V2Hsim simulator: investigation of selected Vehicle-to-Home use-cases

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***Abstract.***  *This paper presents a simulation tool to explore V2H strategies using realistic input data on PV, home demand, EVs, and tariffs. Users can test scenarios by adjusting season, location, vehicle type, and behavior. Results are visualized along with key performance indicators. A case study showed that larger EV batteries do not always improve performance under short connection times. Expert testing confirmed the tool’s usability and relevance for both analysis and education.*

***Key words:*** *Vehicle-to-home (V2H), simulation tool, battery size impact, context-aware energy management*

# 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 [1], [2], [3], [4].

 Among Vehicle-to-Everything (V2X) solutions, Vehicle-to-Home (V2H) stands out as a promising approach. It enables bidirectional energy exchange between an EV and a home (Figure 1), turning the vehicle into both a flexible storage unit and a support system for the home [5]. This synergy between the home and the vehicle opens new opportunities for improving energy self-sufficiency, reducing electricity bills and easing peak demand 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 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 V2H use cases (UCs) and energy strategies. The tool enables quick UCs testing, supports educational use, and facilitates comparisons across countries, seasons, and home profiles. It features a visual, parameter-driven interface, based on inputs, calculates key performance indicators (KPIs) such as flexibility, savings, and energy self-sufficiency.

 In this paper, we present the simulation tool and explain its structure and internal logic. Additionally, we explore a set of test UCs representing different levels of correlation between home demand and EV connection. We compare how the EV battery size affects system performance, including energy autonomy, flexibility, and cost savings. The results of internal testing and expert feedback are discussed. Finally, we reflect on the broader value of such tools for both research and education and suggest directions for future development.

A diagram of a house and car

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Figure 1: V2H concept and energy flow diagram

# V2Hsim simulation tool and methodology

We developed a Python-based simulatorV2Hsim, designed to model 24-hour energy exchange between components in a V2H system with an hourly resolution. An interactive version of the tool is available online[[1]](#footnote-1), the interface is presented in Figure 4. The system includes four components: home electricity demand, photovoltaic power plant (PV), the EV. The energy grid 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.

 Further section 2 describes the simulator’s structure in detail, starting with the input data and modelling assumptions, followed by the rule-based simulation algorithm. Additionally, the outputs, the calculated KPIs, and the visualization of the tool is presented. Finally, we present the typical UCs that can be explored through the tools interface.

## Input data and assumptions

For the simulation the tool uses realistic and context-specific input data. The used input data is presented in Figure 2. For PV generation, we compute hourly profiles for each month and for the selected country and consequently city, using irradiance data from PVGIS, 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. PV generation profile is automatically adjusted to reflect each location’s solar potential and seasonal variation.

  Home electricity demand is defined using five behavioural profiles from the literature [7], such as “Morning Glory” or “Evening Users”. Each profile captures a 24-hour consumption pattern, expressed as a normalized hourly distribution (sum = 1), and is then scaled by multiplying each hourly value by the chosen total daily energy demand.

 Users can also choose between different EV types, with battery capacities ranging from 40 to 80 kWh. We assume that the EV is connected to the 11 kW charging station (CS). They also need to define connection times (arrival and departure) to reflect typical routines or operational constraints in EV usage.

In addition to connection times, users must specify the EV’s state of charge (SoC) at plug-in and the desired SoC at plug-out, which defines the battery’s availability for energy exchanges during the connection window.

 Electricity prices and tariffs follow a three-block time-of-use structure off-peak, mid-peak, and peak defined for each city. The energy grid constrains are predefined in the tool. These dynamic prices guide charging or discharging decisions when PV production is insufficient and enabling cost optimization under realistic energy market conditions and the underlying decision process is provided in section 2.2.

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Figure 2: General structure of the V2Hsim simulation tool. Inputs feed a rule-based algorithm that computes energy flows, SoC, and key performance indicators.

## Rule-based algorithm

The V2Hsim follows a rule-based algorithm that prioritises energy self-consumption in the V2H concept. PV energy is first used to meet home 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 be 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 EV charges to meet desired SoC at plug out.

 The EV can only interact with the system during its connection period, defined by the selected arrival and departure times. All the input 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 home, the battery, and the grid. It also computes KPIs, such as the

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Figure 3: Simplified decision tree of the rule-based algorithm

energy charged and discharged (in kWh), the contribution of PV and the utilized flexibility, defined as the energy that the EV provided (discharged) to support the home and consequently reduce costs. A simplified presentation of the algorithm is in Figure 3.

## Outputs and KPIs

The simulator outputs are a combined visual and numerical summary. As shown in Figure 4, the main chart displays four hourly curves over 24-hours: electricity demand (black), PV production (orange), battery flow (yellow), and EV SoC (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 colour reflects local time-of-use pricing and grid tariffs: green (off-peak), white (mid-peak), and red (peak). Visualization in Figure 4 illustrates how the system reacts to PV input, household demand, EV battery status, and grid tariffs. On the right, a summary panel displays calculated KPIs, including:

* energy charged to the EV (from PV or grid),
* energy discharged from the EV,
* activated flexibility (EV support to the home),
* PV usage during EV connection period,
* Energy self-sufficiency
* Savings compared to a home without V2H

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Figure 4: Visual interface and of the V2Hsim tool

The outputs of the V2Hsim tool are also presented in Figure 2.

## Uses cases

This section presents the selected UCs for demonstration and user testing to evaluate the simulation tool’s performance and usability. Selected UCs are presented in table 1. Each scenario represents a typical residential V2H setup with varying vehicle connection times and SoC parameters, reflecting different user behaviours and needs. These cases help validate the V2Hsim capacity to model realistic V2H interactions and provide meaningful feedback on its practical application.

Table 1: Definition of the three test UCs

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **UC** | **Arrival**  **Time** | **SoC at plug in** | **Departure**  **Time** | **SoC at plug out** |
| **UC1 -** "workday home” | 4 AM | 40 % | 8 AM | 80 % |
| **UC2 -**“weekend home” | 7 PM | 50 % | 11 AM | 90 % |
| **UC3** - “work employee’s car” | 4 AM | 20 % | 8 AM | 90 % |

UCs presented in table 1 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.

The selected UCs also served as a basis for gathering users’ feedback, contributing to its iterative development

# Case study of the EV battery size impact

To understand how battery size influences V2H performance, we conducted a comparative analysis using two EVs under identical conditions. The test scenario simulated a summer day in Paris, following UC2 (Table 1), with a 9 kWp PV system.

 The only difference between the two scenarios was battery capacity: a small EV (Renault Zoé, 40 kWh) versus a large EV (BMW iX3, 80 kWh), both connected to the CS with 11 kW charging and discharging power. Although the BMW charged significantly more energy overall (38.9 kWh vs. 22.9 kWh for the Zoé), both vehicles achieved similar performance results, they discharged exactly 6.9 kWh to support the home, achieved the same activated flexibility score of 45.4 %, and utilized PV production similarly during connection (24.11 kWh), with 19.21% directly covering home consumption. Energy self-sufficiency was identical at 86.3% (Figure 5).

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Figure 5: Impact of 40kWh and 80 kWh EV battery capacity size on selected KPIs

 Interestingly, the smaller EV 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 [8]. Charging needs and connection times dominate system behaviour, leaving excess activated flexibility potential unused. Without longer availability or greater PV generation, oversizing the battery can lead to underutilized flexibility.

# Internal testing with domain experts

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 testing.

 After a short introduction, they explored a predefined scenario set for Ljubljana during summer, using the “Evening users” home profile and a 12 kWp PV system. Using this setup as a baseline, participants then tested three UCs defined in table 1, which differed only in EV connection times and SoC states. This allowed them to observe how small behavioural changes, such as arriving earlier or aiming for a higher final charge and consequently SoC could influence system performance.

 Throughout the simulations, users examined both graphical outputs (energy flows, SoC etc.) and KPIs (flexibility, energy self-sufficiency and cost savings). They then completed a short survey covering both factual aspects and subjective impressions.

 A summary of the responses is in Figure 6. Among the three tested UCs, UC1 was by far the most appreciated. It was the most frequently selected scenario across all dimensions: flexibility, energy 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 EV, strong solar integration, and economic benefit. Its early morning connection window and relatively low initial SoC may have allowed the system to maximize EV battery usage without compromising the desired SoC at plug out.

 In contrast, UC2 and UC3 received fewer positive mentions. They were 2 times 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, this 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.

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Figure 6: User perception for the three tested UCs

Overall, V2Hsim 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, and extending the simulation window beyond 24 hours. One participant emphasized the tool’s potential for teaching energy related flexibility and user behaviour in academic settings.

# Conclusion

This paper presents a V2Hsim simulation tool designed to explore V2H strategies across different UCs and specifications, cities, seasons, and home demand profiles. Through a simple visual interface, it graphically presents the results and calculates KPIs such as activated flexibility, cost savings, and energy self-sufficiency, supporting both technical assessment and potential educational use.

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

 A case study on battery size showed that, under short connection times, larger EV battery capacities do not necessarily enhance performance. This shows the tool can test real-world trade-offs and question 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 and real-time data integration, enhancing the tool’s value for research and educational us

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