Comparison of different co-located renewables and storage energy management schemes within an energy community

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***Abstract*—Energy cooperatives in Belgium play a vital role in the energy transition by installing renewable energy capacity at customers' premises and ensuring its efficient operation. These cooperatives typically sell the electricity they generate to their customers through pay-as-produced power purchase agreements. However, the increasing frequency of low and negative electricity prices can incentivise customers to curtail their offtake from the cooperative, posing a financial risk to the cooperative's business model. The deployment of Battery Energy Storage Systems is proposed as a mitigation strategy in such contexts. This paper investigates various BESS ownership and operational models, quantifies the associated cost savings, and assesses the potential reduction in curtailment volumes. The findings indicate that integrating BESS can significantly lower power offtake costs and reduce energy curtailment. Furthermore, the study examines how different operational strategies influence total energy costs and highlights the need to investigate profit-sharing mechanisms between cooperatives and BESS owners.**

***Index Terms*—BESS usage, community energy sharing, renewable energy cooperatives, RES integration, tolling agreements.**

I. INTRODUCTION

To meet the 2030 renewable energy targets of the European Union (EU), Belgium has proposed that by 2030, 21.7% of the gross final energy consumption will be from renewable energy sources (RES) [1]. In this context, several energy cooperatives in Belgium (such as Campina Energie [2], Ecopower [3], etc.) are promoting the adoption of renewable energy by investing in its production and supplying green electricity to their members [4] and are expected to play a significant role in achieving these targets. These cooperatives also focus on engaging citizens in renewable energy projects. They invest in and install RES capacity at the premises of their members (hereafter referred to as the customers) and sell the produced energy to these customers via an agreed-upon power purchase agreement (PPA). These energy cooperatives own decentralised photovoltaic (PV) plants in addition to other renewable energy installations. These PV plants are installed at or near customer locations, such as schools or office establishments (a school is considered a customer location in the rest of the paper as an example use case).

The decentralised PV plants are connected behind the meter to the customer (i.e., the school), the only entity directly connected to the grid. Under this setup, the PV plant and, by extension, the energy cooperative are compensated for their electricity generation according to a PPA. Any interaction between the PV plant and the grid, such as power injection, occurs only through the school. Consequently, the school pays the energy cooperative for the actual electricity generated, and if there is excess generation, the surplus is injected into the grid, and the school receives compensation for this power injection. In some cases, the school may also own PV installations, meaning the injected excess includes electricity from both its own PV system and that of the energy cooperative. However, with the recent trend of negative electricity prices (in 2024, prices were negative 17% of the time in at least one bidding zone in the EU [5], including 404 hours in Belgium), this model faces increasing challenges. There is a clear upward trend in the number of hours per year with lower (and negative) electricity prices, which can significantly affect the financial returns from grid injection, as the school is now required to pay for injecting power into the grid. In such cases, the school may choose to curtail generation when the injection prices are negative or opt to optimise their power offtake costs (from the grid and the energy cooperative). However, this expected curtailment, and the school's decision to optimise only its costs rather than the combined costs of both the school and the energy cooperative, can have negative consequences for the cooperative. Specifically, the cooperative receives no compensation for curtailed energy, thereby weakening its business case. Moreover, the renewable generation potential of the PV plant is not fully utilised, resulting in a loss of clean energy that could otherwise have been used.

The use of Battery Energy Storage Systems (BESS) can be considered a viable option to minimise curtailment and thereby improve the business case for energy cooperatives, while also ensuring efficient utilisation of installed PV generation capacity. The authors in [6] have presented a study for the use of BESS to minimise curtailment and increase self-consumption for a residential PV. Assuming that the energy cooperative installs a BESS at the PV plant site, several important questions arise: Should the BESS be used only to reduce curtailment or also for energy arbitrage (and what

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benefits would be achieved in each case)? What is the BESS's potential in reducing curtailment? Who should operate the BESS? And how will negative electricity prices influence the benefits of BESS usage? Additionally, there is both a challenge and an opportunity to allow the school to operate the BESS while compensating the energy cooperative, which is similar to the tolling model [7] used for conventional gas power plants. To the best of the author's knowledge, no case study has yet examined these questions in the Belgian context. To address this research gap, this paper presents an optimisation tool with the aim of making the following contributions:

- A comparison between community-level and school-level optimisation, demonstrating their impact on total costs and curtailment volumes across various scenarios.
- An analysis of the benefits of BESS in reducing costs and curtailment volumes, based on real-world data from Belgium.
- An investigation into how increasing negative electricity prices affect the injection costs when BESS is deployed.
- An assessment of the influence of a BESS operator (school or energy cooperative) on total costs and curtailment volumes.
- A comparison of different governance and operational models for integrating BESS. This comparison assesses a tolling model, in which the BESS is owned by the energy cooperative but operated by the school, highlighting its potential advantages as a supporting mechanism for PPAs.

The Section II presents the developed optimisation tool, followed by a case study in section III with the test system description and the corresponding results. The section IV concludes the paper with a summary of key findings.

II. ENERGY MANAGEMENT MODEL

The optimisation model aims to minimise the total electricity consumption costs of the community (or individual members) of $\mathcal{H}$ members with a 15-minute time resolution over the considered period. Optimisation is performed for each day using a rolling horizon approach, and the objective is mathematically formulated as follows:

$$\min \sum_{h \in \mathcal{H}} \sum_{t \in \mathcal{T}} \left(C^{grid}_{h,t} + C^{comm}_{h,t} \right) + \sum_{h \in \mathcal{H}} \rho_h o^{\hat{m}}_{h,d}. \tag{1}$$

$C^{grid}_{h,t}$ and $C^{comm}_{h,t}$ in (1) are the individual members' costs for energy offtake from the grid and the energy exchange among the community members and are calculated as shown in (2). In the Flemish region of Belgium, the consumers are subject to a capacity-based network tariff based on their monthly peak offtake. The monthly peak capacity tariff and monthly peak offtake are represented by ρ_h and $o^{\hat{m}}_{h,d}$, respectively, in (1).

$$\begin{aligned} C^{\text{grid}}_{h,t} = {} & \left(\tau^{\text{TSO},o}_{h,t} + \tau^{\text{DSO},o}_{h,t} + \lambda^{o}_{h,t} \right) o^{\text{grid}}_{h,t} + \left(\tau^{\text{TSO},i}_{h,t} \right. \\ & \left. + \tau^{\text{DSO},i}_{h,t} - \lambda^{i}_{h,t} \right) i^{\text{grid}}_{h,t}, \quad \forall t \in \mathcal{T},\ \forall h \in \mathcal{H}, \end{aligned} \tag{2a}$$

$$\begin{aligned} C^{\text{comm}}_{h,t} = {} & \left(\tau^{\text{TSO},o}_{h,t} + \tau^{\text{DSO},o}_{h,t} + \lambda^{o,\text{comm}}_{h,t} \right) o^{\text{comm}}_{h,t} + \left(\tau^{\text{TSO},i}_{h,t} \right. \\ & \left. + \tau^{\text{DSO},i}_{h,t} - \lambda^{i,\text{comm}}_{h,t} \right) i^{\text{comm}}_{h,t}, \quad \forall t \in \mathcal{T},\ \forall h \in \mathcal{H}. \end{aligned} \tag{2b}$$

In (2), the TSO offtake tariff, the DSO offtake tariff, the retail electricity offtake price, the TSO injection tariff, the DSO injection tariff and the electricity injection price are represented, respectively, by $\tau^{\text{TSO},o}_{h,t}$, $\tau^{\text{DSO},o}_{h,t}$, $\lambda^{o}_{h,t}$, $\tau^{\text{TSO},i}_{h,t}$, $\tau^{\text{DSO},i}_{h,t}$ and $\lambda^{i}_{h,t}$. The offtake and injection prices for electricity offtake and injection from within the community are represented by $\lambda^{\text{o,comm}}_{h,t}$ and $\lambda^{\text{i,comm}}_{h,t}$ respectively. The power offtake and injection from grid and the community for an individual member are represented respectively by $o^{grid}_{h,t}$, $i^{grid}_{h,t}$, $o^{comm}_{h,t}$, and $i^{comm}_{h,t}$. The total power offtake ($o_{h,t}$) and injection ($i_{h,t}$) for an individual member are calculated as follows:

$$o_{h,t} = o^{\text{grid}}_{h,t} + o^{\text{comm}}_{h,t}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{3a}$$

$$i_{h,t} = i^{\text{grid}}_{h,t} + i^{\text{comm}}_{h,t}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{3b}$$

The total community offtake and injection are calculated as shown below:

$$o^{\text{comm}}_{h,t} = \sum_{\substack{k \in \mathcal{H} \\ k \neq h}} o^{\text{comm}}_{h,k,t}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{4a}$$

$$i^{\text{comm}}_{h,t} = \sum_{\substack{k \in \mathcal{H} \\ k \neq h}} i^{\text{comm}}_{h,k,t}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{4b}$$

The following constraints ensure that the total community energy offtake equals the total community energy injection.

$$o^{\text{comm}}_{h,k,t} = i^{\text{comm}}_{k,h,t}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \quad \forall k \in \mathcal{H}, \quad h \neq k, \tag{5}$$

The following constraints ensure that the offtake and injection by a member are not considered as community flows to or from that member.

$$o^{\text{comm}}_{h,h,t} = 0, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{6a}$$

$$i^{\text{comm}}_{h,h,t} = 0, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}. \tag{6b}$$

The monthly peak consumption for month m for member h is calculated as per the following equation;

$$\hat{o}^{m}_{h,0} = 0, \quad \forall h \in \mathcal{H},\ \forall m \in \mathcal{M}, \tag{7a}$$

$$\hat{o}^{m}_{h,d} \geq o^{\text{grid}}_{h,t}, \quad \forall h \in \mathcal{H},\ \forall m \in \mathcal{M},\ \forall d \in \mathcal{D}_m,\ \forall t \in \mathcal{T}_{m,d}, \tag{7b}$$

$$\hat{o}^{m}_{h,d} \geq \hat{o}^{m}_{h,d-1}, \quad \forall h \in \mathcal{H},\ \forall m \in \mathcal{M},\ \forall d \in \mathcal{D}_m. \tag{7c}$$

The peak consumption $o^{\hat{m}}_{h,d}$ is set to 0 at the beginning of each month for the member, as shown in (7a). The daily peak offtake $o^{\hat{m}}_{h,d}$ is updated each day as the maximum of the grid offtake for that day and the monthly peak offtake from the past day, as shown in (7b) and (7c).

The generation from the installed PV system is calculated as per the following, with C^{PV}_{h} being the instantaneous PV capacity factor and $P^{\text{PV}}_{h,t}$ as the PV peak installed capacity:

$$i^{\text{PV}}_{h,t} = C^{\text{PV}}_{h} P^{\text{PV}}_{h,t}, \quad \forall t \in \mathcal{T}. \tag{8}$$

The BESS follows the following constraints:

$$s^{\text{BAT}}_{h,t} = s^{\text{BAT}}_{h,t-1} + \eta^{\text{BAT}}_{h} o^{\text{BAT}}_{h,t} - \frac{i^{\text{BAT}}_{h,t}}{\eta^{\text{BAT}}_{h}}, \quad \forall h \in \mathcal{H}^{\text{BAT}}, \quad \forall t \in \mathcal{T}, \tag{9a}$$

$$0 \leq o^{\text{BAT}}_{h,t} \leq P^{\text{BAT}}_{h}, \quad \forall h \in \mathcal{H}^{\text{BAT}}, \quad \forall t \in \mathcal{T}, \tag{9b}$$

$$0 \leq i^{\text{BAT}}_{h,t} \leq P^{\text{BAT}}_{h}, \quad \forall h \in \mathcal{H}^{\text{BAT}}, \quad \forall t \in \mathcal{T}, \tag{9c}$$

$$0 \leq s^{\text{BAT}}_{h,t} \leq C^{\text{BAT}}_{h}, \quad \forall h \in \mathcal{H}^{\text{BAT}}, \quad \forall t \in \mathcal{T}. \tag{9d}$$

The battery state-of-charge (SOC) is linked to the previous hour's SOC by (9a) with $s^{BAT}_{h,t}$, $s^{BAT}_{h,t-1}$, η^{BAT}_{h}, $o^{\text{BAT}}_{h,t}$ and $i^{\text{BAT}}_{h,t}$ representing the battery SOC at hour t, battery SOC at hour

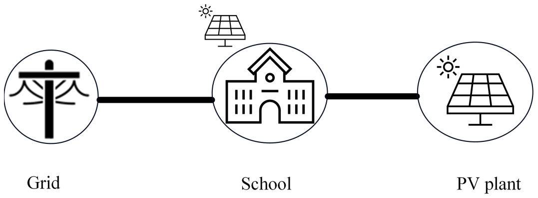

Fig. 1. Considered test system

$t-1$, battery efficiency, battery offtake (charging) volume, and battery injection (discharging) volume, respectively. In (9), the battery power and the maximum storage capacity of the BESS are represented by P_h^{BAT} and C_h^{BAT}, respectively.

The energy balance for member h is represented as follows, where $o_{h,t}$, $i_{h,t}$, $o_{h,t}^{\text{init}}$, $i_{h,t}^{\text{PV}}$, $o_{h,t}^{\text{BAT}}$ and $i_{h,t}^{\text{BAT}}$ denote, respectively, the offtake, injection, base demand, PV injection, battery offtake and battery injection:

$$o_{h,t} - i_{h,t} = o_{h,t}^{\text{init}} - i_{h,t}^{\text{PV}} + o_{h,t}^{\text{BAT}} - i_{h,t}^{\text{BAT}}, \ \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}. \tag{10}$$

The power offtake and injection for each member is also subjected to the connection capacity as per the following:

$$0 \leq o_{h,t} \leq o_h^{\max}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}, \tag{11a}$$

$$0 \leq i_{h,t} \leq i_h^{\max}, \quad \forall t \in \mathcal{T}, \quad \forall h \in \mathcal{H}. \tag{11b}$$

The optimisation model is described in detail in [8], [9] and is not repeated here for the sake of brevity.

III. CASE STUDY

A. Test system and assumptions

To compare different energy management schemes within a community, a community consisting of a school and an energy cooperative as its members is considered[1]. The school owns a PV installation with a peak capacity of 117 kWp, while the energy cooperative has invested in an additional 118 kWp PV installation on the school's site, as shown in Fig. 1. There is only one grid connection for the community (only the school is connected to the grid); hence, the TSO and DSO tariffs apply only to the net offtake and injection at this connection.

In the considered community, various configurations for PV generation curtailment and BESS ownership and operational control are possible. To ensure a comprehensive analysis, this paper examines multiple scenarios encompassing these options. In the reference scenario (S1), it is assumed that the community does not curtail any power injections into the grid, regardless of the power injection prices. Scenario S2 considers the case where the school curtails its power injection based on electricity injection prices; however, it buys all the power generation from the energy cooperative. In scenario S3, the school may choose not to offtake power from the energy cooperative, leading the energy cooperative to curtail generation accordingly. Scenario S4 combines both options, allowing the school to curtail its own PV generation and also control offtake from the energy cooperative. Scenario S5 introduces a BESS operated by the energy cooperative, with curtailment allowed at both the energy cooperative and the school. However, the energy cooperative is restricted to using BESS for arbitrage and is not allowed to offtake from the grid; the BESS serves only to minimise curtailment. Scenario S6 extends S5 by permitting the BESS to also offtake power from the grid. Thus, engaging in arbitrage via smart charging and discharging actions (which is also the case for scenarios S7 and S8). In scenario S7, the BESS is operated by the school, and both the school and the energy cooperative can curtail power. Finally, in scenario S8, the BESS is operated by the school, with the energy cooperative supplying power into the school as produced, without curtailment. Scenario S8 is designed to optimise BESS operation and, at the same time, ensure that the energy cooperative does not incur losses due to power curtailment. The overview of the considered scenarios is shown in Table I.

TABLE I
SCENARIO DESCRIPTION

Scenario	Curtailment by	BESS operator	Remarks
S1	No curtailment	No BESS	
S2	School	No BESS	
S3	Energy cooperative	No BESS	
S4	Both	No BESS	
S5	Both	Energy cooperative	No arbitrage
S6	Both	Energy cooperative	
S7	Both	School	
S8	School	School	

A time-varying baseload profile derived from the historic consumption data is considered for the school. The community is subjected to time of use (ToU) prices for electricity offtake, and the injection prices are considered as dynamic (with consideration of day-ahead electricity market clearing prices for Belgium). It is assumed that the BESS capacity, efficiency, and c-rate are 200 kWh, 95% and 0.25, respectively. The community PV generation follows the actual PV generation capacity factor for Belgium. The analysis is carried out for a time period from 10/11/2022 to 17/09/2024, during which injection prices (based on day-ahead electricity prices) were negative for 5.98% of the time.

B. Results and analysis

We next present an analysis highlighting the potential of BESS, comparing community-wide versus school-specific optimisation, and examining the effects of payment provisions, negative prices, and the impact of BESS operation responsibility on the BESS operation and curtailment decisions.

1) Usefulness of the BESS: The analysis of the usefulness of BESS for the considered community in terms of curtailment volume is presented as case-1 in Fig. 2. It can be seen that as we move from S1 (the current setting without any curtailment) to S4 (where the curtailment decision is based on economic gains), there is an increase in the volume of power curtailed. These curtailment decisions reduce the school's cost; however, they also result in reduced revenue for the energy

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[1] It is important to note that Belgian regulations require a minimum of three members to establish an energy community. In this study, however, only two members are considered in a "community" to clearly demonstrate the study outcomes. The simulation tool itself is agnostic to community size and can be applied to configurations with any number of members.

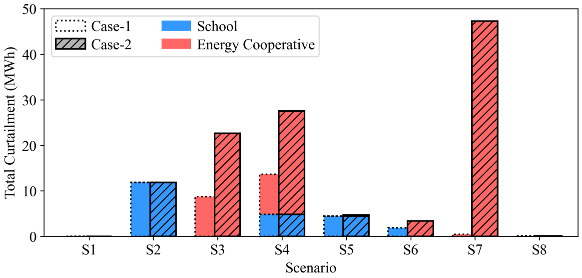

Fig. 2. Total curtailment volume for different scenarios

cooperative due to the pay-as-produced PPA, as shown in Fig. 3. As we move to the scenarios with the availability of BESS, the curtailment volume decreases. It is observed that for S5 (BESS operated by the energy cooperative and used solely to minimise its curtailment), only the school experiences curtailment, with a volume similar to that of S4. As we transition to S6, which enables the BESS to be used for power offtake (curtailed power from the school and from the grid), the curtailment volume further decreases. For S7 with the BESS operated by the school, it is seen that there is curtailment at the energy cooperative; however, the total curtailment volume is less than that of S6. Furthermore, with no curtailment allowed at the energy cooperative in S8, there is curtailment only at the school, and the total curtailed volume is less than in all the previous scenarios. Thus, it is evident that the availability of BESS helps to reduce power curtailment.

Fig. 3 shows the variation in the net cost for the community for different scenarios. It can be seen that the availability of curtailment options (e.g. scenario S3 and S4) leads to a reduction in the school offtake cost and the net cost for the community. At the same time, it is also seen that the energy cooperative injection costs also decrease, implying a reduction in the energy cooperative's revenue. It is seen for case-1 that the availability of BESS, even without using it for arbitrage (i.e. no grid offtake), results in a substantial 8% (relative to S1) reduction in the net cost, as shown for S5 in the figure. Furthermore, using BESS for smart charging and discharging reduces the net cost by an additional 3%, as can be seen for scenario S6 in the figure. When the school in scenario S7 operates the BESS, the net cost is reduced by an additional 12%. This reduction in the cost as compared to S6 is on account of a reduction in the curtailment volume (as shown in Fig. 2) and exclusion of BESS charging and discharging efficiency-related costs. In S6, the BESS is operated by the energy cooperative. When it is used for offtake from the grid or school (to minimise curtailment), the energy cooperative faces a net loss because the BESS's charging and discharging volumes differ due to its efficiency (the efficiency is 95%, hence there is a total loss of 10%). This issue does not arise in S7, where the school operates the BESS. Scenario S8 results in a marginal reduction in total cost compared to S7, as there is only a marginal increase in power consumption from the energy cooperative installation.

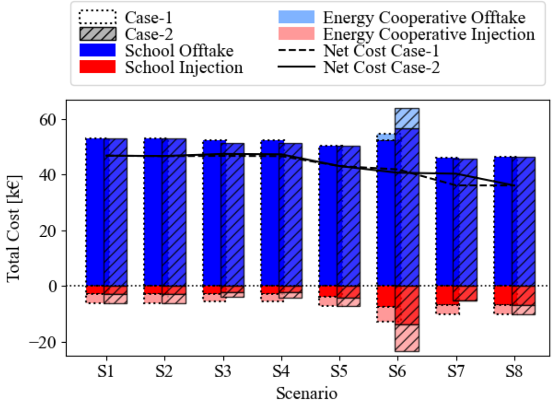

Fig. 3. Variation of total cost for different scenarios

TABLE II
VARIATION IN COST WITH NUMBER OF HOURS WITH NEGATIVE PRICES

	Hours with negative prices (%)			
	6	10	15	20
Scenario-S1 Cost [€]	979.89	1633.15	2449.72	3266.30
Scenario-S8 Cost [€]	12.63	21.05	31.57	42.10
Savings [€]	967.26	1612.10	2418.15	3224.20

2) Impact of optimisation for community vs optimising for school: Fig. 2 and 3 illustrate how the optimisation scope for the community (Case-1) compared to the school (Case-2) influences curtailment decisions and total cost. The Fig. 2 shows that case-2 leads to higher energy cooperative curtailment (hence lower revenue for the energy cooperative), and the Fig. 3 shows that case-1 results in a lower cumulative net cost. A comparison of curtailment volume and net cost highlights the benefits of optimising for the school at the cost of a loss to the energy cooperative.

It is observed that for S7, case-2 results in a lower net cost compared to case-1. This reduction is primarily due to a higher curtailment volume for the energy cooperative, which hampers its business case and leads to underutilization of the produced renewable energy. Furthermore, the distribution of costs and benefits varies depending on the scope of the optimisation. As expected, optimisation for the school reduces the revenue of the energy cooperative. It can also be seen that with restrictions in the curtailment options (for S1 and S8), both case-1 and case-2 result in exactly the same overall costs.

3) Impact of negative prices: This section compares the expected cost of power injection into the grid for different levels of negative injection prices over a year. These results are based on an ex-post extrapolation. The Table II presents costs for the current setup (S1) and scenario S8. For comparability, the S8 costs are calculated only for the time intervals in which grid injection incurred a cost in S1. The results show that as the number of hours with negative prices increases, the total cost of power injection into the grid also rises for S1. However, with the availability of BESS and curtailment options (as in S8), this cost can be reduced.

4) Impact of BESS operator: The impact of BESS operation either by the school or the energy cooperative on the curtailment volume is shown in Fig. 2. For case-1 and scenario S6, the BESS is operated by the energy cooperative, and

TABLE III
BESS usage for Case-1

Scenario	S5	S6	S7	S8
Total offtake (MWh)	35.44	68.5	132	132.88
Total injection (MWh)	31.98	61.82	119.13	119.93

curtailment is observed at the school. As there is a fixed cost for community flow (equal for offtake and injection), and at the same time, there is power loss due to BESS efficiency (10% as explained above), it is not economically beneficial for the energy cooperative (and the community) to charge the BESS with the school's surplus power. Consequently, this excess power is curtailed by the school. Similarly, when the BESS is operated by the school for S7, there is still some curtailment by the energy cooperative. As such, scenario S8, when no curtailment is allowed by the energy cooperative, appears to be the most favourable scenario for minimising the power curtailment and maximising BESS utilisation.

5) Impact of payment provisions for grid injection and offtake: In a tolling agreement, the asset owner (e.g., a power plant) grants a buyer or third party the right to control and operate the asset within the power system [7]. This concept is extended here to BESS operation in scenario S7, where the energy cooperative owns the BESS and the school operates it to minimise total community costs. A comparison of S6 and S7 shows that S7 lowers the community's total cost, indicating that school-operated BESS can yield higher overall benefits. Moreover, as shown in Table III for scenarios S7 and S8, BESS utilisation increases when the school operates it. As such, in these cases, the tolling provisions enable a more efficient use of BESS capacity and generate additional community profits. These additional profits should also be shared with the BESS owner. Accordingly, the design of an appropriate profit-sharing mechanism, such as a separate PPA between the BESS operator and owner for each MWh exchanged, or a fixed monthly fee, requires further investigation.

The Table IV compares the impact of energy cooperative payment provisions for scenario S6. In the "grid tariff" case, the energy cooperative pays both grid offtake and injection tariffs for BESS smart charging and discharging. In the "no grid tariff" case, the cooperative pays only community-flow charges to the school, while the school bears the grid offtake and injection tariffs associated with BESS operations. As shown, the "no grid tariff" arrangement reduces net costs by 15.55% in Case-1 and 20.69% in Case-2 relative to "grid tariff" payment provisions. This result highlights the need for a dedicated PPA for the smart charging and discharging of BESS in the S6 scenario setup to maximise community benefits and a fair distribution of benefits.

IV. CONCLUSION

The expected increase in negative electricity prices may incentivise large customers to curtail renewable energy generation, which could reduce the revenue of energy cooperatives, thereby weakening their business case and also leading to the underutilization of renewable energy. In such situations, the various stakeholders will likely seek to optimise their profits or minimise losses associated with power injection into the grid. The deployment of BESS can serve as a risk mitigation strategy against these anticipated curtailments, acting as an effective countermeasure.

TABLE IV
Variation in costs for payment provisions

Cost component [k€]	Case-1		Case-2	
	Grid tariff	No grid tariff	Grid tariff	No grid tariff
School Offtake	50.09	52.22	51.69	56.72
School Injection	-2.35	-7.54	-3.33	-13.91
Energy cooperative Offtake	7.75	2.47	14.19	7.25
Energy cooperative Injection	-5.95	-5.32	-10.94	-9.43
Net Cost	49.53	41.83	51.61	40.63

This paper demonstrates the benefits of optimising energy management at the community level rather than for a single stakeholder (in this case, the school). Using actual load and PV generation profiles, it is shown that community-level optimisation yields better overall outcomes in terms of net costs and total curtailment volume compared to school-specific optimisation. The paper also examines the influence of the BESS operator (through a tolling arrangement) on BESS usage and overall system costs. The paper also highlights the savings associated with the use of BESS systems due to an increase in the number of hours with negative electricity prices.

Overall, the analysis presented in this paper concludes that BESS will play a crucial role in enabling the cost-optimal utilisation of renewable energy sources owned by energy cooperatives. As a direction for future work, studies could focus on the tolling model for BESS operations, examining its implications under different PPA structures. The framework could also be extended to assess the economic viability of BESS investment in community settings.

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