ROAD FREIGHT ELECTRIFICATION AROUND THE WORLD USING ELECTRIC ROAD SYSTEMS

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Abstract

Electric heavy goods vehicles (HGVs) require large batteries for sufficient range, which makes them heavy and reduces their efficiency. On their own, they are unlikely to be sufficient for countries with long travelling distances in remote areas. Hence, this work investigates the feasibility and impact of electrifying heavy goods vehicles across countries using electric road systems (ERS) that use overhead catenary cables to power HGVs, thus reducing the need for very large batteries.

In this analysis, specific journeys from three countries were studied to obtain the necessary battery sizes. The journeys analysed include a long-haul international journey on the A20-H401 corridor in Canada, a single-day long-haul journey and a multi-day ‘tramping’ journey in South Africa, and three multi-drop journeys in the UK. The ERS locations in Canada are chosen along the A20-H401 corridor, while those in the UK and South Africa are based on a cost break-even study. It is shown that using the ERS results in reduced battery size requirements of less than 350 kWh for most journeys, thus reducing costs and increasing payload capacity. The ERS also supplements static charging infrastructure well for journeys that are not entirely on the ERS.

Keywords: Electric Heavy Goods Vehicles, Electric Road Systems, Dynamic Charging, Road Freight Electrification

1. Introduction

Heavy goods vehicles (HGVs), despite being small in number as compared to passenger cars, are large contributors to CO_2 emissions by road transport. HGVs account for 18% of the emissions by road transport in the UK Ainalis et al. (2020). In India, road transport contributes to around 13% of the total CO_2 emissions, of which HGVs constitute around 29% IEA (2017). Meanwhile, in South Africa, the logistics sector contributes to around 9.3% of all emissions Goedhals-Gerber et al. (2018), and HGVs constitute around 27% of road transport emissions DoT (2018). Therefore, the decarbonisation of road freight is critical to reaching global net zero goals, with a focus on long-term solutions. Some of the long-term decarbonization pathways being explored currently include green hydrogen fuel cell electric HGVs, biofuel HGVs and battery electric HGVs. However, green hydrogen fuel cell HGVs are not as efficient as battery electric HGVs in terms of 'well-to-wheel' energy and emissions (Haugen et al., 2021), and biofuel HGVs are restricted by insufficiency in the biofuel supply chain (Panoutsou et al., 2021). At the same time, battery electric HGVs require large batteries to meet their range requirements, which adds weight, cost, and embodied carbon emissions and reduces their energy efficiency (WEF, 2021).

One of the potential solutions to this problem is to construct 'electric road systems' (ERS) (Nicolaides et al., 2018) that can charge HGVs on the move, thus reducing charging stop times and battery sizes (de Saxe et al., 2022). While there are many possible implementations of ERS, it is more efficient and simpler to use overhead catenary cables that can charge HGVs through a pantograph (Gustavsson and Hacker, 2019; Navidi et al., 2016), shown in Figure 1. Such infrastructure can be easily installed on existing motorways with minimal land use for poles and substations. The pantographs can be retrofitted on electric HGVs at low cost and are retractable, thus allowing for lane changes. Consequently, the cables can have gaps to allow for overhead bridges or road signs.

While past studies have investigated the impacts and feasibility of ERS at the national level (Taljegard et al., 2019; Teixeira Sebastiani, 2020; Ainalis et al., 2022), there is a need to quantify its impact on the worldwide electrification of road freight and to understand the differences in its effectiveness in diverse geographies. Based on this motivation, this paper presents several case studies that show the impact of using ERS for road freight electrification. The impact of ERS can be investigated by estimating the battery sizes required for an HGV for specific trips with and without the ERS.

This analysis uses a drive cycle synthesiser that generates a drive cycle and a vehicle model that follows it, as done by de Saxe et al. (2022) and Deshpande et al. (2022). Locations for the ERS are used based on studies by Kayser-Bril et al. (2021) and Deshpande et al. (2023a), of which the latter highlighted locations for the ERS with an attractive cost-breakeven period. The assumptions made in this study include vehicle specifications for calculating energy consumption, which are different for the two vehicle types used in the case studies, in addition to those made for ERS locations in the respective studies.

A major contribution of this analysis is understanding how the benefits of ERS infrastructure on vehicle battery sizes vary in different countries while resulting in reduced battery size requirements for most journeys. The rest of this paper presents the methodology used for estimating energy

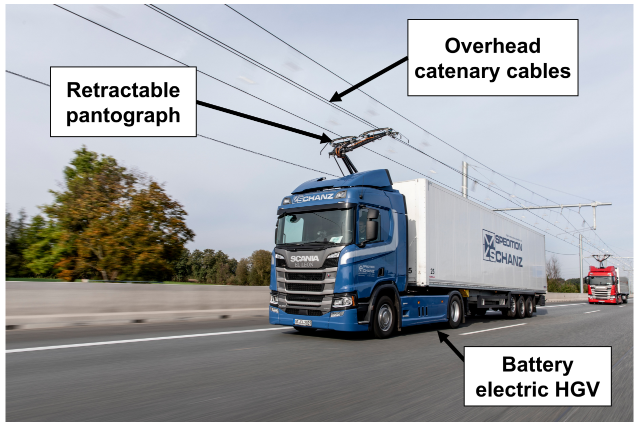

Figure 1 – Overhead catenary implementation of ERS (Siemens Mobility GmbH, 2021)

consumption and choosing ERS locations, followed by a set of case studies and conclusions drawn from them.

2. Methodology

To determine the benefits of using ERS, it is necessary to first highlight locations where it is financially feasible to construct ERS. This paper uses the methodology presented by Deshpande et al. (2023a) and the ERS locations highlighted in the same paper for the UK and South Africa. Based on the ERS locations obtained, a vehicle energy consumption model developed by Madhusudhanan and Na (2020) is used to estimate the battery sizes required for several journeys with different charging scenarios.

2.1. Battery Sizing

This analysis uses ERS locations in conjunction with the drive cycle of an HGV for a specific journey to estimate its energy consumption and required battery size. The drive cycle is generated using a drive cycle synthesiser and simulated using a vehicle model, as shown in Figure 2 and explained below.

2.1.1. Drive Cycle Synthesiser

The drive cycle synthesiser used here, developed by de Saxe et al. (2022) and used further by Deshpande et al. (2023b), uses the origin, destination and rest stops to generate a route for the vehicle using HERE Maps. It then overlays the specified ERS locations on the route to generate the desired drive cycle, a binary ERS presence signal and a charging signal. The duration of the rest stops and the type of charging available there can also be customised to add static charging to the charging signal. The information about the speed and elevation of the route along with the charging and ERS signals is then passed on to the vehicle model.

2.1.2. Vehicle Model

The vehicle model, used by de Saxe et al. (2022), is based on a battery electric bus model developed by Madhusudhanan and Na (2020) and validated by Madhusudhanan et al. (2021). The model was modified for a 44-tonne electric HGV with ERS and static charging by de Saxe et al. (2022) and validated using data from Siemens and Scania.It is assumed that the ERS supplies 300 kW of power, of which 150 kW is used to provide traction at motorway speeds of up to 90 km/h and 150 kW is used to charge the battery. The model generates a 'followed' drive cycle along with the battery state of charge (SoC) based on the HGV's energy consumption over the drive cycle and the charging opportunities. The lowest 'dip' in the SoC is used to estimate the required battery size for that journey. The drive cycles for some journeys are discussed further in the Case Studies section.

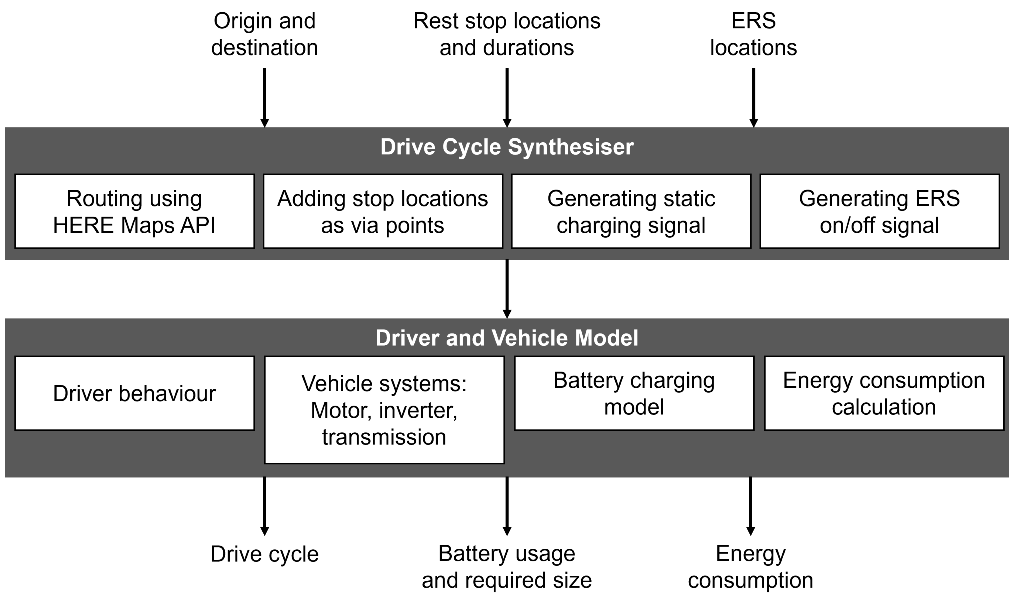

Figure 2 – Drive cycle synthesiser and vehicle model (de Saxe et al., 2022)

2.2. Data Processing

The battery size analysis is performed for three use cases in three different countries, Canada, the UK and South Africa. The data for these journeys is collected as follows. For journeys in the UK and South Africa, the data is taken from a study on fast chargers by Deshpande et al. (2023b).

1. **Canada A20-H401**
   The first case study in Canada analyses an ERS section on the A20-H401 corridor simulated by Kayser-Bril et al. (2021), which is one of the busiest freight routes in the country. It connects major Canadian cities such as Quebec City, Montreal and Toronto to major US cities such as Detroit. There is also a lot of road freight entering and exiting this corridor on the US side. The journey simulated here is from a warehouse in Montreal to another warehouse in Detroit, covering around 930 km.
2. **UK Supermarket**
   The data for the supermarket, based in the UK, was obtained from the analyses done by de Saxe et al. (2022) and Deshpande et al. (2023b). Three of their most popular multi-drop trips, originating and ending in Aylesford, were chosen for this analysis. The ERS locations chosen are based on the cost breakeven model by Deshpande et al. (2023a). Cases (a) and (b)

from the cost breakeven model for England are used here, which denote the base case and an increased electricity profit margin, respectively.

3. **South Africa Operator**
   The journey data for the logistics operator, based in South Africa, was obtained from the study by Deshpande et al. (2023b). One of the selected trips was from Durban to Johannesburg and Pretoria, which is a single-day trip, and the other was a 'tramping' journey originating in Durban as well. The ERS locations chosen are again based on the cost breakeven model by Deshpande et al. (2023a), considering cases (a) and (b) from the cost breakeven model for South Africa, that denote the base case and an increased electricity profit margin, respectively.

3. Case Studies

This section evaluates the impact of ERS on the battery sizes required for specific HGV journeys in three countries. The first case study in Canada is based on the electrification of a single corridor and its impact on international journeys on that corridor. The other two studies in the UK and South Africa consider cross-country journeys taken from Deshpande et al. (2023b). The ERS networks are derived from a cost breakeven analysis by Deshpande et al. (2023a).

3.1. Canada A20-H401

The journey chosen for this analysis is shown in Figure 3. The battery sizes required for this journey are estimated for three scenarios – no charging, one charging stop and ERS charging. The vehicle parameters used for this simulation are for a 36T Class 8 truck 'Tesla Semi', with a motorway cruising speed of 100 km/h. Since this truck has lower aerodynamic drag compared to a standard 44-tonne HGV, the drag coefficient is chosen as 0.36 (CleanTechnica, 2022).

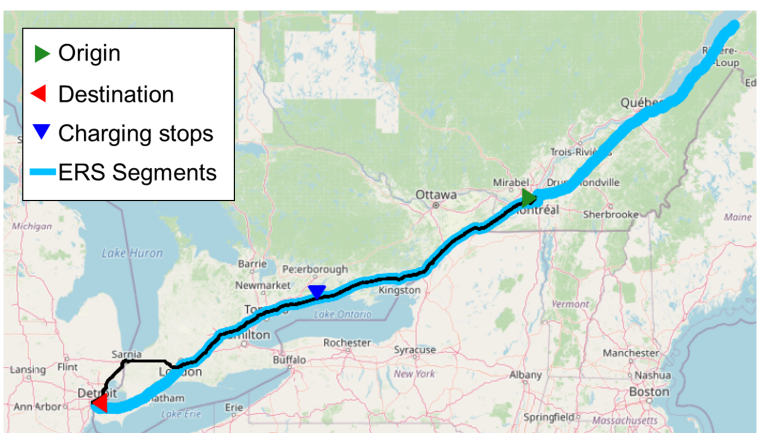

Figure 3 – Simulated journey on the A20-H401 corridor in Canada

The simulated battery dip profiles for the three scenarios are shown in Figure 4 with the generated drive cycle and elevation profile. When there is no charging during the journey, the battery dips continuously. The static charging stop is placed midway through the journey at a Tesla supercharger such that the battery size required does cross 850 kWh. This represents a current possible approach to charging but also results in a 1-hour increase in the journey time due to the added charging stop. When there is ERS on the A20-H401 corridor, this journey can be completed within the same time as a diesel HGV, and with a smaller battery size requirement.

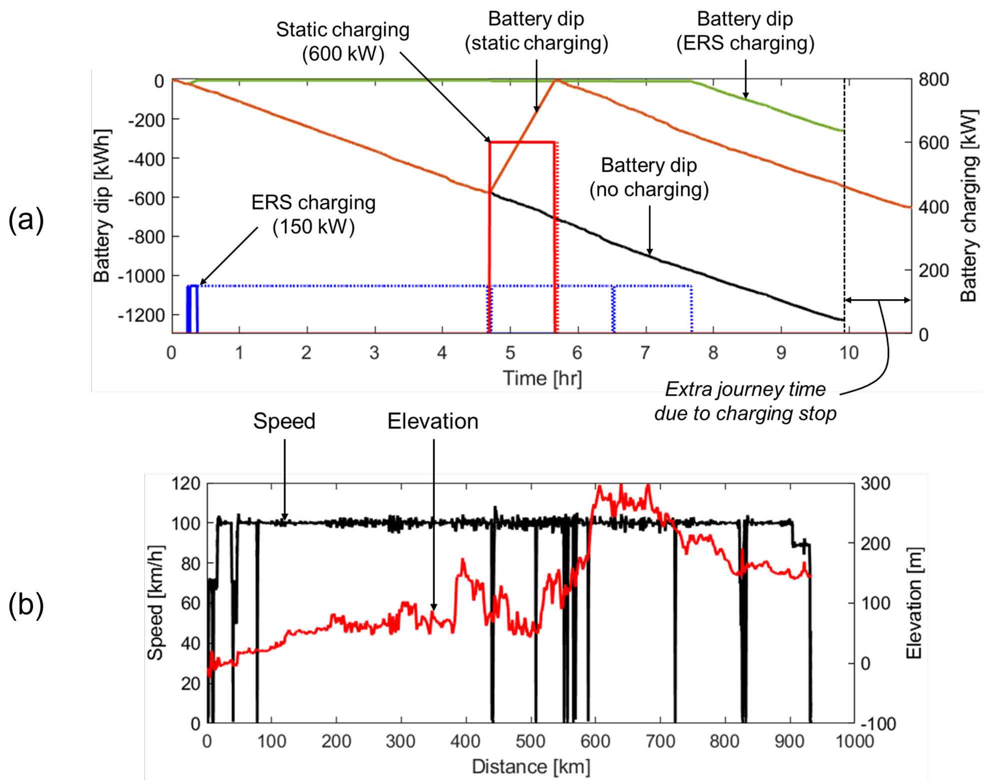

Figure 4 – (a) Battery dip and charging profiles, and (b) drive cycle speed and elevation profiles for the simulated journey on the A20-H401 in Canada

The battery sizes required in these scenarios along with the maximum payload that can be carried with that size of battery are shown in Table 1. The battery size needs to be chosen such that it only dips to around 80% of its maximum capacity. Hence, the required battery size is obtained by dividing the largest dip by 0.8. The maximum payload is calculated by subtracting the weights of the tractor (without the battery), the battery and the empty trailer from the gross vehicle weight, which is 36 tonnes. The weight of the tractor is 12 tonnes and that of the empty trailer is 4 tonnes (InsideEVs, 2022). The weight of the battery is calculated using the energy density of a Tesla battery, which is 0.186 kWh/kg (Tesla, 2022).

As seen in Table 1, using the ERS on this corridor results in a reduced battery size and smaller journey time compared to the static charging scenario. This also results in reduced costs and battery weight, thus resulting in an increased payload capacity of almost 3 tonnes. While many journeys on this corridor may originate or end on it, adding ERS there can similarly help electrify other journeys that enter or exit the corridor.

Table 1 – Battery size requirements and payload capacity for the journey in Canada

Charging Scenario	Required Battery Size (kWh)	Battery Weight (tonnes)	Max Payload (tonnes)	Journey Time (min)
No charging	1538	8.2	16.3	596[#]
Static charging (SC)	818	4.5*	20*	656
ERS charging	325	1.4	22.8	596[#]

*assuming an 850 kWh battery with the current charging strategy, [#]similar to diesel HGV assuming no other stops.

3.2. UK Supermarket

The battery size analysis for a supermarket in the UK is done for three 'multi-drop' journeys originating and ending at their depot in Aylesford, shown in Figure 5. Journey #1 is from Aylesford - Eastbourne - Lewes - Marylebone - Aylesford, Journey #2 from Aylesford - Bloomsbury - Kensington Gardens - Ramsgate - Aylesford and Journey #3 from Aylesford - Saxmundham - Woodbridge - Kingston - Aylesford. Journeys #1 and #2 only have drop-off stops. Journey #3 also has a rest stop on the last trip, as regulations require drivers to rest for 45 minutes after 4.5 hours of driving. The vehicle model is calibrated to suit a 44-tonne 6-axle HGV travelling at motorway speeds of 90 km/h, as done by de Saxe et al. (2022). The battery sizes required for each of these journeys

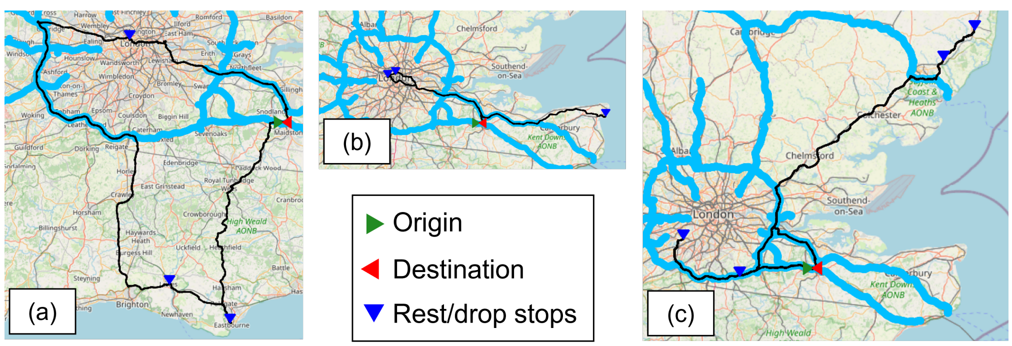

Figure 5 – (a) Journey #1, (b) Journey #2 and (c) Journey # for the UK supermarket

are shown in Table 2 for ERS scenarios (a) and (b). It can be seen that with the ERS and charging at drop locations, the largest battery size required is around 226 kWh, which is a feasible battery size. The ERS configuration does affect journey #3 significantly as new additions in scenario (b) overlap the route taken. Only charging the vehicle at the rest stop is not enough for a small battery, as the rest stop is towards the end of the journey. Different rest stop strategies such as splitting the rest stop into two may be explored to utilise the stop periods better, such that one of the rest stops occurs earlier in the journey.

3.3. South African Operator

For this analysis, two journeys are selected from those of a fleet operator in South Africa: a single-day journey from Durban to Pretoria via Johannesburg, and a multi-day 'tramping' journey. The vehicle parameters are assumed to be the same as that in the UK, for a 44-tonne 6-axle HGV.

Table 2 – Battery size requirements for multi-drop supermarket journeys in the UK

Journey	**Battery size (kWh)**					
	No charging	**ERS**	**SC**	**ERS + SC**	**DC**	**ERS + DC**
ERS case (a)						
Journey #1 (UK)	818	456	–	–	336	223
Journey #2 (UK)	700	230	–	–	310	99
Journey #3 (UK)	1152	475	847	475	466	226
Required battery size	1152	475	1152	475	466	226
ERS case (b)						
Journey #1 (UK)	818	413	–	–	336	223
Journey #2 (UK)	700	230	–	–	310	99
Journey #3 (UK)	1152	172	847	172	466	79
Required battery size	1152	413	1152	413	466	223

SC: static charging at rest stops, DC: static charging at drop locations.

The single-day journey, shown in Figure 6, originates in Durban and ends at Pretoria. It uses the 'N3' highway and is one of the most frequent trips for this operator. It has two rest stops along the way to Johannesburg, the first one for 30 minutes and the second one for 15 minutes. It then has a drop-off stop in Johannesburg for 2 hours, before proceeding to end the journey in Pretoria.

Figure 6 – Journey #1 for the logistics operator from Durban to Pretoria via Johannesburg with ERS case (a)

The multi-day tramping journey, shown in Figure 7 has one 15 minutes rest stop on day 1 and four rest stops of 15 minutes each on day 2. On day 3, the first 3 rest stops are 15 minutes each and the final one is for 1 hour, and on day 4, both rest stops are for 15 minutes each.

The results with the required battery sizing for different charging cases for journey #1 of the logistics operator are shown in Table 3 for ERS scenarios (a) and (b) from Deshpande et al. (2023a). The results are only represented in terms of the battery sizes here as other benefits such as reduced journey times and increased payload capacities would follow, as seen in the previous study.

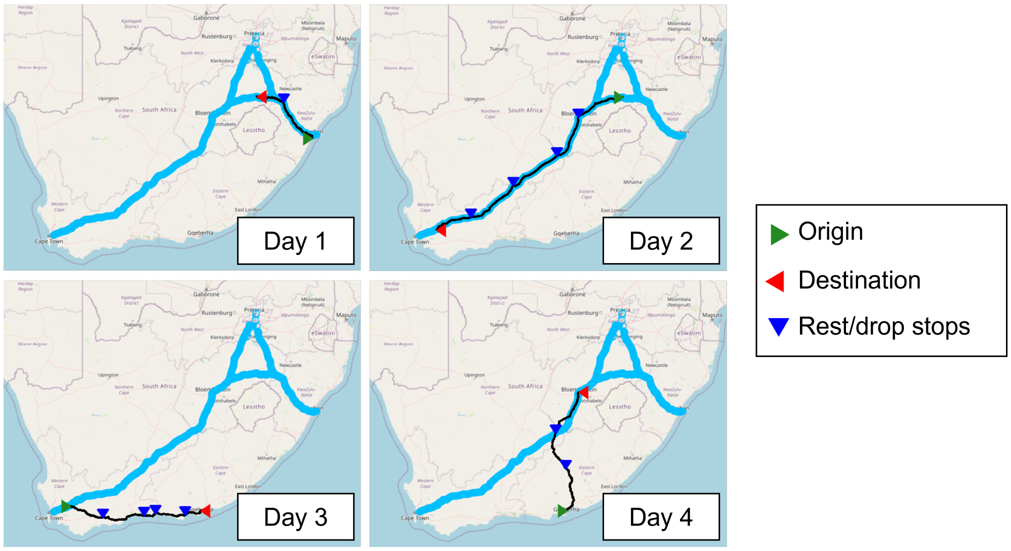

Figure 7 – Journey #2 over 4 days for the logistics operator in South Africa with ERS case (a)

As seen in the table, when there is no ERS, the battery sizes even with static charging exceed 1000 kWh, which is not a feasible battery size for an electric HGV. Rest stop charging does not have an impact when there is ERS in both cases, as the ERS keeps the battery fully charged. Charging at the drop-off point in Johannesburg reduces the required battery size further to 147 kWh with ERS scenario (a). In ERS scenario (b), the battery size remains at 95 kWh even with drop charging as there is ERS on the Johannesburg-Pretoria section as well.

Table 3 – Battery size requirements for journey #1 of the logistics operator in South Africa

Journey #1 (South Africa)	Battery size (kWh)					
	No charging	**ERS**	**SC**	**ERS + SC**	**DC**	**ERS + DC**
ERS case (a)						
Durban - Johannesburg - Pretoria	1708	193	1138	193	1534	147
ERS case (b)						
Durban - Johannesburg - Pretoria	1708	95	1138	95	1534	95

SC: static charging at rest stops, DC: static charging at drop locations.

The battery sizes required for the multi-day tramping journey are shown in Table 4. As seen in the table, the trips on days 1 and 2 are almost entirely on the ERS in both scenarios, (a) and (b). Hence, the required battery size is less than 50 kWh with the ERS in both cases and is not influenced by the addition of static charging. In the absence of ERS, the battery sizes exceed 900 kWh even with static charging, which is not a feasible size.

The trips on day 3 of the tramping journey are entirely off the ERS. Adding rest stop charging halves the battery size required to 726 kWh. Meanwhile, the smallest battery required for the trips

Table 4 – Battery size requirements for journey #2 of the logistics operator in South Africa

Journey #2 (South Africa)	Battery size (kWh)					
	No charging	ERS case (a)	ERS case (b)	SC	ERS (a) + SC	ERS (b) + SC
Day 1: Durban - Bethlehem	1139	50	50	949	50	50
Day 2: Bethlehem - Worcester	2116	20	20	1355	20	20
Day 3: Worcester - Port Elizabeth	1472	1472	1472	726	726	726
Day 4: Port Elizabeth - Bloemfontein	1589	1320	1177	1209	942	799
Required battery size	2116	1476	1476	1355	942	799

SC: static charging at rest stops.

on day 4 is 799 kWh with ERS scenario (b) and rest stop charging. While these battery sizes are not entirely unfeasible, the required battery is still very large and adds significant weight. These off-ERS trips may need the addition of either biofuel-based range extenders or more frequent charging stops, thus enabling the use of smaller batteries there.

4. Conclusions

This paper evaluated the impact of ERS on the electrification of road freight in terms of the battery sizes required for electric HGVs. It was shown that using the ERS in addition to static charging helps reduce the battery sizes required for most types of journeys. Different types of journeys in Canada, South Africa and the UK such as single-day long-haul, tramping and multi-drop were analysed and compared. It was seen that while the benefits of static charging depend on the locations of rest stops, using the ERS results in the reduction of battery sizes whenever a trip passes through the ERS network.

Using the ERS on the A20-H401 corridor in Canada eliminated the need to stop and charge, thus reducing journey times while also increasing payload capacity by as much as 3 tonnes. The journeys on the ERS in South Africa were seen to need batteries smaller than 100 kWh. For the parts of the journeys that were outside the ERS, the requirement reached higher than 700 kWh, for which an HGV would require a range extender or more charging stops to maintain small batteries. On the other hand, since the ERS network in England was spread across a large part of the road network, the required battery sizes remained low, i.e., around 200 kWh, for all the day-long trips analysed here. This shows the benefits of using ERS in all the countries while also showing a variation in how strategies for decarbonising road freight would differ across geographies and economies.

This study provides insight that supports the installation of ERS in both developed and developing countries, as well as countries with diverse geographies and freight types. It motivates the development of a universal solution for electrifying HGVs with a common modular platform that can serve different markets. While battery technology may undergo significant developments in the future in terms of size and weight reduction, long-range battery electric HGVs will continue to benefit from dynamic charging techniques like the ERS as the battery capacity needed will remain proportional to the journey length. It remains to be seen in further research what the practicalities of such an implementation look like, such as studying the impact of an ERS network on both logistics operations and vehicle manufacturers.

5. Acknowledgement

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6. References

- Ainalis, D., Thorne, C., and Cebon, D. (2020). White Paper: Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost. Technical report, The Centre for Sustainable Road Freight.
- Ainalis, D., Thorne, C., and Cebon, D. (2022). Technoeconomic comparison of an electric road system and hydrogen for decarbonising the UK's long-haul road freight. *Research in Transportation Business and Management*, page 100914.
- CleanTechnica (2022). How Pepsi's Tesla Semis Will Change Hauling. `https://cleantechnica.com/2022/12/10/how-pepsis-tesla-semis-will-change-hauling/` [Accessed 30-04-2023].
- de Saxe, C., Ainalis, D., Miles, J., Greening, P., Gripton, A., Thorne, C., and Cebon, D. (2022). Vehicle and charging requirements for an electrified road freight system demonstrator in the UK. *Proceedings of the Transport Research Arena*. [Accepted].
- Deshpande, P., de Saxe, C., Ainalis, D., Miles, J., and Cebon, D. (2022). Accelerating road freight electrification in various countries using electric road systems. In *9th International Workshop on Sustainable Road Freight, Cambridge, UK*. The Centre for Sustainable Road Freight. `https://www.csrf.ac.uk/9th-international-workshop-on-sustainable-road-freight/`.
- Deshpande, P., de Saxe, C., Ainalis, D., Miles, J., and Cebon, D. (2023a). A Breakeven Cost Analysis Framework for Electric Road Systems. *Transportation Research Part D: Transport and Environment*.
- Deshpande, P., de Saxe, C., Ainalis, D., Miles, J., and Cebon, D. (2023b). Analysis of Fast Charging Arrangements for Electric Heavy Goods Vehicles. *IEEE 26th International Conference on Intelligent Transportation Systems (ITSC)*.
- DoT (2018). Green Transport Strategy for South Africa: (2018-2050). Technical report, Department of Transport.
- Goedhals-Gerber, L., Freiboth, H., and Havenga, J. (2018). The Decarbonisation of Transport Logistics: A South African Case Study. *Southern African Business Review*, 22.
- Gustavsson, M. G. H. and Hacker, F. (2019). Overview of ERS concepts and complementary technologies. Technical report, CollERS: Swedish-German research collaboration on Electric Road Systems.
- Haugen, M. J., Paoli, L., Cullen, J., Cebon, D., and Boies, A. M. (2021). A fork in the road: Which energy pathway offers the greatest energy efficiency and CO2 reduction potential for

low-carbon vehicles? *Applied Energy*, 283.

- IEA (2017). CO2 Emissions from Fuel Combustion. Technical report, International Energy Agency.
- InsideEVs (2022). How Much Does Tesla Semi Weigh Without A Load? `https://insideevs.com/news/624326/tesla-semi-weight-no-load/` [Accessed 30-04-2023].
- Kayser-Bril, C., Ba, R., Whitmore, J., and Kinjaparu, A. (2021). Decarbonization of long-haul trucking in Eastern Canada – Simulation of the e-Highway technology on the A20-H401 highway corridor. Technical report, CPCS and Chair in Energy Sector Management, HEC Montréal.
- Madhusudhanan, A. K., Ainalis, D., Na, X., Garcia, I. V., Sutcliffe, M., and Cebon, D. (2021). Effects of semi-trailer modifications on HGV fuel consumption. *Transportation Research Part D: Transport and Environment*, 92:102717.
- Madhusudhanan, A. K. and Na, X. (2020). Effect of a Traffic Speed Based Cruise Control on an Electric Vehicle's Performance and an Energy Consumption Model of an Electric Vehicle. *IEEE/CAA Journal of Automatica Sinica*, 7(2):386–394.
- Navidi, T., Cao, Y., and Krein, P. T. (2016). Analysis of wireless and catenary power transfer systems for electric vehicle range extension on rural highways. In *2016 IEEE Power and Energy Conference at Illinois, PECI 2016*. Institute of Electrical and Electronics Engineers Inc.
- Nicolaides, D., Cebon, D., and Miles, J. (2018). Prospects for Electrification of Road Freight. *IEEE Systems Journal*, 12(2):1838–1849.
- Panoutsou, C., Germer, S., Karka, P., Papadokostantakis, S., Kroyan, Y., Wojcieszyk, M., Maniatis, K., Marchand, P., and Landalv, I. (2021). Advanced biofuels to decarbonise European transport by 2030: Markets, challenges, and policies that impact their successful market uptake. *Energy Strategy Reviews*, 34.
- Siemens Mobility GmbH (2021). eHighway – Solutions for electrified road freight transport. `https://press.siemens.com/global/en/feature/ehighway-solutions-electrified-road-freight-transport` [Accessed 20-07-2022].
- Taljegard, M., Thorson, L., Odenberger, M., and Johnsson, F. (2019). Large-scale implementation of electric road systems: Associated costs and the impact on CO2 emissions. *International Journal of Sustainable Transportation*, 14(8):606–619.
- Teixeira Sebastiani, M. (2020). *Impacts of electric highways for heavy-duty trucks*. PhD thesis, UC Irvine.
- Tesla (2022). Tesla Model S Data Sheet. `https://dis.epa.gov/otaqpub/display_file.jsp?docid=54291&flag=1` [Accessed 30-04-2023].
- WEF (2021). Road Freight Zero: Pathways to faster adoption of zero-emission trucks. Technical report, World Economic Forum. `https://www3.weforum.org/docs/WEF_RFZ_Pathways_to_faster_adoption_of_zero_emission_trucks_2021.pdf`.