SIMULATION-BASED ANALYSIS OF CAR-SHARING ELECTRIFICATION IN LÜBECK

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Topic and Research Questions

Individual motor traffic still a large source of greenhouse gas emissions. Electric vehicles (EVs) have the potential to reduce carbon emissions; the positive effects can be even greater in a car sharing context, when vehicles are shared among several users and thus the initial cost and carbon "backpack" of battery production is faster amortized. In addition, during idle times when the vehicles are parked and connected to the grid, their batteries can be used as buffers to store excess electricity and feed it back to the energy grid during peak demand times.

However, several challenges emerge when using EVs to replace internal combustion engine (ICE) vehicles in a car sharing fleet: EVs have limited range, and charging takes significantly longer than re-fueling ICE vehicles. Both could affect the ability of car sharing services to meet customer demands, potentially impacting customer satisfaction and acceptance. Also, charging the vehicles puts an additional load on the energy grid. Thus, replacing existing ICE vehicles in a car sharing fleet by EVs gives rise to several questions: given representative, historic vehicle booking patterns, how many trips could no longer be served due to range limitations? Even if trips would fit in terms of range, are there consecutive bookings that could not be served because there is not enough time to re-charge between trips? How does the electrification affect the load curve of the energy grid?

In this work, we obtained data from a car-sharing company in the city of Lübeck, Germany. The company operates a comprehensive round-trip (also known as two-way) car-sharing model, where customers collect a car from a designated location and subsequently return it to the same location upon completion of their usage. The data we collected is for the duration of 2.5 years, from January 2018 to June 2020. During this period, a total of 161,839 orders were executed. The orders were carried out using a fleet of 291 vehicles out of which 37 are already electric vehicles. We observed 20,143 trips were executed using EVs, corresponding to 12.5% of the share of total trips, respectively. The EV segment covered 673,290 km while the non-EV segment covered 7,449,412 km. The average trip distance was 50.16 km, and the average daily traveled km per car per day was 30.35 km.

Approach and Methodology Used

Previous studies on fleet electrification have primarily focused on the impact of private vehicle electrification on the local energy system (Klingert & Lee, 2022), and urban mass public transport (Zhou et al., 2023).

For our analysis, we used operational data from the car-sharing service, that encompasses various aspects such as trip distance, vehicle type, start and end times, pickup and return locations, and trip duration. To evaluate the implications of transitioning the entire fleet to electric, we created an EV equivalent for each ICE vehicle. This involved categorizing the vehicles into different classes based on their size and body type, then identifying the most popular vehicle in each class and finding its EV counterpart within our data. We assigned specific attributes such as battery size, consumption rate, and

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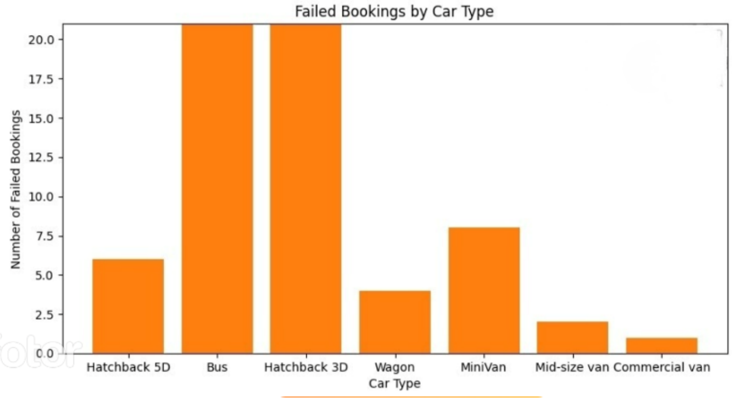
power intake to the newly constructed fleet of EVs. Post-trip recharging was carried out using a Level 2 DC charger with 20 kW power. In addition, understanding the effects of electrification of car-sharing fleet requires data from the local electricity grid to understand times with high and low supply and demand. In this work, we utilized public available energy data for Schleswig-Holstein. This data provides us with information about different energy sources, peak and low production times, and consumption patterns. Additionally, we obtained energy pricing information from a local energy provider, which is helpful to incorporate price information and simulate its effect on customers. In order to analyze the data and study the potential impact of electrification on car sharing service and the grid, we used a multi-agent simulation (MAS) tool (Ali, et al., 2023) where we modeled different types of agents including customers, the car-sharing company, and the energy grid system. In our simulation, a customer agent sends a request to use a vehicle for mobility needs. This request is evaluated by the car-sharing company agent (represented by a booking controller) to determine the vehicles' availability. A vehicle is unavailable if the requested distance cannot be covered by the vehicle (due to range or charging limitations). The grid agent in our simulation provides information on grid load and also the energy prices. The car-sharing company will use this information to price the booking request, or determine when to feed back energy from the vehicles to the local grid.

Current Results and Outlook

Using this setting, we ran simulations of different "what-if"-analyses. One example is shown in Figure 1. The diagram shows the number of bookings that were rejected as a result of battery limitations, that is, the requested trip distance exceeded the range the EV can travel. Based on these analyses, we aim to understand the short and long-term implications of car-sharing fleet electrification. In the short term, we are interested in the immediate operational challenges, such as determining the optimal fleet size and composition to meet current demand with

Evs. In the long-term, we are interested in how fleets of EVs can serve as mobile, swarm-based energy storage, that can absorb excess electricity from the grid during off-peak hours and feed it back during peak demand, while meeting its primary objective to satisfy customers' mobility needs. One approach to address this involves AI-supported forecasting and recommendations (Thoma et al., 2023) to optimally balance the two conflicting concerns of peak shaving and user mobility needs.



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