**BESS for increased renewable energy consumption and energy resilience in Swedish energy community**

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**Abstract:**

*This paper investigates the techno-economic viability of Battery Energy Storage Systems (BESS) in an industrial energy community in Sweden. Through scenario analysis of a case study involving three buildings with 5 MW of installed PV capacity, we examine how BESS can address grid limitations that currently result in wasted renewable energy. Our findings demonstrate that establishing an energy community without BESS increases PV self-consumption from 38% to 65% and reduces grid-purchased electricity by 15%. Adding a 1440 kWh BESS further enhances self-consumption to 74% and reduces grid purchases by 19% compared to the base scenario. However, economic analysis reveals that while electricity purchase costs decrease across scenarios, reduced grid sales revenue results in nearly identical net electricity costs. This suggests that current simplified BESS operation strategies and electricity pricing mechanisms may not fully capture the economic potential of such systems. Our research provides valuable insights for optimizing community energy systems in Nordic contexts and identifies pathways for enhancing their economic viability.*

***Keywords—****Battery energy storage system (BESS)*, energy community, resilient energy system*.*

**1. Introduction**

In the face of escalating climate change and the pressing need for sustainable energy solutions, energy communities have emerged as a transformative approach to democratise and decentralise our energy systems [1]. These communities represent a paradigm shift, allowing citizens, local authorities, and small businesses to actively participate in energy production, consumption, and management, rather than being passive recipients of centralized energy services [2].

The European Union has recognized the potential of energy communities, with approximately 3,000 such initiatives spread across 12 countries as of 2023 [3]. Countries like Germany and Denmark, with strong traditions of community ownership and social enterprises, lead the way with 1,750 and 700 energy community initiatives, respectively [4]. In Sweden, approximately 200 energy community initiatives have been reported, indicating a growing interest but also significant room for expansion [5].

At the heart of energy communities lie resource-efficient buildings, which serve as the cornerstone for enhancing efficiency and promoting sustainability [6]. These buildings engage in a diverse range of activities, including renewable energy generation, distribution, consumption and sharing, as well as integration of electro-mobility and energy storage [7]. Among them, energy storage plays a pivotal role, particularly in Sweden's evolving energy landscape [8]. Battery Energy Storage Systems (BESS) offers complementary benefits to the flexible energy system. BESS provide balancing and flexibility for intermittent renewable sources, enhancing grid resilience and energy efficiency. Moreover, the participation of BESS in flexibility markets can provide additional revenue streams, further incentivizing their adoption.

This paper presents a case study that investigates the techno-economic viability of utilizing BESS in a community-based energy system in a Swedish industrial area. In this industrial area, one energy user operates its activities in a large building for logistic services. The building has installed PV panels of 5 MW as rated capacity. However, due to limitations of the local power grid, most of the overly produced PV electricity goes to waste. The building user therefore intends to investigate the techno-economic viability of utilizing a BESS to increase PV self-consumption. Meanwhile, several tenants of neighboring buildings intend to reduce grid dependence, thus expressing interests on buying the overly produced PV electricity from the local PV producers. BESS can in this case serve to balance the temporal mismatch between local supply and demand.

Given this background, this paper intends to tackle the following research questions:

1. To which extent can the BESS help to reduce grid-purchased electricity and increase the PV self-consumption for the local PV producer?
2. To which extent can the BESS help to facilitate energy sharing with other energy buyers in the energy community?
3. What is the economic viability of installing a BESS for energy sharing in this energy community?

**2. Case study description and methodology**

In this study, the local PV electricity producer is named as building A, the potential buyers that are interested to share the overly produced PV electricity are named building B and C. Figure 1 illustrates the establishment of this energy community in the industrial area, where Fig 1(a) illustrates the energy system before the energy community was established (without BESS and energy sharing), and Fig 1(b) illustrates the system with energy community established (BESS installed and energy sharing enabled).

A close-up of several electrical towers

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A diagram of a building

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**Fig. 1**. Illustration of the energy community in the Swedish industrial area

**2.1 Data collection and scenario establishment**

In this case study, the buildings purchase electricity the power grid. Such data are acquired from the local power grid operator. The data has hourly time resolution for 8760 hours. The PV electricity sold to the grid from building A is also provided by the grid operator, in hourly time resolution. The PV electricity generation data from the PV panels are provided by the building owner. The data is 5 min resolution and averaged into 1 hour time resolution. The electricity price data is also hourly resolution obtained from ENTSO-E. Table 1 below lists the information of the raw data used for the model.

**Table 1.** Raw data for the energy community model.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Time resolution | Number of data points | Unit |
| Electricity purchased | 1 hour | 8760 | kW |
| PV electricity sold | 1 hour | 8760 | kW |
| PV electricity generation | 5 min | 105 055 | W |
| Electricity price | 1 hour | 8760 | € / MWh |

In this case study, 3 scenarios are established

* Scenario 1 (S1) – Base scenario: only consider building electricity demand and PV self-consumption, no energy community established, meaning no virtual PV power sharing and no battery installed.
* Scenario 2 (S2) – Energy community: an energy community is established among building A, B and C which enables virtual PV power sharing from A to B and C. No battery installed.
* Scenario 3 (S3) – Energy community + BESS: the energy community is further enhanced by a BESS system. In this scenario, the battery has energy capacity of 1440 kWh and power capacity of 750 kW.

Given these 3 scenarios, the indicators used to evaluate and compare scenarios are: PV self-consumption rate, total electricity purchased from the grid, and the total electricity cost.

**2.2 Modelling methodology**

The system model is built using Python. Figure 2 illustrates the modelling flow. The modelling consists of 4 steps. The first step collects and aggregates raw data. After cleaning and preparing the collected raw data, the simulation module in step 2 takes in the processed data to generate results, considering different scenario setups including the energy community module and BESS module. Then, the scenario analysis module calculates the performance indicators of the 3 scenarios and compares them. Finally, the visualization module visualizes the results. The modelling code is available at [xx].

A diagram of a process

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**Fig. 2.** Illustration of modelling methodology

In the modelling step, the energy community module enables PV virtual sharing. The BESS simulates battery charging and discharging processes. The simulation timestamp is 1 hour. The operation strategy of the BESS is set to be ‘simple’, meaning when there is excess PV electricity production, it is always prioritized to charge the BESS than selling the PV electricity to the grid for price arbitrage. Meanwhile when it comes to deficit PV power production, BESS always prioritizes discharging to fulfill building demand, then to discharge completely to the grid rather than wait for a certain price threshold for price arbitrage.

Figure 3 shows the simulation dashboard for selected 72 hours in the month of May. The dashboard shows the hourly variation of PV output, self-consumed PV electricity, charge/discharge process, load and battery state of charging, as well as electricity price.

A graph of a price

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**Fig. 3.** Simulation dashboard

**3. Results and discussions**

The results of different scenarios are presented in this section, followed by discussions that further interprets the scenario results.

* 1. **Scenarios**

Figure 4 displays the simulation results for the 3 scenarios. Scenario 1 is the reference scenario which only considers building electricity demand and PV self-consumption, no energy community established, meaning no virtual PV power sharing and no battery installed. Scenario 2 refers to the energy community established among building A, B and C, which enables virtual PV power sharing from A to B and C. No battery installed. Scenario 3 (S3) refers to the energy community further enhanced by a BESS system.

A graph of energy consumption

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**Fig. 4.** Modelling results of Scenario 1, 2 and 3 (S1, S2, S3)

The top-left panel shows the results of PV self-consumption rate in 3 different scenarios. In S1 (Base scenario), the PV self-consumption rate is 38%. S2 (Energy community) has much higher PV self-consumption rate than S1 (Base scenario), which is 65%. With the BESS installed (S3, Energy community + BESS), PV self-consumption rate can be further enhanced, reaching 74%, almost 2 times of the self-consumption rate of the Base scenario.

The bottom-left panel shows the grid purchased electricity in 3 scenarios. In S1, the grid purchased electricity is 4725.5 MWh annually. In S2 which an energy community is established and PV power virtual sharing is enabled, grid purchased electricity can be reduced to 4032 MWh, 15% less compared with S1. In S3 which this energy community is further enhanced by a BESS, the grid purchased electricity can be further reduced to 3822.8 kWh, 19% less compared with S1.

The right panel shows the costs of purchasing grid electricity, the revenues of selling electricity to the grid, as well as the net electricity costs in 3 scenarios. S1 (Base scenario) has higher electricity purchase cost, which is 285.8 k€ annually, followed by S2 (Energy community) 248.4 k€ and S3 (Energy community + BESS) 237.8 k€. However, S1 has much higher revenue from selling electricity, which is 69.2 k€. S2 and S3 has much lower revenues which are 31.9 k€ and 22.1 k€ respectively. The next electricity costs of the 3 scenarios do not demonstrate significant difference, which are 216.6 k€, 216.6 k€ and 215.8 k€ respectively.

**3.2 Discussion and limitations**

**Technical performance**: The analysis demonstrates a clear technical benefit from both energy community establishment and BESS implementation. The PV self-consumption rate increases substantially across scenarios, from 38% in the base scenario (S1) to 65% when establishing an energy community (S2), and further to 74% when adding BESS capabilities (S3). This represents a nearly two-fold improvement in PV self-consumption when comparing S3 to the base scenario, indicating significant potential for local renewable energy utilization.

The grid-purchased electricity shows corresponding reductions, decreasing from 4,725.5 MWh annually in S1 to 4,032 MWh in S2 (15% reduction) and 3,822.8 MWh in S3 (19% reduction). These findings confirm that both energy communities and BESS can contribute substantially to grid independence and local energy autonomy.

**Economic performance**: The economic analysis reveals a more nuanced picture. While electricity purchase costs decrease progressively from S1 (285.8k€) to S2 (248.4k€) to S3 (237.8k€), the revenue from selling excess electricity to the grid also decreases significantly from S1 (69.2k€) to S2 (31.9k€) to S3 (22.1k€). Consequently, the net electricity costs remain almost identical across all three scenarios (216.6k€ for S1 and S2, 215.8k€ for S3).

This finding suggests that the current simplified BESS operation strategy, which prioritizes self-consumption over price arbitrage, may not maximize economic returns from the battery system. Advanced operation strategies could potentially improve economic performance through e.g. time-of-use optimization that prioritizes discharging during peak price periods, forecasting-based charging/discharging to anticipate price fluctuations, participation in ancillary service markets where available, or dynamic allocation of battery capacity between self-consumption and grid services. It could also be that under current electricity pricing mechanisms and regulatory frameworks, the economic case for energy communities and BESS may be less compelling than the technical case. The minimal difference in net costs across scenarios raises important questions about the economic viability of BESS investments for energy sharing purposes in this particular context.

The lack of significant economic differentiation between scenarios calls for deeper analysis of the return on investment for BESS implementation. With a BESS capacity of 1,440 kWh and power rating of 750 kW, the capital expenditure would be substantial. Given the marginal improvement in net electricity costs (only 0.8k€ annually between S2 and S3), the payback period for BESS investment would likely be extended beyond what would typically be considered financially attractive.

**Model limitations**: The model has several limitations that could be addressed in future research. First, the current analysis does not account for battery degradation over time, which would impact long-term performance and economics. Second, the fixed battery size (1,440 kWh) may not represent the optimal capacity for this specific application; sensitivity analysis of different battery sizes would provide more comprehensive insights. Third, the model assumes perfect foresight of energy production and consumption, whereas real-world implementation would face forecast uncertainties.

**4. Conclusions and future works**

This research demonstrates that energy communities and BESS present significant technical advantages for enhancing renewable energy utilization in industrial settings. The establishment of an energy community alone substantially increased PV self-consumption from 38% to 65%, while the addition of BESS further improved this to 74%. These improvements translate to meaningful reductions in grid dependency, with grid purchases decreasing by 15% and 19% in the energy community and BESS scenarios, respectively.

However, our economic analysis reveals important considerations for implementation. Despite reduced electricity purchase costs across scenarios, the corresponding decrease in revenue from grid sales resulted in minimal differentiation in net electricity costs. This finding underscores the need for more sophisticated BESS operation strategies and regulatory frameworks that better reflect the multiple value streams BESS can provide.

Future research should focus on optimizing BESS operation through advanced strategies such as time-of-use optimization, forecasting-based charging/discharging, and participation in ancillary service markets. Sensitivity analysis of different battery capacities would help identify optimal sizing for specific applications. Additionally, models that account for battery degradation and forecast uncertainties would provide more realistic long-term assessments.

The development of innovative business models that can better monetize the multiple services of BESS, alongside policy frameworks that recognize the broader system benefits of community energy initiatives, will be crucial for improving the economic viability of such systems. These advancements could transform the potential of energy communities from primarily technical achievements to economically compelling investment opportunities that accelerate the transition to sustainable energy systems.

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