WattRoutes: Smart Planning for Electric HGV Charging Infrastructure

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Abstract

The transition to battery electric heavy-goods vehicles (eHGV) to deliver on net-zero policies poses significant challenges to all enabling stakeholders. While the availability of eHGVs, particularly from major manufacturers, shows promise, there remains a notable gap in research and policy concerning the necessary charging infrastructure network to support eHGV operators nationwide. The major challenge associated with the transition relates to identifying areas where there is both a need for eHGV charging and suitable power network capacity to supply high-capacity chargers. A successful transition to eHGV requires a considered approach given the diverse needs of license holders and constraints in power transmission and distribution networks.

The paper presents the early-stage data sources that underpin the design of several eHGV charging infrastructure planning tools. It is believed that an open and data-driven approach with the core objectives of identifying optimal charging locations, quantifying energy requirements and assessing power grid readiness, will help stakeholders of various scales. The developed process leverages data analytics to pinpoint key routes and locations of optimized eHGV charging infrastructure.

1. Introduction

In Scotland, the UK and Internationally, the transition to battery electric heavy goods vehicles (eHGV) to deliver on net-zero policies poses significant challenges to all enabling stakeholders [1] [2]. The recent commercial availability of eHGV, particularly from major vehicle manufacturers, is promising with many 'real-world' operational case studies emerging [3] [4] [5]. While market maturity and capital costs of eHGV are currently higher than combustion engine counterparts, these costs are expected to decrease with market volume and technology improvements.

To support the uptake of eHGV, a wider research and policy gap exists and relates to the en-route charging network required to support eHGV operators across the country. This network aims to provide confidence to eHGV operators as they dispatch vehicles across wider geographic areas. It could be argued that 'obvious' locations for charging infrastructure already exist at present-day service stations across the country. However, supporting eHGV at the edge of the trunk road network and in "off-trunk-road" environments is particularly difficult as outlined by the Scottish Government's Zero Emission Truck Taskforce [6].

Ensuring 'ahead-of-need' expansion of charging infrastructure for eHGV fleet is crucial for maintaining a reliable and efficient transport network. Well-positioned infrastructure has been shown to improve user experience in the electrification of passenger vehicles [7]. Aligning infrastructure availability to coincide with regulatory working breaks, for example, may increase the productivity of workforces by minimizing operator involvement during refueling and therefore raising productivity. A well-coordinated strategy for grid expansion and charging infrastructure placement is essential for reducing environmental impacts of the sector which are estimated to be 1.83 $MtCO_2e$ in Scotland in 2021 [8].

This paper identifies relevant datasets and initial data transformations to help quantify the electrical requirements of eHGV and the associated grid-connected charging infrastructure. The approach presented is centered around publicly available data and includes traffic flow counts, governmental transport statistics, product datasheets and industry insight. This evidence-based approach allows for development of targeted charging solutions, ensuring that the infrastructure is tailored to the specific demands of the Scottish transportation landscape often characterized by small single carriageways which are slow to traverse. Utilizing datasets provided by transmission and distribution grid operators, WattRoutes will map future charging infrastructure requirements to current grid capabilities to help support network operators in their ahead-of-need planning.

2. Background

In Scotland, 90% of the 5,600 fleet license holders operate a portfolio of ten vehicles or fewer, with an additional 8% managing fleets with <50 vehicles [6]. Given that most license holders fall within the category of operating smaller fleets, it becomes crucial to implement policies and incentives that cater to these businesses' specific needs and constraints. This is vital for preventing the inadvertent exclusion of SMEs (small and medium-sized enterprises) and ensuring that the benefits of the net-zero transition are distributed equitably across the industry. A major challenge associated with the transition relates to identifying areas where there is both a need for eHGV charging but also suitable power network capacity to supply chargers from both a power and energy perspective. Therefore, a successful transition to eHGV in Scotland

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requires a considered approach given the diverse needs of license holders and constraints in power transmission and distribution networks.

In November 2021 the United Kingdom government pledged that all HGVs sold must be fully zero emission at the exhaust by 2040, and all new HGVs under or equal to the weight of 26,000 kg must be zero-emission at the tailpipe by 2035 [9]. To meet this target a mixture of technologies is expected to contribute, however, it is anticipated that battery-electric solutions will play a major role in decarbonizing tailpipe emissions of this sector. Looking back to early 2010, the focus of deploying electric passenger car infrastructure was to ensure a nationwide charging network for EV users. The deployment was broadly ad-hoc in nature. However, as the number of installed charging units increased, more targeted infrastructure deployment practices have been adopted widely by industry. Projects such as FASTER developed data-driven approaches to infrastructure deployment using open data to underpin the analysis [7].

The "WattRoutes" project leverages data analytics to pinpoint key routes and locations for the placement of optimized eHGV charging infrastructure. The project ensures that the charging infrastructure aligns with the diverse needs of operators situated both in urban and rural communities through use of rurality indexes and traffic demand data. To address the challenge of grid availability, WattRoutes assesses existing grid capacity and makes recommendations as to where transmission or distribution upgrades are required. Utilizing datasets provided by the transmission and distribution grid operators, the project ensures that the charging infrastructure aligns with the current grid capabilities, mitigating potential constraints and laying the groundwork for future developments. This approach promotes the development of a reliable and resilient charging network which can be realized through minimal grid reinforcement.

3. Modelling Approaches

Three of the modeling approaches developed through the project are outlined in this paper. This analysis looks to determine:

a) Charging infrastructure characteristics and spatial requirements,
b) Vehicle technical specifications,
c) Transport flow modeling, and,
d) Power network hosting capacity analysis.

Fig. 1 presents the topology of the motorway and major trunk roads across the Scottish mainland. The existing service stations used by HGV drivers as rest and refueling sites are also outlined in the diagram. It is worth highlighting that this paper does not include analysis of islanded communities as strategic alignment with ferry provision is expected to play a major role in island infrastructure deployment. Adjacent work in the SeaChange project is developing a time-based harbor and port toolkit which considers impacts of eHGV movements to and from port locations while also considering power-take-off loads such as reefers (Refrigerated Containers) [10].

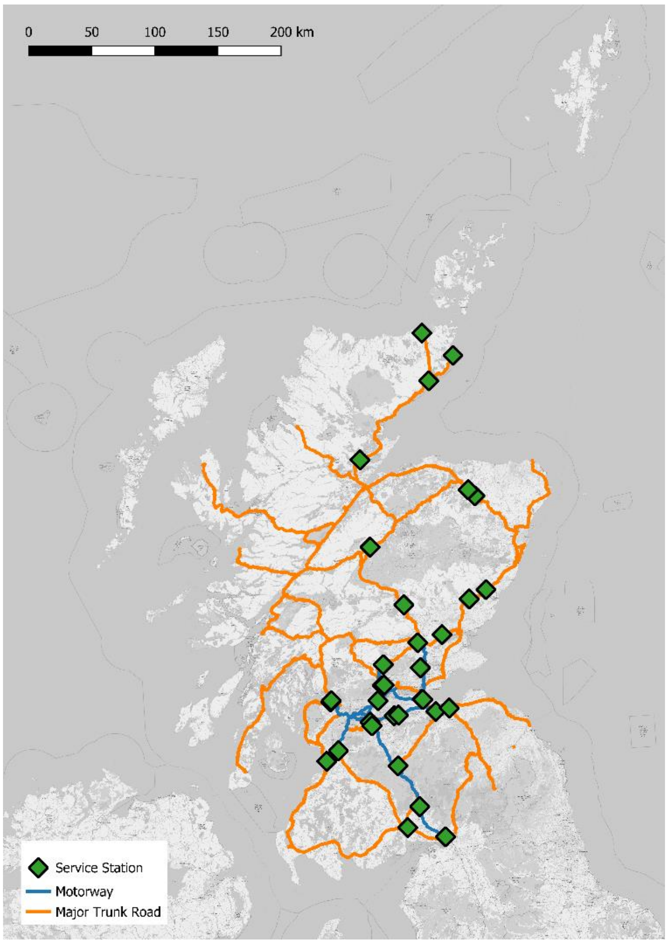

Fig. 1 Scotland motorway and major trunk road network.

3.1. *Charging infrastructure characteristics and spatial requirements*

Charging of eHGV can be broadly classified into three categories: a) overnight, b) at destination and c) en-route. Overnight charging (or charging during non-active hours) is expected to take place at depot or at designated truck stops with a charging opportunity window of 6-8 hours at a charging rate of between 50-150 kW. Destination charging is expected to have higher power requirements, with many sites settling on 150-350 kW for this application with dwell times expected for between ~1-2 hours. En-route charging is expected to have the highest power rating with between ~350-1,200 kW and charging times expected to correspond with rest breaks of 45 minutes [11]. National Grid Group has predicted 70-90% of future refueling to take place at depot [12]. En-route charging hubs will generally require dedicated grid connection due to their megawatt scale. The location of these hubs must a) balance user-convenience, b) be strategically placed to provide a true geographic spread across the country to promote the just-transition, and, c) align with power network capacity. Project experience of deploying passenger EV charging infrastructure notes grid connection capacity as the biggest cost variable between sites [13].

Table 1 summarizes the electrical parameters for a subset of DC eHGV chargers produced by two manufacturers with ratings varying from 24 kW to 1,200 kW.

A review of the spatial requirements of several eHGV charging hubs was conducted for a sample of European countries including Norway, Sweden and the Netherlands. An extract of the review for the Netherlands is presented in Table 2. Note that the smaller area-per-bay values represent sites more suited for smaller rigid eHGV charging.

Table 1 Summary of eHGV DC charging systems manufactured by Kempower [14] and DAF Paccar [15].

Manufacturer	**Name**	**Rated Power (kW)**	**Max. Current (A)**	**Max. Voltage (V)**
Kempower	Mega Satellite (MCS)	1,200	1500	1,250
Kempower	Mega Satellite (CCS2)	560	700	1,250
Kempower	Liquid Cooled Satellite	400	500	1,000
Kempower	Satellite V2	400	500	800
DAF	PacMobile 20	24	60	920
DAF	ChargeMax 50	50	125	920
DAF	ChargeMax 90	90	300	920
DAF	ChargeMax 120	120	300	920
DAF	ChargeMax 180	180	300	920
DAF	PowerChoice 350	350	500	920

Table 2 Site characteristics of selected eHGV charging hubs in the Netherlands.

Name	**Number of Bays**	**Area per Bay (m2)**	**Connectors**	**Rating (kW)**	**Energy Density (kW/m^2)**
Leap24 Schagen	6	40	6	160	4.0
FIETEN ELECTRIC	4	16	4	400	24.7
Leap24 Steenwijk	6	30	6	160	5.3
Leap24 Hoogeveen	4	30	4	120	4.0
Kriterion Studentenpomp	2	35	2	400	11.4
Leap24 Badhoevedorp	5	18	5	300	16.4
OG Hoofddorp	9	30	9	110	3.7
TotalEnergies Terschuur Palmpol	2	16	2	175	10.9
AVIA Enschede Twekkeler ES	2	35	2	400	11.4
TotalEnergies Ede - De Veenen	2	16	2	175	10.9
Greenpoint Ede	2	30	2	70	2.3
OG Nieuwendijk	1	20	1	100	5.0
Watthub Geldermalsen	36	90	36	400	4.4
Leap24 Nijmegen	8	20	8	160	4.4

3.2. *Vehicle specifications*

Table 3 presents a summary of selected technical parameters for several on-the-market and close-to-market eHGV from a selection of major manufacturers. Parameters have been extracted from manufacturer datasheets and publicly accessible technical literature. Real world ranges and efficiencies are likely to vary depending on several factors including vehicle speed, terrain, payload, weather condition etc. During modeling, additional de-rating factors are applied to account for real world efficiencies in the absence of operational data. Real world operational data is key to better understanding battery duty cycles and charging behaviors.

Table 3 Summary eHGV specifications for several manufacturers and truck sizes [16] [17] [18] [19].

Make	**Model**	**Vehicle Type (Rigid/Tractor)**	**Gross Vehicle Weight (1,000**	**Battery Capacity (kWh)**	**Range (km)**	**Efficiency (kWh/km)**
DAF	XB	R	12	141	160	0.88
DAF	XB	R	16	282	310	0.91
DAF	XF	R	29	315	290	1.09
DAF	XF	R	29	525	460	1.14
Renault	D E-Tech	R	18	565	560	1.01
Renault	D Wide E-Tech	R	26	375	315	1.19
Volvo	FH Aero Electric	T	44	540	300	1.80
Volvo	FM Low Entry	R	32	360	200	1.80
Volvo	FE Electric	R	27	375	275	1.36
Volvo	FL Electric	R	16	565	450	1.26
MAN	eTGX	T	44	400	325	1.23
MAN	eTGX	T	44	480	400	1.20
MAN	eTGX	R	28	240	195	1.23
MAN	eTGX	R	28	480	400	1.20
Mercedes Benz	eActros 300	T	19	336	220	1.53
Mercedes Benz	eActros 300	R	27	336	300	1.12
Mercedes Benz	eActros 400	R	27	448	400	1.12
Mercedes Benz	eActros 600	R	28	600	500	1.20
Mercedes Benz	eActros 600	T	22	600	500	1.20

3.3. *Transport flow modelling*

To adequately cover both geospatial and user demand across the country, several modeling approaches were considered as part of WattRoutes. While geospatial analysis promotes nationwide coverage, demand analysis is vital to ensure that there is sufficient capacity at hubs with high utilization rates. High-demand sites need to be dimensioned to reduce the probability of a driver queuing to access charging infrastructure. Queuing is dynamic and will vary across periods of the day/week/year. Table 4 presents the average annual daily HGV traffic flow for each of the 32 local authority administrative regions of Scotland. Annual Average Daily Flow (AADF) is the mean (over a full year) number of vehicles passing a point in the road network each day [20]. This dataset helps demonstrate areas of the country where higher HGV movements are currently observed in relation to a local authority population and land mass.

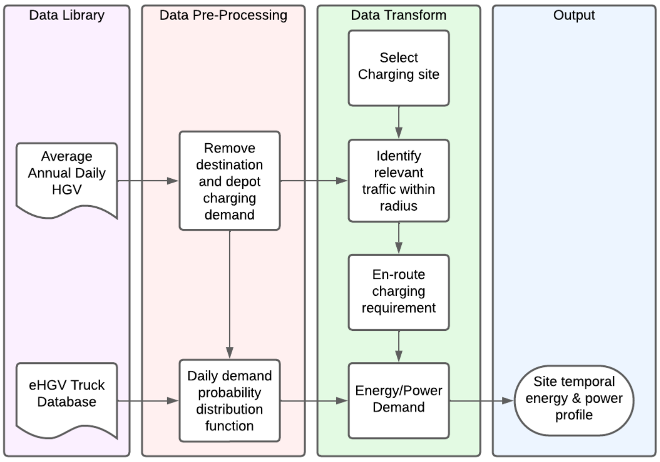

Fig. 2 Data transformation summarizing traffic flow modeling to energy and power profiles.

AAFD values are further disaggregated to a vehicle classification level for each local authority area. Table 5 presents national daily average and maximum daily distances for the six HGV body types. Probabilistic curves for each classification type were created on a regional and local level based on average and maximum daily distances travelled. Fig. 2 presets a summary of the traffic flow to electrical parameter data transformation. This transformation relies on data inputs from Table 3 - Table 5. The data in Table 3 and Table 5 suggests that the larger on-board vehicle battery capacities are approaching the range for average daily distance requirements across vehicle classifications. The upper range requirement of long-distance articulated vehicles will need to be met via en-route charging.

Table 4 Average annual daily HGV flows by local authority.

Local Authority	**Average Annual Daily Flow HGV**	**Population**	**Area (km^2)**	**Average HGV density (#/km^2)**
Aberdeen City	425	224,190	186	2.283
Aberdeenshire	191	263,750	6,313	0.030
Angus	269	114,660	2,181	0.123
Argyll & Bute	72	87,920	6,907	0.010
City of Edinburgh	531	514,990	263	2.018
Clackmannanshire	177	51,750	159	1.112
Comhairle nan Eilean Siar	28	26,120	3,056	0.009
Dumfries & Galloway	411	145,770	6,426	0.064
Dundee City	351	148,350	60	5.853
East Ayrshire	353	120,390	1,262	0.280
East Dunbartonshire	168	108,980	174	0.966
East Lothian	260	112,450	679	0.382
East Renfrewshire	408	97,160	174	2.347
Falkirk	536	158,450	297	1.805
Fife	316	371,340	1,325	0.238
Glasgow City	790	622,820	175	4.512
Highland	121	235,710	25,653	0.005
Inverclyde	156	78,340	160	0.974
Midlothian	246	97,030	354	0.694
Moray	171	94,280	2,238	0.076
North Ayrshire	151	133,490	885	0.170
North Lanarkshire	932	340,930	470	1.982
Orkney Islands	45	22,020	990	0.046
Perth & Kinross	326	151,120	5,286	0.062
Renfrewshire	549	184,340	261	2.105
Scottish Borders	125	116,820	4,732	0.026
Shetland Islands	56	23,020	1,467	0.038
South Ayrshire	251	111,560	1,222	0.205
South Lanarkshire	708	327,430	1,772	0.400
Stirling	277	92,530	2,186	0.127
West Dunbartonshire	282	88,270	159	1.772
West Lothian	479	181,720	428	1.120

Table 5 Summary of Scottish HGV population and duty cycle [21].

Vehicle Classification	**Gross Vehicle Weight (1,000 kg)**	**Proportion of HGV Fleet (%)**	**Average Daily Distance (~km)**	**Maximum Daily Distance (~km)**
Small Rigid	3.5 → 7.5	22	230	450
Medium Rigid	7.5 → 17	7	325	575
Large Rigid	17 → 25	15	325	575
Very Large Rigid	>25	21	350	575
Small Articulated	<33	5	350	675
Large Articulated	>33	30	450	800

3.4. Power network hosting capacity analysis

The power network hosting capacity analysis process is summarized in Fig. 3. The approach is outlined in more detail in [7] however the key output from this process is a ranked-order list of candidate sites for consideration which highlights the risk of a site being costly or slow to realize. On-site generation and storage options may be added to the process to reduce grid peaks.

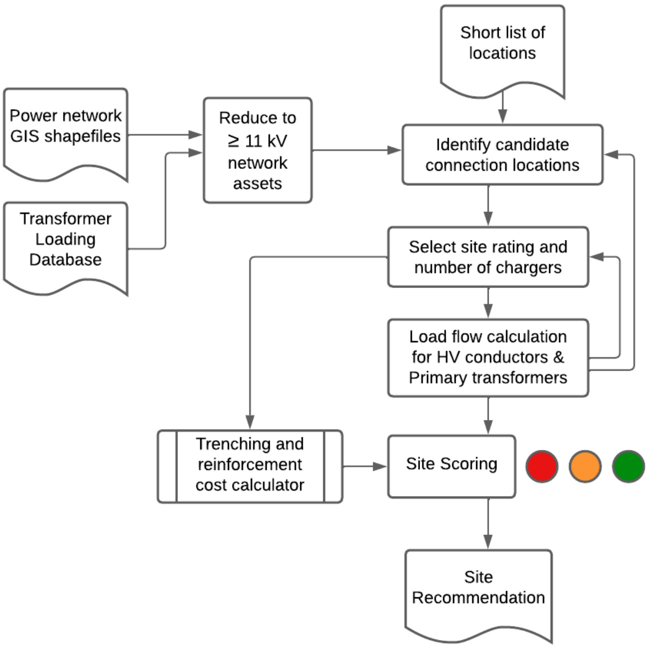

Fig. 3 Summary of power capacity assessment process.

4. Case Study

This case study provides a brief example of the coverage gained through placing HGV charging at existing rest stops on the Scottish road network. To represent driving time on maps, isochrones (iso = equal, chrone = time) are often used. Fig. 4 presents time isochrones of a HGV driving time of 1 hour from all existing rest stop sites. This process highlights several areas of the Scottish mainland that would be considered inconvenient to reach (i.e. over 1 hour drive). The developed process allows these gaps to be filled in various fashions. Noting that large lengths of the main trunk road network are not covered by one hour driving times to designated rest sites where charging infrastructure is assumed, additional eHGV charging hubs were modeled at 13 additional locations and outlined in Fig. 5. These locations were selected first through the power capacity analysis outlined in Fig. 3 to ensure that only sites capable of supporting megawatt scale charging hubs were included then secondly by the Scottish Government Urban Rural Classification 6-fold classification [22]. This classification was used to promote sites closer to more populous areas for driver safety and driver convenience considerations. The isochrone analysis was re-applied for these sites where it was found that with the additional 13 charging hubs a 100% coverage of the motorway and major trunk road network could be achieved. The selected sites are all within proximity of primary distribution capacity while being located ≤1 km from the trunk road network as demonstrated in Fig. 5.

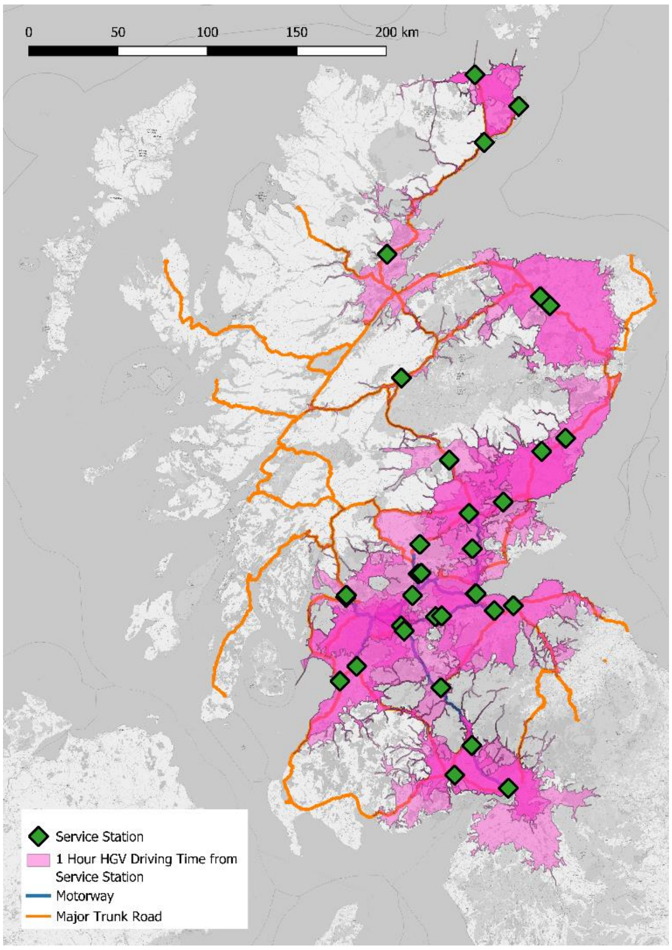

Fig. 4 Isochrones outlining 1 hour HGV driving time from service stations on the motorway and trunk road network - Scotland.

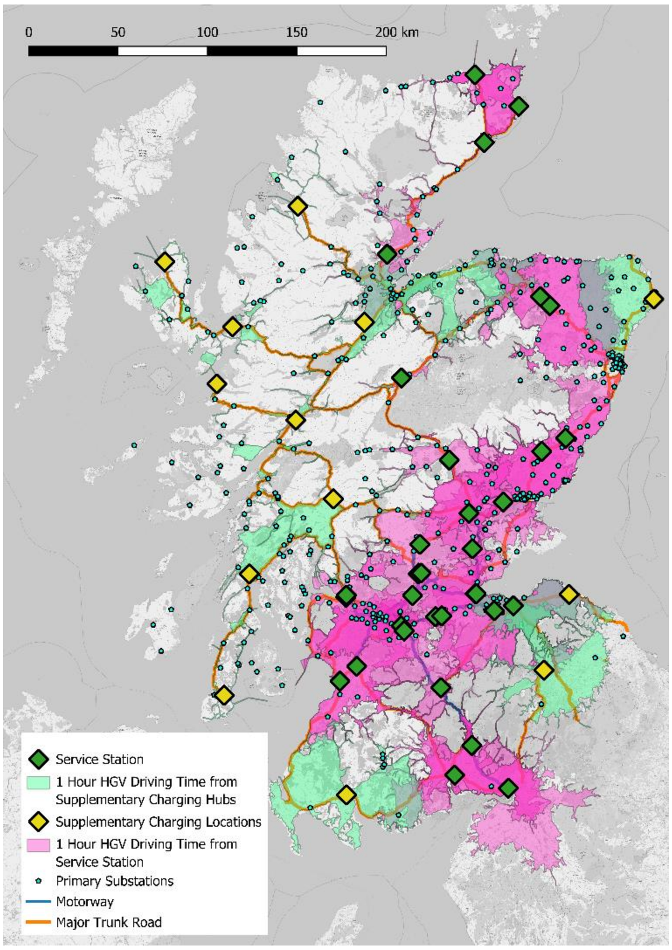

Fig. 5 Isochrones demonstrating 100% coverage with 1 hour HGV drive time with supplementary charging locations.

5. Discussion and Future Work

The work presented in this paper represents a snapshot of the initial findings for the WattRoutes project and aims to highlight relevant data sources which may be transferable to other regions. The project developed a series of practical tools to allow questions and "what-if" analysis to be conducted quickly by relevant stakeholders. Further documents relating to this project will be published in addition to this article.

Immediate next steps include ensuring that electrical capacities at existing service stations can support the anticipated demand for each site. The United Kingdom has observed several occasions in recent years that demonstrate how reliant the UK is on the haulage network and how localized issues can lead to nationwide knock-on effects [23] [24]. It is necessary that adequate volume and redundancy in design is considered when developing future eHGV charging networks.

Additional technologies such as grid-scale battery storage may also allow the optimal use of renewable resources and help balance the need for grid reinforcement and the large grid connections required to rapidly charge eHGV fleets. These solutions may feed well into service stations in Scotland which are located in more rural areas where renewable developments at a suitable scale can be developed.

6. Conclusion

The work presented in this paper summarizes elements of the WattRoutes project and outlines several data sources and transforms applied. The ability to consider multifaceted geospatial searches allows eHGV and power network planners to quickly determine optimal sites to locate charging infrastructure. Additional work developed by the project considers depot location but has been excluded from this paper for brevity purposes.

This work contributes to the innovation landscape by providing an evidence base that supports 'ahead-of-need' investment decisions for distribution and transmission network operators. Traditional infrastructure planning often reacts to increased demand, leading to potential delays and inefficiencies. WattRoutes, through its probabilistic modeling and data-driven approach, enables stakeholders to proactively plan for the anticipated uptake in demand associated with eHGV charging infrastructure.

7. Acknowledgements

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