Promoting Electrification of Regional Rail Transport through Shared Charging Infrastructure with Road Vehicles

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EXTENDED ABSTRACT

Electrification of regional railway systems constitutes a promising strategy for reducing greenhouse gas (GHG) emissions and improving air quality in the transportation sector. While full electrification via overhead line equipment (OLE) is technically viable for high-density corridors, it is often not economically justified on low-traffic routes due to high infrastructure costs relative to usage levels. Battery-electric trains (BETs) have therefore emerged as a potentially cost-effective and operationally flexible alternative. However, the reliance on large onboard battery systems—required to span extended un-electrified segments—brings about several drawbacks, including significant capital and lifecycle costs, and notable environmental impact related to battery manufacturing and charging facilities. To address these challenges, this study proposes a shared charging infrastructure model for both rail and road vehicles, combining static and dynamic charging strategies. Static charging refers to energy transfer while the train is stationary, usually at stations, and can be implemented with relatively low capital investment. Dynamic charging involves supplying energy during motion via Electric Road System (ERS) technologies. Solutions developed by companies such as Alstom [1],

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Electreon [2], Honda [3], and Elonroad [4]—originally intended for road applications—utilize conductive strips or inductive pads embedded along the vehicle path, and are proposed here for potential investigation and adaptation in shared rail–road contexts. A MATLAB-based simulation model is developed based on the Borlänge–Malung railway corridor in Sweden, a 129-kilometre regional line with 12 intermediate stops. The train modeled in the study is 15 meters long, weighs approximately 30 metric tons, and has an average auxiliary power demand of 15 kilowatts (kW) (These parameters are based on data provided by Flagship Project 6: FUTURE [5].). The estimated energy consumption for a full round trip—factoring in route topography, driving profiles, and stop patterns—is around 230 kilowatt-hours (kWh). Two battery charging configurations are evaluated. In the first, the train is equipped with a 300 kWh battery charged once at the origin, resulting in deep discharge cycles and associated accelerated battery degradation. In the second, a smaller 210 kWh battery is supported by three intermediate static charging sessions—each lasting two minutes—at selected stations. The simulations suggest that this distributed static charging approach can help reduce battery capacity needs, lower battery-related manufacturing emissions by up to 30%, and extend battery life by reducing depth of discharge (DoD). In same scenario, a hybrid setup is investigated, in which short dynamic charging segments (500 meters before and after selected stations) supplement the static chargers. Although this approach offers further reduction in DoD and could potentially halve the environmental impact and cost related to battery manufacturing, it requires significantly higher upfront investment. Elonroad's pricing data indicate that the capital cost of rail-compatible dynamic charging infrastructure scales significantly with the total length of deployment, making extensive implementation economically challenging without shared usage. As such, dynamic charging may be more viable when deployed in contexts where its use is shared with multiple vehicle types and rail applications represent a relatively small share of total demand. A design of the shared road-rail infrastructure would obviously be subject to the regulation guaranteeing safety of rail system and train operations. To assess the overall cost-benefit trade-off, a sensitivity analysis is performed. It shows that increasing the number of static charging stations leads to battery cost reductions, primarily due to improved battery longevity, until a saturation point is reached. Beyond this point, the marginal benefits taper off. In one example, operating a train with a 300-kWh Lithium Iron Phosphate (LFP) battery and a single static charger yields a life-cycle battery and charging infrastructure cost of approximately €0.017 per kilometer. However, when six static chargers are shared with other electric vehicle users (with rail usage representing only 20% of the total charging load), the cost per kilometer is reduced below the baseline case. This improvement is not only attributable to cost-sharing but also to shallower DoD, which enhances battery longevity and, correspondingly, reduces the environmental impact linked to battery manufacturing and associated carbon dioxide (CO_2) emissions. Although dynamic charging may offer some operational flexibility, its cost-effectiveness depends on widespread cross-sector participation. If trains only account for a small fraction, e.g. 1%, of the total energy transferred by a shared ERS system, and dynamic segments are deployed at multiple points along the route (e.g., six segments of 1 km each), the total system cost can still be lower than for a train relying solely on a large battery and a single static charger. Nevertheless, this relies heavily on external demand and coordinated infrastructure planning. From a system-level perspective, shared charging infrastructure, whether static or dynamic, may contribute to a more resilient and efficient transport energy network. Such developments are consistent with the European Union's broader strategic objectives for sustainable mobility and emissions reduction, as outlined in long-term climate and energy policy frameworks [6]. The proposed infrastructure-sharing approach could therefore represent one promising pathway toward more affordable, scalable, and sustainable regional rail electrification. In summary, this study suggests that integrating shared charging infrastructure into regional rail operations may help address the technical and economic challenges of battery-electric trains. A balanced deployment of static and dynamic charging, particularly when utilized by both rail and road vehicles, can reduce battery size requirements, mitigate CO_2 emissions from battery production, and lower total system costs. While further research and real-world trials are needed, the findings highlight the potential of shared, multimodal energy infrastructure as a viable enabler for cleaner and more sustainable transportation.

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