Optimizing Charging Strategies for Shared Autonomous Electric Vehicles to enhance Decarbonization of the Transport Sector

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Abstract

The transition to electric vehicles has disrupted mobility patterns. However, further disruption is imminent with autonomous driving technology, expected to operate primarily within shared fleets (e.g., Waymo or Moia). This paper defines "shared" to include both ride-hailing and ride-sharing systems, forming Shared Autonomous Electric Vehicle Fleets. These fleets represent a fundamental shift in vehicle utilization, charging, and control. While the transition to EVs stresses the electric power system—due to increased demand and peak loads—SAEVs could reduce charging demand by increasing vehicle occupancy and enhancing charging flexibility through centralized fleet management. However, their environmental impact depends on fleet size, operations, and charging strategies. This study seeks to answer the following research question: *How do SAEV-specific charging strategies influence grid load balancing/stability, marginal emissions, and overall/operational grid efficiency compared to private EV charging strategies in Germany?* I use empirical mobility data from Germany and integrate it with real-world electricity grid data using a merit-order approach. Results show that SAEV emissions, when charged according to SAEV strategies, are up to 25% lower compared to private EV strategies.

Introduction and Motivation

The transition to electric vehicles (EVs) can mitigate climate change but puts significant stress on the electric grid due to increased demand and amplified peak loads. Current electrification targets are insufficient to meet CO2 reduction goals (Milovanoff et al., 2020). Shared Autonomous Electric Vehicles (SAEVs) promise to address this issue by reducing the overall charging demand through increasing occupancy and improving flexibility with regards to charging timing due to centralized control within fleet management. Further, SAEVs can provide ancillary services (vehicle to grid) such as demand response (peak shaving) as they differ from private vehicles in terms of duty cycles, human-less operation and decoupling from regular working hours and capabilities such as self-organized charging (Pruckner & Eckhoff, 2020). While (Li et al., 2022), (Zhang & Chen, 2020) and (Estandia et al., 2021) provide valuable insights into the benefits of smart charging and SAEV-grid interactions in U.S.-based contexts, these studies primarily focus on operational efficiency or emissions in isolation, often neglecting real-world power system constraints; moreover, their findings lack generalizability to the German context due to differing grid structures and travel patterns.

Applied Method

This study distinguishes between SAEV fleet charging strategies and private EV strategies. The SAEV strategies considered are Charging Inverse to Netload, Charging Inverse to Travel Demand, and Uniform Charging. For private EVs, I analyze Home Overnight Charging, Daytime Workplace Charging, and Daytime Public Charging (Li et al., 2022; Märtz et al., 2022). I simulate the charging demand profiles using empirical mobility data from Germany (*Mobilität in Deutschland*, 2017) and integrate these profiles with hourly real-world electricity grid data. The simulation models electricity generation using the merit-order and calculates SAEV charging emissions from marginal emissions. Each charging strategy is evaluated based on its impact on load balancing, emissions and fleet operations under various renewable energy availability scenarios and different SAEV penetration levels.

Results

The findings highlight that SAEV charging strategies significantly impact both emissions and grid efficiency. SAEV travel demand follows typical commuting patterns, with peaks in the morning and early afternoon. Charging Inverse to Netload is the most effective strategy, aligning charging with high renewable energy availability, reducing both peak grid demand and emissions. In contrast, Uniform Charging leads to a constant load, with minimal impact on emissions and grid efficiency. Charging Inverse to Travel Demand, while reducing grid congestion, results in higher emissions during periods of low renewable generation, as charging occurs during the night. Emissions from private EV-based strategies are up to 25% higher than SAEV-specific strategies, primarily due to lower utilization of renewable energy. In terms of grid efficiency, SAEV-specific strategies improve grid load balancing, especially compared to private EV strategies, which increase existing demand peaks.

Conclusions

Under the German power grid, SAEVs can be less carbon-intensive than private EVs, when operated under optimized charging strategies. SAEV-specific charging strategies not only improve grid efficiency but also provide substantial emissions reductions, highlighting the environmental benefits of optimizing charging behavior based on renewable energy availability and fleet operation rather than mimicking private EV strategies. There is no conflict between SAEV fleet operations and optimized charging, suggesting that operational efficiency and grid efficiency can go hand-in-hand. CO2 emissions from SAEVs increase with fleet expansion, but total emissions are inversely correlated with occupancy rates, meaning higher occupancy leads to more efficient environmental outcomes. This study contributes to the literature by examining the role of SAEVs in decarbonizing transportation, focusing on their impact on grid efficiency and emissions reduction. The findings emphasize the necessity of SAEVs alongside private EVs and highlight the need for policies that support renewable-aligned charging strategies, such as carbon taxes or dedicated charging stations. For SAEV fleet operators, the study shows that aligning charging strategies with renewable energy generation not only enhances operational efficiency but also improves grid stability. For researchers, the study provides a foundation for further exploration into the impact of SAEVs on the German power market, using derived charging profile as inputs for power system models.

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