# ELECTRIFYING RAILWAY STATION PARKING: ENHANCING SCOTLAND'S SUSTAINABLE MOBILITY

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## Abstract

Recognising the importance of mass electrification of transport demand and the reduction of energy demand, the Scottish Government has committed to reducing car kilometres travelled by 20% by 2030. This necessitates a reduction in the number of daily car journeys and an overall change in attitude towards how cars are used. With an expected increase in the number of commuters using multi-modal travel and low carbon public transport infrastructure there is an increasing need for EV charging infrastructure to support the transition between different travel options. At present, there are 162 EV chargers installed across 17% of Scotland's rail stations with 64% of rail stations accommodating vehicle parking. This study considers the hypothesis that rail stations located in different geographic areas with different levels of available parking will have unique EV charging infrastructure requirements leading to varying impact on distribution networks. A geospatial analysis of existing EV charging installations is first carried out, followed by a statistical hosting capacity assessment of the network infrastructure located at two rail station sites. The research provides valuable insights for local government, distribution network planners, and stakeholders in the transport sector, facilitating the development of sustainable integrated mobility ecosystems.

## 1. Introduction

Various pathways have been proposed to meet the United Kingdom's (UK's) legally-binding net-zero greenhouse gas emissions target [1] [2]. They are generally in agreement that (i) mass electrification of transport demand is a cost-effective way to shift demand away from fossil fuel use, (ii) a reduction in energy demand will reduce the scale of investment needed for net-zero, and (iii) time- and space-based flexibility in electricity demand can avoid or defer the need for network reinforcement.

In Scotland, there is a commitment to reduce car kilometres travelled by 20% by 2030 (against a 2019 baseline) [3]. This necessitates a reduction in the number of daily car journeys taken and an overall change in attitude towards how cars are used in the daily lives of commuters. This will partly manifest in an increase in multi-modal travel of which the low carbon rail network will play a central role. As of 2020/21, Scotland had approximately 2,744 kilometres of rail network (904 kilometres that is electrified) and 358 operational rail stations [4] as shown in Figure 1.

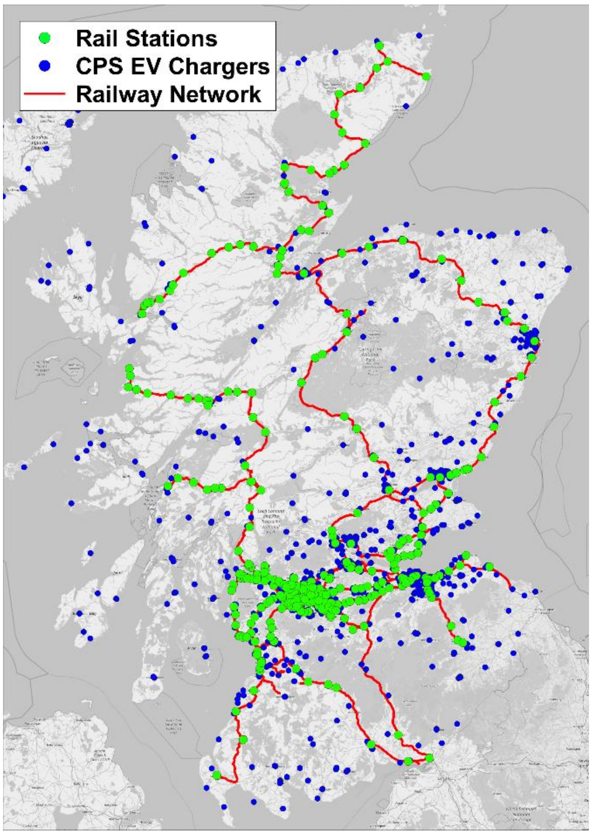


**Figure 1: Map of Scottish rail network, rail stations and ChargePlace Scotland EV charging network.**

Currently, many commuters choose to drive to rail stations and then travel by rail to their destination with 64% of rail stations in Scotland accommodating vehicle parking. As a result, limited EV charging infrastructure has been installed at, or within proximity to, several rail stations across Scotland allowing commuters to transition between different low carbon modes of transport, fostering a more sustainable and integrated mobility ecosystem. With the 20% car kilometres reduction target, an expected increase in the number of commuters using multi-modal travel and low carbon public transport infrastructure is driving the need for an increase in EV charging infrastructure at these sites. This increase must be balanced with the recognition that walking and cycling should become the preferred mode of transport for 'short' journeys [3]. Therefore, rail stations in various geographical settings will require distinct future EV charging infrastructure requirements. This presents a challenge for electrical distribution network planners given the potential increase in demand at these often-rural locations and the temporal demand requirements that are inherently driven by commuter travel behaviour.

Therefore, this work explores the impact of electrified rail station parking in Scotland by considering the unique demand requirements of rail station EV charging infrastructure and the subsequent impact on distribution network hosting capacity with the intention of informing local government, policymakers, distribution network planners and stakeholders in the transport sector.

## 2. Geospatial Analysis

This section describes the process developed to analyse existing EV charging infrastructure within proximity to rail stations across Scotland. Several data sources are used, and a brief description of each is provided. The analysis presented supports the hypothesis that different rail stations will have unique EV charging infrastructure requirements leading to varying impact on distribution networks.

### *2.1. Datasets and Information Mapping*

ScotRail Trains Limited, trading as "ScotRail", is owned by the Scottish Government and operates passenger rail services in Scotland. Their website provides detail on all relevant rail information including the likes of timetabling, fare prices and passenger services [5]. They also provide detailed information on a station-by-station basis including information on parking facilities and bike storage. For this work, a python script is developed to extract all information associated with each individual rail station from the ScotRail website, assuming that all information is up to date at the time of extraction.

ScotRail also operates an existing network of EV charge points and there are currently 162 dedicated EV chargers located at 61 stations across Scotland [6]. Access to ScotRail's EV charging infrastructure is achieved via ChargePlace Scotland (CPS) which is Scotland's national EV charge point operator, owned by the Scottish Government [7]. From 8 January 2024, a standard EV charging tariff of £0.43p/kWh is used for all ScotRail EV charge points with an overstay cost of £12.00 per 12 hours also applied [6]. The CPS website includes detailed information on charger install location, status, type, utilisation and uptime [7]. This dataset is used to obtain all relevant information for the CPS chargers corresponding to each individual rail station.

In addition to the detailed information obtained from the ScotRail website, the Office of Rail and Road (ORR) publish annual estimates of the number of entries/exits (based primarily on ticket sales) and interchanges at each station in Great Britain (GB) [8]. Whilst providing this aggregated information the dataset also provides the latitude and longitude coordinates for each station. Through correlation with the ScotRail website information this allows for the creation of a dataset that provides both spatial and technical information for all rail stations in Scotland.

To classify the rail stations based on their location, the Scottish Government's 6-fold Urban Rural Classification (URC) is used [9]. This classifies Scotland into categories based on population and accessibility, which considers drive time analysis to distinguish between remote or accessible locations. Population categories are defined based on "Settlements" which are groups of high-density postcodes whose combined population rounds to 500 people or more. Large Urban Areas have populations of 125,000 or more, Other Urban Areas range from 10,000 to 124,999, Small Towns from 3,000 to 9,999, and Rural Areas have populations under 3,000. Accessible Areas are within a 30-minute drive from the centre of a Settlement with a population of 10,000 or more, while Remote Areas have a drive time exceeding 30 minutes. The spatial information for the 6-fold URC is mapped to the detailed rail station dataset providing a means to distinguish between rail stations in different areas.

Distribution Network Operators (DNOs) in GB typically hold geographic information system (GIS) records for their assets to assist with operation, management and planning. Distribution network GIS data was made available to the authors by Scottish Power Energy Networks (SPEN), one of two DNOs responsible for distribution networks in Scotland. The information associated with their secondary transformers is of specific relevance to this work.

### *2.2. Travel Distance and Time Dependency*

As information on whether a rail station has EV charging infrastructure onsite (i.e. in the dedicated rail station car park) is not currently recorded in detail, a GIS transformation is used to identify existing charging infrastructure within the CPS network that is adjacent to each station. To facilitate this, Openrouteservice's (ORS) time-distance-matrix API is used [10]. This allows for the computation of time and distance for multiple routes simultaneously for various transport modes. This is based on techniques that efficiently apply shortest path theory e.g. Core-ALT, which is a well-known preprocessing-based speed-up technique for Dijkstra's algorithm. For this work,

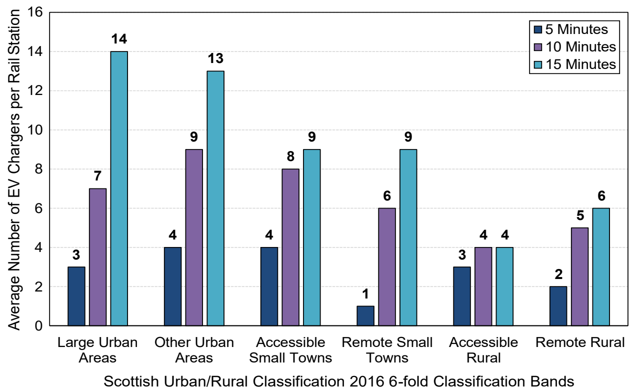


**Figure 2: The average number of EV chargers per rail station within a 5, 10 and 15 minute walk for each URC band.**

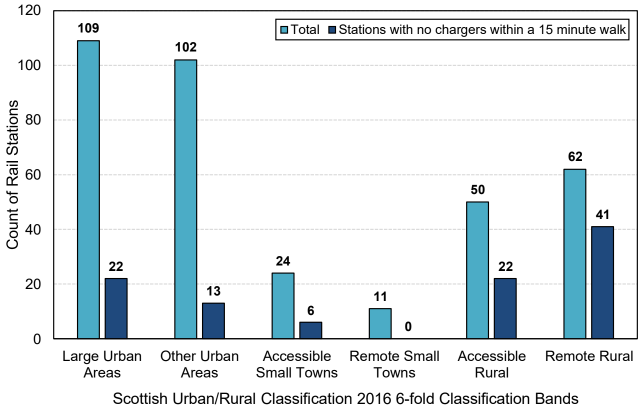


**Figure 3: Summary of the total number of rail stations and the stations with no chargers within a 15 minute walk for each URC band.**

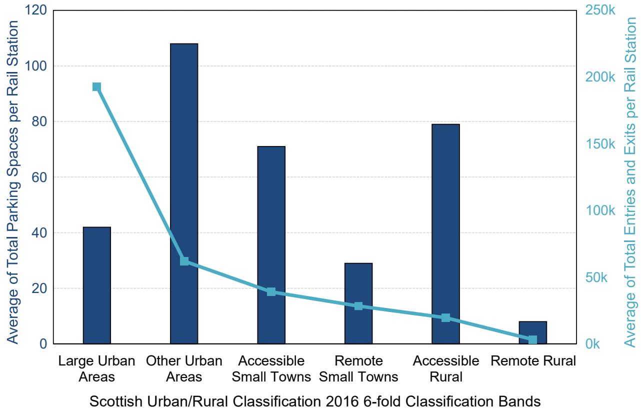


**Figure 4: The average number of parking spaces and the average entries/exists per rail station for each URC band.**

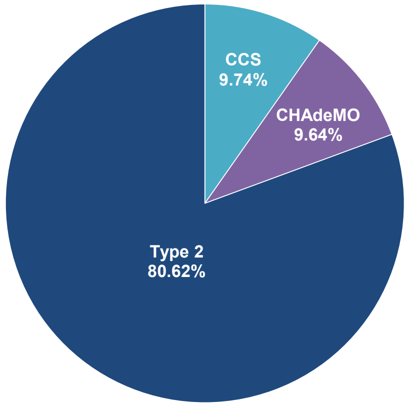


**Figure 5: Summary breakdown of the different charger types for all chargers with a 15 minute walk of the rail stations.**

walking time between the chargers and the rail station is considered as the primary constraint for the driver i.e. drivers looking to charge their EV would aim to do so as close as possible to the rail station which would intuitively be measured by how long it would take to walk from their vehicle to the station. Therefore, to obtain the walking time from the chargers relative to individual rail stations, the respective latitude and longitude coordinates are used. The coordinates of each rail station are passed to the API along with the coordinates of each charger and the walking time in minutes from the station to each charger is returned. A count is then performed to determine the quantity of chargers accessible within a 5, 10 and 15 minute walk of the station.

Figure 2 highlights the average number of chargers within the categorised walking times for rail stations classified by the URC. The figure highlights that there tends to be more EV chargers on average within walking distance in urban areas than rural areas. Note that as not all chargers considered here are installed at dedicated rail station parking it makes sense for urban areas and small towns to have more chargers nearby than stations in a rural setting. Conversely, stations in a rural setting are more likely to be isolated thus having an increased need for dedicated charging onsite with limited options nearby. Therefore, greater focus should be placed on supporting the role out of EV charger installations in accessible and rural areas to encourage consumers to commute by rail into urban areas rather than driving directly.

Of the 358 operational rail stations in Scotland, 104 had no chargers within a 15 minute walk of the station. Figure 3 shows the distribution of these stations relative to the URC. The figure highlights that rail stations with no adjacent charging infrastructure are predominately in a rural environment. This is to be expected as rural rail stations have a much lower average annual usage in terms of the total entries/exists as shown Figure 4. Unfortunately, there is no visibility of the transport mode e.g. walking, cycling or by vehicle of these entries nor whether a vehicle parked at the station or not.

Figure 5 provides a summary of the different charger connection types for all chargers with a 15 minute walk of all rail stations in Scotland. Type 2 AC connectors are evidently the most popular with 'rapid' DC CCS (Combined Charging System) and CHAdeMO having a relatively equal share.

**Algorithm 1** Monte Carlo Assessment Approach

$f: Transformers\ (T) \rightarrow Rail\ Stations\ (S)$
**for** $s \in S$ **do**
  $Obtain\ total\ number\ of\ parking\ spaces\ (P_s)$
  $t = f(s)$
  $Obtain\ maximum\ rating\ of\ transformer\ t\ (t_{max})$
  **for** $p \in Penetrations$ **do**
  $Calculate\ number\ of\ EV\ chargers\ (P_{ev} = p \times P_s)$
    **while** $i < 5000$ **do**
      Apply base demand assumption for station s
      Sample EV charging profiles based on $P_{ev}$
      Aggregate base and EV charging demand
      Calculate daily hosting capacity $(h)$
      Store $h$ for every iteration
      $i = i + 1$
    **end while**
    **return** average of $h$ for each $p$
  **end for**
**end for**

## 3. Hosting Capacity Assessment

This section describes the approach taken to assess the impact of EV charging demand on secondary transformers currently installed to meet rail station service demand. The method takes a statistical approach to EV demand modelling and a Monte Carlo impact assessment is performed to ascertain transformer hosting capacity.

### 3.1. *Methodology*

A Monte Carlo assessment technique is used with multiple iterations to account for variation in EV charging demand as summarised by Algorithm 1. The secondary transformer (typically 11 kV:400 V) associated with each rail station is first obtained. It is assumed that the sole function of the nearest secondary transformer to the rail station is to meet rail station ancillary service demand e.g. demand from electronic ticket machines and car park lighting. Therefore, the installation of any EV charging infrastructure would also be supplied accordingly. A conservative base loading of 10% of the transformer rating is assumed to account for the ancillary demand.

The total number of available parking spaces at each station is then determined as is the corresponding transformer rating. Several uptake penetration scenarios are then considered (0-100% in 20% increments). The number of EV chargers to be installed is then proportionally calculated based on the total number of parking spaces. Synthesised EV charging demand profiles are sampled and combined with the base demand to obtain a representative daily demand profile at a half hourly resolution for the site. An average daily hosting capacity for each transformer at each EV penetration level is then obtained.

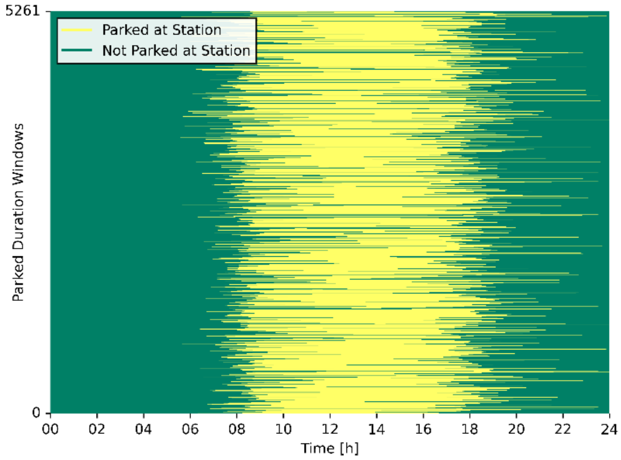


**Figure 6: Heat map showing the parked duration windows versus time.**

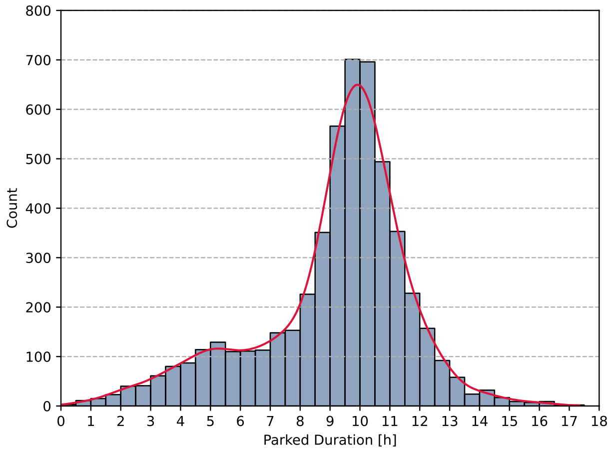


**Figure 7: Distribution of the parked duration windows.**

### 3.2. *EV Demand Modelling*

Opportunities for EV owners to plug in their vehicles for charging depends on when they start and finish their journeys and what the destinations are. These journeys also dictate what the minimum amount of energy in each charge will be. This determines the temporal pattern of electricity demand for EV charging. Therefore, to account for EV charging by consumers specifically at rail stations as part of this work, trip data recorded through the UK National Travel Survey (NTS) -- an annual household survey designed to monitor trends in personal travel which is completed by around 15,000 people in the UK each year where they record all trips taken over a 7-day period -- is used [11]. The 7-day period recorded differs between the individuals recording the data, hence minimising any bias from seasonal effects and holidays.

The NTS contains two tables of relevance to this study: a trip dataset and a stage dataset. The trip dataset contains data pertaining to the distance, duration, time/day of departure, mode of transport and trip destination. The stage dataset represents stages of those trips. In this work, outward-return trip pairs are analysed if the outward trip has a rail stage preceded by a car (driver) stage, and there exists a corresponding return trip in the same individual's travel diary with a rail trip followed by a car (driver) trip. In doing so, it is assumed that the individual's car is left at the rail station car park from the end of the first car stage to the beginning of the second car stage (i.e. that of the return trip).

A beta distribution with tuned parameters ($\alpha = 2$ and $\beta = 5$) is used to define the battery state of charge (SoC) on arrival at the rail station [12]. The maximum allowable charge gain within parked time constraints is then sought by each vehicle. This gives a modal SoC on arrival of 20% and a mean of 29%. For the vehicle battery capacity, a typical range of battery sizes (24, 30, 40, 60 and 75 kWh) obtained from existing vehicles is sampled [13]. In terms of charge point power ratings, 1.44 kW, 3.6 kW, 7.4 kW and 22 kW AC charging was considered. An inverter efficiency of 88% and a typical constant current – constant voltage charging profile for lithium-ion batteries is used to constrain charging power as described in [14].

Figure 6 shows a heat map of over 5000 parked duration windows emphasising the time at which vehicles are typically parked at rail stations. The figure highlights that the parked windows predominantly start between 06:00 – 08:30 which aligns with when commuters would typically travel for work that begins at 09:00. Figure 7 shows a distribution for these parked duration windows based on the duration of each window. The figure shows that the distribution is almost gaussian around the hours that typically align with the length of the average workday (7-8 hours) whilst factoring in commute time, though there is a slight deviation around the five hour mark.

## 4. Case Studies

Two case study rail stations and subsequent parking facilities are used to demonstrate the method in this work. They are chosen as they offer varying levels of available parking and have distinct URCs. Newton Lanark station has a total of 245 parking spaces and falls within a Large Urban Area and Bathgate station has 570 parking spaces and falls within an Other Urban Area. Figure 8 shows an aerial image for each case study rail station and their respective parking facilities. Figure 8 also highlights the nearest secondary transformer to each station where the ratings are 500 kVA and 1000 kVA, respectively.

## 5. Results and Discussion

The hosting capacity results are shown in Figure 9 and Figure 10. These figures show a comparison of installing different rated EV chargers at multiple penetrations for each of the case study rail stations. The figures highlight that as additional EV chargers are installed the transformer headroom (used analogous to hosting capacity) decreases. When the headroom is negative, this indicates that the transformer was unable to adequately satisfy charging demand and the transformer would be overloaded. The

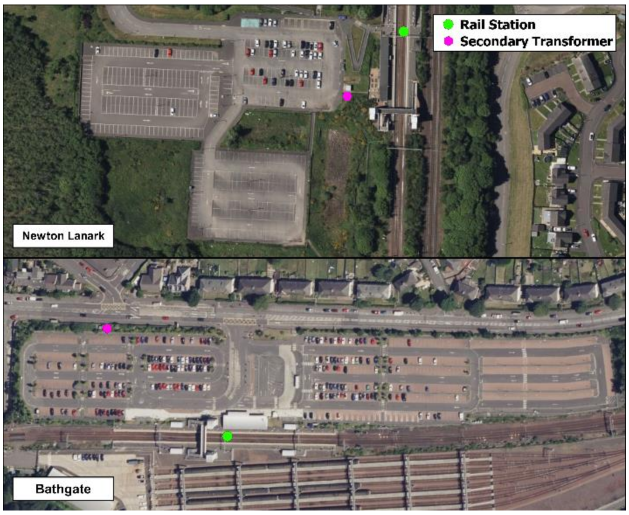


**Figure 8: Aerial imagery of both rail station case studies showing vehicle parking and their dedicated transformers.**

results indicate that in general the slow chargers have less of an immediate impact in terms of a significant morning peak and their impact is more sustained over a longer period. On the other hand, the fast chargers see a significant morning peak in comparison and cause significant overloading at high penetrations.

The results confirm that there is significant opportunity for smart charging at rail stations through scheduling or optimisation. There is also the opportunity to determine what level of electrification is necessary to fully satisfy demand through improved, ahead of need, forecasting. This will support the timely delivery of appropriate infrastructure plans and will require visibility of rail station parking usage beyond existing levels.

## 6. Conclusion

This paper has explored the challenges with electrifying rail station parking in Scotland. The work initially carries out a geospatial analysis of rail stations and existing EV charging installations to provide visibility of the current levels of electrification and to support the hypothesis that rail stations located in different geographic areas with different levels of available parking will have unique EV charging infrastructure requirements leading to varying impact on distribution networks. This is followed by a statistical hosting capacity assessment of the network infrastructure located at two case study rail station sites. This includes detailed EV demand modelling informed by rail station trip data and a Monte Carlo analysis. The findings demonstrate that the installation of higher rated fast chargers without 'smart charging' will see a significant impact on transformer hosting capacity when installation volume increases. Lower rated chargers have less of an immediate impact though tend to have high utilisation over longer periods. Planners will need to consider a blend of different charging install rates for optimum use of existing capacity and to meet unique rail station charging requirements. With this, the research presented has revealed several potential

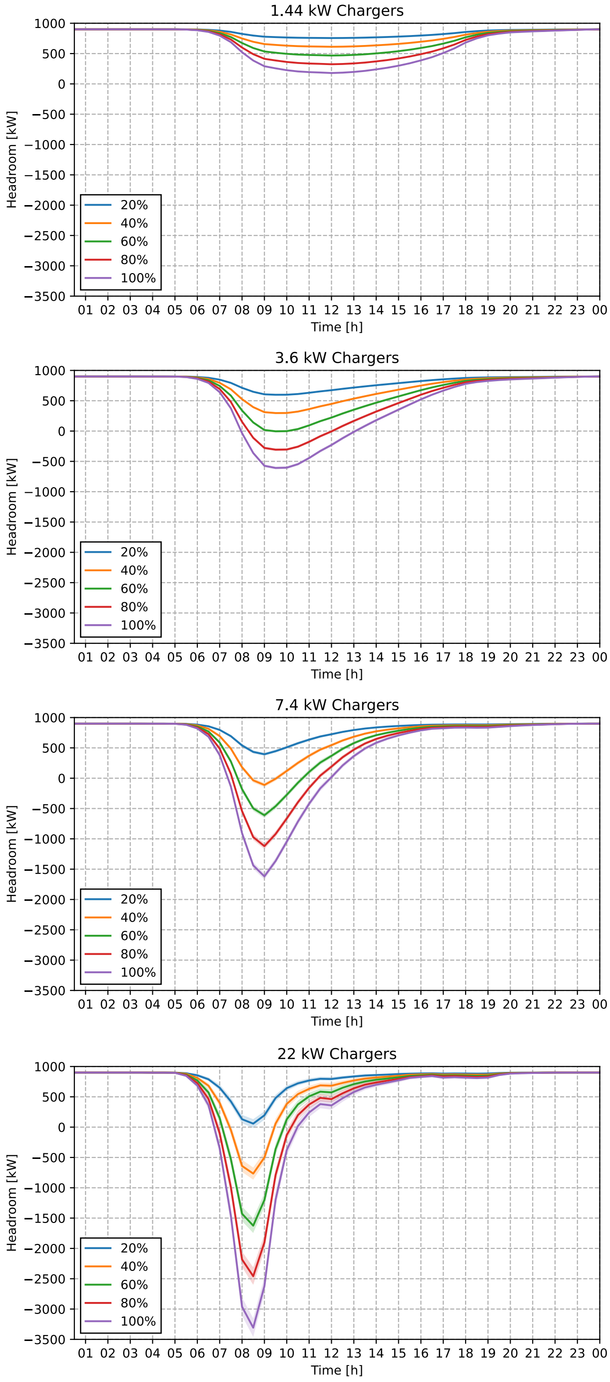


**Figure 9: Comparison of installing different rated EV chargers at multiple penetrations for Bathgate.**

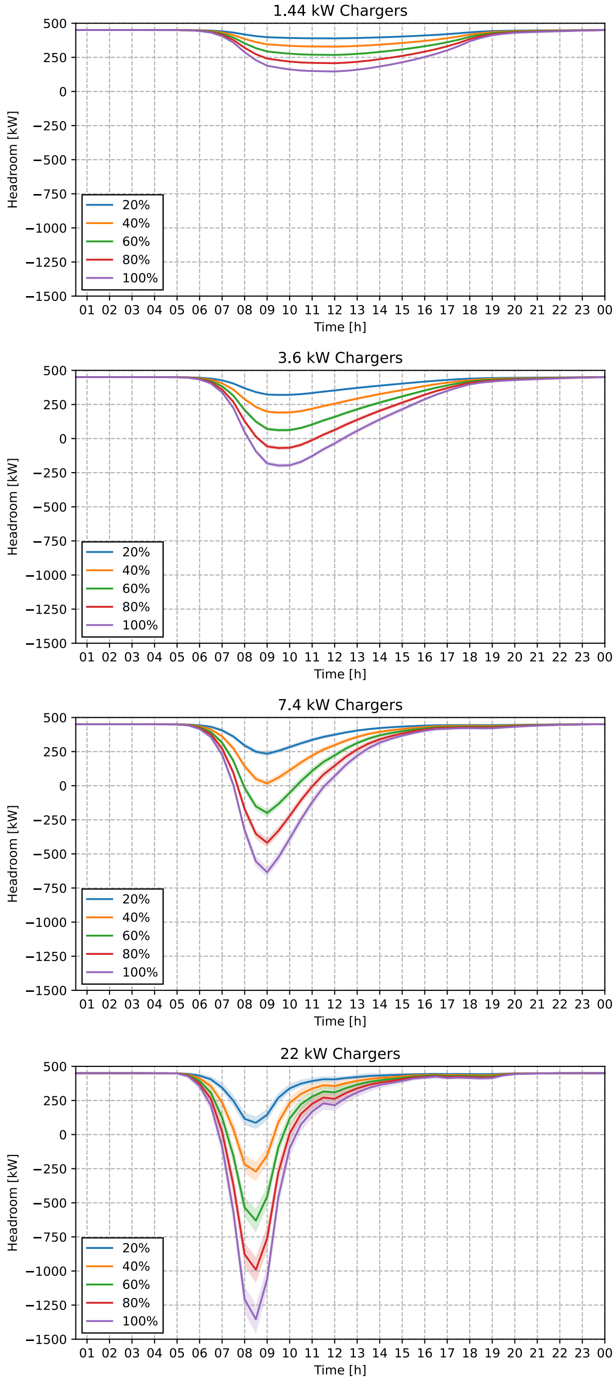


**Figure 10: Comparison of installing different rated EV chargers at multiple penetrations for Newton Lanark.**

avenues for further research that can inform decision making for local government, distribution network planners, and stakeholders in the transport sector.

## 7. Future Work

Future work would involve conducting the assessment across all rail stations in Scotland to provide ScotRail and the respective DNOs with visibility of the potential impact of rail station EV charging on distribution network infrastructure. Further research around multi-modal travel and the utilisation of rail station EV infrastructure is necessary. There remain several outstanding questions that require further exploration e.g. will rail stations in particular areas require more EV charging than others? How might this correlate with available bike storage space? Will the addition of EV infrastructure defer users from taking more sustainable healthier options such as walking or cycling when intending to travel by rail or might it encourage an uptake in rail travel as opposed to commuters driving to their end destination? What impact would an emphasis on the installation of EV charging infrastructure have on car mileage reductions targets?

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