DecarboN8

Place-based decarbonisation for transport

Operation and Performance of Transport Infrastructure Chargepoints: End of Project Report

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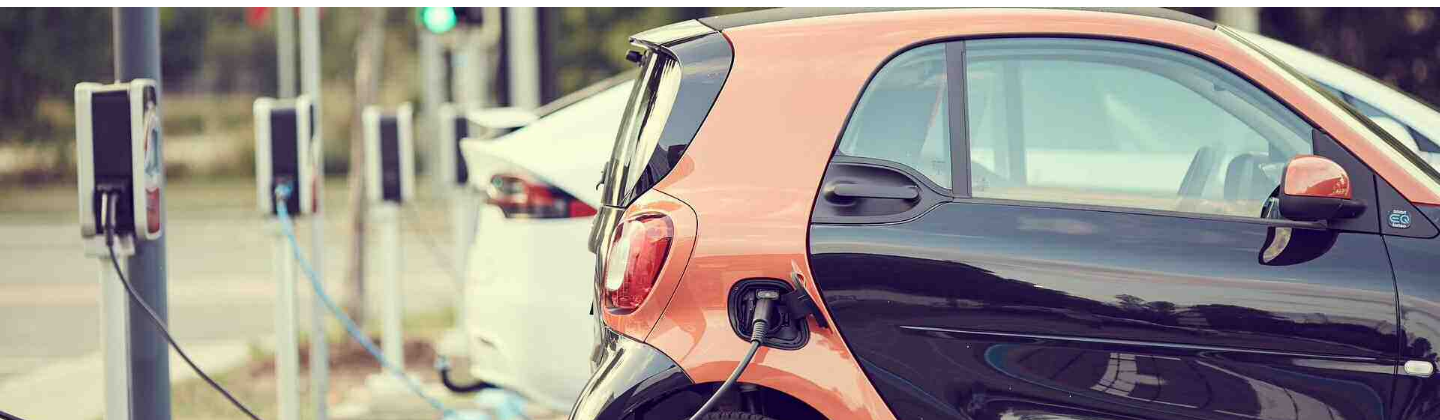
July 2022



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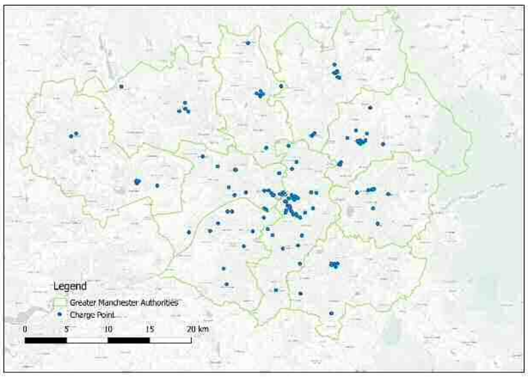
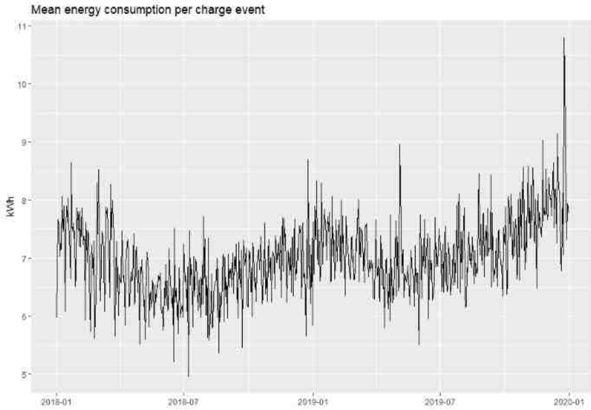
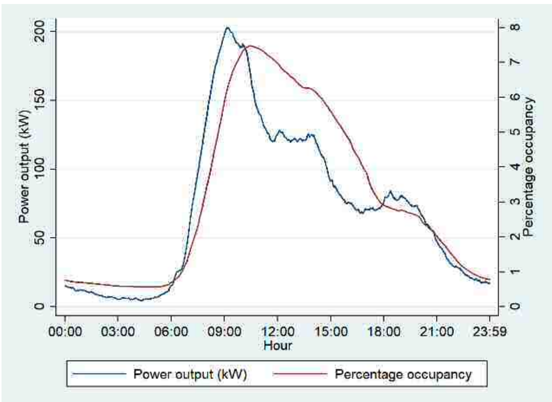
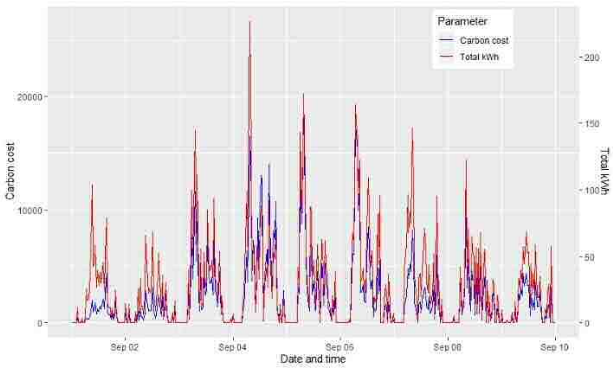
Executive Summary

Networks of Electric Vehicle chargepoints are expanding at pace as the provision of infrastructure gears up to serve the growing proportion of the car stock that is electrically driven. Operational data is starting to become available from these networks, which hold records on each user interaction. This data can be used for a host of purposes from understanding who is using the network, which sites are proving popular, the impact of the network on local power distribution, and the economic value of the network. This report delivers a spatial-temporal assessment of usage patterns on the network present in Greater Manchester for 2018 – 19.









Network operation is depicted in the four charts above, showcasing (from top-left to bottom-right) the layout of the network in the wider region, the daily power demand through the study period, the average power demand by hour-of-the-day, and the carbon emissions attributable to network power demand. From the analysis, a few broad findings can be put forward:

- The network has experienced growth in terms of power demand through 2019, driven in part by more registered users
- Seasonality trends are present, with network use being subdued during the summer months
- The biggest user group are single-use, indicating that the network is serving drivers that are travelling through the region
- Periods are present in the afternoon when occupancy levels of vehicle on the network are above power consumption, indicating potential for smart-charging and vehicle-to-grid activities
- Network power demand generally coincides with when fossil fuel generation is active, though periods are present when power demand is associated with much lower grid emissions

Introduction

Transitioning car fleets to Electric Vehicles (EVs) is expected to deliver much of the carbon savings required from the transport sector over the next 25 years to meet global climate change objectives. This transition is being supported by considerable investment in public charging infrastructure, such as the £400 million LEVI scheme recently announced by the United Kingdom Government to install chargepoints in residential locations that lack access to off-street parking. As EV chargepoint networks begin to take shape, the data derived from network operation has the potential to offer insights on issues such as how power demand can be managed, where chargepoints prove popular, and what degree of accessibility the public have to charging opportunities. The academic and pratitioner communities are beginning to explore these operational datasets to reveal these insights.

This report summarises charge event data obtained from the EV charging station network managed by Transport for Greater Manchester (TfGM) for the years 2018 and 2019. TfGM operates 127 charging stations across the Greater Manchester region. The network is quite uniform in terms of the charge points offered at the charging stations; most are 7kW chargers, whilst only a handful are rapid 50kW DC chargers.

The summary of the network's operation focuses on key performance aspects covering descriptive statistics, time series analysis, and spatial demand profiling. Alongside this, a carbon accounting exercise is conducted which links charge events with grid emission factors to estimate the amount of carbon dioxide being generated through network operation. These analysis steps covering data cleaning, data transformation, and statistical analysis are recorded in an open-source repository that shares the code necessary to apply the process. This open-source repository can act as a starting point for other researchers or charge station operators to conduct a similar analysis of network operation.

Chargepoint Network Overview

The network of EV chargepoints in Greater Manchester was established in 2013, and as of 2018, the network had 127 7kW chargepoints and a small set of 3 50kW rapid chargers. The network is owned by TfGM and is operated under license by the private infrastructure solutions company Iduna. Initially, electricity supplied by the network was free for EV drivers. However, a use fee was subsequently introduced partially in response to the considerable increase in wholesale energy prices since the start of 2022. During 2018, just under 65,000 unique charge events were recorded on the network, which resulted in a cumulative power demand of 554 MW. The location of these chargepoints is presented in Figure 1, with the network spread throughout the Greater Manchester region.

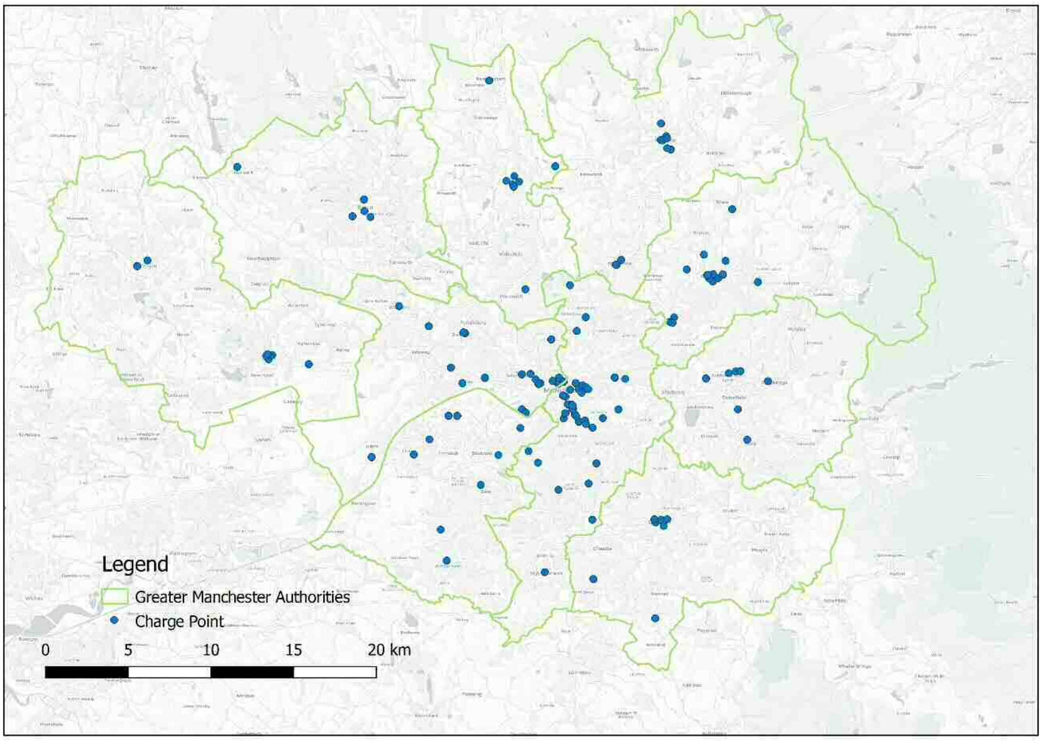


Figure 1: Location of the chargepoints within Transport for Greater Manchester's Electric Vehicle infrastructure network

Data Sources

The TfGM EV chargepoint network operates a back-office system that records each individual charge event. This project makes use of charge event data for the years 2018 and 2019, with just under 166,000 charge events taking place during the study period. For each charge event, several pieces of information are available, which are described in Table 1. The contents of the data relate to the charge event itself (i.e., energy consumption, temporal characteristics, location of charge, charge point model) and the user of the system. Each user can be identified by a unique userid, and many users have registered their vehicle type as well (though this field is not mandatory and is only available in the 2018 data).

Table 1: Data inventory for the charge events occurring on the TfGM Electric Vehicle infrastructure network

Variable name	Description	Unit
Charge event	Unique charge event identifier	165,862 unique charge events
Userid	Unique user identifier	6,297 unique user id's
Cpid	Charge point identifier	359 unique cpid's
Connector	Connector number where vehicle was plugged in	419 unique connectors
Site	Charging station name	127 charging stations
Model	Charge point model	7 charge point models
Group	Organisation hosting the charging station	35 hosting organisations
Start date	Start date	Day of year
Start time	Start timestamp	Time (minutes)
End date	End date	Day of year
End time	End timestamp	Time (minutes)
Total kWh	Energy consumed	kWh
Vehicle*	Vehicle type that was plugged in	50 unique vehicle types

*Please note that 'vehicle' is only available for 2018 and for a limited number of users.

This charge event dataset is complemented by an asset inventory which provides location-based information for each charging station. The Cpid variable is common in both the charge event data and asset inventory, which allows each charge event to be assigned to a particular charge station on the network. This asset inventory is described in Table 2.

Table 2: Asset inventory for each charge station present on the TfGM Electric Vehicle infrastructure network

Variable name	Description	Unit
Cpid	Charge point identifier	359 unique cpid's
Site	Charging station name	127 charging stations
model	Charge point model	7 charge point models
Latitude	Coordinate for charge station location	Degrees
Longitude	Coordinate for charge station location	Degrees

Data Cleaning

To prepare the charge event data for analysis, a series of data cleaning and perpetration steps are conducted. Charge events that have missing values in the start or end timestamps or the total kWh are removed from the dataset. After this, 158,493 observations are retained. Further, charging stations that are not accessible to the public (e.g. being restricted to TfGM staff) are filtered out as well, which excludes 2,500 charge events. Extreme values in the charge event duration (i.e., events with a duration of less than 5 minutes, and exceeding 24 hours) and energy consumption (less than 0.5 kWh and events exceeding 100 kWh) are removed from the dataset. After this final step, 124,869 charge event observations remained.

Analysis Plan

The analytical steps followed in this project are summarised in the Phase 1 component of Figure 2. This covers a sourcing and cleaning of the charge event data, combining this data with emission factors from regional electricity generation, and the production of data visualisations scripts to chart the dataset. Each of these steps is recorded in a data processing repository hosted on the GitHub code sharing platform.

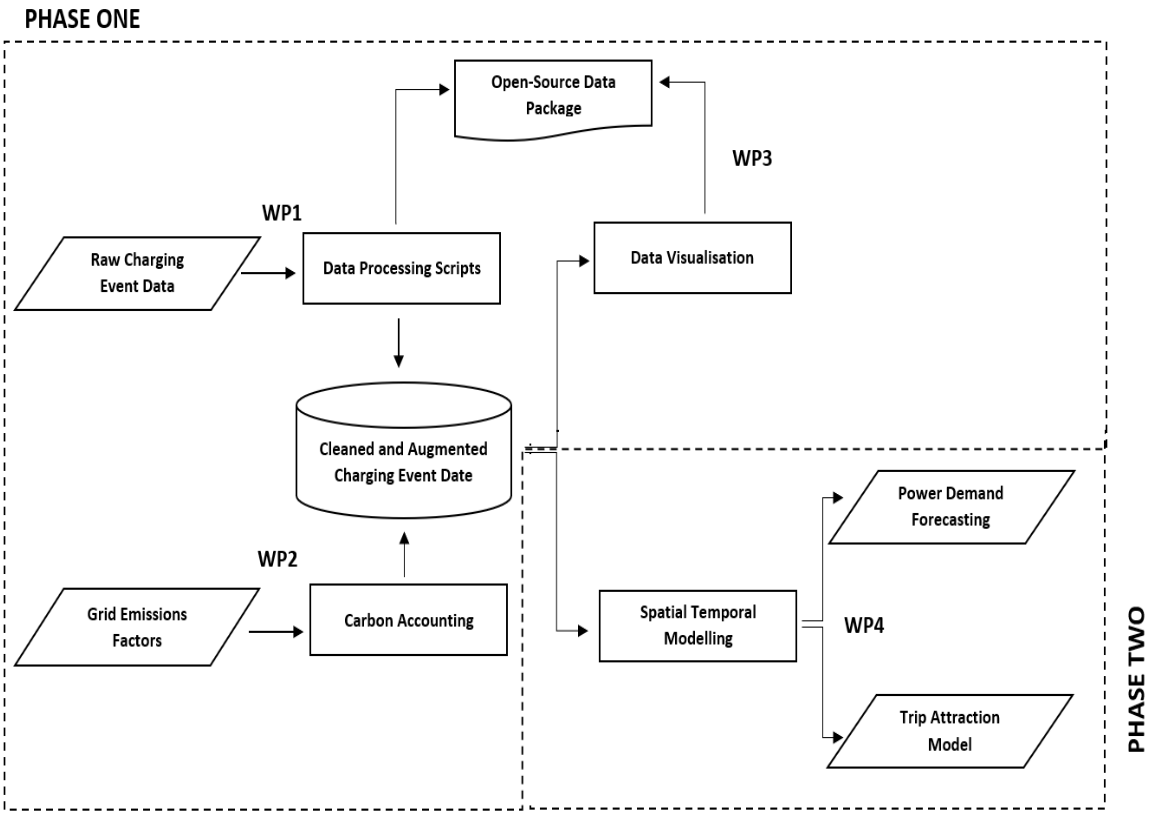


Figure 2: Overview of the analytical process followed in the project, with Phase 1 representing the work carried out in the initial stage

Network Level Statistics

Figure 3 displays the geographic variation in charge events during the study period. To contextualise the locations of these charging stations, the Dual Carriageway Road network is added, as well as workplace population densities (light shades signifying greater densities of workers). It becomes obvious that many charging stations are clustered around areas with higher workplace population densities, and/or near the Dual Carriageway Road network. The most successful charging stations are situated within the Manchester ring road, within the city centre, or at a strategic park and ride location.

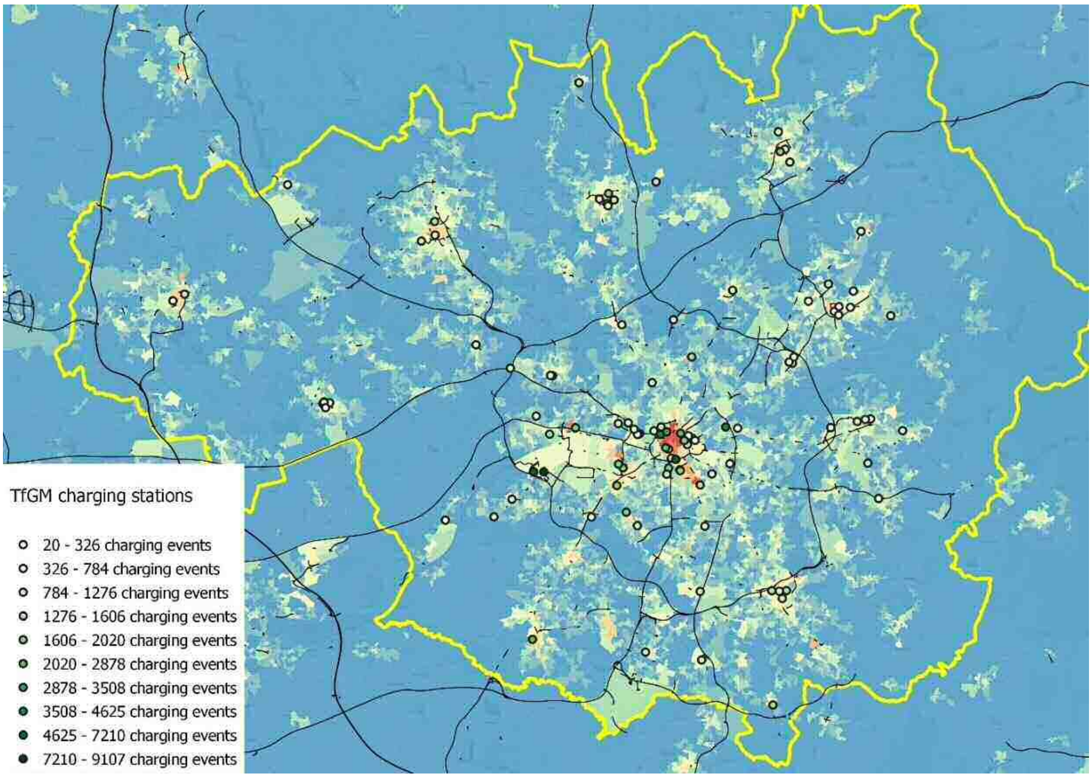


Figure 3: Charging stations in the Greater Manchester region (Dual Carriageway Road network and workplace population density)

Figure 4 [upper panel] shows the daily number of charge events on the TfGM network throughout the study period, whereby a growth rate is observed from summer 2018 to the end of the time series in 2019 . Figure 4 [lower panel] shows the average daily energy consumption per charge event during the study period, where seasonality effects are clearly visible. During colder months, the average energy demand per charge event tends to be slightly higher than that during the summer. This could be motivated by EVs requiring more energy to maintain warmth in the cabin and for battery packs being less efficient in colder temperatures. A prominent growth trend is also visible in the later part of the dataset for both of these time series. Daily network use increased in the autumn and winter of 2019, motivated by an increase in EV ownership in the Greater Manchester area (I.e. more unique users engaging with the network during this period as compared to earlier periods). Daily average energy consumption per charge event is also growing in the later part of 2019. This observation could be motivated by new EV registrations with larger battery packs that require more power to attain a full charge.

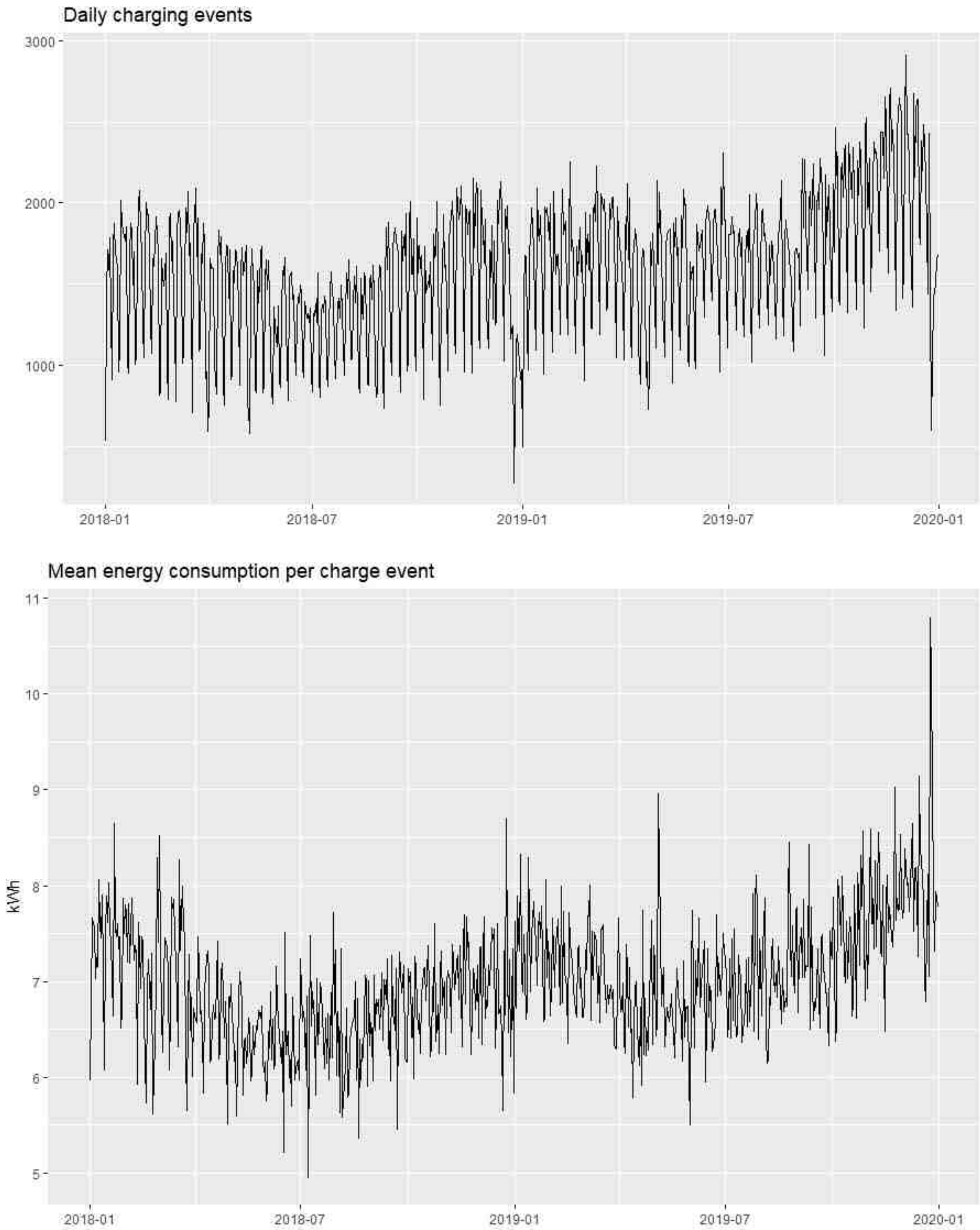


Figure 4: Time series of [upper panel] daily charge events and [lower panel] daily average energy consumption per charge event on the network throughout 2018 - 19

The start and end timestamps allow for the duration of each charge event to be calculated. This duration can be split up into total plug-in duration (i.e. the time between the EV being connected and disconnected from the chargepoint) and charging duration (i.e. time in which the EV was receiving power from the chargepoint). This charging duration variable is estimated using the power output of the chargepoint and the total quantity of energy consumed during the charge event. Figure 5 [upper panel] displays the average daily plug-in duration for charge events throughout the study period with a slight downward trend being visible, implying that users are being briefer in terms of their interaction with the network. In terms of charging durations, a more regular rhythm is observed throughout the time series, whereby the chargepoints are activity distributing power for longer periods during the colder months of the year.

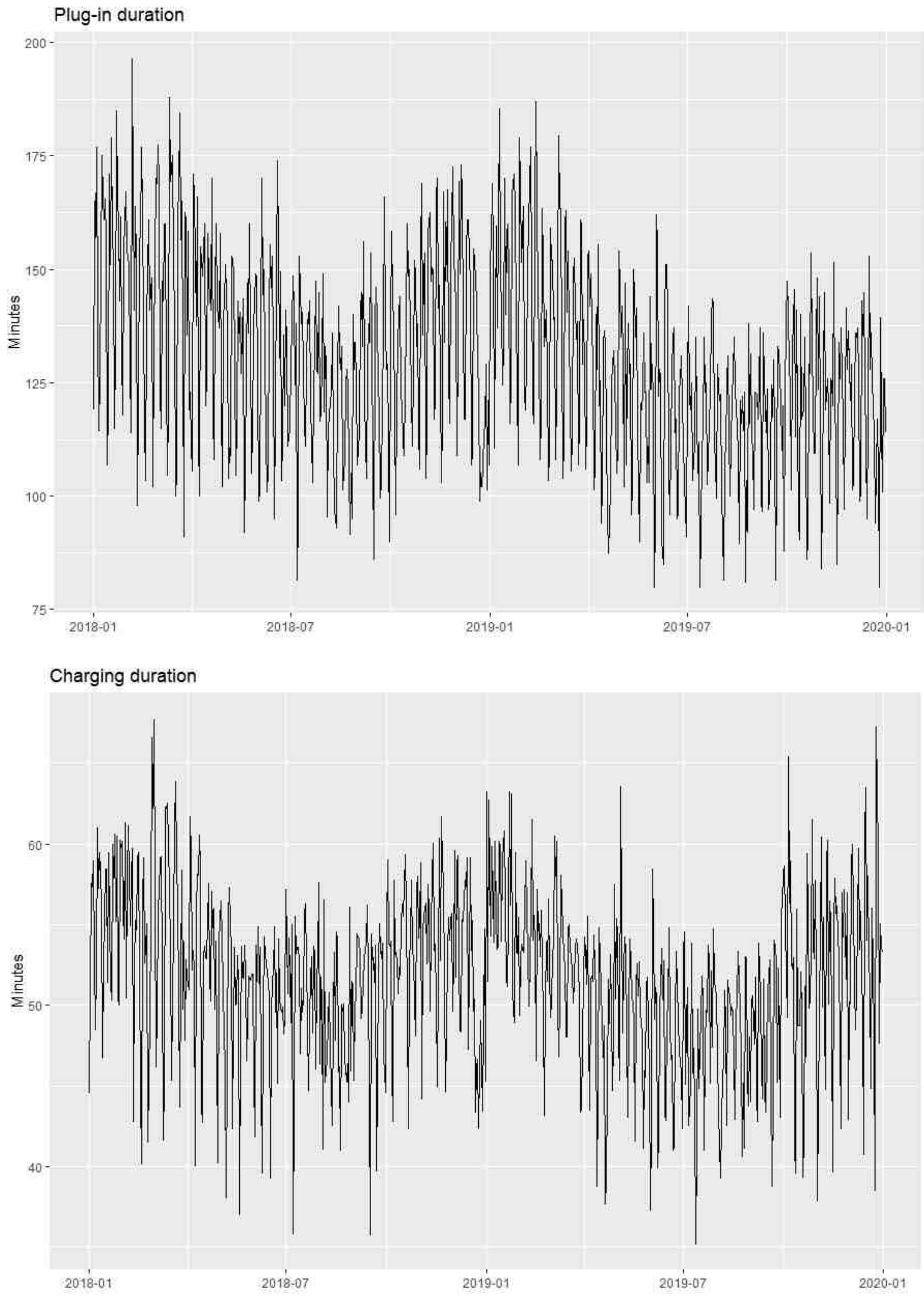


Figure 5: Time series of [upper panel] daily average plug-in duration per charge event and [lower panel] daily average charging duration per charge event on the network throughout 2018 - 19

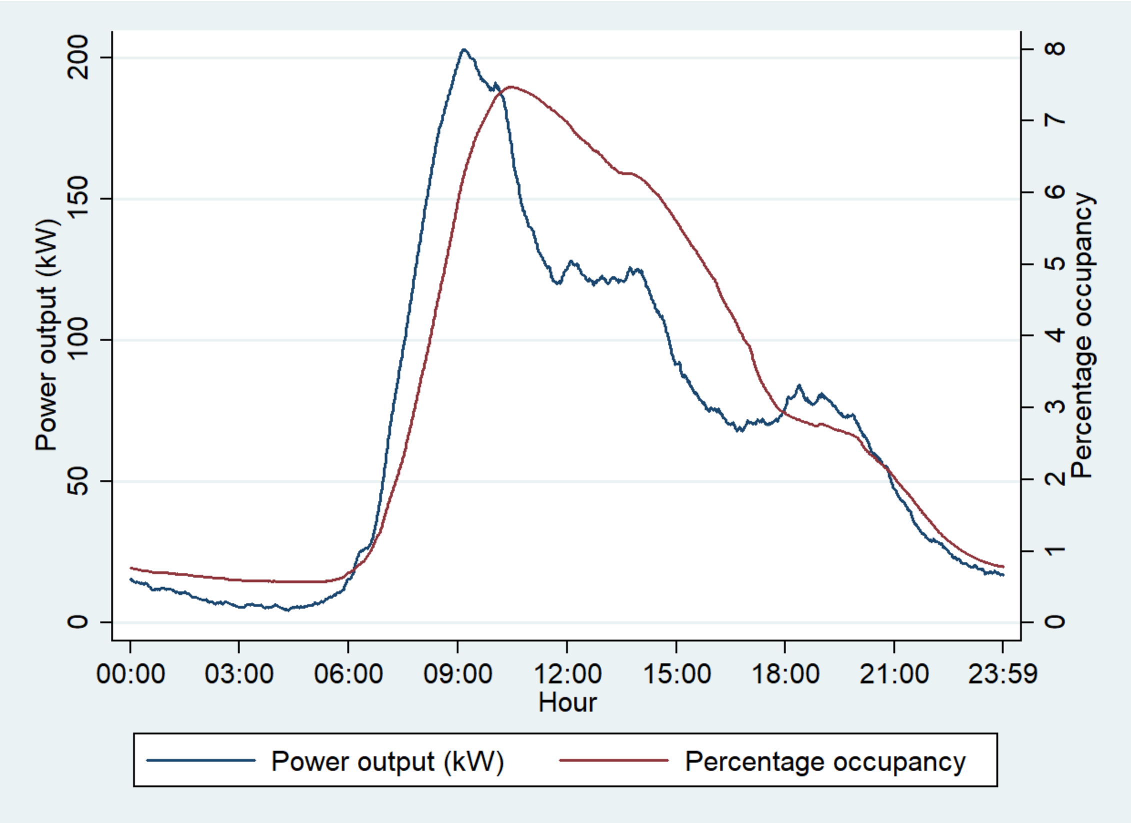


Figure 6: Average network power demand and occupancy for weekdays throughout 2018-19

Occupancy and power output profiles have been generated for 2018 and 2019 to consider the efficiency of the system. Figure 6 shows the weekday profiles and Figure 7 the weekend profiles. It is noteworthy that occupancy on the network is generally low, whereby 8% of the chargers are typically occupied at the start of the day (09:00), which subsequently declines for the remainder of the day. Power output peaks at around 09:00, and it seems there is scope for vehicle-to-grid practices in the late morning and early afternoon period, signified by the separation between the power output and occupancy trends. It should be noted that the occupancy percentage assumes that all charging stations are fully available throughout the time series, and that each chargepoint can cater for two vehicles simultaneously. The power output figure assumes that each vehicle receives as much power as the charge point is maximally rated for, whilst in reality this power output is likely somewhat lower, and depends on battery management software, state of charge, total number of vehicles plugged in to the charge point, and so on.

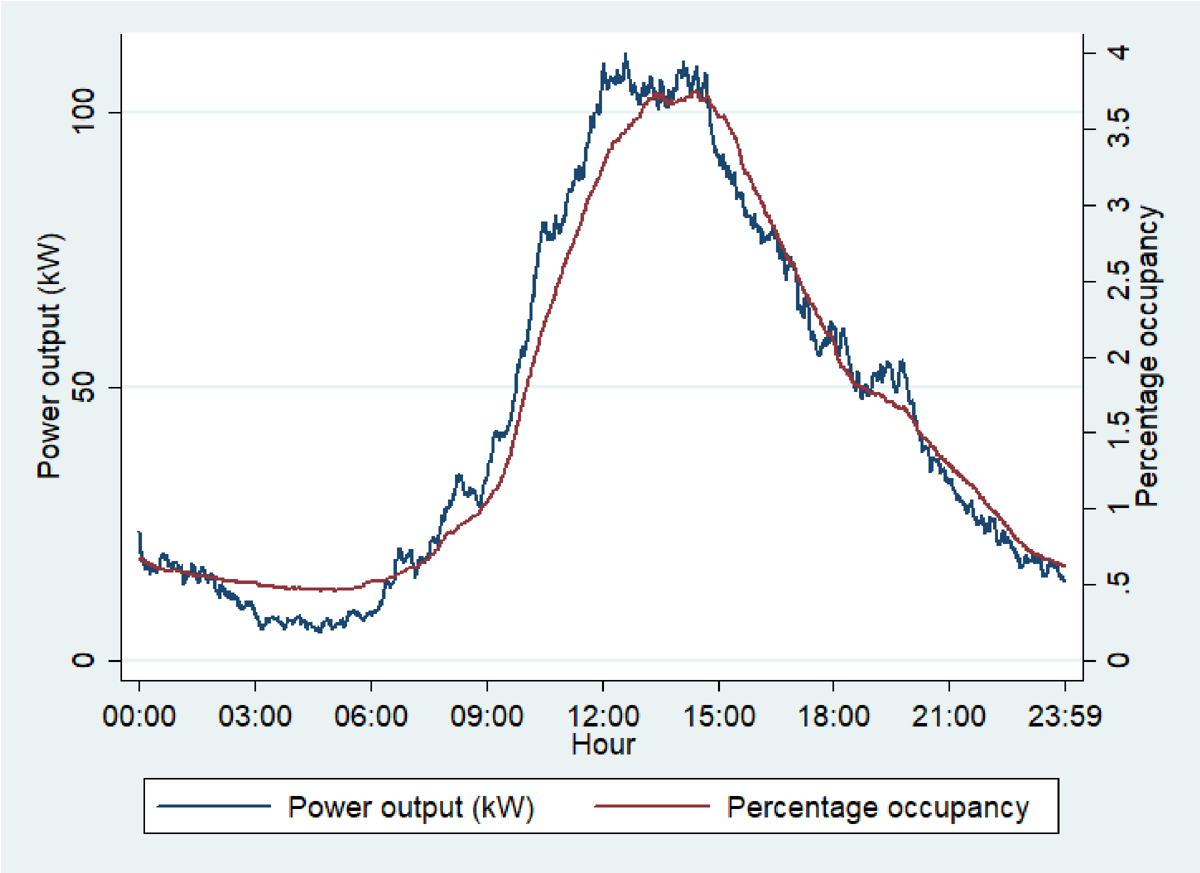


Figure 7: Average network power demand and occupancy for weekends throughout 2018-19

The power demand and occupancy profiles displayed in Figures 6 and 7 can mask some extreme observations that occur on the network. To make these extreme observations apparent, Figures 8 displays the distribution of occupancy (lower panel) and power output (upper panel) on the network throughout 2018 – 19. While the average network power output level is around 50 kW, rare occasions are present when the power demand peaks to more than 450 kW. In the case of network occupancy, the average is around 10 EVs being plugged-in at a given time, though this can peak to over 80 vehicles being connected to the network during rare occasions.

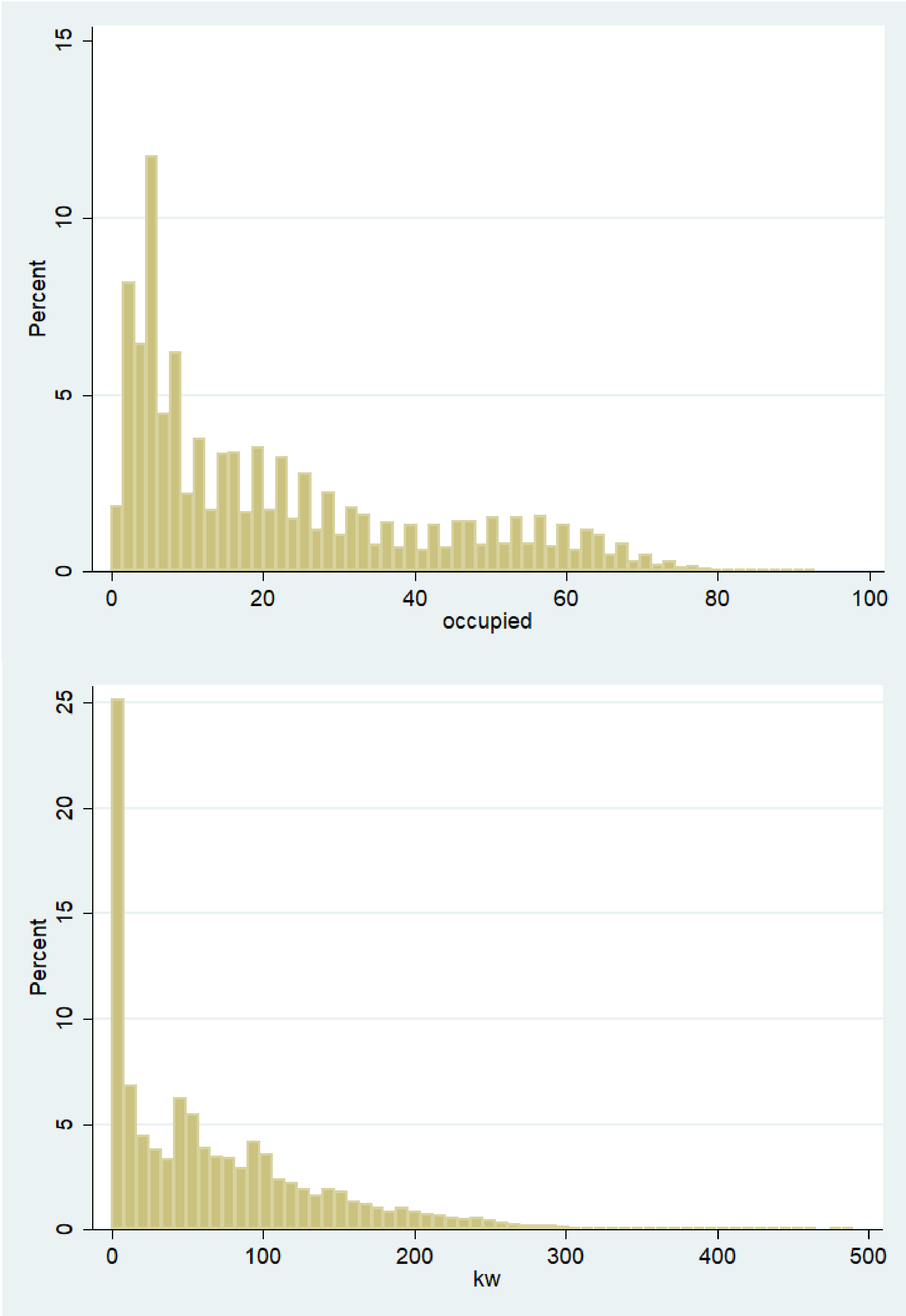


Figure 8: Histogram displaying the distribution of [upper panel] EVs plugged into the network and [lower panel] energy demand on the network throughout 2018-19

Site Level Statistics

The charts so far presented display the situation across the entire network, which overlooks what is occurring at given chargepoints. The network is heterogeneous in terms of its composition, with some charging stations attracting a lot of demand, whilst others attract considerably less demand. Figure 9 demonstrates the heterogeneity in plug-in durations by charging station. Most stations have an average plug-in duration of between 100 and 200 minutes, however there are several outliers which denote stations where the average plug-in duration is in excess of 300 minutes. At such outlier stations, there is a high level of idle connection time where EVs are plugged into the chargepoint but no energy is being distributed. This demonstrates the importance of looking below the 'network level' to consider the variation that is present at different sites and between different charging events.

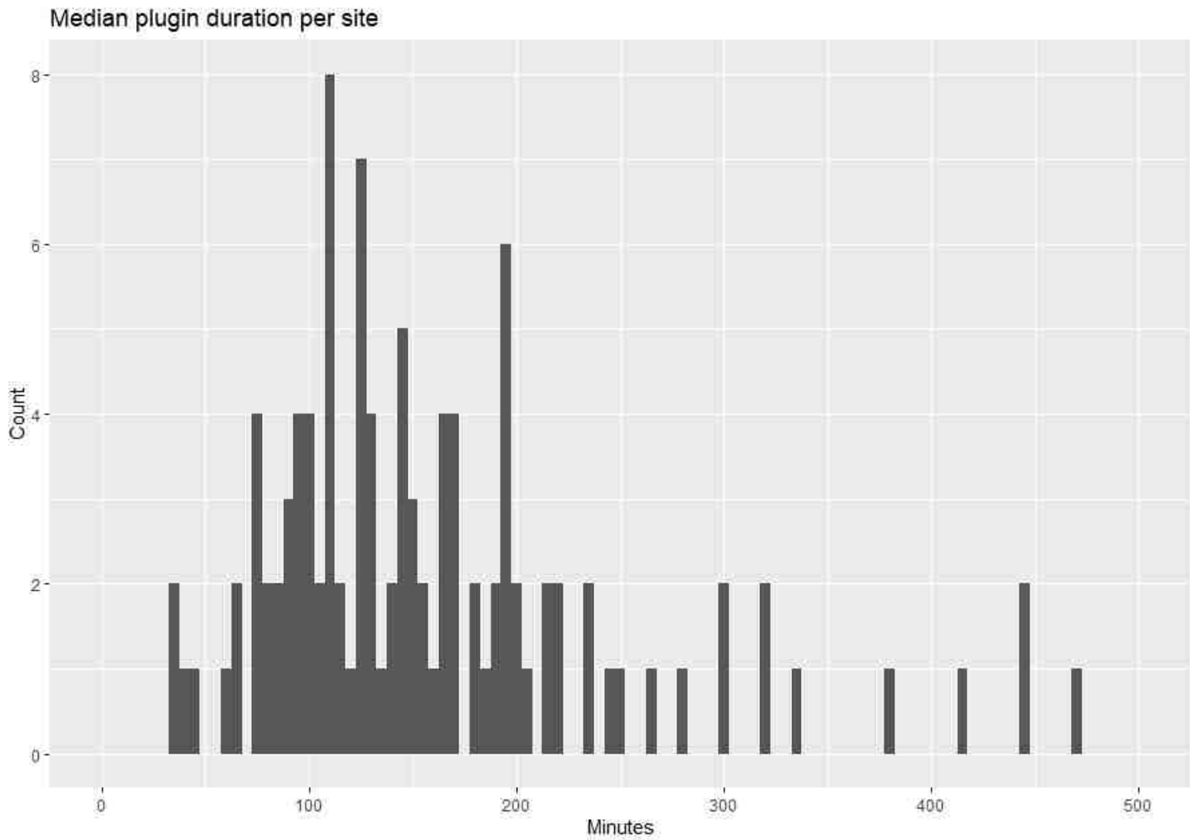


Figure 9: Histogram displaying the distribution of average plug-in durations per charging station

A similar though slightly less pronounced right-skew is presented in the distribution of average energy demand per charging station. This statistic is exhibited in Figure 10 and indicates that the average amount of kilowatts distributed by a charging station on the network is 7.5 kWh, though there are a handful of stations that on average distribute upwards of 12 kWh. This type of data can be useful when considering the commercial arrangements for the network, as some stations that have high levels of occupancy but low levels of energy distribution per event may require the application of connection fees or minimum charges per visit.

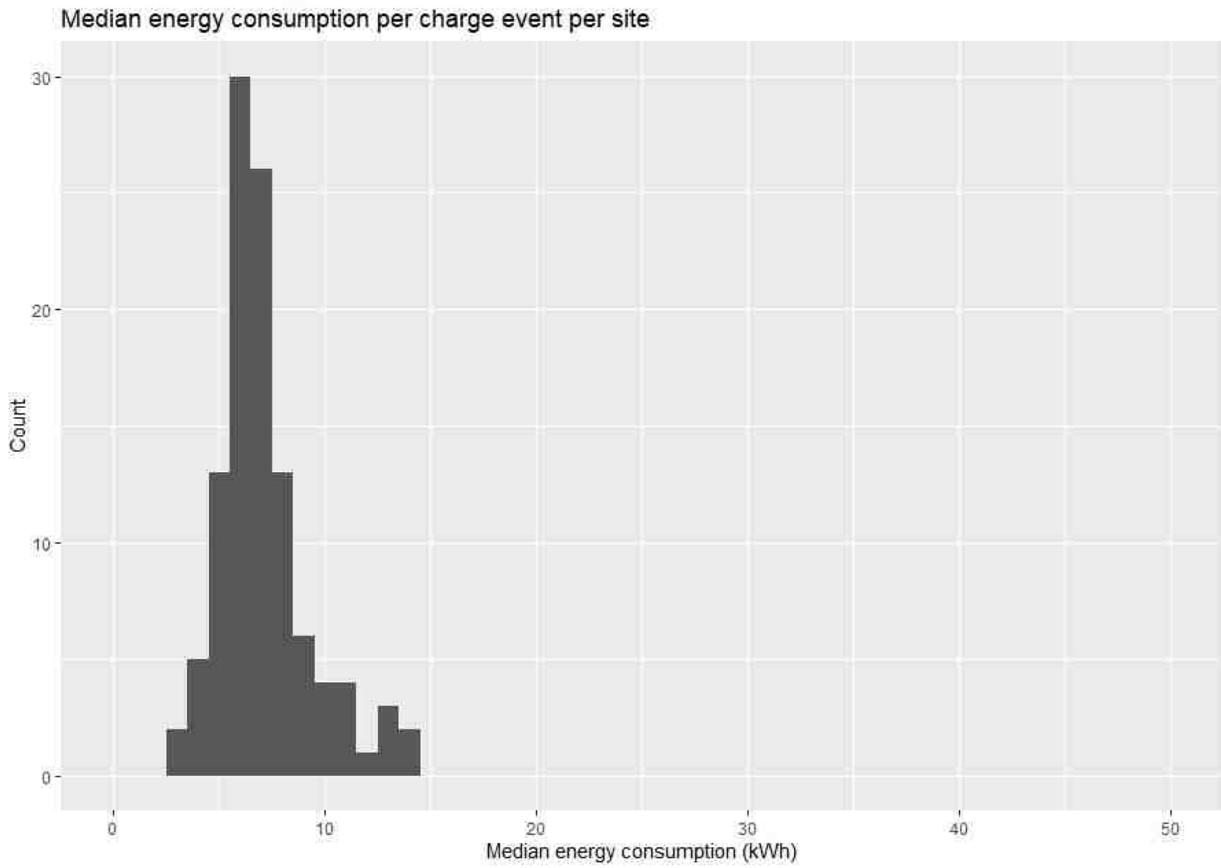


Figure 10: Histogram displaying the distribution of average energy demand per charging station

Charge Event Statistics

Charging events on the network display a considerable range which is showcased in Figure 11 [upper panel] in terms of the distribution of plug-in times on the network. Many events are less than 200 minutes, whilst events exceeding 400 minutes are rare. Figure 11 [lower panel] displays the duration of network charge events where power is actively being distributed (i.e. transferred from the chargepoint to the EV) and demonstrates that most of the energy is transferred within 100 minutes. There is thus, as observed earlier, a potential for Vehicle to Grid, as many vehicles have long idle plug-in times denoted by the different between plug-in durations (i.e. Figure 11, upper) and charging durations (i.e. Figure 11, lower).

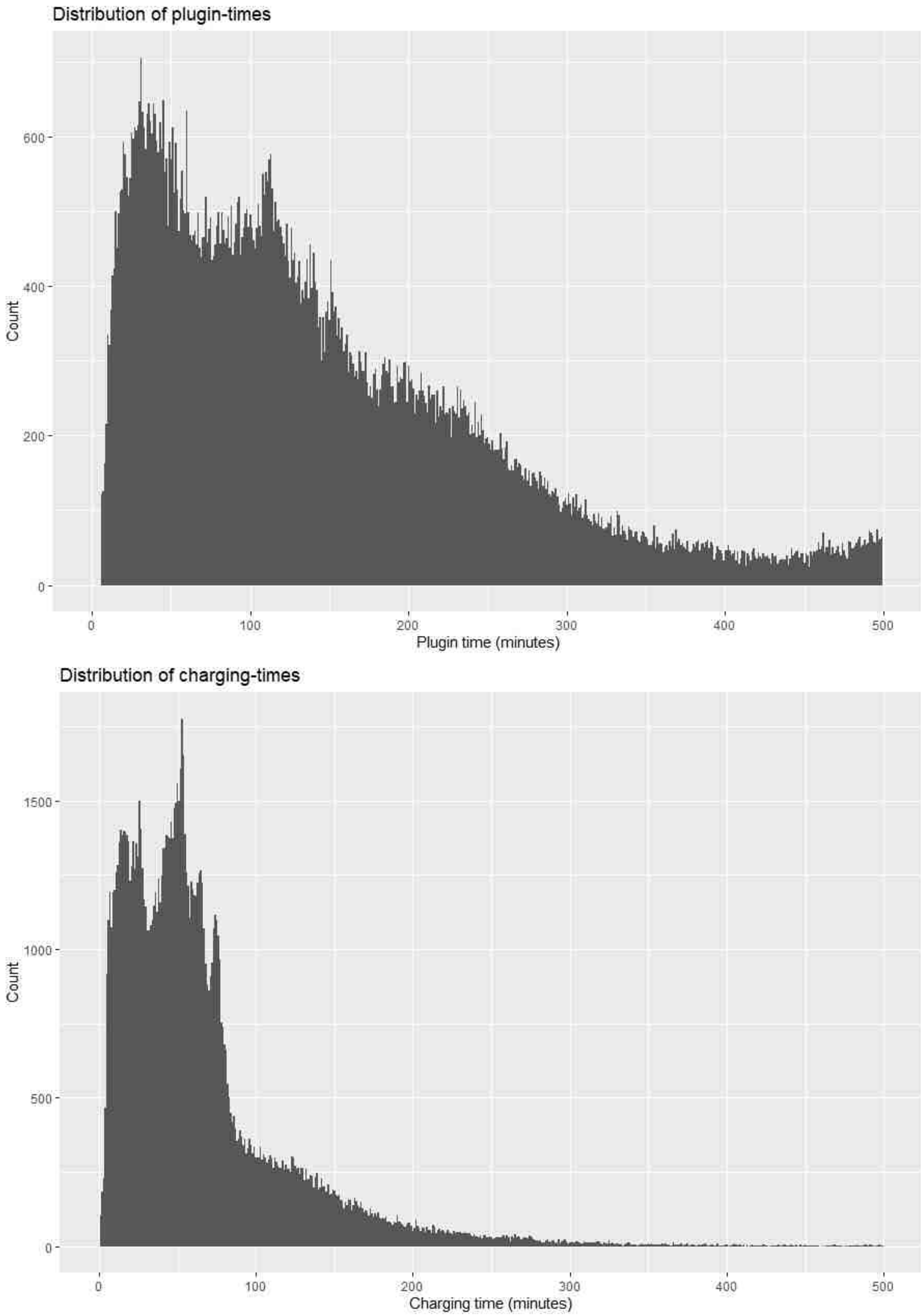


Figure 11: Histogram displaying the distribution of charge events on the network by [upper panel] plug-in durations and [lower panel] charging durations

Most of the charge events consume less than 10kWh, with an average of around 7.5kWh (Figure 12). This could indicate that the network is used mainly for 'top-up' charging, as most EVs have batteries where capacities greatly exceed 10kWh.

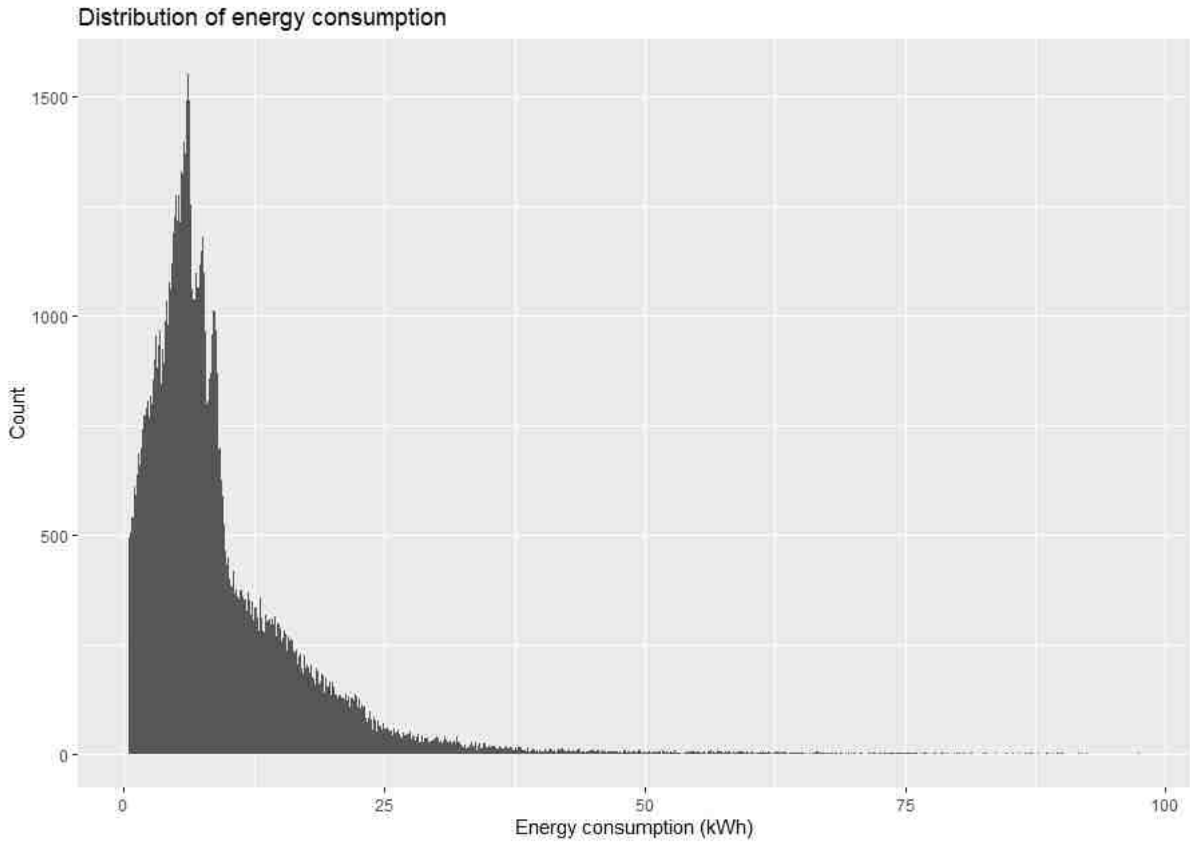


Figure 12: Histogram showcasing the distribution of energy demand for each charge event on the network

User Statistics

One of the unique strengths of the charge event dataset for the TfGM EV network is that it contains a unique user ID, which allows the analysis to consider how users are interacting with the infrastructure on an individual basis. Many users appear to be incidental users of the network. This is demonstrated by Figure 13, whereby the most common frequency of interaction with the network by a user is a single charge event. From the 6,297 users, a total of 1,600 have only used the network once. This suggests that around a quarter of users on the network could simply be passing through the region and recharging their EV whilst on-route to another destination.

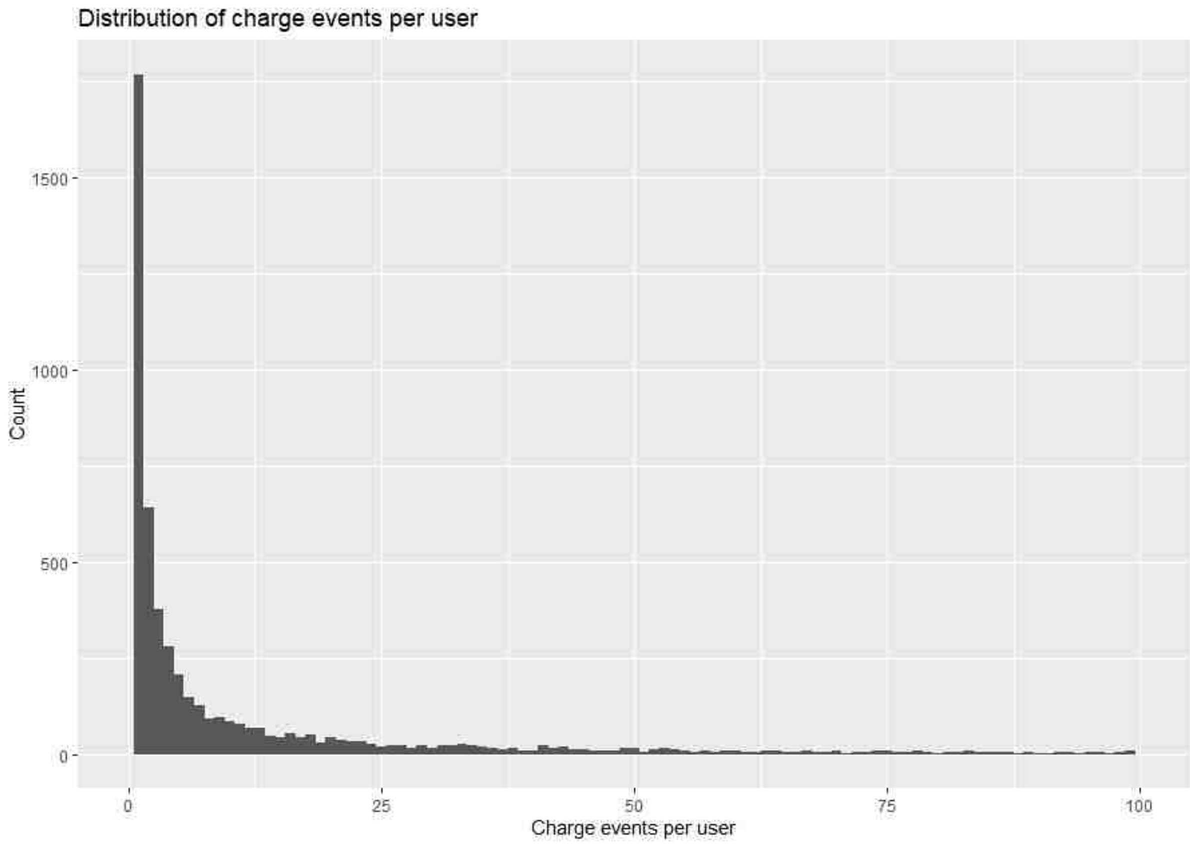


Figure 13: Histogram displaying the distribution of charge events per user on the network during 2018-19

Carbon cost analysis

The final stage of this project involves linking the charge event data from the EV network to regional emission factors relating to electricity generation. This allows the analysis to consider the carbon dioxide emissions associated with each charge event. To demonstrate this association, Figure 14 displays a time series overlap between network energy demand and the carbon dioxide emissions of the grid for a week in September. For the most part, the lines are in close alignment, which indicates that EVs are being charged on the network when fossil fuel (e.g. coal and gas) generation are being used to supply the electricity. There are some instances of divergence, such as on the morning of the 2nd of September, where the carbon cost of EV charging is noticeably lower than the energy demand on the network. These moments represent opportunities for the network to recharge EVs with relatively little carbon dioxide emissions and could be incentivised through pricing mechanisms.

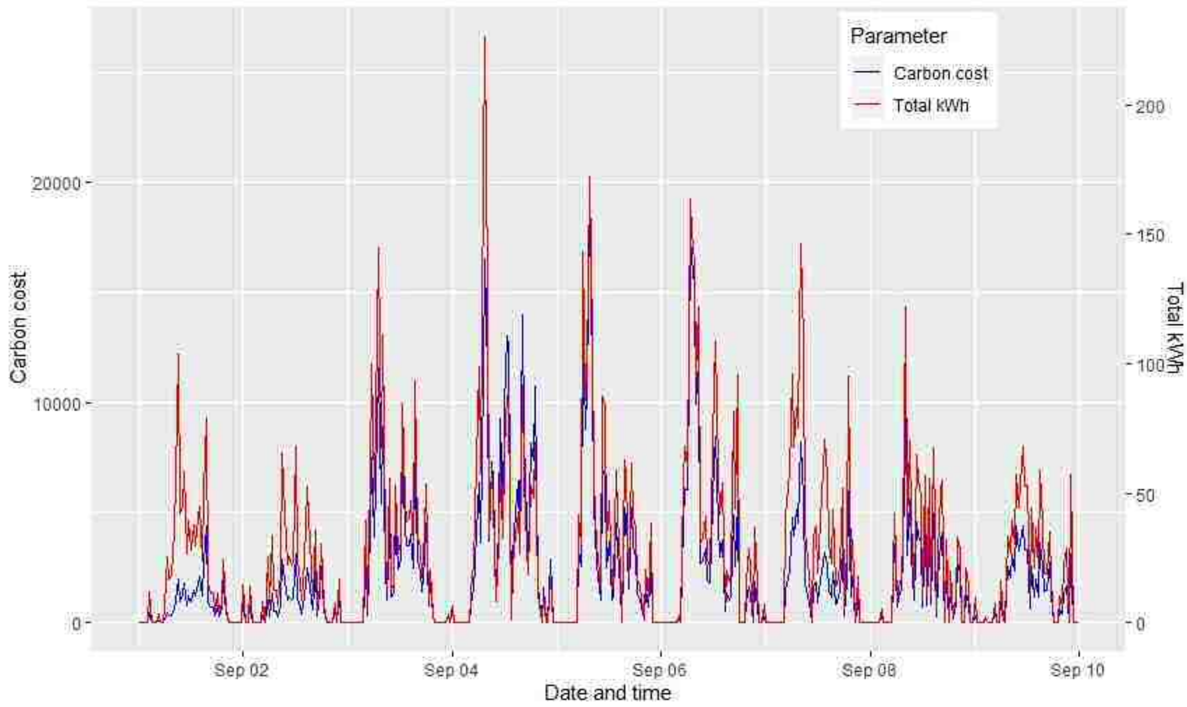


Figure 14: Time series of a week in September 2018, displaying overlap between energy demand on the chargepoint network (red line) and grams of CO_2 associated with each charge event (blue line)