Development of Tools for Simulating V2H Scenarios in Residential Settings

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***Abstract.*** *This paper presents a simulation tool designed to explore residential Vehicle-to-Home (V2H) energy strategies under diverse real-world conditions. Built with a visual and user-friendly interface, the tool enables quick scenario testing based on parameters such as season, location, vehicle type, and user behavior. It calculates key performance indicators* *including use cases of electric vehicles in residential contexts, focusing on energy self-sufficiency, flexibility, and cost savings, using realistic demand, PV generation, and dynamic tariff profiles.*

*The tool was evaluated through realistic use case scenarios. and internal user testing involving energy experts. Results confirmed its ability to reflect contextual variations and support both technical analysis and educational use. A comparative study also revealed that larger EV batteries do not always yield better performance under short connection periods.*

*By making complex energy interactions accessible without requiring advanced modeling skills, the simulator serves as a valuable support tool for researchers, students, and local stakeholders involved in energy transition planning.*

# Introduction

The increasing share of renewable energy in power systems calls for greater flexibility. At the same time, electric vehicles (EVs) emerge as a growing but still underused source of distributed energy storage. As transportation becomes increasingly electrified, the correlation between traffic patterns and electricity demand is also intensifying, revealing new interactions between the energy and mobility sectors [4,5].

 Among Vehicle-to-X (V2X) solutions, Vehicle-to-Home (V2H) stands out as a promising approach. It enables direct energy exchange between an EV and a home, turning the vehicle into both a flexible storage unit and a support system for the household. This synergy between the house and the vehicle opens new opportunities for improving solar self-sufficiency reducing electricity bills, and easing stress on the electrical grid.

 In recent years, a growing number of simulation tools have been developed to support energy system analysis and the integration of distributed energy resources. However, few of these tools are specifically designed to explore Vehicle-to-Home (V2H) strategies in realistic residential contexts. Existing platforms such as HOMER Energy, GridLAB-D, or OpenDSS focus on broader energy systems or grid-level analysis Academic studies often rely on custom-built models in MATLAB or Simulink, but these remain difficult to access and reuse outside specific research environments [6].

 To address this gap, we developed V2Hsim, a lightweight and open-source simulation tool tailored for evaluating residential Vehicle-to-Home (V2H) scenarios and energy strategies. The tool allows for quick use cases testing, supports educational use, and enables comparisons across countries, seasons, and user profiles. It features a visual, parameter-driven interface that calculates key performance indicators such as flexibility, savings, and self-sufficiency.

 In this paper, we present the simulation tool and explain its structure and internal logic. We then explore a set of test cases representing different household–EV scenarios, compare the impact of battery size, and discuss the results of internal testing and expert feedback. Finally, we reflect on the broader value of such tools for both research and education and suggest directions for future development.

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Figure 1. V2H concept and energy flow diagram

# Simulation tool and methodology

We developed a Python-based simulator, V2Hsim, designed to model 24-hour energy exchange between components in a Vehicle-to-Home (V2H) system with an hourly resolution. An interactive version of the tool is available online at [appv2h.streamlit.app](https://appv2h.streamlit.app" \t "_new). The system includes four interacting components: household electricity demand, photovoltaic (PV) generation, the EV battery, and the power grid, which is represented through hourly energy prices (peak, mid-peak, and off-peak tariffs) and used to compute the net load curve when local production and storage are insufficient.

 Section 2 describes the simulator’s structure in detail, starting with the input data and modeling assumptions, followed by the rule-based simulation algorithm. It then explains the generated outputs, the key performance indicators (KPIs), and the way the tool visualizes results. Finally, we present the typical use cases explored through the interface.

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Figure 2 : Overview of the tool

## Input datas and assumptions

We use realistic and context-specific input data to run the simulation. For photovoltaic (PV) generation, we compute hourly profiles for each month using irradiance data from PVGIS [7], assuming a panel efficiency of 20.5 %. These values are scaled according to the installed

peak power, which typically ranges from 9 to 15 kWp depending on the selected city. The simulator includes five cities—Ljubljana, Paris, Copenhagen, Lisbon, and Athens—and the PV profile automatically adjusts to reflect each location’s solar potential and seasonal variation.

 Household electricity demand is defined using five behavioral profiles from the literature [8], such as “Morning Glory” or “Evening Users”. Each profile captures a 24-hour consumption pattern, expressed as a normalized hourly distribution, and is then scaled to match a selected daily energy demand.

 Users can choose between different EV types, with battery capacities ranging from 40 to 80 kWh and a power exchange capacity of 11 kW. They also define connection times (arrival and departure) to reflect typical routines or operational constraints in fleet usage.

 Electricity prices follow a three-block time-of-use structure—off-peak, mid-peak, and peak—defined for each city. These dynamic prices guide charging decisions when PV is insufficient, enabling cost optimization under realistic energy market conditions.

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Figure 3 : Structure of the V2Hsim simulation tool.

## Rule based algorithm

The simulation follows a rule-based algorithm that prioritizes energy self-consumption. Photovoltaic (PV) energy is first used to meet household demand. If additional energy is needed, the EV battery may discharge to support the home, as long as three constraints are respected: the power exchanged cannot exceed 11 kW, the battery SoC must stay between 20 % and 100 %, and the user-defined target SoC at departure must be reached. When surplus PV or low-cost electricity is available, the battery charges under the same constraints.

 The EV can only interact with the system during its connection window, defined by the selected arrival and departure times. All technical parameters used in this logic are defined in Section 2.1.

 The simulation produces hourly values for the SoC and for energy flows between the PV system, the household, the battery, and the grid. It also computes key performance indicators, such as the energy charged and discharged (in kWh), the contribution of PV and EV to household demand, and the available flexibility, defined as the energy the EV can shift in time to support the home or reduce costs.

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Figure 4 : Simplified decision tree of the simulation algorithm

## Outputs and KPIs

The simulator outputs a combined visual and numerical summary. As shown in Figure **2**, the main chart displays four hourly curves over a 24-hour period: electricity demand (black), PV production (orange), battery flow (yellow), and EV state of charge (blue dashed). Battery flow is positive when charging and negative when discharging. Green and red dots mark the EV’s arrival and departure times, and the background color reflects local time-of-use pricing: green (off-peak), white (mid-peak), and red (peak). This visualization illustrates how the system reacts to solar input, demand, battery status, and tariffs.

On the right, a summary panel displays key performance indicators, including:

* energy charged (from PV or grid),
* energy discharged,
* flexibility (EV support to the house),
* PV usage during connection,
* self-sufficiency (share of demand met without the grid),
* savings compared to a fully grid-based scenario.

## Uses cases

This section presents the use cases selected for user testing to evaluate the simulation tool’s performance and usability. Each scenario represents a typical residential V2H setup with varying vehicle connection times and target state of charge (SoC) parameters, reflecting different user behaviors and needs. These cases help validate the tool’s capacity to model realistic V2H interactions and provide meaningful feedback on its practical application.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Use case | Arrival  Time | Initial  SOC | Departure  Time | Target  SOC |
| UC1 | 4AM | 40% | 8AM | 80% |
| UC2 | 7Pm | 50% | 11AM | 90% |
| UC3 | 4AM | 20% | 8AM | 90% |

These scenarios encompass typical daily schedules and battery management strategies, allowing users to explore the impact of connection windows and SoC targets on energy flows, cost savings, and flexibility. They also serve as a basis for gathering user feedback on the tool’s interface and outputs, contributing to its iterative improvement.

# Results : Case study, impact of the battery's size

To assess how battery size influences V2H performance, we conducted a comparative analysis using two vehicle configurations under identical conditions. The test scenario simulated a summer day in Paris, following UC2, with a 9 kWp PV system.

 The only difference between the cases was battery capacity: a small EV (Renault Zoé, 40 kWh) versus a large EV (BMW iX3, 80 kWh), both with the same 11 kW charging power. Despite the BMW charging more energy overall (38.9 kWh versus 22.9 kWh for the Zoé), the performance results were very similar. Both vehicles discharged exactly 6.9 kWh to support the household, achieved the same flexibility score of 45.4%, and utilized PV production similarly during connection (24.11 kWh), with 19.21% directly covering household consumption. Self-sufficiency was identical at 86.3%.

 Interestingly, the smaller battery produced slightly higher cost savings (€0.92 versus €0.88), mainly due to lower reliance on the grid. These results show that for short connection durations and moderate solar input, increasing battery size does not necessarily improve performance. Charging needs and connection times dominate system behavior, leaving excess capacity unused. Without longer availability or greater PV generation, oversizing the battery can lead to underutilized flexibility. This similarity in performance is clearly illustrated in Figure 5.

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Figure 5 :. Impact of battery size on performance indicators for the same scenario (Paris, summer weekday).

# Results : Internal testing with domain expert

To evaluate the simulator, five researchers and engineers from the University of Ljubljana, experts in energy systems but not involved in the tool’s development, participated in a structured user test.

 After a short introduction, they explored a predefined scenario set in Ljubljana during summer, using the “Evening users” household profile and a 12 kWp photovoltaic system. Using this setup as a baseline, participants then tested three use cases from the EV4EU project (see Section 2.4), which differed only in EV connection times and SoC targets. This allowed them to observe how small behavioral variations—such as arriving earlier or aiming for a higher final charge—could influence system performance.

 Throughout the simulations, users examined both graphical outputs (battery flow, SoC evolution) and key numerical indicators (flexibility, self-sufficiency, cost savings). They then completed a short survey covering both factual aspects and subjective impressions.

 A summary of the responses is shown in Figure 5. Among the three tested use cases, UC1 was by far the most appreciated. It was the most frequently selected scenario across all dimensions: flexibility, self-sufficiency, cost savings, and overall preference. This consensus suggests that users found UC1 to offer the best compromise between effective energy exchange with the vehicle, strong solar integration, and economic benefit. Its early morning connection window and relatively low initial SoC may have allowed the system to maximize battery usage without compromising the end-of-day charge target.

 In contrast, UC2 and UC3 received fewer positive mentions. They were rarely identified as the most performant scenario on any single KPI, and even less frequently chosen as the best configuration overall. While some participants acknowledged their specific features—such as the low initial SoC in UC3 or the long connection period in UC2—these did not translate into a strong perceived advantage. This suggests that small variations in timing and SoC targets can significantly affect system performance, but do not always yield better outcomes.

 Overall, the simulator was positively received. Users appreciated the clarity of the visuals, the ease of use, and the ability to observe how different parameters affect results. Suggestions included adding tooltips for KPIs, enabling result export in table format, and extending the simulation window beyond 24 hours. One participant emphasized the tool’s potential for teaching energy flexibility and user behavior in academic settings.

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Figure 6 : User feedback on the three tested scenarios (UC1, UC2, UC3).

# Conclusion

This paper presented a simulation tool designed to explore Vehicle-to-Home (V2H) strategies across different cities, seasons, and user profiles. Through a simple visual interface, it delivers key performance indicators such as flexibility, savings, and self-sufficiency, supporting both technical assessment and educational use.

 Initial testing with domain experts confirmed its usability and conceptual consistency. Participants were able to interpret key trends, identify performance variations across scenarios, and provided constructive suggestions for future improvement. These insights contributed directly to refining the interface and validating the overall approach.

 A case study on battery size showed that, under short connection times, larger capacities do not necessarily enhance performance. This highlights the tool’s ability to test realistic trade-offs and challenge assumptions.

 The simulator stands out for its flexibility, ease of use, and ability to support non-specialists in exploring V2H scenarios. Future developments may include multi-day simulations, EV fleet aggregation, and real-time data integration.

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 Future developments may include multi-day simulations, aggregated EV fleets, or real-time data integration, enhancing the tool’s value for research, policy, and local energy planning

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