Battery electric vehicles' contribution to the viability of charging from below electric road system based on individual driving patterns

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Battery electric vehicles' contribution to the viability of charging from below electric road system based on individual driving patterns

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Summary

This study uses detailed driving patterns to model the benefits of implementing an Electric Road System (ERS) in Sweden with charging from below technology that is usable by passenger Battery Electric Vehicles (BEVs). This technology would increase the utilization of ERS infrastructure and possibly lead to significant cost savings in BEVs by enabling smaller batteries. Our results show that the required average battery capacity could drop up to 76 % and the expected savings of using smaller batteries range between 0.17 and 6.5 M€/ERS km for a total of 2900-9300 M€. The economic net benefit is heavily dependent on the percentage of cars switching to BEV and ERS placement.

1 Research Questions

Electrifying freight, particularly the long-haul trucks whose growth and greenhouse gas (GHG) emissions that have grown rapidly over the past few decades, has few viable options. Charging From Below (CFB) on Electric Road System (ERS), either conductive or inductive, although less well established, has the advantage of providing charging to passenger battery electric vehicles (BEVs). Overhead line technology, on the other hand, serves only heavy vehicles and buses. The expected ERS infrastructure cost using overhead conductive lines is about 1 M€/ km [1], while it ranges between 0.4-2.7 M€/km for rail and inductive technologies [2, 3, 4]. The difference between the two options might be huge in some cases. However, selecting a technology that benefits more vehicle types is attractive, especially when the benefits are large. For instance, the charging of passenger cars along the road would increase the utilization of ERS infrastructure and electric vehicles and therefore strengthen their economic standing. A second advantage is that it may enable smaller batteries in battery electric vehicles (BEV), or increase the electric drive fraction and utilization of the already reasonable small battery in Plug-in Hybrid Electric Vehicles (PHEV). For passenger cars, CFB on ERS could be an alternative to fast charging stations, especially for longer trips.

Therefore, there is a crucial societal choice to be made for infrastructure for possible electric roads: either the more established overhead technique servicing only the heavy traffic and busses or utilize CFB to include passenger vehicles. To make a deliberate and good choice good assessment is needed. For that purpose, several ERS assessments including BEVs have been conducted earlier on the effect on the BEV charging and battery size due to ERS, such as [5, 6, 7, 8]. However, they were based on some general assumptions only. Thus, to our knowledge, there has not been any research on the effects and implications of BEV charging on ERS based on real driving of individual vehicles. This work will contribute to the assessment of BEVs in the CFB alternatives based on individual real car movement patterns. Primarily, this research aims to investigate specifically the BEV contribution to the viability of CFB on ERS based on individual real movement patterns for representative passenger cars in Sweden. The research identifies benefits to passenger BEVs by assessing possible reduction in battery capacity while meeting all driving needs. The research also examines the cost savings of reduced battery capacities with ERS.

2 Methodology

The research inspects the expected BEV usage of ERS by modelling individual driving patterns. The research utilizes GPS loggings for 412 cars with data loggings for 30 days or more. They are extracted from the Swedish car movement database [9] measured between 2010-2012. The database contains the use of cars representative in car size and fuel types in Western Sweden, which is a representative part for all Sweden in urban and rural areas, city and household size, and population density. The loggings are filtered and projected on the road network. To explore the full potential benefits of ERS, BEVs are assumed to be charged (besides on ERS) at home or overnight only. Single trips are therefore regrouped to represent a “Daily Driving” (DD) with a full battery charge at the start of driving. A temporal approach is followed to group the trips: trips are grouped if the parking time in between does not exceed 1) 10 hours or 2) 8 hours if the parking time includes 03:00 am. The procedure resulted in 20,411 DDs with mean travel time and distance of 63 minutes and 54 km, respectively

For simplicity, all BEVs are assumed to use 0.18 kWh/km independent of for instance road conditions and traffic, load and weather. This corresponds to the average energy use in a larger Swedish EV trial using VW e-Golf.

ERS is assumed to be installed on the Swedish European (E) and National (N) roads, both of which represent 4% of the total road network in Sweden. Six ERS cases that include different lengths and traffic distributions are investigated: all E roads alone, all N roads alone, and also 25%, 50%, 75% and 100% of road lengths of both E and N roads, prioritized by traffic volume (Figure 1). The study inspects three different charging rate options while using ERS: 1.0, 1.5 and 2.0 times the assumed BEV specific energy use of 0.18 kWh/km.

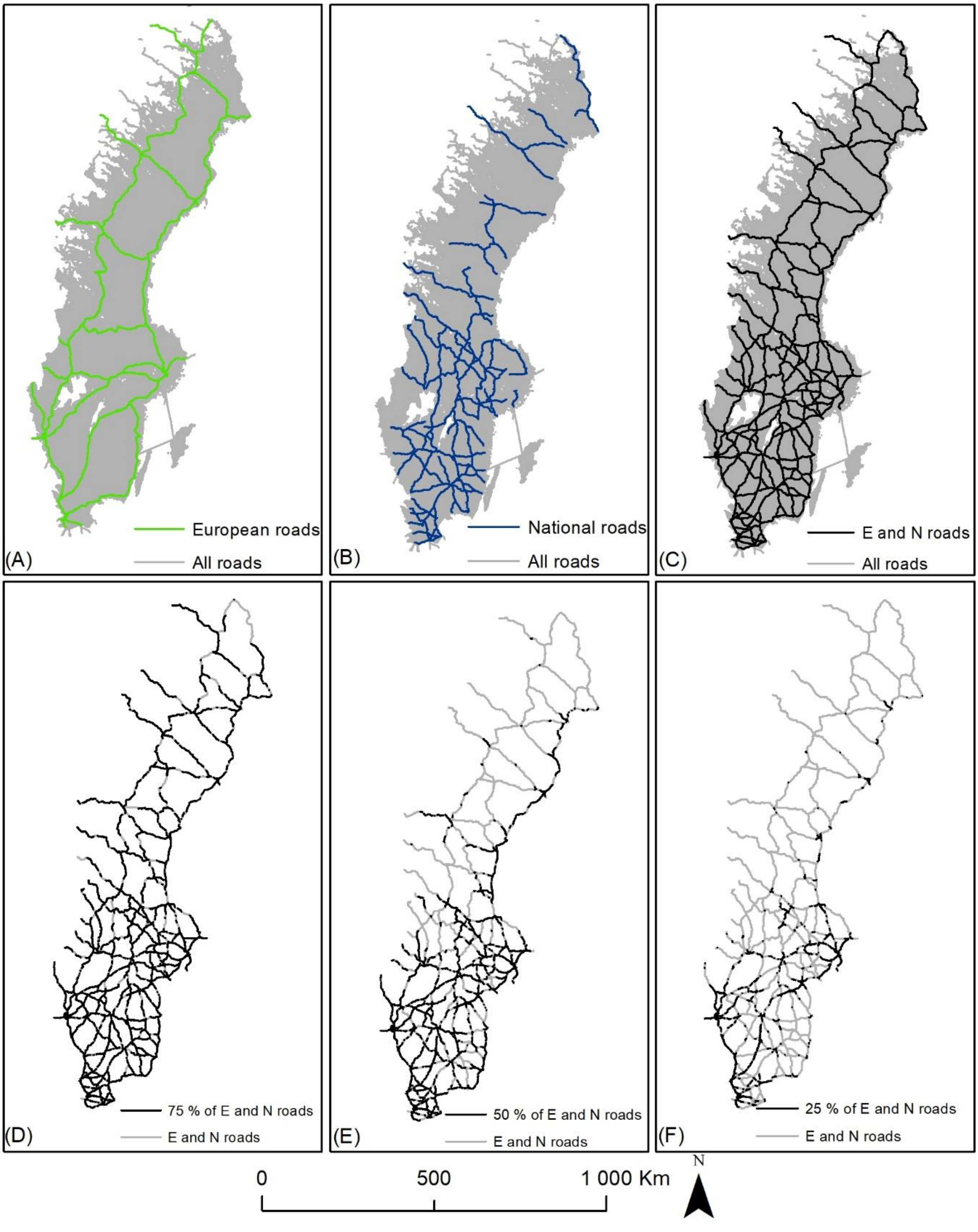

Figure 1 (A) *Swedish European (E),* (B) *national (N) roads, and* (C-F) *100%, 75%, 50% and 25% shares of E and N roads together, prioritized by traffic volume.*

3 Results

ERS utilization

As expected, the analysis shows that applying ERS to more road lengths increases the coverage of DD with ERS. However, even though both E and N roads have equal lengths, their covered DD with ERS were very different. More specifically, using 50% traffic-selected lengths of both E and N roads results in higher coverage of ERS distance compared with 100% E or 100% N only, which shows the importance of considering both the lengths and traffic while placing ERS.
Primarily, both short and long (over 150 km) distances of DD were covered by ERS. However, long DD distances benefited the most from ERS. For instance, using 100% of both E and N roads covered almost 100% of DD. while using 25% of both E and N roads covered less than 30% of long DD.

Effects of battery size

With a small battery, not all DDs can be fulfilled. When no ERS is assumed, utilizing battery capacities of 10,15, 30 and 85 kWh, leaves 31%, 19%, 5.6% and 0.34%, respectively, of the DD distances not completed (Figure 2). However, with ERS, the not-completed distances of DD drop significantly with utilized battery capacity (Figure 2). For instance, using 100% of both E and N as ERS, a 10-kWh battery fulfills more than 96% of DD distances. On the other hand, using only 25% of E and N as ERS, a 30-kWh battery could complete more than 99.5% of DD distances. We can also note that the resulting non-completed DD differ only slightly between the three considered charging options (Figure 2).

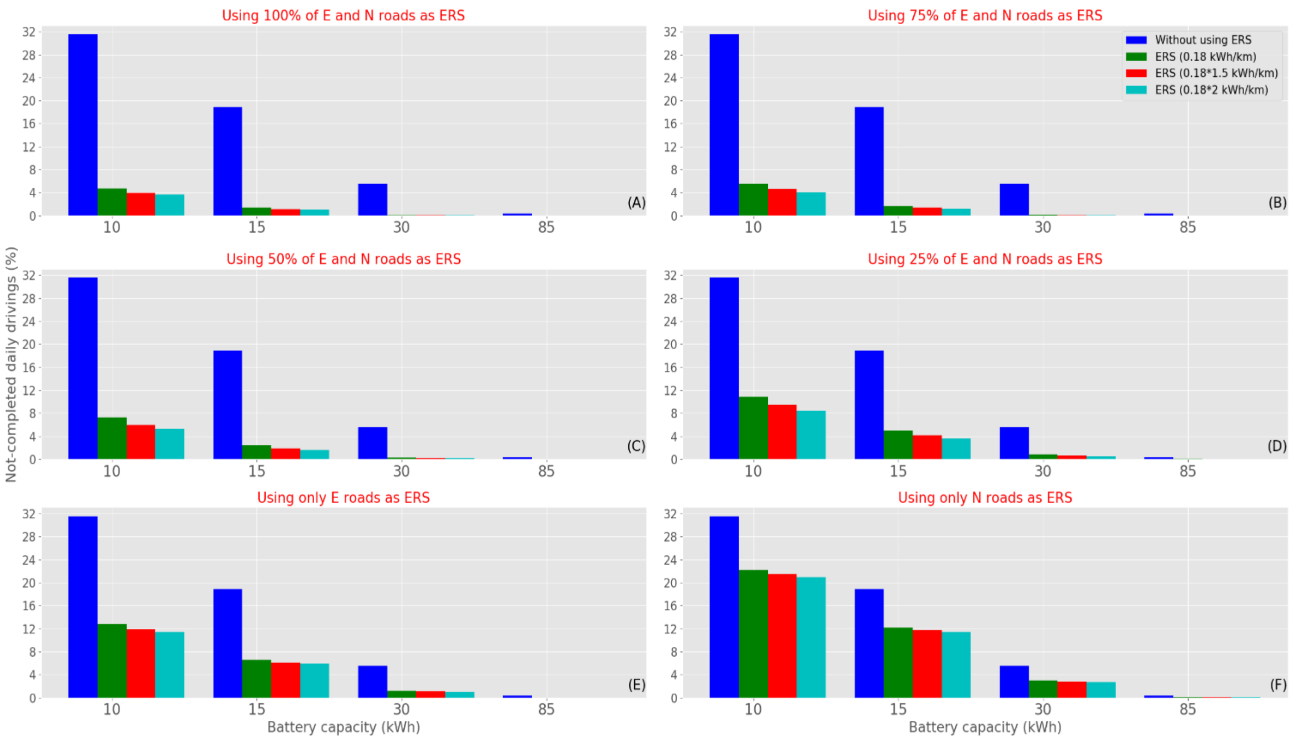

Figure 2 Not-completed share of DD distances for different ERS scenarios A)-F) and different battery sizes (x-axis).

Possible reduction in battery capacity

The study also investigates the required battery capacity to fulfill all DDs. Kernel density estimators for all considered cases are shown in Figure 3. The figure clearly indicates the reduction in required battery capacity to cover DDs. Using 100% of both E and N, the mean necessary capacity is reduced from 49 kWh to almost 12 kWh, a reduction of 76 % of battery capacity (Figure 3.A). Likewise, for using 25% of both E and N, the reduction in battery capacity is 62%.

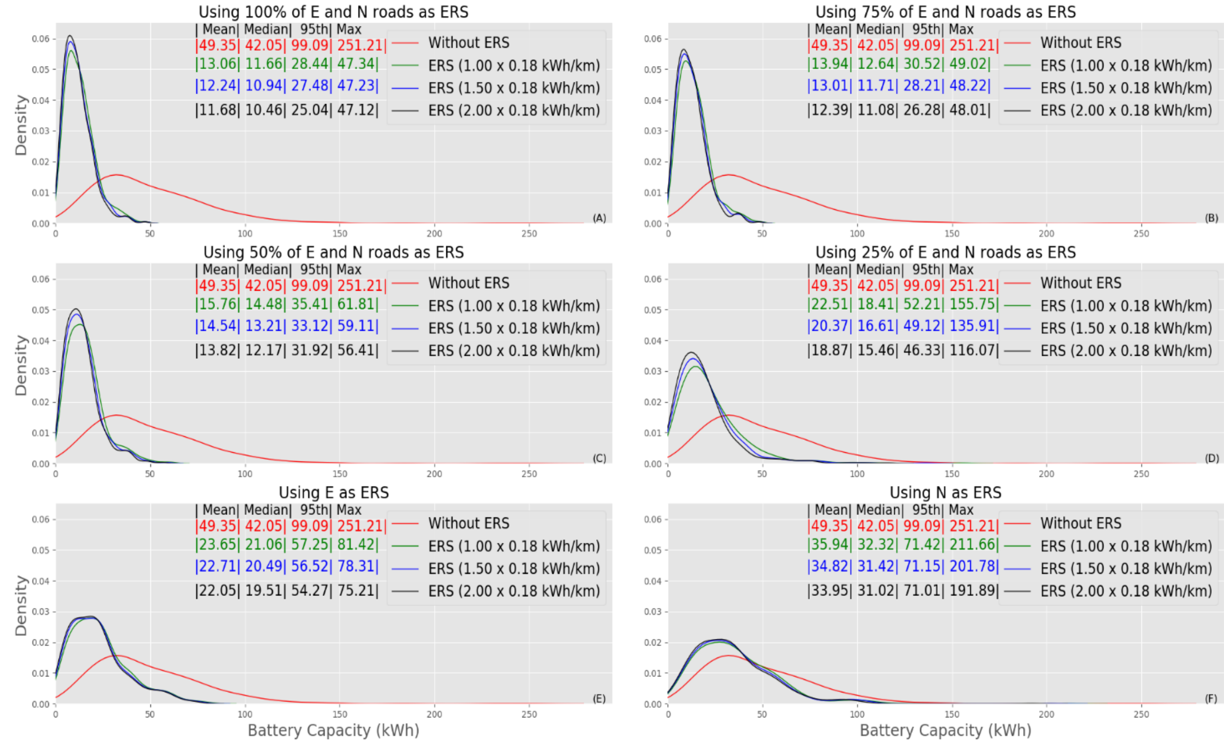

Figure 3 Simulated required battery capacity to cover all DDs.

ERS savings

Several studies have forecasted the ERS infrastructure cost. However, the uncertainty in the infrastructure cost of ERS at present is still large for many reasons, including that ERS is still an immature technology under development. For rail, inductive and conductive technologies, the estimates vary between 0.4 and 2.7 M €/km, including the components both for the electric road infrastructure in both directions and the electricity system network to the road [2, 3, 16, 4].

The ERS infrastructure cost can be compared to the possible savings in BEV battery capacity costs. The price of lithium-ion batteries used in BEV dropped from 300 $/kWh in 2015 [10, 11, 12] to as low as 190-250 $/kWh in 2017-2019 [13, 8, 14, 15], and is expected to reach a range of 100- 160 $/kWh in 2025-2030 [12, 8]. We investigate the cost of savings, resulting from reducing the mean capacities (Figure 3) with a predicted battery cost of 120 $/kWh (~106 $€_{2019}$/kWh) in all identified ERS cases. This calculation is also dependent on the share of passenger cars switching to BEVs. There is currently a total of 4.9 millions private vehicles in Sweden.

The analysis suggests that the savings for a km of ERS through reduced battery size range between 0.17-6.5 M€/ERS km. Different variables (i.e. ERS placement, BEV share of cars and charging rate) affect the estimated benefits from ERS differently. The economic net benefit is heavily dependent on the percentage of cars switching to BEV and ERS placement and less on the ERS charging rate. Sweden will benefit the most of ERS on 25% (traffic-wise) of both E and N with a charging rate of 2 × 0.18 kWh/km, which will cost between 1000-6500 M€. Depending on the participating BEV share, the gains in reducing battery capacity ranges between 3900 and 15800 M€, resulting in gross savings of 2900-9300 M€. In most considered cases, ERS infrastructure cost is less than its expected benefits.

Acknowledgments

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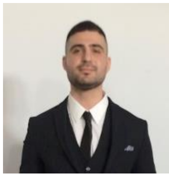

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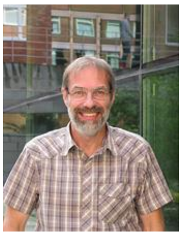

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