Development of an Optimized Network of Electric Charging and Hydrogen Refueling Stations for Sustainable Road Freight Transport

Master‘s Thesis of Satish Kore

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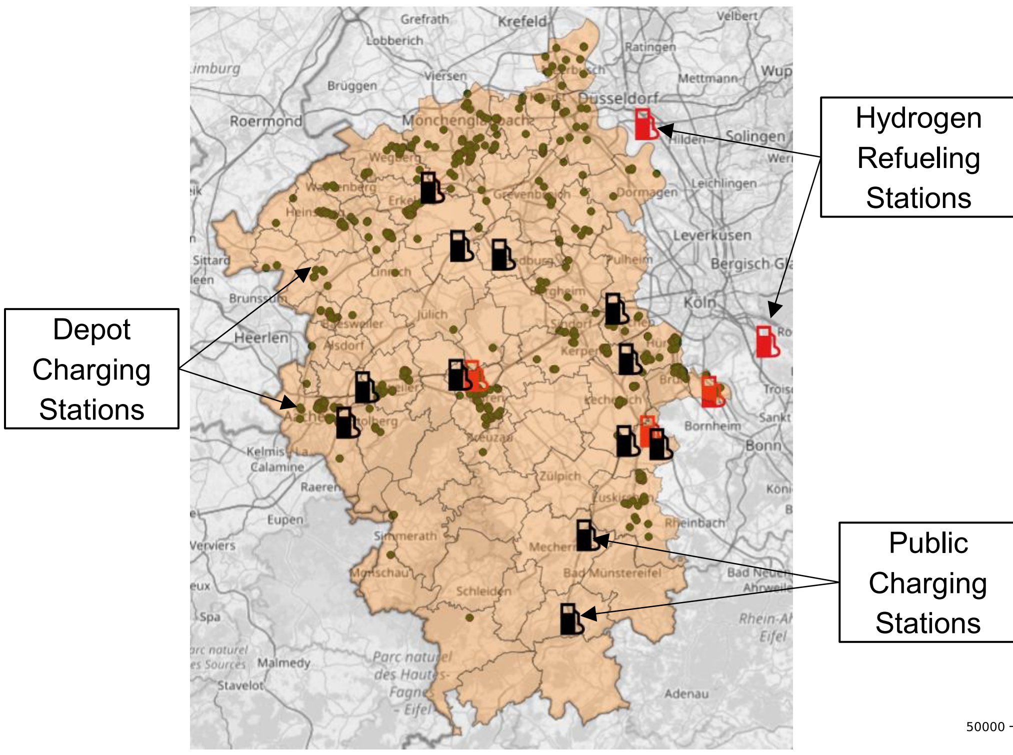
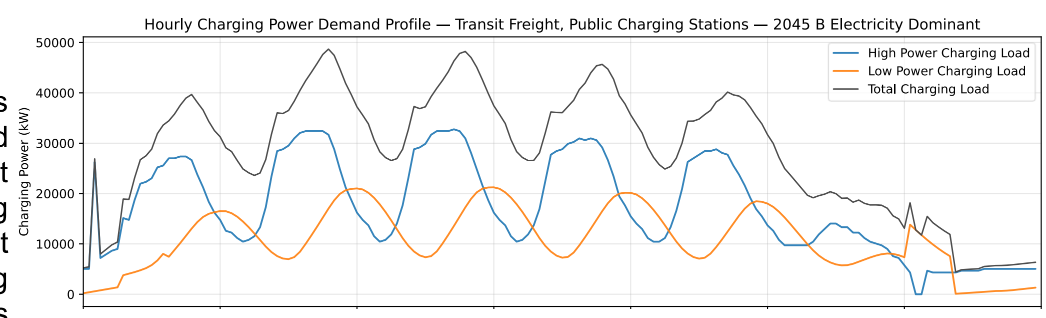
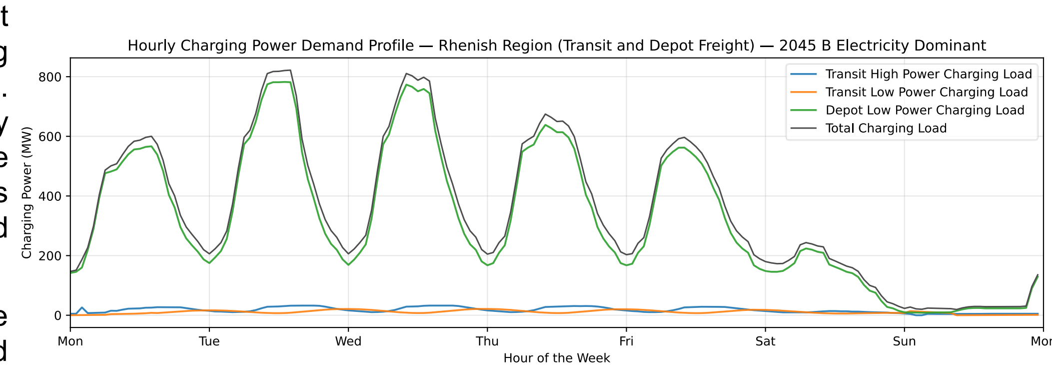


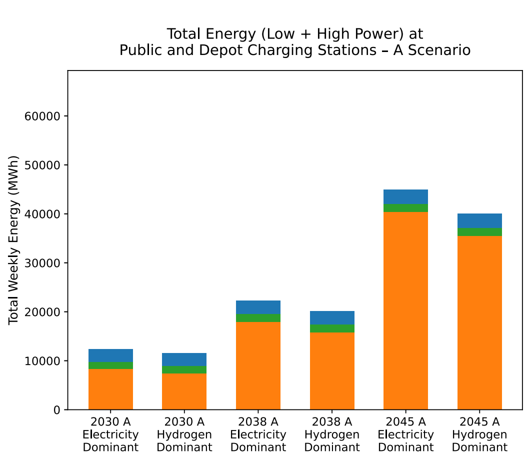
Decarbonizing road freight transport is critical to achieving national and EU climate goals. Zero-emission trucks, both battery-electric and hydrogen fuel cell, are key solutions, however their widespread adoption depends heavily on the availability of charging and hydrogen refueling infrastructure. This research focuses on identifying optimal locations for electric charging and hydrogen refueling stations and estimating the associated energy requirements for freight trucks in 2030, 2038, and 2045 within the Rhenish area of North Rhine-Westphalia under diverse future energy pathways. Using freight flow data from the national road freight demand model for Germany, this thesis develops models to estimate electric charging and hydrogen refueling energy demand for road freight vehicles. The analysis shows that electricity demand for charging will dominate future energy needs, reflecting the higher adoption potential of battery-electric technology compared to hydrogen fuel cell trucks.

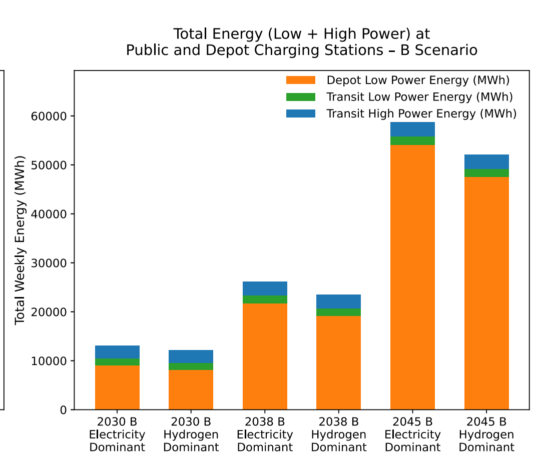
An electric energy and hydrogen refueling estimation model was developed using origin–destination flows and stop data generated from the freight demand model, incorporating mandatory rest periods of 45 minutes and 9 hours in accordance with driving regulations. The model distinguishes electric energy demand at public charging stations utilized by freight vehicles transiting through the region, comprising high- and low-power chargers installed along key corridors in the Rhenish area, and depot charging stations equipped with low-power chargers at existing industrial sites serving freight trucks originating within the region. Hydrogen refueling stations were similarly identified along the key corridors, and hydrogen energy demand was estimated at these locations. The analysis considers medium- and heavy-duty trucks to provide a comprehensive assessment of future charging and refueling infrastructure needs.

Future energy requirements were estimated under multiple scenarios that incorporate different industrial growth pathways and drivetrain shares (battery-electric and hydrogen fuel cell) for the target years. The model outputs a range of metrics for both electric charging and hydrogen refueling facilities, including charger counts, load profiles, charger utilization profiles, and weekly energy demand, among others.









The study shows that across all future pathways, battery-electric charging infrastructure represents the largest share of total supply and facility counts, with low-power charging remaining dominant throughout the time horizon. Depot facilities account for the majority of installed chargers, increasing from 607 units in 2030 to 2,817 units in 2045, while charger requirements at public charging stations grow more modestly but remain operationally critical for serving transit freight vehicles. Hydrogen refueling infrastructure, by contrast, is geographically concentrated at a limited number of stations. Although total hydrogen demand increases over time, infrastructure requirements remain largely constant due to the lower adoption of hydrogen fuel cell technology in the coming years.

Future work could incorporate detailed trip data from individual freight vehicles to capture more nuanced freight movement behaviour, enabling the development of a more granular analytical framework.