Simulation tool to model the levelized cost of driving of battery swapping heavy duty vehicles

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Abstract

The successful electrification of heavy-duty transportation depends on an economically feasible transition. This study develops a simulation model to optimize the Levelized Cost of Driving (LCOD) for battery-swapping battery electric trucks (BS-BETs) compared to diesel trucks (DTs). The model calculates energy consumption based on gross vehicle weight (GVW) and simulates heavy-duty vehicle (HDV) movements. The model optimizes battery-swapping station (BSS) parameters, including location, number of chargers, spare batteries, charger power, battery capacity, and charging schedules using Finnish electricity spot prices.

A case study on a 125 km route between Hamina and Joutseno in Finland, involving four HDVs, demonstrated that BS-BETs can be a cost-effective alternative to DTs. Cost efficiency was influenced by battery prices and electricity spot-price fluctuations. Low battery pack price (100 €/kWh) and high electricity price variability favored more spare batteries, while high battery pack costs (300 €/kWh) and stable electricity price required fewer. In all scenarios, a single optimally located BSS was enough to support the fleet.

The findings highlight the economic feasibility of BS-BETs for fixed-route transport in Nordic conditions, addressing gaps in European battery-swapping research. These insights guide policymakers and logistics stakeholders in promoting sustainable heavy-duty transportation.

Introduction and Motivation

Freight transportation causes around 8 % of the total greenhouse gas emissions annually (Ritchie 2020). There is, therefore, imperative to study alternative methods to arrange freight transport using low or even zero-emission motive powers.

Applied Method

A model was developed in MATLAB to simulate the movement and consumption of HDVs based on the GVW of the HDV. Effect of weather and road inclination was left out as simplification measure. BS-BETs and DTs were considered in the model.

A case study involving four HDVs transporting goods in four shifts i.e. completing 16 trips, between Hamina and Joutseno via Luumäki located in Finland was analyzed. The developed model optimized location of BSS, number of chargers, charger rated power, battery capacity, number of spare batteries at the BSS and battery charging scheduling. Hourly electricity prices from Finland from years 2020 to 2023 were used in the case study. Possible BSS locations included the terminal points (Joutseno and Hamina) and a midway site (Luumäki). Three battery pack prices (100, 200, 300 €/kWh) were used in the analysis to assess the impact of battery price on the optimization outcomes. Another sensitivity analysis considered interest rates (3, 6, 9 %) to evaluate the effect of unknown economical situation.

Results

The results indicate that using BS-BETs for freight transportation can be economically viable option. The levelized cost of driving using BS-BETs is ~30% lower than using conventional diesel powered HDVs. Only one optimally located BSS at Luumäki, midway along the route, was required. Optimal charging strategy involved charging spare batteries with C-rate of 1. Scenarios where battery pack price was high and electricity prices were stable, low number of spare batteries proved to be cost-effective solution. Conversely with high electricity price fluctuation and low battery pack price, high number of spare batteries was economically more feasible option due to allowing charging with off-peak electricity.

Conclusions

This study introduced a simulation tool to optimize the levelized cost of driving for BS-BETs, demonstrating their economic viability compared to DTs for fixed-route freight transport. Using a case study set in Finland, the model optimized BSS parameters under varying electricity prices and battery pack costs, revealing that BS-BETs can be economically viable option for freight transportation. Future research should refine cost data and compare BS-BETs to other technologies like hydrogen and megawatt charging systems for broader insights.

References

Ritchie, Hannah. 2020. Cars, planes, trains: where do CO_2 emissions from transport come from? Our World in Data. Available: https://ourworldindata.org/co2-emissions-from-transport