Simulation Architecture for Electric Vehicle Charging Optimization in Dresden's Ostra District

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Abstract: The integration of electric vehicles (EVs) into urban transportation systems presents significant challenges and opportunities for cities aiming to optimize energy usage and reduce emissions. This paper presents a simulation architecture to optimize EV charging in Dresden's Ostra District as part of the Mobilities for EU project. The proposed architecture leverages the Simulation of Urban Mobility (SUMO) to model traffic patterns and vehicle movements, while a custom energy management system facilitates smart and bidirectional charging capabilities. By incorporating the Amitran methodology to evaluate CO2 emissions, the architecture aims to provide insights into the sustainability impacts of various charging strategies. The simulation environment allows for the exploration of ”what-if” scenarios, enabling city planners and fleet managers to assess the implications of different charging strategies on energy consumption and grid stability. Collaboration with the city of Dresden will be essential for validating the simulation with real data, enhancing model accuracy and supporting informed decision-making. Ultimately, this research aims to contribute to the growing body of knowledge on sustainable urban mobility and provide a valuable tool for optimizing EV integration in smart cities. Future work will focus on expanding the simulation framework to include additional variables such as renewable energy sources and user behavior patterns, further enhancing its applicability in real-world scenarios.

1 INTRODUCTION

The integration of electric vehicles (EVs) into urban transportation systems presents both challenges and opportunities for cities striving to reduce emissions and optimize energy usage (Apata et al., 2023; Mahmod et al., 2015; Wang et al., 2024b; Wang et al., 2024a). This is particularly relevant in the context of bidirectional charging and smart charging technologies (Vehicle-to-Grid (V2G), Vehicle-to-Building (V2B)), which enable dynamic energy management and grid support (Wang et al., 2024a). To validate the scalability of the project, it can integrate with existing data in a small data set. This paper has a goal to highlight how the architecture can connect with the city of Dresden. As the adoption of EVs continues to grow, it is crucial to develop simulation frameworks that can model the complex interactions between EVs, charging infrastructure, and the power grid. Such frameworks enable city planners and fleet managers to explore various scenarios, optimize charging strategies, and assess the impact of EVs on the local energy system (Rehman et al., 2019; Wang et al., 2024a).

Within the Mobilities for EU project, the Ostra district in Dresden, Germany, serves as an ideal testbed for implementing and evaluating an EV charging simulation architecture. However, the current project scope, which involves only 2-3 EVs and charging stations, limits the observable impacts on energy savings, CO2 reduction, and green energy integration. To address this limitation, we propose designing a scalable simulation architecture that, when validated with real data from the city, can model larger scenarios and provide meaningful insights into the benefits of EV integration. By leveraging the capabilities of SUMO and integrating it with software for connecting EVs to charging stations, we aim to

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create a comprehensive simulation environment that can address the unique challenges faced by the Ostra district. This approach will not only facilitate the assessment of current systems but also provide insights into future developments and strategies for sustainable urban mobility.

This concept paper aims to explore the significance of simulation in assessing the real impacts of V2G and smart charging technologies on urban energy systems and sustainability. By leveraging co-simulation tools and methodologies, we will analyze the interactions between EVs, charging infrastructure, and the power grid. The findings will inform our approach and ensure that our simulation architecture effectively evaluates the sustainability impacts of these technologies.

1.1 Methodology and Scalability

This section focuses on the overall methodology and scalability. While there is a limited data set, it provides a basic framework to begin with.

- **Integration of SUMO for Traffic Simulation:** This allows for accurate scalable modeling of traffic scenarios with a limited range of EVs.
- **Development of a Custom Software Model:** A model for generating optimized charging plans that enable smart charging and peak shaving.
- **Incorporation of a Systematic Approach:** We will assess CO2 emissions based on the Amitran methodology, including a well-to-tank analysis to evaluate both direct and indirect emissions.
- **Modular Design for Easy Integration:** The modular design promotes an easy design with algorithms.
- **Utilization of Simulated Data:** Existing studies will provide simulated data to model scenarios such as smart charging and peak shaving, ensuring alignment with sustainability goals.
- **Future Collaboration:** We aim to collaborate with the city of Dresden to obtain validation, enhancing the accuracy of the simulation models and supporting informed decision-making.

The resulting architecture can function as part of the foundation architecture in the project, to integrate existing technologies to connect with a large architecture. We aim to contribute to the growing body of research on EV integration and smart charging strategies in urban environments. The architecture can serve as a valuable tool for city planners, fleet managers, and energy providers to explore the potential impacts of EVs on local transportation and energy systems, and to develop optimized solutions for charging infrastructure and energy management.

2 BACKGROUND AND PROJECT DESCRIPTION

2.1 Overview of the Mobilities for EU Project

The Mobilities for EU project aims to enhance urban mobility through innovative solutions that integrate electric EVs with smart charging infrastructure and advanced traffic management systems. This initiative focuses on optimizing energy consumption and reducing emissions in urban areas (MobilitiesforEU, 2024; Barbierato et al., 2022), particularly as EV adoption continues to grow. By aligning with broader sustainability goals, the project seeks to create a more efficient and environmentally friendly urban transport system.

2.2 Simulation Architecture Development

As part of this project, we are developing a comprehensive simulation architecture to model the complex interactions between EVs, charging infrastructure, and the power grid. By leveraging the capabilities of SUMO, we aim to create a dynamic simulation environment that can replicate various traffic scenarios and EV charging behaviors (Krajzewicz et al., 2012; Kurczveil et al., 2014).

2.3 Importance of Simulation

Simulation architectures are crucial for understanding the impacts of V2G and smart charging technologies. They enable city planners and fleet managers to explore ”what-if” scenarios—hypothetical situations that allow for the evaluation of potential strategies and decisions without the risks associated with real-world implementation (Rehman et al., 2019; Steinbrink et al., 2018). This capability is essential for conducting low-cost analyses of various outcomes, helping decision-makers visualize the implications of different actions. For instance, simulations can assess the effects of changes in driver behavior, variations in the number and types of EVs, modifications to charging infrastructure, and shifts in energy prices and grid conditions (Krajzewicz et al., 2012). By simulating these scenarios, our architecture will assist fleet managers in anticipating challenges, identifying optimal strategies, and making informed decisions regarding EV fleet operations (Rehman et al., 2019). Ultimately, the dynamic simulation environment created with SUMO will provide critical insights (Krajzewicz et al., 2012) to support the Mobilities for EU project's goals of optimizing energy usage and reducing emissions in urban areas. Fleet managers use V2G strategies to optimize the overall energy output and cost. While for the Mobilities for EU project, the city planners are looking into scalable architecture for implementation.

2.4 Co-Simulation and Integration

The components of the simulation architecture are designed to communicate through a centralized data exchange mechanism, ensuring synchronized operation. By employing a publish/subscribe model, the architecture facilitates efficient data sharing between components, enabling real-time updates and dynamic adjustments to charging strategies based on simulation data. This integration will enhance our understanding of the interactions between EVs and charging infrastructure and their impact on urban energy systems (Rehman et al., 2019; Rohjans et al., 2013).

Co-simulation provides a powerful framework for studying complex systems by enabling the coupling of multiple simulation units. This capability allows for a comprehensive analysis of their interactions and the exploration of various scenarios that can inform strategic decision-making (Barbierato et al., 2022). The insights gained from these simulations will not only support our immediate objectives but also contribute to a broader understanding of how integrated EV systems can enhance urban mobility and sustainability.

3 OBJECTIVES AND SCOPE

The primary objective of the Mobilities for EU project is to contribute to sustainable urban mobility solutions that improve the efficiency of electric vehicle (EV) charging while supporting broader goals of reducing carbon emissions and enhancing the livability of urban environments (MobilitiesforEU, 2024). This initiative recognizes the increasing adoption of EVs and the necessity for innovative strategies to manage their integration into existing infrastructure.

To achieve these objectives, we will develop a comprehensive simulation architecture that models the complex interactions between EVs, charging infrastructure, and the power grid. Initially, we will incorporate simulated data to model scenarios such as smart charging and bidirectional charging, which are essential for peak shaving and optimizing grid performance. These scenarios will allow us to assess the impact of various charging strategies on energy consumption and grid stability.

Looking ahead, the architecture will be tested and validated with limited city of Dresden Data. The long-term vision is based on co-simulation architecture.By utilizing a co-simulation framework, we aim to explore urban mobility dynamics holistically, facilitating the assessment of current systems and informing future developments and strategies for sustainable urban mobility.

4 ARCHITECTURAL FOUNDATIONS

This section outlines the key methodologies and tools chosen for our simulation architecture, justifying their selection based on their relevance to the Mobilities for EU project goals and their potential for scalability.

4.1 Co-Simulation Frameworks

Co-simulation is vital for analyzing complex systems, enabling the coupling of multiple simulation units to assess their interactions. Rehman et al. (2019) emphasize the importance of integrating simulation tools using High-Level Architecture (HLA), facilitating distributed simulations that allow for the evaluation of interactions between EVs, charging infrastructure, and the power grid (Rehman et al., 2019). This integration is crucial for understanding the sustainability implications of these technologies, as it helps identify strategies that optimize energy usage and reduce emissions. By leveraging co-simulation frameworks, our study aims to create a more accurate representation of EV interactions within urban environments.

4.2 Sustainability Methodology

The Amitran methodology provides a systematic framework for evaluating the impact of information and communication technology (ICT) measures on CO_2 emissions in the transport sector. Developed within the European Union FP7 project Amitran, this methodology outlines a comprehensive approach to assess the effects of ICT on energy efficiency and emissions (Mahmod et al., 2015). Our research will adapt elements of this framework to evaluate how

Vehicle-to-Grid (V2G) and smart charging technologies contribute to reducing CO2 emissions and enhancing urban sustainability. This adaptation is essential for quantifying the environmental benefits of our proposed simulation architecture.

4.3 Challenges of EV Integration

Integrating EVs into urban environments presents various risks and challenges, including infrastructure limitations and user acceptance. Apata et al. (2023) highlight the necessity for robust simulation architectures that support decision-making for urban planners and fleet managers (Apata et al., 2023). Addressing these challenges is essential for successful EV integration and requires simulations that effectively model the sustainability implications of EV adoption. The insights from these studies directly inform our approach to developing a simulation architecture that considers both technical and social factors related to EV integration.

4.4 Demand Response Strategies

Wang and Paranjape (2014) evaluate the impact of demand response strategies on EV penetration using multi-agent-based simulations. Their findings underscore the importance of assessing how demand response can influence EV charging behavior and grid stability (Wang and Paranjape, 2014). To analyze the effects of demand response on sustainability outcomes, we will aim to utilize the architecture that can allow us to analyze the effects of demand response on sustainability outcomes, ensuring that our strategies positively contribute to energy efficiency and emissions reduction.

4.5 Utilizing SUMO for Traffic Simulation

SUMO is an open-source tool for simulating traffic scenarios. The latest versions also include EV models and charging behaviors. Traffic Control Interface (TraCI) uses a TCP based client/server architecture to provide access to SUMO (Wegener et al., 2008). Kurczveil et al. (2014) and Krajzewicz et al. (2012) discuss how SUMO enables accurate simulation of intermodal traffic systems, including road vehicles and charging infrastructure (Kurczveil et al., 2014; Krajzewicz et al., 2012). To enhance the realism of our traffic simulations and to improve the overall effectiveness of our simulation architecture by providing critical data on vehicle movements and charging patterns. we will also be using SUMO to test our system.

In summary, these choices form the foundation of our simulation architecture, each selected for its ability to contribute to the project's goals and potential for scalability. While we acknowledge the current limitations in available data, this architecture is designed to grow and adapt as the project progresses, providing increasingly valuable insights into EV integration and sustainable urban mobility. The Amitran methodology will be instrumental in assessing CO2 emissions reductions associated with V2G technologies. Furthermore, understanding the challenges outlined in existing literature will help us design a robust simulation architecture that addresses both technical limitations and user acceptance issues. Collectively, these studies provide a solid foundation for developing our comprehensive simulation framework aimed at optimizing electric vehicle charging in Dresden's Ostra District.

5 SIMULATION ARCHITECTURE DESIGN

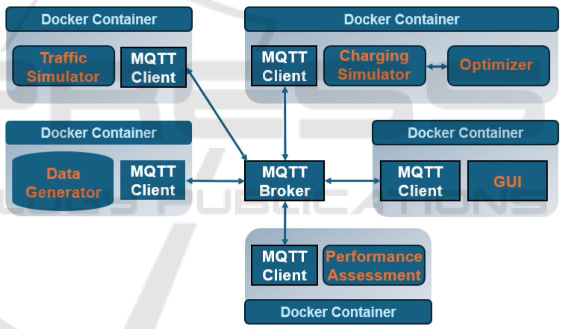

Figure 1: Simulation architecture.

The primary objective of this simulation is to analyze energy consumption and the charging dynamics of EVs during the event. As an illustrative example, we will simulate a scenario where vehicles arrive at a football game, connecting to bidirectional charging stations that allow for both charging and discharging of energy. During the three hours of the game, we aim to simulate the energy consumption at the stadium and evaluate the total charging power over time, comparing scenarios with and without smart charging and bidirectional charging. By designing a scalable simulation architecture, we can evaluate the potential impacts of larger-scale EV integration on energy savings, CO2 reduction, and potentially renewable energy utilization.

5.1 High-Level Architecture Design

Figure 1 presents a high-level architecture of the simulation system, illustrating the main components and their interactions. The architecture is designed to ensure that all components work together seamlessly, providing a comprehensive analysis of EV integration in the Dresden Ostra District.

This architecture follows HLA framework, which facilitates effective communication and integration among simulation components, ensuring synchronized operation and real-time data exchange (IEEE, 2010). By adhering to the HLA standards, we enhance the scalability and modularity of our simulation environment, allowing for the incorporation of various models and optimization strategies.

5.2 Key Components of the Simulation

The architecture consists of several key components, each designed to operate independently while communicating through a centralized data exchange mechanism:

5.2.1 Traffic Simulation with SUMO

SUMO serves as the foundational tool for simulating traffic patterns and vehicle movements within the Dresden Ostra District. It enables the simulation of various scenarios involving the arrival and departure of vehicles, including their routes and battery state of charge. SUMO generates critical data for Charging Simulation (CS), including:

- **Arrival Times:** Accurate modeling of vehicle arrivals reflects realistic traffic conditions during events, such as football games at the Heinz-Steyer-Stadion, essential for predicting charging demand.
- **Battery State of Charge (SoC):** SUMO tracks the SoC of each electric vehicle (EV) upon arrival, allowing EMS to prioritize charging based on individual vehicle needs, and facilitating efficient smart charging strategies. The change in a vehicle's energy content done by SUMO is determined by summing the gains in its kinetic, potential, and rotational energy from one discrete time step to the next, and then subtracting the losses due to various resistance factors (Kurczveil et al., 2014).
- **Route Information:** By simulating vehicle routes, SUMO provides insights into traffic flow and congestion, aiding in the planning of charging station placements and energy distribution during peak demand.

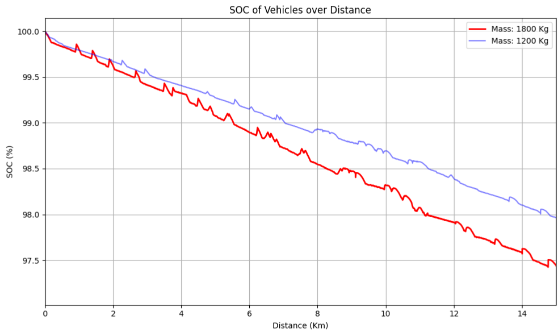

Figure 2: SoC Fluctuations in SUMO.

The data generated by SUMO informs CS, enabling it to optimize charging strategies. This integration allows for the exploration of various ”what-if” scenarios, helping city planners and fleet managers assess the implications of different charging strategies on energy consumption and grid stability. As the project progresses, collaboration with the city of Dresden will be crucial for validating simulation outputs with real-world data, enhancing model accuracy and supporting informed decision-making regarding EV integration and charging infrastructure development

5.2.2 Charging Simulation (CS)

CS is an important component of the simulation architecture, designed to optimize the charging processes of electric vehicles (EVs) based on simulated data from SUMO. Initially, CS will operate using outputs such as SoC and arrival times of vehicles, which are generated by the traffic simulation. CS will consist of two primary modules: **smart charging** and **traditional charging**, each with distinct functionalities. The smart charging module leverages that the data provided by SUMO to create optimized charging schedules that consider various factors, including:

- **Dynamic Charging Optimization:** This module utilizes simulated data to adjust charging times based on predicted grid conditions, electricity prices, and anticipated energy demand. By analyzing the SoC of incoming EVs, the system can prioritize charging during off-peak hours or when renewable energy generation is high, thereby reducing costs and emissions (Liu et al., 2020).
- **Bidirectional Charging Capabilities:** The smart charging module supports bidirectional charging (V2G/V2B), allowing EVs to discharge energy back into the grid during peak demand periods. This functionality not only enhances grid stability but also provides financial incentives for EV owners, as they can benefit from selling energy back

to the grid.

- **User Preference Management:** Users could input their charging preferences, such as desired departure times and minimum SoC levels. The smart charging module ensures that these preferences are met while optimizing the overall charging strategy to align with grid conditions.
- **Simulation-Based Decision Making:** Initially, the module will rely on simulated data to model various scenarios, assessing how different charging strategies impact energy consumption and emissions. This will allow for a comprehensive analysis of the potential benefits of smart charging technologies before real-world data is integrated (Topçu and Oğuztüzün, 2017).

Traditional Charging Module (first-come-first-serve uncoordinated charging): The traditional charging module serves as a baseline scenario, where vehicles charge immediately upon arrival without any optimization. This approach enables a direct comparison with the smart charging strategies, highlighting the advantages of dynamic charging management.

5.2.3 Cost and Emissions Assessment Module

This module analyzes outputs from CS to calculate cost saving, energy consumption, and CO2 Emissions.

- **Cost Saving:** This component will calculate the financial benefits achieved through optimized charging schedules. By analyzing the charging patterns and electricity prices, the module will identify periods where charging can be shifted to reduce costs, such as during off-peak hours when electricity rates are lower. Initial results from simulated data will highlight potential cost savings for fleet managers and urban planners, demonstrating the economic viability of smart charging strategies.
- **Energy Consumption:** The module will assess the total energy consumed by the EVs during charging and the savings achieved through optimized charging schedules. By comparing energy usage across different charging strategies (e.g., traditional vs. smart charging), the module will provide insights into how much energy can be saved when employing renewable energy sources or shifting charging times to align with periods of low demand. This analysis will be supported by data generated from CS, allowing for real-time monitoring of energy consumption.
- **CO2 Emissions:** In this concept paper, we introduce the plan to assess CO2 emissions reduction as part of future research. We aim to utilize the Amitran methodology, which provides a systematic approach to evaluate the environmental impact of ICT measures in the transport sector (Mahmod et al., 2015). This will involve calculating emissions based on the energy mix used for charging (e.g., the proportion of renewable energy versus fossil fuels) and the efficiency of the charging process. Simulations will explore various charging strategies and their potential impacts on emissions, allowing for a comprehensive assessment of how different approaches contribute to sustainability goals.

5.2.4 Graphical User Interface (GUI)

The GUI facilitates user interaction and scenario management, allowing stakeholders to visualize the impacts of different charging strategies on energy usage and emissions. Real-time feedback is provided to users regarding optimal charging times based on grid conditions and carbon intensity, enhancing decision-making capabilities.

5.2.5 Communication and Data Exchange

Communication and Data Exchange The components of the simulation architecture are designed to communicate through a centralized data exchange mechanism, ensuring synchronized operation. To facilitate this, we utilize a Message Queuing Telemetry Transport (MQTT) broker as the centerpiece of our communication strategy. MQTT is a lightweight messaging protocol that enables efficient data sharing between components with low latency, making it ideal for real-time applications (Yerlikaya and Dalkılıç, 2018).

Additionally, we implement Docker containers to encapsulate each component of the simulation architecture. This containerization ensures that all components can operate independently while maintaining seamless communication through the MQTT broker. The use of Docker allows for flexible integration with other services in the future, facilitating scalability and modularity in our simulation environment (Paraiso et al., 2016).

5.3 Scenario: EV Integration in the Dresden Ostra District

This scenario explores the potential of smart charging strategies within the Dresden Ostra District, using a high-demand event (a football game) as a conceptual test case. A simulated 500 vehicles are modeled. To test the system, we assumed a percentage (70%) for the EVs with bidirectional charging capabilities.

The logic from the test can be used for more or less data sets. Of the simulated 350 EVs, 50 are modeled as not participating in the V2G/V2B program. This allows us to test the capabilities of the system when people will be not participating. The remaining 300 EVs participate in the simulated smart charging program. The goal for the participation would be to test data sharing.

The scenario focuses on the period surrounding the football game at the Heinz-Steyer-Stadion, from 5:30 PM to the start of the game at 7 PM. The simulation is for peak savings from the integrated architecture, which is the goal of the paper. It focuses on scalability and the ability to function, from one data setting into another. This scenario intends to evaluate the scaling logic model under controlled conditions, testing the main data sets.

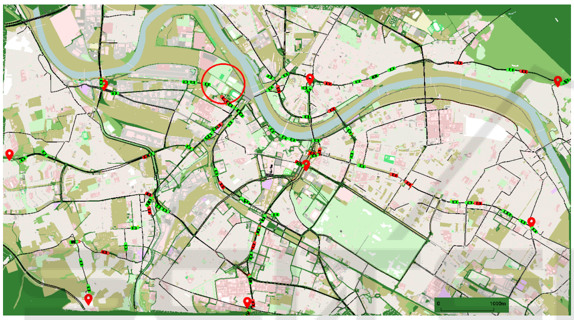

Figure 3: SUMO for this Scenario: The map of Dresden was imported using osmWebWizard. The 8 Pin-points represent the starting and ending area of the vehicle. The red circle denotes the area of interest, i.e. Ostra District. Green vehicles are EVs and red Vehicles are fuel cars. The vehicle size was exaggerated for visual purposes.

This simulation serves as a test run to evaluate our current scheduling logic model and gather initial findings. It aims to analyze energy consumption and charging dynamics during the event. As vehicles arrive, they will connect to bidirectional charging stations that allow for both charging and discharging. The performance of the smart charging program will be assessed against traditional charging methods to evaluate the effectiveness of these strategies in optimizing energy usage.

6 RESULTS ON DIFFERENT SCENARIOS

This section presents the specific scenarios designed for the simulation and outlines the approach for assessing cost savings, energy consumption, and preliminary findings from simulated data. The scenarios will explore the effectiveness of smart charging strategies compared to traditional charging methods.

6.1 Scenario Selection

Smart Charging vs. Traditional Charging: This scenario will compare the energy consumption, cost implications, and peak demand reduction of implementing smart charging strategies against conventional first-come, first-served charging methods. The smart charging module incorporates bidirectional charging capabilities, allowing EVs to discharge energy back into the grid during peak demand periods.

6.2 Initial Results

The simulation examines the energy dynamics at a stadium where 350 EVs arrive randomly between 6 PM and 7 PM, with SoC levels ranging from 40% to 80%. In this setup, 50 EVs do not participate in vehicle-to-building (V2B) and charge their vehicles on a first-come, first-served basis.

Figure 4 shows EVs' arrival distribution and associated charging demands in each time interval. The SUMO provides the arrival time and SoC for each EV, allowing us to calculate the charging demand required for all vehicles arriving within each specific time window. The blue bars represent the number of EVs arriving in each 15-minute interval, while the red line represents the energy needed to charge these EVs. The peak arrival of EVs occurs between 6:15 PM and 6:30 PM, with over 120 EVs arriving during this time, corresponding to the highest energy demand of approximately 1400 kWh.

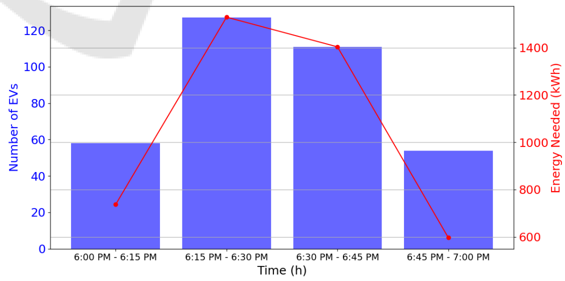

Figure 4: Arrival distribution of EVs and their associated charging demands in each time interval.

Figure 5 shows a comparison of the stadium baseload, the event-day baseload, the uncoordinated EV charging demand, and the effect of peak shaving using a smart charging algorithm. The base energy consumption of the stadium is represented by the purple-shaded area, which remains relatively consistent throughout the day. On event days, such during a football match, the baseload increases, as indicated by the yellow region, due to higher energy usage. The red highlighted region represents the extra demand caused by uncoordinated EV charging using traditional methods. This spike occurs during peak hours in the early evening, when a significant number of EVs begin charging simultaneously. This uncoordinated charging creates a strain on the grid, further increasing the load during already high-demand periods. However, with smart charging strategy, represented by the green region, shows how the peak load can be effectively flattened. By shifting the charging times of EVs to off-peak periods and coordinating charging demands, the smart charging algorithm successfully reduces the peak by approximately 20%. Despite this peak shaving, the EVs are still able to depart with their required SoC of 80%, ensuring that user requirements are met while also alleviating pressure on the grid.

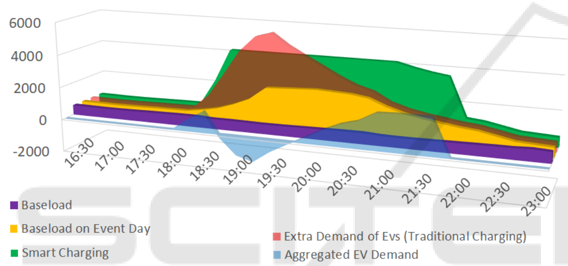

Figure 5: Comparison of stadium baseload, event day baseload, uncoordinated EV charging demand, and peak shaving using smart charging.

In Figure 6 (a), the comparison between traditional and smart charging methods is presented with a y-axis showing the aggregated EV demand. The red line illustrates the aggregated EV demand using traditional charging, while the blue line represents the aggregated demand using a smart charging algorithm. Under traditional charging, a significant demand spike occurs between 19:00 and 20:30, coinciding with the event-day peak load, further stressing the grid. In contrast, smart charging shifts the demand to off-peak periods, flattening the load curve and contributing to peak shaving.

Figure 6 (b) represents the individual EV demand for two randomly selected vehicles over time. The green and purple bars show the charging plans of EV1 and EV2, revealing that during the peak demand interval, both EVs are discharging for most of the duration.

Table 1 compares electricity prices and associated costs for different charging methods. It includes the minimum, mean, and maximum electricity prices from the grid (SPOT, 2024). The table compares the average costs of charging using traditional and

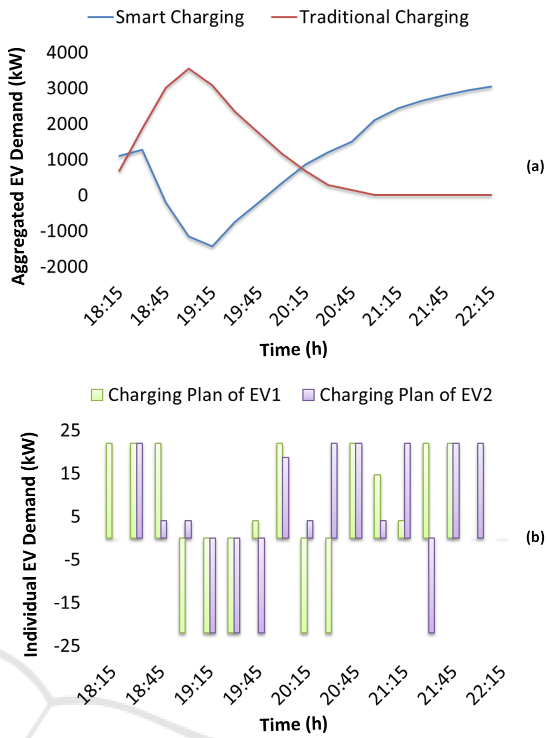

Figure 6: (a) Comparison of aggregated EV charging demand using traditional vs. smart charging, (b) Individual charging plans of randomly selected EVs.

smart charging methods during the period from 18:00 to 22:00. With traditional charging, the average cost is €0.184 per kWh. However, by employing smart charging techniques, this cost is reduced to €0.170 per kWh. As shown, the average cost with smart charging is quite close to the mean grid electricity price for the selected duration, indicating that smart charging can effectively optimize costs.

Table 1: Electricity Price for the period between 18:00 to 22:00.

Category	Price(€/kWh)
Minimum Electricity Price	0.064
Mean Electricity Price	0.172
Maximum Electricity Price	0.264
Average Cost with Traditional Charging	0.184
Average Cost with Smart Charging	0.170

The preliminary findings from the simulated data demonstrate the potential effectiveness of smart charging strategies in reducing costs and optimizing energy usage: 1. Peak demand reduction: Smart charging successfully reduced peak load by approximately 20% compared to traditional charging methods; 2. Cost savings: Smart charging reduced the average cost from €0.184/kWh to €0.170/kWh during the 18:00-22:00 period, a 7.6% reduction; 3. Load flattening: Smart charging shifted demand to off-peak periods, effectively flattening the load curve and reducing grid stress.

These results align with the objectives of optimizing energy usage and reducing emissions by: 1. Reducing strain on the grid during peak periods, potentially decreasing the need for high-emission peaker plants; 2. Enabling more efficient use of existing infrastructure and promoting integration of renewable energy sources.

The simulation architecture contributes to the Mobilities for EU project goals by providing a platform to assess both direct effects (e.g., immediate peak reduction) and indirect effects (e.g., potential for increased renewable energy integration) on sustainability and offering insights to overcome behavioral, functional, and market challenges in V2G implementation, as identified in the literature. This approach allows stakeholders to evaluate and optimize V2G strategies before real-world implementation, supporting the transition to more sustainable urban mobility systems.

6.3 Future Research: CO2 Emissions Reduction

In this concept paper, we introduce the plan to assess CO2 emissions reduction as part of future research. By incorporating the Amitran methodology, we aim to evaluate the environmental impacts of different charging strategies, considering both direct and indirect emissions. This analysis will provide a comprehensive understanding of the sustainability benefits of smart charging and bidirectional charging technologies.

7 DATA VALIDATION STRATEGY AND EXPECTED CONTRIBUTIONS

To ensure the accuracy of our simulation results, we will implement a data validation strategy in collaboration with the city of Dresden. This strategy will involve partnering with local authorities and utility companies to access real-time data on EV usage and charging patterns. We will integrate actual data from the city's EV charging infrastructure into our simulation models to enhance their accuracy. Additionally, we will validate our CO2 emissions calculations by comparing them with actual emissions data provided by local environmental agencies, ensuring alignment with the Amitran methodology. The validation process will be iterative, allowing us to refine our simulation models continuously based on feedback from real-world data. This approach will enhance the credibility of our findings and support informed strategies for effective EV integration.

The anticipated contributions of our simulation architecture to the field of urban mobility and electric vehicle integration are significant. Our framework will provide city planners and fleet managers with a robust tool to evaluate the impacts of various EV charging strategies on urban energy systems. Furthermore, we will offer valuable insights into the sustainability benefits of smart and bidirectional charging technologies, including emissions reductions. Our research will also inform urban planning and policy decisions regarding EV infrastructure by identifying optimal charging strategies. Finally, we aim to fill existing gaps in the literature on EV integration and sustainable urban mobility by leveraging co-simulation techniques and the Amitran methodology.

8 CONCLUSIONS

In this paper, we presented a simulation architecture designed to optimize electric vehicle (EV) charging in Dresden's Ostra District as part of the Mobilities for EU project. Our approach leverages co-simulation frameworks, specifically utilizing the Simulation of Urban Mobility (SUMO) and the High-Level Architecture (HLA), to model the complex interactions between EVs, charging infrastructure, and the power grid. Through this integration, we aim to facilitate real-time data exchange and visualization, allowing for a deeper understanding of how these systems interact and impact urban energy dynamics.

The findings from our simulation architecture will provide valuable insights into various charging strategies, enabling city planners and fleet managers to make informed decisions that enhance energy efficiency and reduce emissions. By evaluating scenarios involving smart charging and bidirectional charging technologies, we anticipate identifying optimal strategies for peak shaving and improving grid stability.

Moreover, our research highlights the importance of collaboration with local authorities in validating simulation models with real data, which will further enhance the accuracy and applicability of our findings. The insights gained from this work will contribute to the growing body of knowledge on sustainable urban mobility, providing a robust framework for future studies aimed at integrating EVs into urban environments.

Ultimately, this research not only addresses the immediate challenges associated with EV integration but also lays the groundwork for future advancements in smart charging solutions. As cities continue to adopt EVs as a means of reducing carbon emissions and promoting sustainable transportation, our simulation architecture will serve as a critical tool in shaping effective policies and strategies that support the transition toward greener urban mobility.

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