Energy Proceedings
Vol 61, 2025
ISSN 2004-2965

A Techno-Economic Framework for Using Electric Vehicle Mobility to Support Household Energy During Short-Term Power Outages[#]

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ABSTRACT

The integration of electric vehicles (EVs) into the power infrastructure can be a viable solution to enhance resilience during power outages. This paper proposes a framework to evaluate the techno-economic feasibility of using EV mobility to support household electricity needs during short-term outages under real-world operational limitations. For instance, EVs get charged in functioning power grid and delivers electricity to areas with outages. A rule-based control strategy is developed for energy delivery operation for EVs in order to maximize energy supply as part of a framework. The study assesses performance across key reliability and economic indicators. Simulation results across various scenarios show that personal EVs with sufficient battery capacity can effectively meet household demand in short-term outage scenarios. On the other hand, rented EVs and prolonged outages reduce system efficiency and economic viability. The study can offer valuable insights to stakeholders and policymakers for planning EV-based resilience solutions for future energy systems.

Keywords: electric vehicles (EVs), power outages, vehicle-to-home (V2H), energy resilience, techno-economic analysis, mobile energy storage

1. INTRODUCTION

The rapid advancement of electric vehicles (EVs) has redefined their role beyond conventional transportation. Their integration into the power infrastructure makes them a viable solution to provide enhanced resilience to the system. EVs can store surplus energy during off-peak periods and discharge it back to the grid during peak demand or in emergency situations by working as mobile energy storage units [1, 2]. This bidirectional energy exchange enables EVs to play a crucial role in outages to provide backup power supply and extend their support for critical infrastructure [3].

The development of Vehicle-to-Home (V2H) technology has further strengthened this role. For example, the study in [4] demonstrated how EVs can manage household operations in the event of outages while taking care of a minimum comfort level. Similarly, study in [5] explored the potential of EVs parked in parking lots to restore power in a low-voltage distribution system during outages. Furthermore, [6] proposed the use of rented large capacity electric buses during emergencies in order to support the grid and their dispatch and scheduling under disaster scenarios. The work in [7] presented an incentive-based approach to encourage EV participation in load restoration using a modified IEEE 33-bus system during outages caused by disasters.

To sum up, despite the growing interest in integrating EVs for resilience services using V2H application for outages, the literature still lacks a comprehensive assessment of the economic and technical feasibility together. A holistic evaluation is essential to understand the practical potential of EVs as mobile energy storage solutions in terms of outage scenarios and emergency needs. It may also be insightful for the stockholders and policymakers to make better decisions.

To address this gap, this study proposes a structured framework to assess the full techno-economic potential of EVs in energy delivery during short-term outages, considering their mobility, operational flexibility, as well as the existing pricing models. Specifically, this paper makes the following contributions:

- Proposes a scenario-based evaluation framework that considers key parameters such as load variation, outage duration, ownership patterns, and distance to recharge and deliver energy.

[#] This is a paper for the Resilient-Applied Energy Symposium and Forum: Resilient energy systems (Resilient2025), Sep. 23-25, 2025, Västerås, Sweden.

- Conducts a detailed literature review to extract realistic economic and technical parameters relevant to the EV based outage solution,
- Develops a rule-based control strategy for EV dispatch and operation under practical constraints during outage scenarios, enabling responsive and energy sharing through EV mobility in order to minimize unmet load.

The organization of the paper is as follows. Section 2 describes a proposed overall framework and controlling strategy. Section 3 provides information on the case study and scenario definition. Section 4 presents the results and discussion. Finally, conclusions are drawn in Section 5.

2. METHODOLOGY

This study proposes a framework to evaluate the techno-economic evaluation for EV mobility to deliver electricity to the home during power outages. The proposed approach involves real-world operational constraints and multiple cost structures based on various realistic conditions.

2.1 Overview of proposed framework

The system consists of a single household with a bidirectional charger and have also access to EV chargers. The proposed methodology consists of several key steps. First, we collect real-world load profiles, EV specifications, and cost data. Then, we systematically define the scenarios spanning diverse technical configurations, demand conditions and ownership properties. Next, a rule-based energy delivery control strategy is conducted to perform hourly demand-supply balance regulation under outage conditions, utilizing EV mobility to minimize unmet load subject to realistic operational constraints. Finally, simulation outputs are processed to key performance indices measuring reliability, economic viability, and battery health impact. Figure 1 shows the framework architecture.

2.1.1 Step 1: Data Collection and Parameterization

In this step, load profiles, EV data, and outage data are gathered for further analysis. Hourly load profiles are obtained from real-world data for the area described in the case study. EV battery capacities are selected from common real-world EVs to represent standard, mid-range, and large capacities. Cost data related to electricity, outage compensation, battery degradation and charging are also derived from real-world data. Detailed explanations of data collection and assumptions are also provided in the case study section.

2.1.2 Step 2: Scenario Generation

Various scenarios are generated based on demand and outage conditions, technical conditions such as battery capacities and travel distances and ownership-based participation. More details can be found in Table 1.

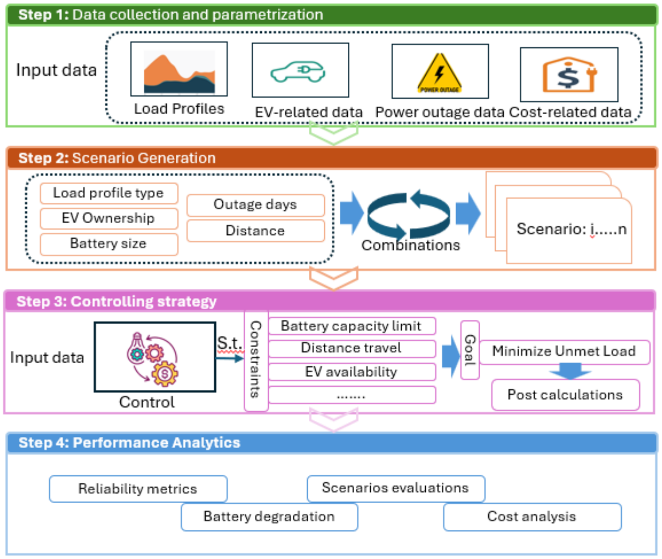

Figure 1. Proposed framework for techno-economic evaluation of EV mobility for resilience

2.1.3 Step 3: Controlling strategy

Energy balancing is performed using a rule-based approach on an hourly basis during outage conditions, considering EV mobility. The goal is to minimize unmet load subject to practical constraints such as travel distance, battery capacity, and EV availability. The post calculation is then performed to calculate. The detailed workflow is explained in a subsequent subsection.

2.1.4 Step 4: Performance Analytics

Post-simulation presents performance evaluation using multiple indicators such as reliability, economics and battery health. The reliability indicator provides insights into unmet load and load served during outages. Economic metrics capture the overall cost for different scenarios in terms of electricity prices, outage compensation costs and charging costs. In case of battery health, battery degradation and its related cost are also evaluated.

In summary, the proposed framework provides a comprehensive techno-economic evaluation of the electricity delivery prospect through EV mobility under outage conditions. It captures realistic operational behaviors and provides insights into system reliability, cost-effectiveness and battery degradation and its cost.

2.2 Control strategy workflow

This study proposes a rule-based control strategy to utilize electric vehicles (EVs) for supporting household energy needs during power outages. The flowchart of the logic is shown in Figure 2.

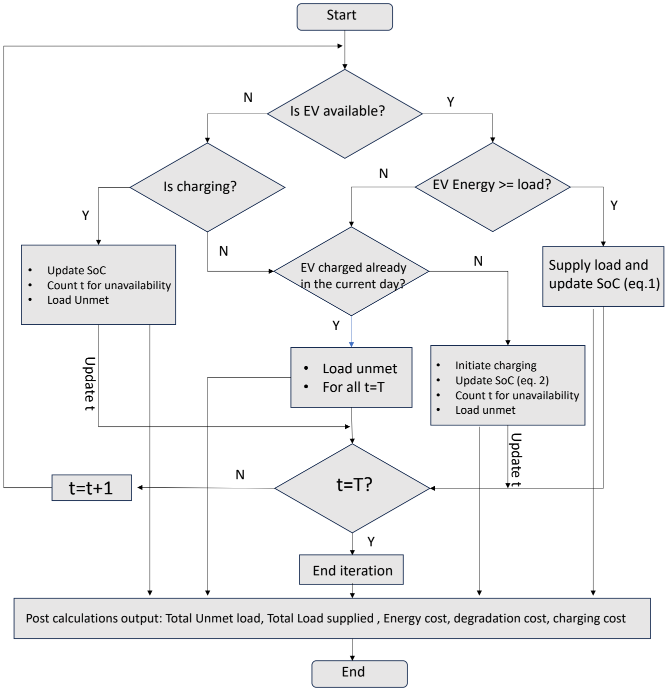

Figure 2. Flow chat for rule-based controlling strategy

At each hourly timestep, the system first checks whether the EV is currently available to the premises. If unavailable, the load is marked as unmet, and the EV's state of charge (SoC) remains unchanged. If EV is unavailable due to charging, loop will continue to record unmet load and time due to EV unavailability. If EV is available, then system calculates the usable battery energy and checks whether it is sufficient to serve the current load. If yes, the load is served and the SoC (SoC_t) is updated accordingly, as per Equation (1).

$$SoC_t = SoC_{t-1} - \left(\frac{P_t}{B_{EV}}\right) \times 100\%, \tag{1}$$

Where P_t (kWh) energy during time interval t and B_{EV} (kWh) is the battery capacity and SoC_{t-1} is the previous timestep SoC.

If the available energy is insufficient, the system evaluates whether the EV is eligible for charging (if it has not already been charged today) because only one time charging per day is assumed, therefore at the start of a new day, the system permits the EV to be charged again, ensuring that the one-charge-per-day rule is maintained.

If so, the EV initiates a charging process, the charge cycle count is incremented, and the EV is made unavailable for the duration of charging and travel. The load is marked as unserved, and the SoC (SoC_{new}) is updated after traveling home using Equation (2). At this time, it also calculates the round-trip travel time (T_t) and charging time (T_C) which gives the total unavailable time T_e as defined by equation (3) under the assumption that once charging starts, the EV remains unavailable until fully charged.

$$SoC_{new} = \left(\frac{B_{EV} - E_{travel,1}}{B_{EV}}\right) \times 100\%, \tag{2}$$

$$T_e = T_t + T_C, \tag{3}$$

$$T_t = 2 \times \left(\frac{D}{S}\right), \tag{4}$$

Where $E_{travel,1}$ (kWh) is the energy required to travel, D is the distance in km between the household and the charging station and s is the average speed in km/h. If the EV has already been charged once that day, the load remains unserved until the next charging opportunity on the following day. In flowchart T is the total hours of outage.

3. CASE STUDY

To evaluate the proposed methodology, a case study is presented with several defined scenarios. The load profiles are to represent real-world data. The data profiles are generated using load profiles from Uppsala [8]. Typical household load profiles are presented as shown in Figure 3. The outage duration is considered up to two days, representing a short-term outage. Battery capacity data is based on commercially available battery models that support bidirectional operation. Charging prices is use as 5.69 SEK/kWh which is obtained from charging station [9] and outage compensations are obtained from the local a Distribution System Operator (DSO) [10] which are assumed as 1200 SEK for 1 day and 2400 for two days outage, respectively. Distances are assumed from charging stations in nearby functioning power networks to present spatial properties. Car ownership is also an important factor and is categorized into three types: personal, rented, and rented with the driver. Table 1*Table* presents the variable factors considered in this study. Table 2 outlines a few scenarios based on these factors, with each scenario varying one factor such as household load, ownership model, outage duration, battery size, or travel distance while keeping others constant.

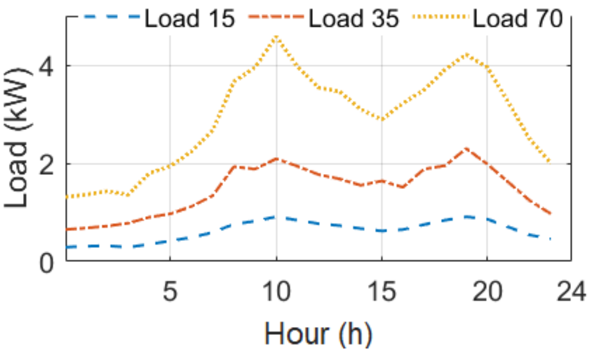

Figure 3. Load profiles for various household sizes

Table 1. Factors considerations with values and descriptions

Factors	Values
Load(kWh)	15,35 and 70
Ownership	Personal, Rented and Rented with driver
Outage duration	1day, 2days
Battery sizes (kWh)	60,77 and 100
Distance (km)	5, 10, 20 and 30

4. RESULTS

This study evaluates the techno-economic feasibility of using electric vehicles (EVs) to supply household electricity during outage conditions. Figure 4 shows the operation of EV delivering energy.

The scenario analysis spans 14 scenarios (SN1–SN14), each varying one factor such as household load, ownership model, outage duration, battery size, or travel distance while keeping others constant. The outcomes include the total cost of energy delivery from the EV, which consists of charging cost, battery degradation cost and renting costs, the additional cost (defined as compensation minus delivery cost), energy supplied and the unmet load, which represents the portion of household energy demand that could not be supplied. The complete results are shown in Table 3.

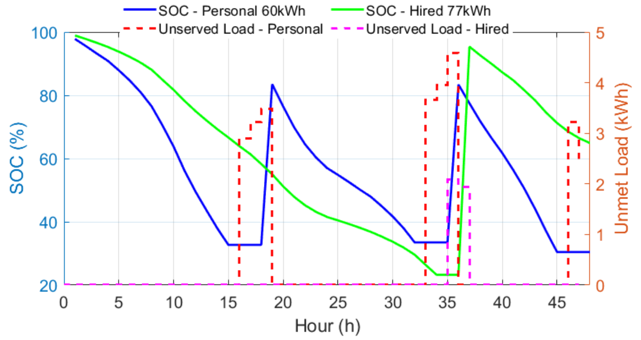

Figure 4 Operation of delivering energy via EV in outage scenario

As shown in Table 3 and Figure 5, the total energy delivery cost varies widely depending on the scenario. Lower household loads (SN2, SN3) and larger EV battery sizes (SN11) reduce delivery costs significantly. For example, reducing the load from 70 to 15 kWh lowers delivery cost from SEK 548.09 to SEK 104.14. In contrast, rented EVs (SN5) and rented EVs with drivers (SN6) result in the highest delivery costs because of the addition of driver cost, exceeding SEK 2700 in case of SN6, due to added service and mobility costs.

Economic viability is further reflected in the additional cost, which represents the difference between the compensation offered for energy support and the actual delivery cost. For example, SN3 yields a large net benefit of SEK1095.86, while SN6 (rented with driver) results in a loss of SEK 1549.17. Figure 2 displays

Table 2. Scenario definitions for the evaluation

Scenarios	Scenario evaluation based on	Load (kWh)	Ownership	Outage duration (day)	Battery size (kWh)	Distance (km)
SN1	Load variation	**70**	Personal	1	60	20
SN2		**35**				
SN3		**15**				
SN4	Ownership	70	**Personal**	1	60	20
SN5			**Rented**			
SN6			**Rented with driver**			
SN7	Outage duration	70	Personal	**1**	60	20
SN8				**2**		
SN9	Battery size	70	Personal	1	**60**	20
SN10					**77**	
SN11					**100**	
SN12	Distance	70	Personal	1	60	**10**
SN13						**20**
SN14						**30**

the unmet load for each case, showing that larger batteries (SN11) and reduced loads (SN2, SN3) eliminate energy shortfalls completely. However, longer outage duration (SN8) significantly increases unmet load to 19.73 kWh, indicating limitations in EV-only backup under extended outage conditions.

Table 3. Scenario-wise results with key performance indices

Scenario	Total Cost (SEK)	Additional Cost (SEK)	Energy Supplied (kWh)	Unmet load (kWh)
SN1	548.09	-651.92	63.05	6.71
SN2	245.35	-954.65	35.08	0.00
SN3	104.14	-1095.86	14.89	0.00
SN4	548.09	-651.92	63.05	6.71
SN5	1529.17	329.17	63.05	6.71
SN6	2749.17	1549.17	63.05	6.71
SN7	548.09	-651.92	63.05	6.71
SN8	1052.04	-1347.96	119.79	19.73
SN9	548.09	-651.92	63.05	6.71
SN10	537.94	-662.06	61.6	8.16
SN11	487.91	-712.09	69.76	0.00
SN12	494.53	-705.47	63.05	6.71
SN13	548.09	-651.92	63.05	6.71
SN14	581.42	-618.58	60.16	9.60

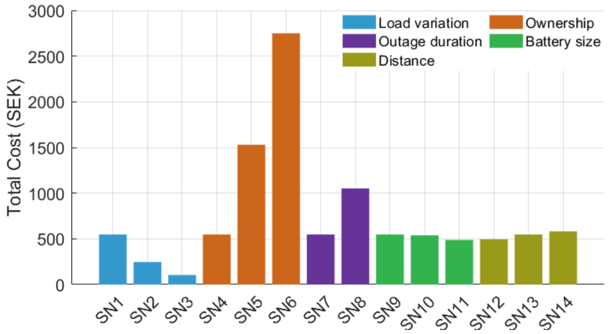

Figure 5. Total energy delivery cost across scenarios

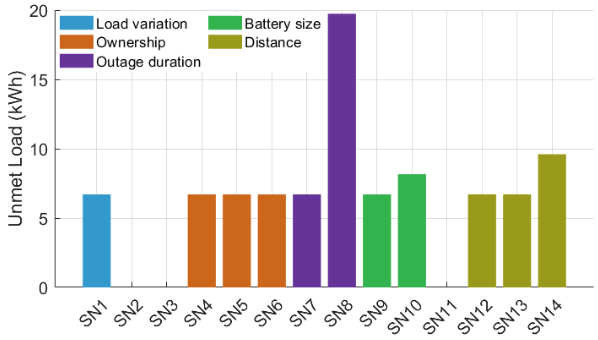

Figure 6. Unmet load across scenarios.

Overall, the results suggest that EVs can effectively support household loads during short outages with proper sizing and usage strategies, but their economic and technical performance deteriorates under longer outages or costly rental arrangements.

5. CONCLUSIONS

This study introduces a framework to evaluate the use of EV electricity delivery from functioning areas of power grid for household energy support during short-term power outages. By incorporating realistic parameters and a rule-based control strategy, the analysis reveals the technical and economic feasibility of EVs as mobile energy sources. Some key findings are highlighted as follows.

- Personal EVs with 100 kWh batteries achieved 100% supply reliability (SN11), demonstrating that larger battery capacities can fully meet household demand during outages without any unmet load.
- Delivery costs dropped by over 80% for low-load households using personal EVs (SN3), indicating strong economic viability when energy demand is modest and EVs are personally owned.
- Under the existing compensation price models in outages, using EVs for electricity delivery to meet household loads is profitable.
- Rented EVs raised delivery costs by up to 5× (SEK 2749.17 in SN6), highlighting that mobility service significantly affects the cost-effectiveness of EV-based backup under outage scenario.

Future work will look into how this solution works in long-term power outage scenarios. Future work will also investigate how business models should be designed to facilitate the electricity delivery via EVs in power outage scenarios. Additionally, future research will explore prioritization of critical loads (e.g., hospitals, shelters) by classifying loads into different importance levels, requiring tailored cost and strategy considerations.

ACKNOWLEDGEMENT

This work was supported by the Energimyndigheten [Grant number: 2023-00498].

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