E3S Web of Conferences **414**, 03011 (2023) https://doi.org/10.1051/e3sconf/202341403011
SUPEHR23

Battery energy storage systems for ancillary services in Renewable energy communities

Tommaso Ferrucci[1*], *Davide* Fioriti[1], *Davide* Poli[1], *Stefano* Barberis[2], *Alberto* Vannoni[2], *Francesco* Roncallo[2,3†], *Carlo* Tacconelli[3], and *Valeria* Gambino[3]

[1]DESTEC, University of Pisa, Largo Lucio Lazzarino, Pisa 56122, Pisa, Italy
[2]Thermochemical Power Group, Dep. of Mechanical Engineering, University of Genova, Italy
[3]EnGreen, Via Elio Vittorini 103, 00144, Rome, Italy

Abstract. This document presents a study on the use of battery energy storage systems in a proposed renewable energy community in Savona, UNIGE Campus. The study compares the outcomes of cooperative approaches with and without flexibility services to a scenario where users do not cooperate. The study concludes that storage systems of relevant size can create new flexible instruments for the power grid and a powerful tool for citizens, which could make the investment into BESS financially viable. The study also suggests that greater transparency and information on hourly energy sales and purchase prices would facilitate awareness among community members and at the same time stimulate discussion of alternative technologies such as batteries to cover the most expensive nighttime periods for users. Overall, the study highlights the potential of battery systems in renewable energy communities in Italy and provides insights into the importance of coupling flexible services with capacity-building activities and awareness campaigns to promote demand-side-response activities and storage technologies.

1 Introduction

Renewable energy communities (RECs) are a powerful resource in Europe to guarantee citizen participation in the transition toward decentralized systems facilitating the overall EU energy transition. The Clean Energy for All [1] and the Renewable Energy Directive (REDII) in 2018 enabled individuals, communities, and local authorities to manage and control their renewable plants and give to private citizens the right to generate, store, consume and sell their energy [2]. The EMI directive in 2019 allowed the participation of RECs in the electricity market for flexibility or energy efficiency mechanisms [3]. Battery energy storage systems (BESS) are seen as an important technological instrument for RECs to approach the management of ancillary services both for the grid quality and increased reliability when dealing with increased renewable energy storage penetration [4].

RECs are still undeveloped in Italy, despite strong interest from communities [5], [6]. According to a report by Legambiente in May 2022 there were 35 RECs in operation, 41

* Corresponding author: tommaso.ferrucci@phd.unipi.it
† Corresponding author: francesco.roncallo@unige.it

under construction and 24 in preliminary stages [7]. However, from the national authority trimestral report of November 2022, there were 17 RECs registered in September 2022 [8]. In the proposed technical paper, the role of BESS in RECs for ancillary services adopting strategies to operate their energy system as an aggregator that can offer flexible services to address congestion for TSO or DSO.

Section 2 will be devoted to the review of different flexibility services adopting BESS and examples of energy communities adopting them. Section 3 will describe the methodology to determine the potential for the case study of the Savona Campus of UNIGE and its neighborhood. Section 4 will include the techno-economic analysis of multiple scenarios. Section 5 will discuss the technical and economical performances of RECs in flexibility services and will highlight relevant insights and recommendations for further developments.

2 Review

2.1 Focus on energy services

Energy services are provided to the electrical grid to improve its stability, reliability, and quality. From a technical perspective, energy services can be provided by a variety of technologies and sources, such as traditional power plants, renewable energy sources, and energy storage systems, according to the requested performances as the time of response and the required energy/power; an example of the types of services and timescale is reported in Figure 1.

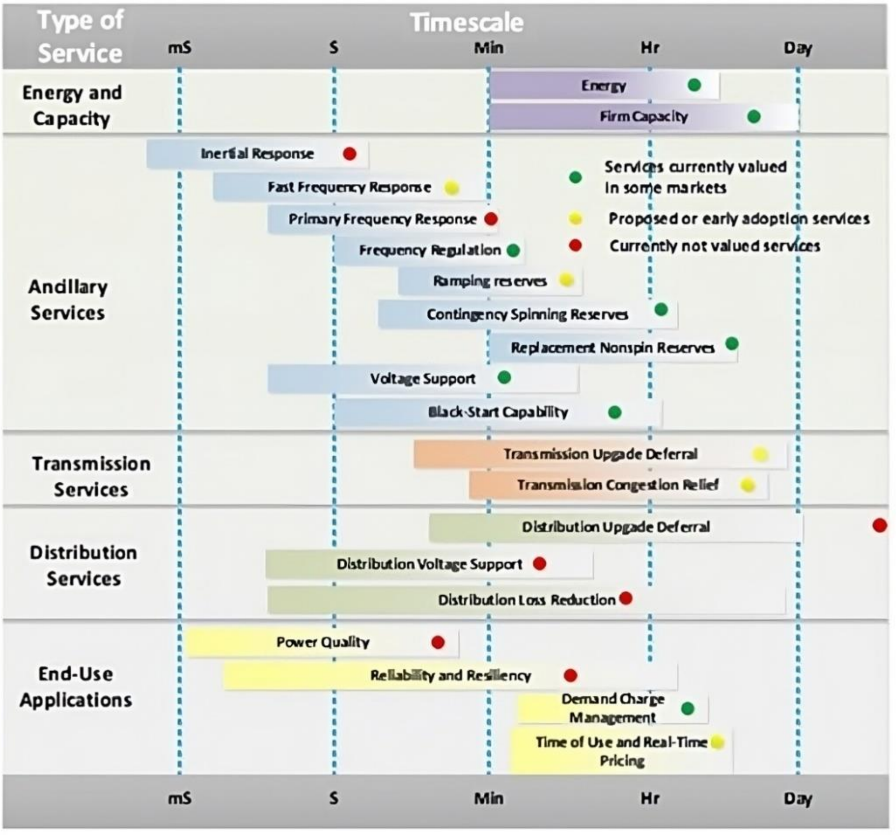

Figure 1: Types of Services and Timescale [9]

These services help to maintain the stability of the electrical grid by quickly responding to changes in energy demand and supply. The provision of energy services can have economic value, as they are remunerated to improve the efficiency of the electrical grid and reduce the costs associated with energy production and consumption and could have an added value in RECs economic viability [10]. As RECs can be equipped with both generation and energy storage assets, different services can be provided by RECs like time shifting, firming capacity, peak shaving, load balancing, voltage support, and arbitrage of energy.

2.2 RECs as a potential grid flexibility actor with BESS

RECs aggregated in a cluster or as a single energy player on the market could participate in ancillary/grid stability services but only if the size of the REC could be higher than 1 MW [11], [12]. However, flexibility mechanisms could fail due to low acceptance of participants and low fairness perception as in [10], [11]. Subscribing to such schemes with different prices may be the opportunity to consume electricity when abundant and therefore, also when the most renewable-based electricity is available [13].

The initiatives developed by pilot projects funded by the European Horizon 2020 (EH2020) programs have been reviewed by performing a search on the Community Research and Development Information Service (CORDIS). The search query included the following keywords: 'renewable energy community', 'energy community', battery, ‘flexibility’ and ‘demand response’. The results are filtered by selecting "Energy" from the field "Domain of application" and "Project" from the field "Collection". The query gave 308 results. Some examples are hereby reported for their cutting-edge adoption of BESS for demand response which is currently state-of-the-art in Europe.

The *DOMINOES*[‡] project was an EU-funded initiative that ended in 2021 and aimed at developing a market-driven approach for advanced operation models and services in the next generation of electricity distribution grids. The project consortium comprised 20 partners from 9 European countries. By designing, developing, and validating a transparent and scalable local energy market solution, the project aimed to enable the discovery and development of new demand response, aggregation, grid management, and peer-to-peer trading services [14], [15].

The *REScoopVPP*[§] project, funded by the EU, created an advanced community-driven smart building ecosystem for energy communities. This ecosystem includes a community-driven flexibility box (*COFY-Box*) and tools to support energy services for aggregators, energy service companies, balance responsible parties, and renewable energy source suppliers. The COFY-Box is based on existing open-source home automation technology and has over 1 600 integrations, making it the first entirely open, affordable, and simple-to-install smart home energy controller. The pilot project led by *Energie Samen* in Heeten, Netherlands, in collaboration with *Endona*, a local cooperative, operates a PV farm and a set of residential salt battery energy system storage. The goal is to reduce traffic at the local substation level, for which *Enexis*, the local DSO, has offered the cooperative a reduced grid fee. [16].

Italian actors are currently participating in 50 multiple pilot projects cited in CORDIS. There is a need for a critical review of the ongoing project on flexibility and demand response as well as the state-of-the-art technologies adopted in this energy sector.

3 Methodology

[‡] For more information: https://cordis.europa.eu/project/id/771066
[§] For more information : https://cordis.europa.eu/project/id/893240

The investment horizon for the cash flow calculation has been set to 20 years, as pointed out by the GSE for what concerns the incentive schemes of RECs in Italy. The analysis will include various scenario variations to gain a better understanding of how user cooperation and flexibility opportunities impact RECs in different engagement contexts. Comparative analysis is pivotal to highlight the cost and benefits of different configurations.

3.1 Demand and Supply

The University of Genova collected hourly measurements of all buildings of the Savona Campus. The total number of hours chosen to represent a typical year of operation has been set to 672. Seven days each season has been chosen to appreciate the seasonality effect of renewable sources but also to consider the influence of different price ranges over the week. The estimation of installed PV systems' production was derived from a selection of twenty-eight representative days extracted from the meteorological year dataset provided by the renewable ninja platform. [17], [18]. The software shows a yearly capacity factor y of 18%. The location of the PV system has been considered at 44.299160, 8.452057 with 15% of technical losses and 38° as the tilted angle.

3.2 Tariff Structure and incentive scheme

The energy community business model structure and economic assumptions for the model have been described in depth by Fioriti et al [19]. The main difference from the original structure is the electricity bill for residential and commercial customers which consisted of four components [**].

1) Energy: The total price charged in the bill is the sum of prices for the following components: energy (PE), dispatch (PD), equalization (PPE), marketing (PCV), and dispatch component (DispBT). For this study, it is important to highlight how the middle hours of the week have a lower price than the peak hours or during weekends. While PE, PD and PPE are linked to the consumption of electricity [€/kWh] PCV and DispBT are fixed charges [€/y].

$$energy\ material\ expenditure = PE + PD + EPP + PCV + DispBT \quad (1)$$

2) Transport charges: These are the amounts invoiced for activities related to electricity delivery and metering. The total price includes the transmission (σ_1), distribution (σ_2) and metering tariff (σ_3) and the UC3 and UC6 tariff components. The fixed charge each year is related to σ_1 while the variable components related to electricity consumption are UC3, UC6 and σ_3. The last component, σ_2, coincides with the peak power tariff [€/kW].

$$transport\ charges = \sigma_1 + \sigma_2 + \sigma_3 + UC3 + UC6 \quad (2)$$

3) System charges: The total price includes the components: A_{SOS} (general charges related to renewable energy support and CIP 6/92 cogeneration) and A_{RIM} (remaining general charges). They are both related to electricity consumption.

$$system\ charges = A_{SOS} + A_{RIM} \quad (3)$$

4) Taxation: This includes excise duties and value-added tax (VAT). It's 10% for domestic users while it's 22% for non-domestic users. The National Energy Authority - ARERA determines all price components in the Protected Market (PM). Prices valid in the first quarter of 2023 were used in this study, as shown in Table 1.

** For more information : https://bolletta.arera.it/bolletta20/index.php/guida-voci-di-spesa/elettricita

Table 1: Commercial and non-commercial users' prices

Type of fee	Energy material expenditure	Transport charges	System charges	Excise duty
Non-commercial users				
Energy [€/kWh]	0.124 / 0.112	0.009	0.030	0.0163 / 0.0151
Fixed [€/POD/y]	58.40	20.64		7.904
Power [€/kW/y]		20.52		2.052
Commercial users				
Energy [€/kWh]	0.139/0.151/0.124	0.010	0.037	0.040/0.043/0.037
Fixed [€/POD/y]	106.260	25.067	16.716	32.570
Power [€/kW/y]		28.750	19.171	10.542

For what concerns the feed-in tariff for the prosumer it has been assumed the price of "Ritiro dedicato" for the latest month available which is February 2023 with a price of 165 €/MWh during F1 brand, 156 €/MWh in F2 brand and 139 €/MWh during F3 brand. Different sell prices are adopted for the flexibility scenario (400 €/MWh for F2 and F3 and 200 €/MWh for F1) from UVAM reward prices [20]. In the Italian regulatory framework for RECs, there are incentives for every kWh shared between users and right now, before the new directive of the Italian government, the total invectives are 118 €/MWh which is calculated hourly as the minimum between the production from renewable sources and the consumption of electricity under the same first cabin.

4 Results

The flexibility services considered for the flexibility scenario are those included in the first and second categories of Figure 1 and are assumed to be adopted by RECs in an optimistic future scenario. It is important to note that currently, these services have not yet been allowed in the Italian market. Cooperative approaches with and without flexibility services need to be compared with the business-as-usual scenario of non-cooperation between users. For conciseness, the graphs of the cooperative case (CO) are shown, while Table 2 also shows parallel results of the noncooperative case (NC) and cooperative case operating flexibility services (CO-FLEX). Comparative analysis is fundamental to give a clear perspective of the opportunities and challenges of BESS for RECs.

Giving an overall perspective Figure 2 shows the energy flows between users of the REC. User1 is representative of the UNIGE campus shared energy mainly with User6 and User7 which are respectively industrial partners and some municipality offices. User8 and User9 are both commercial activities. All these users have a high consumption of electricity during the day.

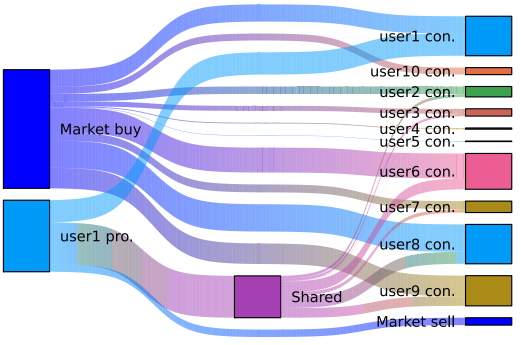

Figure 2: Sankey diagram of the cooperative case

Table 2: Energy, Technical and Economic indicator of CO, CO-FLEX and NC case

Indicator	CO	NC	CO-FLEX
Energy Indicator			
Energy Produced	2161 MWh		
Energy Shared	1261 MWh	0 MWh	1347 MWh
Energy Self-consumed	671 MWh	671 MWh	615 MWh
Energy Non-shared	229 MWh	1490 MWh	199 MWh
Technical Indicator			
PV total size	1384 kW		
BESS total size	0 kWh	0 kWh	210 kWh
Economic Indicator			
CAPEX	1.80 M€	1.80 M€	1.90 M€
Yearly cash flow on energy bills and O&M	-1096 k€	-839 k€	534 k€
Yearly revenues from incentives	1066 k€	0 €	1075 k€

All scenarios reached the maximum capacity of PV and only the CO-FLEX case adopted BESS and converter. It's relevant to notice the differences between the CO and CO-FLEX scenarios. The first one fosters shared energy between the REC during the daily period while the second scenario chooses the adoption of BESS for the sale of electricity when the market price is higher.

5 Conclusions

This research highlighted the importance of BESS of relevant size to create new flexible instruments for the power grid and a powerful tool for citizens that could make financially viable the investment on BESS. In subsidizing electricity generation from renewable sources, priority should be given to projects that are less carbon-intensive and that minimize the impact on the electricity system by applying flexible resources and not only self-consumption.

The role of the university and the public administration of Savona is pivotal to the engagement of the community within the first cabin where the campus is located. An industrial user could be an anchoring load for the REC. Residential households could be targeted at addressing the most vulnerable people or the ones affected by energy poverty.

For what concerns the output of the model some relevant observations are needed. From a technical perspective, the CO-FLEX scenario appears to be the most promising as it generates higher yearly revenues despite a relatively small increase in CAPEX. For what concerns energy indicators, the overall production of the energy systems is the same, but the energy consumed by the whole REC (*energy-self-consumed* and *energy shared*) is higher concerning the CO case.

The sense of community and collective efforts are other pillars of the foundations of cooperatives and RECs. For this reason, flexible services should be coupled with capacity-building activities and awareness campaigns to highlight the importance of demand-side-response activities as well as BESS technologies. Greater transparency on hourly prices would facilitate awareness among RECs members and at the same time stimulate alternative technologies to cover the most expensive nighttime periods for users.

The current Italian regulatory framework imposes 1 MW as the plant limit to access dispatch service markets. Allowing smaller renewable plants to aggregate even under the same primary substation would allow renewable generation systems coupled with BESS to offer flexibility mechanisms. Nevertheless, it is important to highlight three aspects: i) most currently existing UVAM refer to power plants and industrial plants with deferrable electric demand; ii) according to most recent statistics, the Italian TSO is not yet exploiting UVAM flexibility role in the Italian market [12], [21] thus RECs flexibility potential could not be fully yet valorized in Italian scenario, iii) from a regulatory point of view, as RECs are already acknowledged by specific supporting schemes, they could not be acknowledged as UVAM too, to operate on the market offering this type of services.

References

[1] Directorate-General for Energy (European Commission), *Clean energy for all Europeans*. LU: Publications Office of the European Union, 2019. Accessed: Mar. 07, 2023. [Online]. Available: https://data.europa.eu/doi/10.2833/9937

[2] *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance.)*, vol. 328. 2018. Accessed: Dec. 22, 2022. [Online]. Available: http://data.europa.eu/eli/dir/2018/2001/oj/eng

[3] *Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast) (Text with EEA relevance.)*, vol. 158. 2019. Accessed: Dec. 22, 2022. [Online]. Available: http://data.europa.eu/eli/dir/2019/944/oj/eng

[4] L. Maeyaert, L. Vandevelde, and T. Döring, 'Battery Storage for Ancillary Services in Smart Distribution Grids', *Journal of Energy Storage*, vol. 30, p. 101524, Aug. 2020, doi: 10.1016/j.est.2020.101524.

[5] A. Caramizaru and A. Uihlein, 'Energy communities : an overview of energy and social innovation', JRC, 2019.

[6] C. Candelise and G. Ruggieri, 'Status and Evolution of the Community Energy Sector in Italy', *Energies*, vol. 13, no. 8, Art. no. 8, Jan. 2020, doi: 10.3390/en13081888.

[7] Legambiente, 'Legambiente presenta Comunità Rinnovabili 2022 • Legambiente', *Legambiente*, May 26, 2022. https://www.legambiente.it/comunicati-stampa/legambiente-presenta-comunita-rinnovabili-2022/ (accessed Dec. 22, 2022).

[8] 'GSE Relazione trimestrale.pdf'. Accessed: Apr. 12, 2023. [Online]. Available: https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20statistici/GSE%20Relazione%20trimestrale.pdf

[9] 'Summary of potential energy storage services and required response times and durations'. https://greeningthegrid.org/site-images/summary-of-potential-energy-storage-services-and-required-response-times-and-durations (accessed Jun. 13, 2023).

[10] J. M. Zepter, A. Lüth, P. Crespo del Granado, and R. Egging, 'Prosumer integration in wholesale electricity markets: Synergies of peer-to-peer trade and residential storage', *Energy and Buildings*, vol. 184, pp. 163–176, Feb. 2019, doi: 10.1016/j.enbuild.2018.12.003.

[11] F. Bovera and L. Lo Schiavo, 'From energy communities to sector coupling:a taxonomy for regulatory experimentation in the age of the European Green Deal', *Energy Policy*, vol. 171, p. 113299, Dec. 2022, doi: 10.1016/j.enpol.2022.113299.

[12] 'Progetto Pilota per Unità Virtuali Abilitate Miste - UVAM - Terna spa'. https://www.terna.it/it/sistema-elettrico/progetti-pilota-delibera-arera-300-2017-reel/progetto-pilota-uvam (accessed Apr. 13, 2023).

[13] V. M. J. J. Reijnders, M. E. T. Gerards, and J. L. Hurink, 'A hybrid electricity pricing mechanism for joint system optimization and social acceptance within energy communities', *Energy Reports*, vol. 8, pp. 13281–13292, Nov. 2022, doi: 10.1016/j.egyr.2022.10.021.

[14] S. Annala *et al.*, ‘Framework to Facilitate Electricity and Flexibility Trading within, to, and from Local Markets’, *Energies*, vol. 14, no. 11, Art. no. 11, Jan. 2021, doi: 10.3390/en14113229.
[15] R. Faia, J. Soares, T. Pinto, F. Lezama, Z. Vale, and J. M. Corchado, ‘Optimal Model for Local Energy Community Scheduling Considering Peer to Peer Electricity Transactions’, *IEEE Access*, vol. 9, pp. 12420–12430, 2021, doi: 10.1109/ACCESS.2021.3051004.
[16] L. F. M. van Summeren, A. J. Wieczorek, G. J. T. Bombaerts, and G. P. J. Verbong, ‘Community energy meets smart grids: Reviewing goals, structure, and roles in Virtual Power Plants in Ireland, Belgium and the Netherlands’, *Energy Research & Social Science*, vol. 63, p. 101415, May 2020, doi: 10.1016/j.erss.2019.101415.
[17] S. Pfenninger and I. Staffell, ‘Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data’, *Energy*, vol. 114, pp. 1251–1265, 2016, doi: 10.1016/j.energy.2016.08.060.
[18] I. Staffell and S. Pfenninger, ‘Using bias-corrected reanalysis to simulate current and future wind power output’, *Energy*, vol. 114, pp. 1224–1239, Nov. 2016, doi: 10.1016/j.energy.2016.08.068.
[19] D. Fioriti, A. Frangioni, and D. Poli, ‘Optimal sizing of energy communities with fair revenue sharing and exit clauses : Value , role and business model of aggregators and users’, *Applied Energy*, vol. 299, no. May, p. 117328, 2021, doi: 10.1016/j.apenergy.2021.117328.
[20] ‘ARERA - Approvazione delle modifiche, predisposte da Terna S.p.A., al progetto pilota per la partecipazione di unità virtuali miste al mercato per il servizio di dispacciamento (MSD), ai sensi della deliberazione dell’Autorità 300/2017/R/eel’. https://www.arera.it/it/docs/21/070-21.htm (accessed Apr. 12, 2023).
[21] ‘Electricity Market Report 2022’, *Energy Strategy*. https://www.energystrategy.it/prossimi-eventi/electricity-market-report-2022/ (accessed Apr. 13, 2023).