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BIDIRECTIONAL BATTERY ELECTRIC VEHICLES AS DISTRIBUTED ENERGY STORAGE UNDER GRID EXPORT LIMITATION

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Summary

This paper evaluates an energy management system (EMS) based concept in which a bidirectional battery electric vehicle (BEV) operates as mobile distributed storage between residential and office energy systems in Dhaka, Bangladesh. The residential node represents the Public Works Department Staff Quarters and comprises a 17 kWp PV array, 15 kW hybrid inverter, 20.7 kWh stationary battery and four equivalent households. The office node represents the Bangladesh Secretariat and comprises a 112.32 kWp PV array connected to a 100 kW inverter, without stationary storage, and a representative 95 MWh yr^{-1} administrative load. A 60.48 kWh BEV with an assumed 12 km one-way commute connects the two locations. Four operating strategies are compared: reference operation without storage (S0), stationary battery storage (S1), smart workplace EV charging (S2), and EMS-controlled bidirectional BEV operation (S3). Compared with S0, S3 Grid import decreases from 40.23 to 29.89 MWh, corresponding to a 25.7% reduction, while PV curtailment decreases from 37.30 to 32.14 MWh, corresponding to a 13.8% reduction, and increases residential self-sufficiency from 35.3% to 76.6%. The results demonstrate that the BEV can provide both temporal storage and spatial energy transfer by absorbing renewable electricity at the workplace and making stored energy available later at the residential node.

Bidirectional BEV, vehicle-to-home, energy management system, grid export limitation, Bangladesh, rooftop PV, load shedding, distributed storage

Field of application for the findings: Rooftop PV, residential and public-building electrification, distributed storage, smart charging, local grid flexibility and resilience planning.

Addressed audience: Researchers, energy planners, distribution utilities, public-building energy managers, PV designers, e-mobility specialists, EMS developers and grid-integration practitioners

1. Introduction

Increasing electrification of buildings and transport, combined with rapid deployment of distributed photovoltaic systems, creates a growing need for flexible energy-management strategies. A fundamental challenge is the temporal mismatch between PV generation and electricity demand. Solar production is concentrated around daytime hours, whereas residential demand in many applications reaches its maximum during the evening. If export to the distribution grid is restricted, part of the available PV generation may consequently be curtailed.

Stationary battery storage mitigates this mismatch by storing surplus PV electricity and releasing it later. However, a stationary battery can shift energy only in time because it remains physically connected to one location. Battery electric vehicles equipped with bidirectional charging introduce an additional degree of flexibility: electricity can be charged at one location, transported as stored electrochemical energy through normal vehicle mobility, and subsequently discharged at another location.

This concept extends established vehicle-to-grid research, which has demonstrated the potential of controlled EV charging and discharging for power-system balancing, peak reduction and renewable-energy integration (Kempton and Tomic, 2005a, 2005b; Lund and Kempton, 2008; Richardson, 2013; Sortomme and El-Sharkawi, 2011).

The present study focuses specifically on the distinction between temporal flexibility and spatial flexibility. A representative commuting BEV connects a PV-rich office node with a residential node having a pronounced evening demand. During office parking hours, the BEV can potentially absorb surplus PV production. After the normal commute, the stored electricity becomes available at the residential location, where it can reduce evening grid imports or contribute to backup operation.

The case study develops this concept for Dhaka, Bangladesh. Four progressively flexible operating scenarios are evaluated in order to distinguish the contributions of stationary battery storage, smart EV charging and bidirectional BEV operation. The principal performance indicators are PV self-consumption, grid import and export, PV curtailment, residential self-sufficiency, mobile energy transfer and outage resilience.

2. Case study topology and input data

2.1. Locations and component capacities

Two representative energy nodes in Dhaka are considered. The office node represents the Bangladesh Secretariat in the Shegun Bagicha/Shahbag area, while the residential node represents the Public Works Department Staff Quarters in the Ansar Camp area. A commuting distance of 12 km one way, or approximately 24 km per working day, is assumed. This distance is a case-study engineering assumption rather than a measured GPS trajectory.

The overall system architecture is shown in Fig. 1, an integrated energy system combining PV generation, battery storage, EV charging, backup generation, building loads, and the utility grid. The residential node contains rooftop PV, a hybrid inverter, stationary battery storage, household demand, grid connection and a residential EV interface. The office node consists of a substantially larger grid-connected PV array, office demand, a bidirectional EV charging interface and the distribution grid. The BEV creates the only mobile energy-storage connection between the two otherwise independent electrical nodes.

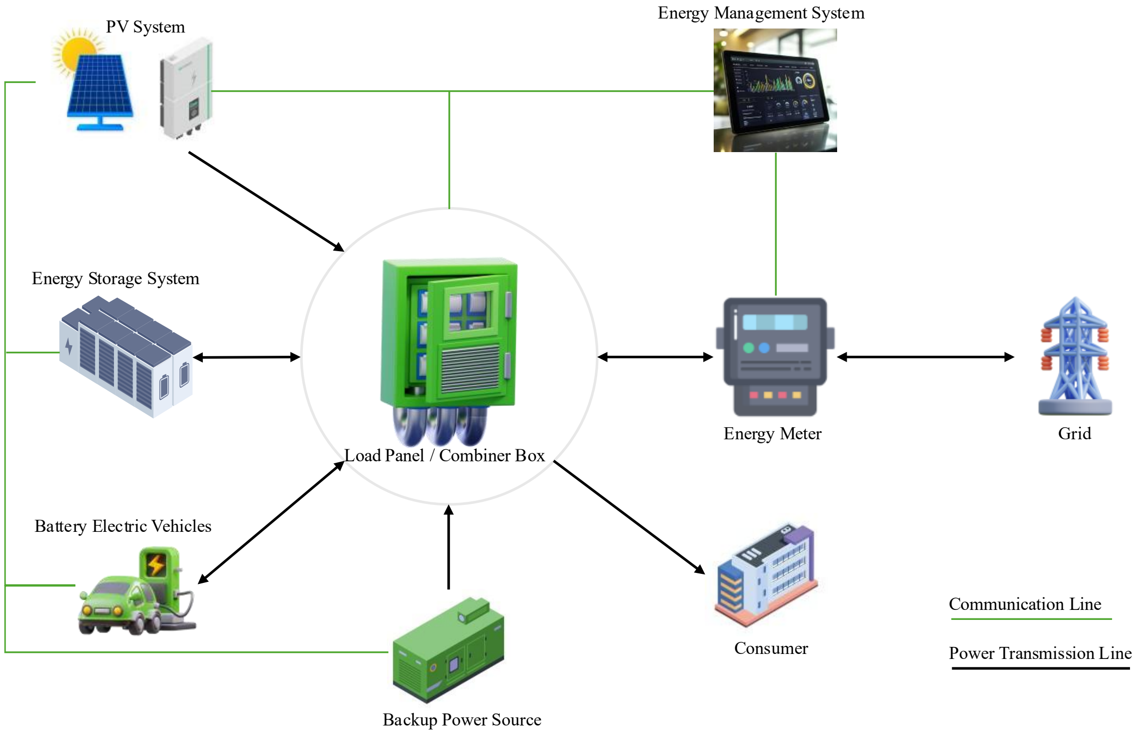

Fig. 1: Integrated PV–battery–EV energy system with grid and centralized energy management.

The capacities and operating assumptions used throughout the analysis are summarized in Tab. 1. The case study considers a 17 kWp residential PV system, corresponding to 30 modules of 585 Wp, while the office array comprises 12 parallel strings, each containing 16 modules of 585 Wp, resulting in: $P_{PV,office} = 16{\times}585{\times}12{=}112.32$ kWp. A 100 kW grid-connected inverter is considered for the office, giving a DC/AC ratio of approximately 1.12. No stationary battery is installed at the office. This configuration deliberately creates a situation in which the BEV can provide flexible storage for workplace PV surplus.

Tab. 1: Locations, component capacities and principal assumptions

Item	Residential node	Office node
Location	PWD Staff Quarters, case-study representation	Bangladesh Secretariat, representative administrative feeder
PV array	17.55 kWp, 30 × 585 Wp	112.32 kWp, 16 × 585 Wp/string × 12 strings
Inverter	15 kW hybrid inverter	100 kW PV inverter
Stationary battery	20.7 kWh usable, 10.5 kW	None
EV connection	7 kW home connection	11 kW bidirectional EVSE
BEV battery	60.48 kWh	Same mobile vehicle
Export constraint	3 kW study limit	20 kW study limit
Annual building load	23.488 MWh yr^{-1}	95.0 MWh yr^{-1}

The 3 kW and 20 kW export limits in Tab. 1 are study constraints rather than national regulatory limits. Bangladesh's Net Metering Guideline 2025 allows eligible renewable-energy consumers to use locally generated electricity and export eligible surplus energy to the distribution network. The artificial caps are introduced here specifically to investigate the technical value of flexible storage under constrained-export conditions.

2.2. Residential demand, office demand and solar resource

The residential input is a study-generated 2025 hourly electricity-demand profile for Dhaka. One equivalent household consumes 5.872 MWh yr^{-1}, and four equivalent households are aggregated to 23.488 MWh yr^{-1}, corresponding to an average demand of approximately 64.35 kWh d^{-1}. The profile contains seasonal scaling and a pronounced evening demand peak.

The absolute demand values are therefore engineering scenario inputs and are not presented as measured smart-meter data from the selected PWD Staff Quarters. Nevertheless, the use of an evening-peaking residential profile is consistent with Bangladesh residential-demand research. Khan (2021), for example, developed a survey-based household demand-profiling methodology for Bangladesh specifically because granular smart-meter data remain limited and demonstrated its applicability around system peak periods.

The solar resource is represented by a study-generated 10 min synthetic Dhaka weather year, rather than measured meteorological-station observations. The resulting annual PV-specific yield is: YPV =1353.2 kWh kWp^{-1} yr^{-1}.

Monthly specific production ranges from approximately 82.7 kWh kWp^{-1} in July to 144.1 kWh kWp^{-1} in March. The simulated annual yield is physically plausible when compared with the World Bank/ESMAP–Solargis assessment for Bangladesh, which reports long-term PVOUT values of approximately 1314–1534 kWh kWp^{-1} yr^{-1} for the 1999–2018 reference period.

The resulting annual residential PV generation is: EPV,res = 17.55 x 1353.2 = 23.74 MWh yr^{-1},

while the revised office system produces: EPV,office = 112.32 x 1353.2 = 151.99 MWh yr^{-1}.

The relationship between monthly residential demand and PV generation is illustrated in Fig. 2. Annual residential generation is approximately equal to annual residential demand; however, Fig. 2 demonstrates that annual-energy equivalence does not imply instantaneous energy balance. Seasonal variation and, more importantly, the mismatch between daytime generation and evening consumption create a continuing requirement for grid exchange or storage.

The office demand is represented by a 95 MWh yr^{-1} administrative-building profile with occupancy primarily during Sunday–Thursday working periods. It is a representative engineering profile and is not presented as measured electricity data from the Bangladesh Secretariat.

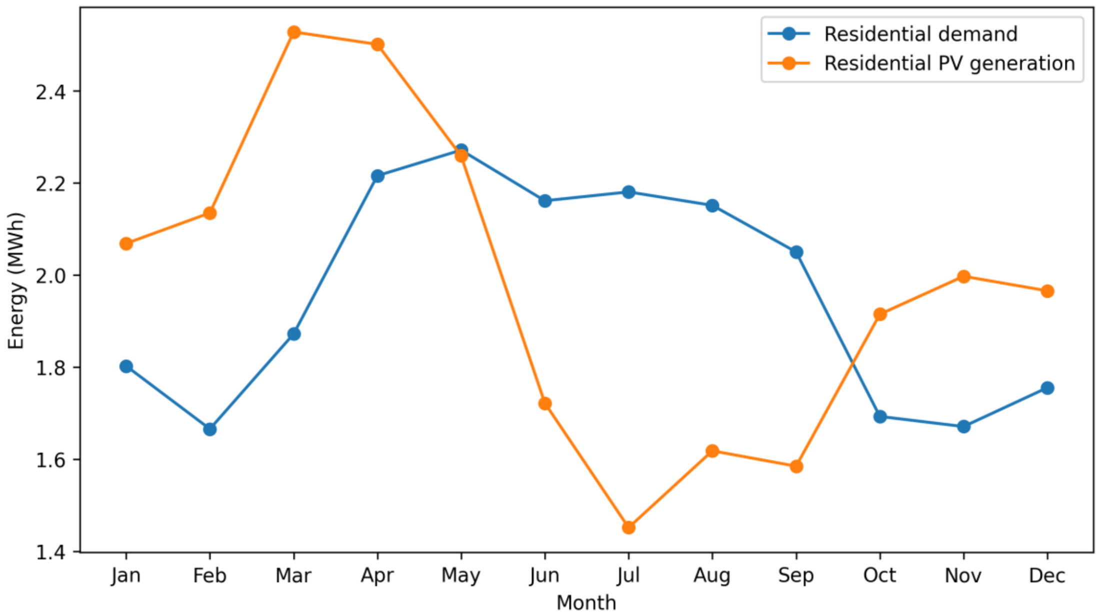

Fig. 2: Monthly residential demand and residential PV generation for the 17.55 kWp array.

2.3. Bangladesh grid and EV-charging context

The study considers load shedding as a resilience issue but does not assume that Dhaka experiences a fixed number of outage hours every day. Official BPDB daily reports demonstrate substantial day-to-day variation. For example, the Dhaka zone recorded 55 MW of load shedding against 5593 MW demand at the evening peak on 23 May 2025, whereas BPDB data for 11 July 2025 reported zero load shedding. This variability justifies the use of controlled outage-duration stress tests rather than an artificial fixed annual outage schedule.

Bangladesh also has an official EV Charging Guideline. The present work should nevertheless be interpreted as a technical bidirectional-charging scenario, not as a claim that every modeled V2H/V2G operating mode is currently permitted for every vehicle, charger or distribution connection. Actual deployment would require compliance with the applicable EV charging, electrical safety and grid-interconnection requirements.

3. Mathematical formulation and EMS operation

For each node, the EMS evaluates the instantaneous balance between PV generation, building demand, storage power and grid exchange.

The basic node power balance is:

$$P_{\mathrm{PV}}(t) + P_{\mathrm{g,in}}(t) + P_d(t) = P_L(t) + P_c(t) + P_{\mathrm{g,out}}(t) + P_{\mathrm{curt}}(t) \qquad \text{(eq. 1)}$$

where charging and discharging terms represent the storage resources connected at the corresponding node.

The stationary-battery energy state is updated according to:

$$E_b(t+1) = E_b(t) + \eta_c P_c(t)\Delta t - \frac{P_d(t)\Delta t}{\eta_d} \qquad \text{(eq. 2)}$$

with the operating constraints:

$$E_{b,\min} \le E_b(t) \le E_{b,\max} \qquad \text{(3a)}$$

$$0 \le P_c(t) \le P_{c,\max},\, 0 \le P_d(t) \le P_{d,\max}. \qquad \text{(eq. 3b)}$$

Battery state of charge is calculated as:

$$SOC_b(t) = 100\frac{E_b(t)}{E_{b,\mathrm{nom}}}. \qquad \text{(eq. 4)}$$

For the BEV, mobility introduces an additional traction-energy term:

$$E_{\mathrm{EV}}(t+1) = E_{\mathrm{EV}}(t) + \eta_{\mathrm{EV,c}} P_{\mathrm{EV,c}}(t)\Delta t - \frac{P_{\mathrm{EV,d}}(t)\Delta t}{\eta_{\mathrm{EV,d}}} - E_{\mathrm{tr}}(t). \qquad \text{(eq. 5)}$$

The trip-energy requirement is calculated from:

$$E_{\mathrm{tr}}(t) = d(t)e_{\mathrm{EV}}. \qquad \text{(eq. 6)}$$

Using an assumed consumption of 0.156 kWh km^{-1} and a 24 km working-day round trip gives approximately:

$$E_{\mathrm{tr,day}} = 24 \times 0.156 = 3.74\ \mathrm{kWh}.$$

Grid export is restricted by:

$$0 \le P_{\mathrm{g,out}}(t) \le P_{\mathrm{exp,max}}. \qquad \text{(eq. 7)}$$

PV self-consumption ratio is defined as:

$$SCR = \frac{E_{\mathrm{PV}} - E_{\mathrm{export}} - E_{\mathrm{curt}}}{E_{\mathrm{PV}}} \times 100. \qquad \text{(eq. 8)}$$

Residential self-sufficiency is:

$$SSR = \left(1 - \frac{E_{\mathrm{grid,import}}}{E_{\mathrm{residential}}}\right) \times 100. \qquad \text{(eq. 9)}$$

For the monthly comparison shown later in Fig. 7, a study-specific **power solvency index (PSI)** is defined as:

$$PSI_m = \left(1 - \frac{E_{\mathrm{grid,import},m}}{E_{\mathrm{residential},m}}\right) \times 100. \qquad \text{(eq. 10)}$$

The PSI is therefore not introduced as a universally standardized grid metric. It is a case-study indicator expressing the fraction of monthly residential electrical demand that can be supplied without importing electricity from the external grid. The symbols used in Eqs. (1)–(10) are summarized in Tab. 2, allowing the equations and subsequent results to be interpreted consistently.

Tab. 2: Symbols, definitions and units used in the mathematical formulation.

Symbol	Meaning	Unit
P_{PV}	PV generation power	kW
P_L	Electrical load	kW
$P_{\mathrm{g,in}}$	Grid import power	kW
$P_{\mathrm{g,out}}$	Grid export power	kW
P_c	Storage charging power	kW
P_d	Storage discharging power	kW
P_{curt}	Curtailed PV power	kW
E_b	Stationary-battery stored energy	kWh
E_{EV}	BEV stored energy	kWh
E_{tr}	BEV traction energy	kWh
SOC	State of charge	%
η_c, η_d	Charging/discharging efficiencies	–
Δt	Simulation time step	h
d	Travel distance	km
e_{EV}	Vehicle energy consumption	kWh km^{-1}
SCR	PV self-consumption ratio	%
SSR	Residential self-sufficiency ratio	%
PSI_m	Monthly residential power solvency index	%

3.1. EMS control strategy

The EMS prioritizes direct utilization of PV electricity by the local load. Surplus generation is subsequently directed to an available storage resource. At the residence, the stationary battery provides the first local storage function. At the office, where no stationary battery is installed, the parked BEV can absorb surplus PV electricity when charging is permitted by vehicle availability, SOC and mobility requirements.

Once storage requirements are satisfied, remaining surplus electricity can be exported up to the study export limit. Any generation exceeding that limit is curtailed.

During periods of insufficient PV generation, the stationary battery or available BEV can discharge according to the EMS logic while respecting minimum SOC and mobility reserves. Grid import supplies any remaining deficit.

The critical distinction is therefore that the stationary battery provides temporal flexibility only, whereas the bidirectional BEV provides both temporal and spatial flexibility.

3.2. Scenario definition

Four scenarios are evaluated progressively so that the benefit of each additional flexibility mechanism can be isolated. These scenarios are summarized in Tab. 3.

Tab. 3: Compared operating scenarios

Scenario	Stationary battery	Smart workplace charging	Bidirectional EV	Purpose
S0	No	No	No	Reference case
S1	Yes	No	No	Benefit of fixed storage
S2	Yes	Yes	No	Benefit of smart EV charging
S3	Yes	Yes	Yes	Benefit of mobile distributed storage

S0 establishes the reference performance of the PV-equipped energy system without flexible storage. S1 isolates the effect of the residential stationary battery. S2 additionally coordinates EV charging with workplace PV availability. Finally, S3 permits the vehicle to discharge at the residential node and therefore represents the complete mobile-energy-storage concept.

4. Results and discussion

4.1. Representative daily operation

The residential power balance for the bidirectional S3 scenario on 16 July 2025 is presented in Fig. 3. Residential PV rises during the morning, exceeds the local load during the solar-production period, and subsequently declines toward the evening. The stationary battery absorbs part of the daytime surplus and later discharges as residential demand increases. The battery charging and grid export is display as negative values, while grid import and storage discharging is displayed as positive values.

The figure also shows the BEV and grid power channels. On this particular representative day, the BEV is inactive for most plotted hours and shows late charging rather than significant V2H discharge. Consequently, Fig. 3 should primarily be interpreted as an illustration of the residential PV–battery–grid interaction for one day. The annual analysis presented later is more representative of the cumulative bidirectional BEV contribution.

The corresponding office operation is shown in Fig. 4. The 112.32 kWp PV array follows a strong daytime production profile, while office consumption is concentrated during working hours. During the selected day, PV generation is sufficient to offset a substantial portion of the office demand and create periods of export.

The BEV-charging channel is included in Fig. 4 to show its position within the EMS architecture. However, the plotted charging power is approximately zero on this selected day, indicating that the workplace-charging criterion was not activated at those particular time steps. Workplace charging occurs on other simulated days and its cumulative contribution is quantified in the annual S2 and S3 results.

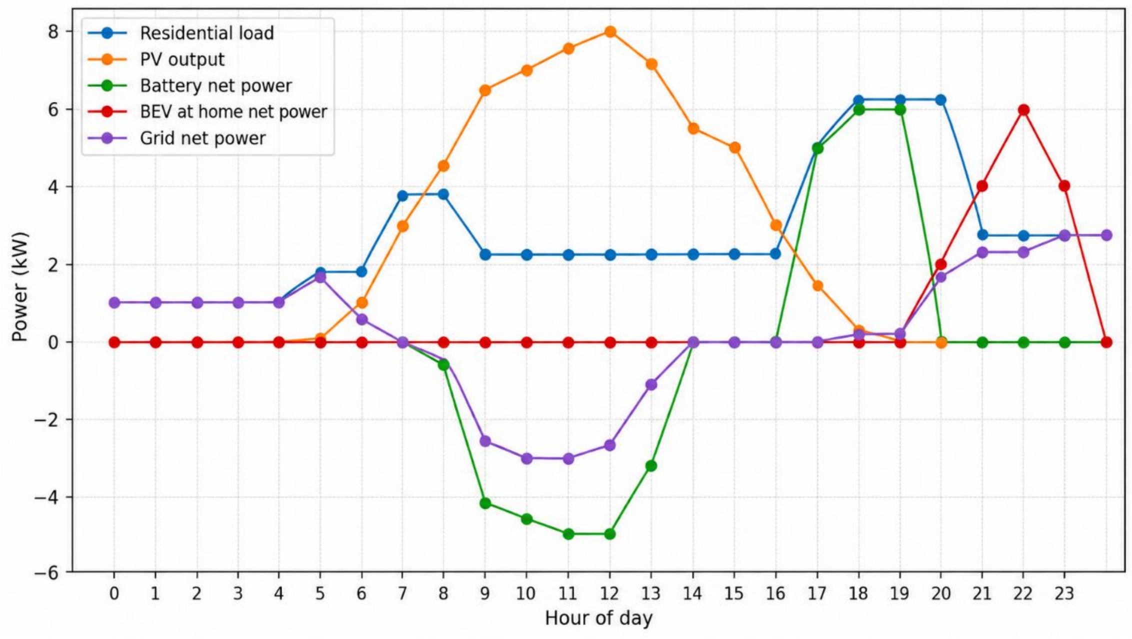

Fig. 3: Representative residential power balance for the S3 bidirectional case on 16 July 2025.

The 20 kW export level shown in Fig. 4 is the study-specific constraint. Where potential export exceeds this limit, the EMS must either redirect energy to available storage or curtail the remaining PV generation.

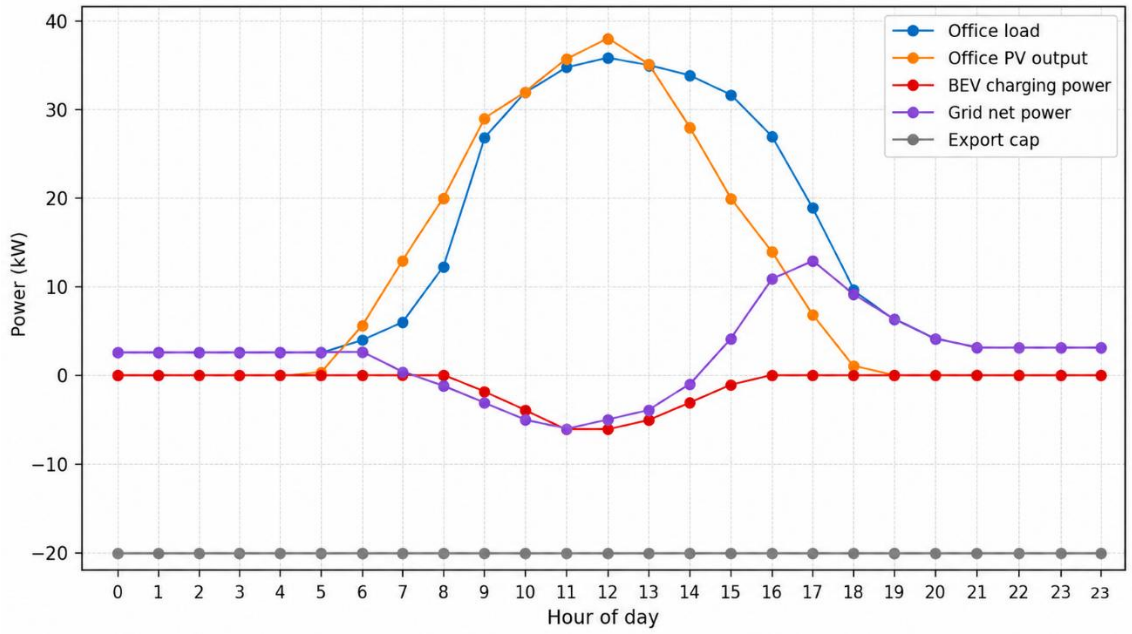

Fig. 4: Representative office PV, load, EV-charging and grid interaction on 16 July 2025 under S3.

4.2. Annual energy comparison

The complete annual results are summarized in Tab. 4. Each successive scenario increases system flexibility, but the magnitude and type of benefit differ.

Introducing the stationary residential battery in S1 reduces total grid import from 40.23 to 34.20 MWh yr^{-1} and increases residential self-sufficiency from 35.3% to 59.9%. This demonstrates the strong value of local temporal storage for matching residential PV production with evening household demand.

Smart workplace charging in S2 produces a further, although smaller, improvement. Total grid import decreases to 33.17 MWh yr^{-1}, while residential self-sufficiency reaches 62.6%. The result reflects improved synchronization of EV charging with daytime workplace PV generation.

The complete bidirectional strategy S3 achieves the lowest grid dependence. Total grid import decreases to 29.89 MWh yr^{-1}, corresponding to a 25.7% reduction relative to S0. Residential grid import decreases from 15.86 to 5.52 MWh yr^{-1}, a reduction of approximately 65.2%.

Tab. 4: Annual performance comparison for the revised 112.32 kWp office PV case

KPI	S0	S1	S2	S3
PV self-consumption (%)	45.1	48.8	49.4	51.5
Total grid import (MWh)	40.23	34.20	33.17	29.89
Total grid export (MWh)	59.14	55.68	55.07	53.15
Total PV curtailment (MWh)	37.30	34.36	33.92	32.14
Residential grid import (MWh)	15.86	9.83	8.79	5.52
Residential self-sufficiency (%)	35.3	59.9	62.6	76.6

The increase in office PV capacity to 112.32 kWp makes the export-limitation problem more visible. The office system produces approximately 151.99 MWh yr^{-1}, considerably more than the representative 95 MWh yr^{-1} office load. With only one BEV and a 20 kW study export limit, the available flexible capacity cannot absorb all surplus solar generation. Consequently, PV curtailment remains significant even in S3.

Nevertheless, curtailment decreases from 37.30 MWh in S0 to 32.14 MWh in S3, corresponding to a 13.8% reduction. Grid export decreases by approximately 10.1%, from 59.14 to 53.15 MWh yr^{-1}. PV self-consumption increases from 45.1% to 51.5%, an improvement of 6.4 percentage points.

These annual energy quantities are visualized in Fig. 5. The progressive reduction in grid import is particularly clear, while the reductions in export and curtailment indicate that progressively more PV generation is retained within the combined home-office energy system.

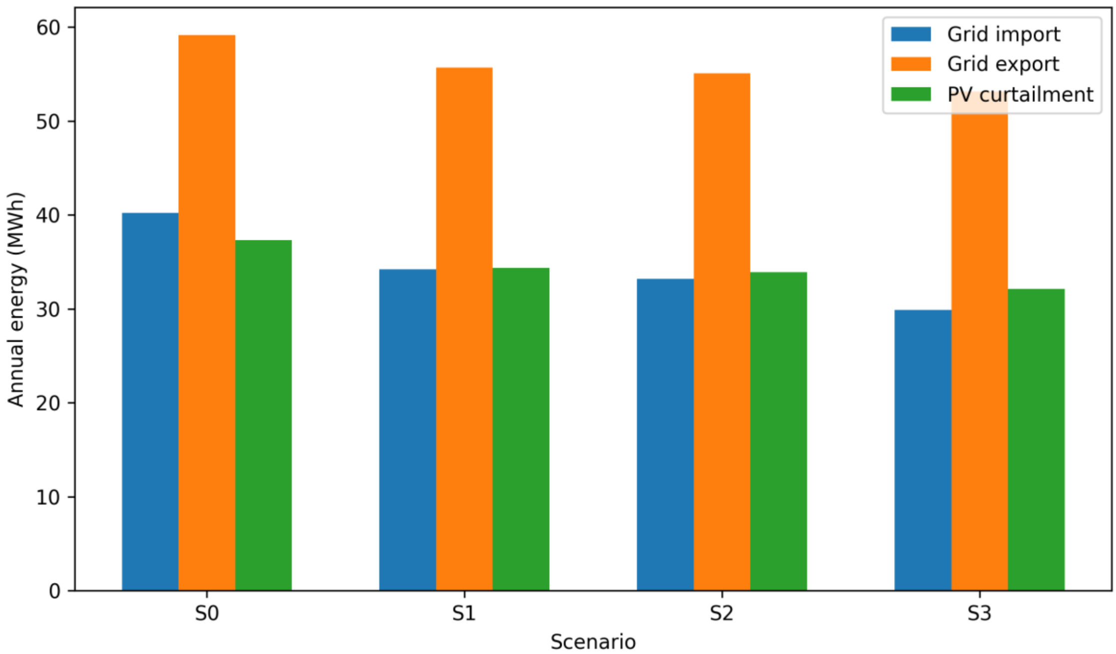

Fig. 5: Annual grid import, grid export and PV curtailment for S0–S3.

The normalized performance indicators are shown separately in Fig. 6. The figure demonstrates that the strongest effect of the flexibility technologies occurs at the residential node: self-sufficiency increases from 35.3% without storage to 59.9% with the stationary battery, 62.6% with additional smart charging and ultimately 76.6% with bidirectional BEV operation.

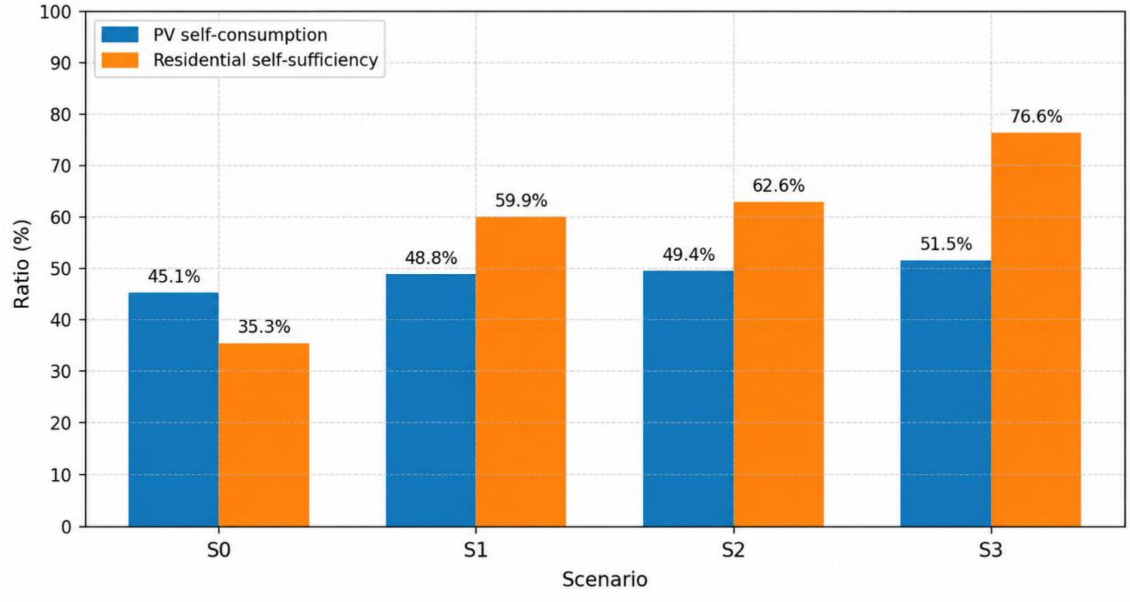

Fig. 6: Annual PV self-consumption and residential self-sufficiency for S0–S3.

4.3. Power solvency with and without EV support

The influence of the BEV is further examined using the monthly power solvency index defined in Eq. (10). Figure 7 compares S1, representing stationary battery storage without bidirectional EV support, with S3, which includes both stationary storage and the mobile BEV.

Without bidirectional EV support, the monthly residential solvency index is approximately 54–64%. With bidirectional operation, the index increases to approximately 62–87%, depending on the month.

The largest improvements occur during months in which evening residential demand is relatively high while workplace PV remains available for charging the vehicle. The result demonstrates an important feature that cannot be achieved by the fixed residential battery alone: renewable electricity generated at the office can be physically relocated to the residential node by the commuting vehicle.

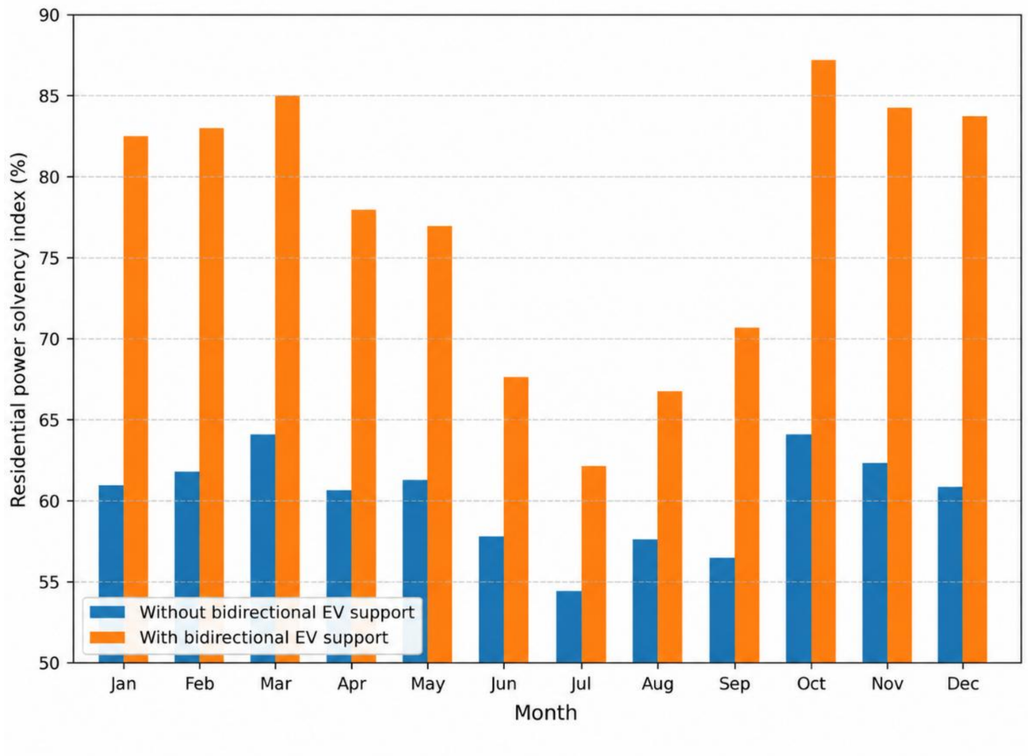

Fig. 7: Monthly residential power solvency index with and without bidirectional EV support.

4.4. Load-shedding resilience

The resilience contribution of storage is evaluated through controlled 1 h, 2 h and 4 h residential outage stress tests, as presented in Fig. 8. These simulations are intended to quantify relative backup capability rather than reproduce a particular historical BPDB outage.

Without storage, the corresponding unserved energies are approximately 6.24, 12.47 and 21.45 kWh. The stationary battery alone reduces these values to approximately 1.22, 7.45 and 16.43 kWh. When the BEV is also available for residential discharge, the remaining unserved energies fall further to approximately 0, 1.77 and 10.75 kWh, respectively.

The 1 h stress case can therefore be completely supported by the combined stationary battery and BEV under the assumed initial storage conditions. For longer outages, the improvement remains substantial, although the available storage eventually becomes insufficient to meet the entire load.

This analysis supports the use of bidirectional EVs as an additional resilience resource, while also emphasizing that their backup value depends on vehicle presence, available SOC and the mobility reserve required for subsequent travel.

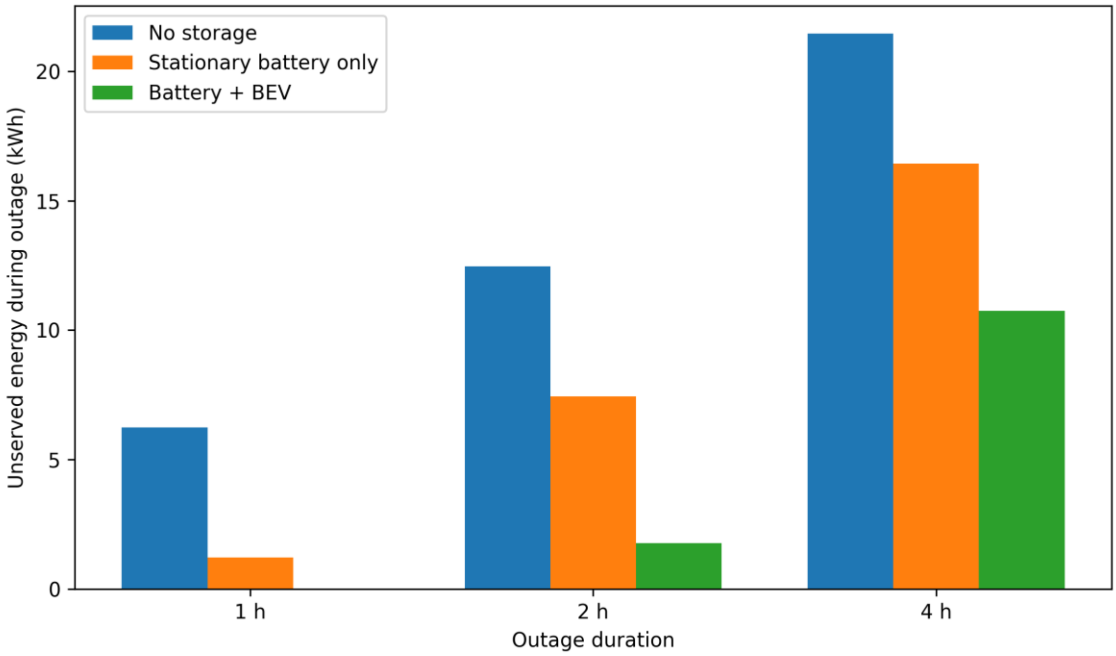

Fig. 8: Unserved residential energy during 1 h, 2 h and 4 h outage stress tests.

4.4. Comparison and benefits

The functional differences among stationary storage, smart charging and bidirectional BEV operation are summarized in Tab. 5.

Tab. 5: Comparison of flexibility options and project benefits

Characteristic	Stationary battery (S1)	Smart charging (S2)	Bidirectional BEV (S3)
Shift energy over time	Yes	Yes	Yes
Shift energy between locations	No	No	Yes
Reduce residential grid import	High	Higher	Highest
Use office PV surplus	No	Yes	Yes
Support evening residential load	Yes	Limited	Yes
Resilience contribution	Yes	No	Yes

Table 5 highlights the central technical contribution of the study. The stationary battery provides reliable local temporal flexibility but cannot exploit renewable generation at another site. Smart charging enables the BEV to consume workplace PV, but the energy remains dedicated primarily to mobility unless vehicle-to-building discharge is enabled. Bidirectional operation combines both functions and enables the BEV to operate as a mobile energy-storage asset.

In S3, the vehicle absorbs approximately 4.75 MWh yr^{-1} at the office and subsequently delivers approximately 3.38 MWh yr^{-1} to the residential node while continuing to satisfy the modeled commuting requirement. The difference between workplace charging and residential discharge represents traction consumption together with charging/discharging losses and other SOC-management effects.

The main benefits of the proposed concept are therefore improved renewable-energy utilization, lower residential grid dependency, reduced system grid import, reduced PV curtailment, increased residential power solvency and enhanced resilience during grid interruptions.

5. Outcome, limitations and future scope

The principal outcome of the study is a quantitative demonstration that a bidirectional BEV can provide additional system value beyond a conventional stationary battery by combining temporal storage with spatial energy transfer.

The final S3 configuration reduces overall grid import by 25.7% compared with the no-storage reference and residential grid import by approximately 65.2%. Residential self-sufficiency increases by 41.3% points, from 35.3% to 76.6%. The power-solvency analysis further shows an improvement in every month when bidirectional EV support is available.

The results also demonstrate a limitation of using only one vehicle with a relatively large workplace PV plant. The 112.32 kWp office array generates about 151.99 MWh yr^{-1}, substantially exceeding the representative 95 MWh yr^{-1} office demand. A single 60.48 kWh BEV cannot absorb all surplus generation, and considerable curtailment remains under the assumed 20 kW export constraint. This result suggests that workplace applications may benefit considerably from a fleet of bidirectional vehicles rather than a single vehicle.

The study nevertheless has several limitations. The residential and office load profiles are representative engineering datasets developed for the considered applications, while the solar resource is based on a synthetic Dhaka weather year. Since actual load profiles can vary substantially between buildings, users, and operating conditions, the selected profiles are intended to represent plausible system behavior rather than a specific metered site. Site-measured load and meteorological data would nevertheless provide an additional level of validation for future case-specific studies. The commuting schedule is deterministic, the route distance is assumed, and economic impacts associated with battery degradation, electricity tariffs and bidirectional-charger investment are not considered.

Future work should therefore use measured PV, meteorological and building-load data from Dhaka; measured vehicle travel and parking schedules; stochastic mobility models; multiple BEVs; battery-aging models; time-varying electricity tariffs; and distribution-transformer constraints. A techno-economic comparison between additional stationary batteries and bidirectional BEV capacity would also be valuable.

Experimental validation represents an important further step. Future demonstrations should evaluate commercially available bidirectional charging equipment and compatible vehicles under applicable Bangladesh electrical, EV-charging and grid-interconnection requirements. Expansion from the present two-node system to a multi-building or district-scale BEV fleet would allow the concept of spatial energy storage to be evaluated at a scale more representative of future sustainable urban districts.

6. Conclusion

This study evaluates a brand-neutral, EMS-controlled home-office energy system in Dhaka in which a bidirectional BEV functions as mobile distributed storage under grid-export constraints. The residential node comprises 17.55 kWp PV, a 15 kW hybrid inverter and 20.7 kWh stationary battery storage, while the office node contains a 112.32 kWp PV system connected to a 100 kW inverter without stationary storage. A 60.48 kWh BEV connects the two sites through an assumed 12 km one-way commute.

The scenario comparison demonstrates progressively increasing benefits from stationary storage, smart workplace charging and bidirectional BEV operation. The complete S3 configuration reduces annual grid import from 40.23 to 29.89 MWh, corresponding to 25.7%, and decreases PV curtailment from 37.30 to 32.14 MWh, corresponding to 13.8%. Residential grid import decreases by approximately 65.2%, while residential self-sufficiency increases from 35.3% to 76.6%.

The power-solvency and outage analyses provide additional evidence that the BEV can support the residential node when it is available and has sufficient SOC. The main contribution is therefore not merely controlled EV charging. Rather, the BEV acts as a mobile distributed energy-storage resource, enabling renewable electricity to be stored at the PV-rich workplace, transported through normal mobility and subsequently used at the residence.

The results support further investigation of bidirectional BEVs as a complementary resource to stationary batteries in PV-rich residential, commercial and district energy systems.

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