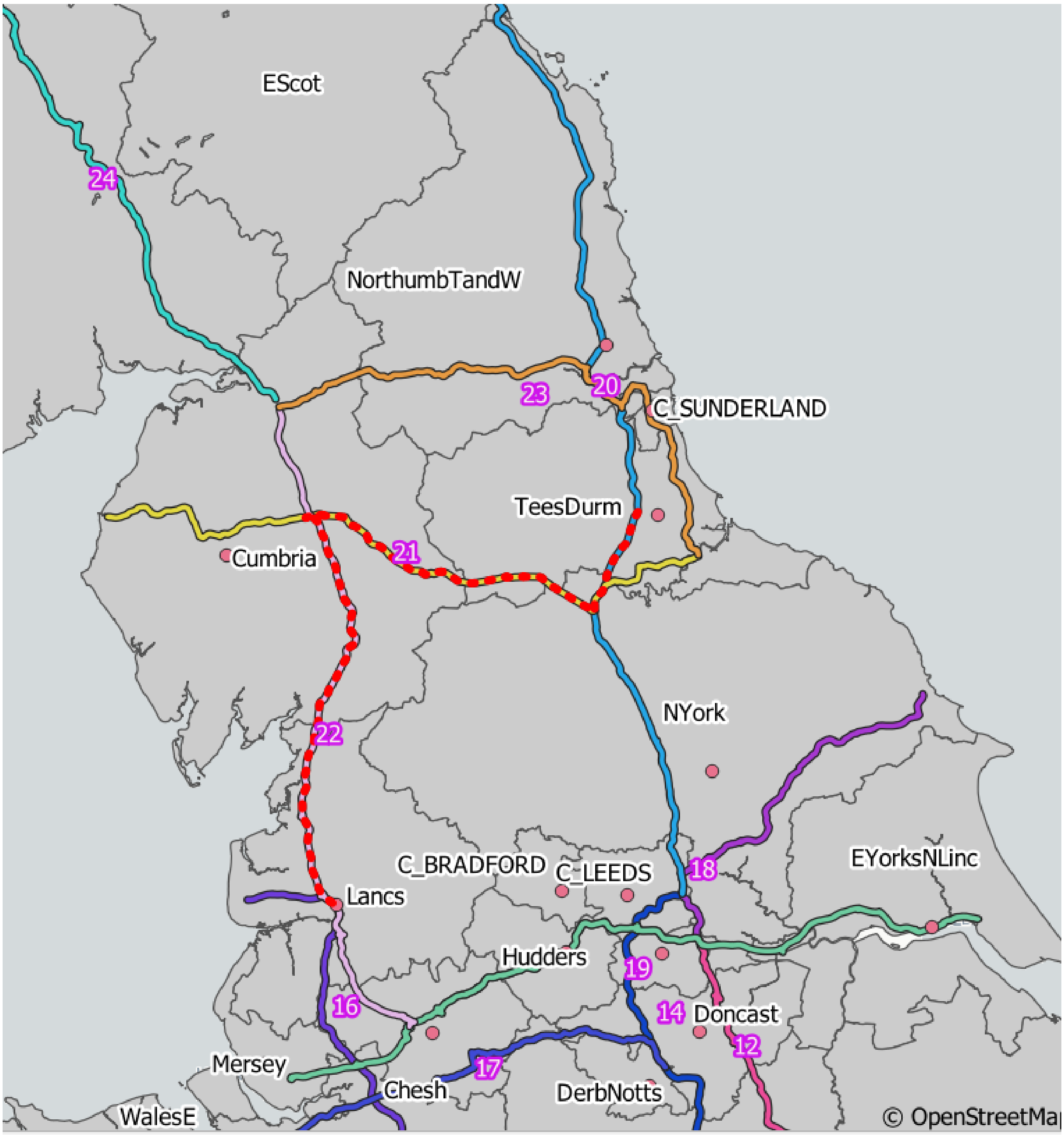
Then, an algorithm to find the shortest path between each pair of centroids was performed using the tool "Shortest path (point to point)" in QGIS. The algorithm was run as a batch process, to iteratively run through each OD pair. A path connecting each pair of centroids is obtained as an output. As an example, **Figure 41** shows the resulting path that connects TeesDurm zone and Lancs zone. This path uses routes 20, 21 and 22. This way, all the zones in the matrix are connected by a set of routes except for the 3 zones in Wales (Northwest Wales, Southwest Wales and East Wales) since the lack of traffic data for Wales, and therefore, no route that traverse that zone.

To aggregate the traffic flow in each route that constitute a path, the average of the following figures was taken:

- Typical Day
- Median Peak Days
- Upper Quartile Peak Demand
- Lower Quartile Peak Demand

Finally, to get the percentage uplift in the matrix, the ratio between Typical Day flow and each of the Peak Days Flow was taken.

Figure 41. Routing Path Example



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