Journal of Physics:
Conference Series

PURPOSE-LED PUBLISHING™

PAPER • OPEN ACCESS

Economic Assessment of a Biogas–PV Based Energy Community: Comparative Analysis With and Without Shared Battery Storage

To cite this article: Marco Puglia *et al* 2026 *J. Phys.: Conf. Ser.* **3351** 012048

View the article online for updates and enhancements.

You may also like

- A PSO-Based Framework for Renewable Energy Communities (RECs) Design
Mattia Paoletti, Mosè Rossi, Flavio Caresana et al.
- Next-Generation District Heating and Cooling: Simulation-Based Design for Renewable Energy Communities
Annamaria Buonomano, Alfredo Gimelli, Giovanni Francesco Giuzio et al.
- Innomed, an Erasmus CB-VET Project for an International Solar Energy Network
Maria Pia Romano, Ahmed Al-Salaymeh, Walaa Al-Smadi et al.



This content was downloaded from IP address 79.13.44.163 on 18/11/2026 at 18:39

Economic Assessment of a Biogas–PV Based Energy Community: Comparative Analysis With and Without Shared Battery Storage

Marco Puglia[1*], Lucia Catellani[2], Maria Elisa Micella[1], Salvatore Cristiano[1], Paolo E. Santangelo[2], Chiara Lodi[3], Simone Pedrazzi[1,4], Paolo Tartarini[1,4]

[1] Dipartimento di Ingegneria 'Enzo Ferrari', Università degli Studi di Modena e Reggio Emilia, Via Vivarelli, 10/1, 41125, Modena, Italy
[2] Dipartimento di Scienze e Metodi dell'Ingegneria, Università degli Studi di Modena e Reggio Emilia, Via Amendola 2, 42122, Reggio Emilia, Italy
[3] Enerplan Spa – Società di ingegneria, Via Donati 41, 41012, Carpi (MO), Italy
[4] H2-MORE, Centro Interdipartimentale di Ricerca e per i Servizi nel settore della produzione, stoccaggio ed utilizzo dell'Idrogeno, University of Modena and Reggio Emilia, Via Università 4, Modena, 41125, Italy

[*]E-mail: marco.puglia@unimore.it

Abstract. Renewable energy communities represent a promising path to increasing the adoption of renewable energy among citizens and businesses. However, like most renewable energy systems, they are often affected by the intermittency of solar power and, where applicable, wind resources. In this context, energy storage systems and bioenergy technologies can help mitigate the impact of renewable generation variability and improve system reliability. This paper presents a preliminary evaluation of different energy community scenarios in which battery storage systems can be shared among users. The analyzed configurations also include a dairy farm equipped with a biogas plant for electricity generation. Biogas systems can provide a more stable supply of electricity and heat, thus improving the overall continuity and flexibility of energy production within the community. Four consumption profiles of real users were considered to assess the potential energy and economic benefits associated with integrating shared batteries and biogas generation into renewable energy communities.

1. Introduction

The transition towards clean energy use at the urban scale is still progressing at a limited pace [1,2], while several technological challenges remain unresolved, including the mismatch between energy generation and consumption and the limited dispatchability of the most widely adopted renewable energy sources [3,4]. In this context, citizen-led, bottom-up initiatives, particularly energy communities, are receiving increasing attention from policymakers and practitioners as community-based approaches to support the transition towards a low-carbon society [5,6]. By enabling citizens to actively participate in the energy market [3,7,8], energy communities can promote greater awareness of energy consumption and facilitate the increasing

penetration of renewable sources through their smart integration and coordinated management within the power system [9,10,11,2,12].

There is currently no universally accepted definition of an energy community (EC), which has resulted in different interpretations and regulatory frameworks across countries. For instance, European Directive 2018/2001 defines a Renewable Energy Community (REC) as a legal entity based on open and voluntary participation, autonomous in nature, and effectively controlled by shareholders or members located in the proximity of renewable energy projects, operating in accordance with the applicable national legislation [13]. Within this framework, a central role is typically assigned to the "prosumer", namely an energy consumer who also produces at least part of their own energy demand through local generation technologies [14].

Depending on national and local regulations, ECs may adopt different bureaucratic and organisational structures, which in turn shape the objectives, constraints, and operational possibilities of both the communities and their members. In the European Union, Article 21 of [13] regulates self-consumption within RECs, while Article 22 defines their rights and obligations, including the production, consumption, storage, sharing, and sale of renewable energy. Nevertheless, each Member State is allowed to implement its own specific legislation, provided that it remains compliant with the Directive [12]. In the Italian regulatory framework, for example, consumers and generators belonging to the same REC must be connected to the same low- or medium-voltage substation [15].

Among distributed generation technologies, photovoltaic (PV) panels represent the most widely adopted energy source, mainly due to their versatility and reliability. Accordingly, more than 91% of the reviewed studies considered PV technology [12]. By contrast, biomass/waste generators have received limited attention in the energy community literature, being addressed in only nine articles [12]. In this study, the energy consumption profile of a real dairy farm was considered, and a biogas power plant fuelled by cattle manure was consequently sized and included as a renewable energy source within the energy community. Energy storage systems play a key role in managing renewable energy generation and ensuring a reliable and resilient energy supply. By integrating energy storage systems, energy communities can store excess electricity produced by renewable energy sources, such as photovoltaic panels or wind turbines, and use it during periods of high demand or when renewable generation is limited. Different storage technologies may be adopted, including batteries, pumped hydro storage, compressed-air energy storage, and thermal energy storage, depending on the specific needs, resources, and geographical characteristics of the community. For instance, when a suitable nearby water source is available, pumped hydro storage may represent a viable option for both energy storage and generation [16]. Within the scenarios analysed in this work, prosumers equipped with batteries are allowed to share the electricity stored in their own storage systems with other members of the community whenever additional electric energy is required. In particular, the case study considers an energy community composed of four real participants: three prosumers equipped with photovoltaic systems and batteries, and one prosumer equipped with a biogas power plant. For the latter, no battery storage system was considered, since, apart from maintenance periods, the electricity generated by the biogas plant can be assumed to remain approximately constant throughout the year. The proposed energy community was then assessed from an economic perspective, with the aim of evaluating the convenience and potential benefits of battery sharing among community members.

2. Model and methods

2.1 Predictive model structure

The predictive techno-economic model to evaluate the energy and economic performance of the Renewable Energy Community (*REC*) was developed in Microsoft Excel. The model processes electricity generation, user demand, storage operation, grid exchanges and economic cash flows over a full annual simulation period. An hourly time-step calculation was adopted to represent the variability of renewable energy production and electricity demand profiles.

The case study includes four representative REC members: a kindergarten, a primary school, a company and a farm. For each member, the model evaluates local photovoltaic production, electricity demand, self-consumption, surplus energy exported to the grid and residual electricity demand. Battery energy storage systems are then introduced to assess their influence on self-consumption, grid exchanges and shared energy. In addition, a biogas generation unit is associated with the farm member in order to evaluate the contribution of an almost constant renewable energy source.

2.2 Photovoltaic generation and load profiles

The photovoltaic electricity production of each member was estimated starting from solar irradiance data obtained from PVGIS [17].

The photovoltaic systems were designed with a peak power capacity such that, over one hour, they could produce an amount of energy equivalent to the maximum annual energy demand of the user [18]. The irradiance series were converted into electrical energy production according to the installed photovoltaic surface and module and inverter efficiency. The photovoltaic energy generated by member *i* at hourly time step was calculated as:

$$E_{PV,i} = G \cdot A_i \cdot \eta_{PV} \cdot \eta_{inv} \quad (1)$$

where $E_{PV,i}$ is the photovoltaic electricity production of member *i* at time step [kWh], G is the solar irradiance incident on the module plane [kWh/m^2], A_i is the total photovoltaic surface installed by member i [m^2], η_{PV} is the photovoltaic module efficiency, and η_{inv} is the inverter efficiency.

The resulting photovoltaic generation profiles were combined with the electricity load profiles of the four *REC* members.

For each member and each time step, the model first calculates the energy balance without storage. The individual self-consumption is defined as the minimum between photovoltaic production and electricity demand:

$$E_{SC,i} = \min(E_{PV,i}, L_i) \quad (2)$$

where L_i is the electricity demand of member i at time step h. The surplus energy exported to the grid is calculated as:

$$E_{sur,i} = \max(E_{PV,i} - L_i, 0) \quad (3)$$

while the residual energy demand (deficit) from the grid is:

$$E_{def,i} = \max(L_i - E_{PV,i}, 0) \quad (4)$$

where $E_{sur,i}$ represents the excess photovoltaic energy and $E_{def,i}$ represents the electricity deficit of the user.

2.3 Battery storage modelling

Battery energy storage systems were included in the model to evaluate their effect on the energy balance of each *REC* member. The main objective of the storage system is to increase self-consumption. For each member, the battery is defined by its nominal capacity $C_{bat,i}$ [kWh] and its maximum charge/discharge power $P_{bat,i}^{max}$ [kW]. As a preliminary sizing criterion, the battery capacity was assumed equal to the maximum load peak recorded by the corresponding user during the simulated year [19]. This criterion was adopted as a fixed reference assumption for the comparative analysis and should not be interpreted as an economically or technically optimized battery size. A systematic optimization or sensitivity analysis of storage capacity was beyond the scope of this preliminary study. The maximum battery charge/discharge power was determined using a C_{rate} equal to 0.5 1/h:

$$P_{bat,i}^{max} = C_{bat,i} \cdot C_{rate} \tag{5}$$

The state of charge of the battery was calculated at each time step. The state of charge depends on the energy stored in the previous time step, the photovoltaic surplus absorbed by the battery and the energy discharged to cover the user electricity deficit:

$$SoC_{i,h} = SoC_{i,h-1} + E_{ch,i} - E_{dis,i} \tag{6}$$

where SoC_i,h is the battery state of charge of member *i* [kWh], *h* time step and *h-1* is the previous time step, $E_{ch,i}$ is the energy charged into the battery [kWh], and $E_{dis,i}$ is the energy discharged from the battery [kWh]. In order to reproduce a more realistic charging behaviour, the maximum charging power was dynamically reduced according to the percentage state of charge. The correction factor f_{SoC} was defined as: 1 if $SoC < 80\%$, 0.5 if $80\% \leq SoC < 90\%$, 0.2 if $SoC \geq 90\%$. The effective charging energy can therefore be expressed as:

$$E_{ch,i} = min(E_{sur,i}, C_{bat,i} - SoC_{i,h-1}, P_{bat,i}^{max} \cdot f_{SoC}) \tag{7}$$

Similarly, the discharge energy used to cover the local deficit is calculated as:

$$E_{dis,i} = min(E_{def,i}, SoC_{i,h-1}, P_{bat,i}^{max}) \tag{8}$$

After battery operation, the final surplus and deficit of each member are updated as follows:

$$E_{sur,i}^{final} = E_{sur,i} - E_{ch,i} \tag{9}$$

$$E_{def,i}^{final} = E_{def,i} - E_{dis,i} \tag{10}$$

These final values represent the actual electricity exchanged with the distribution grid by each member after the contribution of the local battery system.

2.4 Shared energy within the REC

At community level, shared energy was calculated according to the simultaneity between electricity exported to the grid by some members and electricity withdrawn from the grid by other members. For each time step, the shared energy of the *REC* was defined as the minimum between the total final surplus and the total final deficit of all members:

$$E_{sh} = min\left(\sum_{i=1}^{n} E_{sur,i}^{final}, \sum_{i=1}^{n} E_{def,i}^{final}\right) \quad (11)$$

where E_{sh} is the shared energy, and n is the number of *REC* members. The annual shared energy is then calculated by summing E_{sh} over the whole simulation period. This approach allows the model to quantify the energy that can access the incentive mechanisms, since only electricity that is simultaneously injected and withdrawn within the community can be considered shared energy.

2.5 Biogas generation modelling

For the farm, a biogas generation unit was assumed instead of a typical photovoltaic system. The biogas plant was assumed to be powered by livestock manure from the farm. Its electricity production was modelled as a constant hourly generation profile based on the number of lactating animals of the considered farm:

$$E_{bio} = N_a \cdot e_{bio} \quad (12)$$

where E_{bio} is the hourly electricity production from the biogas unit [kWh], N_a is the number of lactating animals, and e_{bio} is the specific hourly electricity productivity per animal [kWh/(h head)]. The value of e_{bio} was estimated in a previous study as 0.0917 kWh/h per animal [20]. To better represent real operating conditions, periodic maintenance shutdowns were also included in the biogas generation profile. The plant was assumed to operate for approximately 8000 hours per year, with scheduled periods of zero production corresponding to two consecutive days of maintenance at the end of each month. The biogas model should therefore be regarded as a simplified representation: feedstock availability was assumed to be sufficient throughout the year, while biogas storage, heat utilization, part-load operation, and detailed operational and maintenance constraints were not explicitly considered

2.6 Coordinated battery management at community level

In addition to individual battery operation described in Section 2.3, two coordinated battery management strategies were implemented at community level. The battery control follows a sequential hierarchical logic: individual operation is performed first to maximize local self-consumption, while coordinated community-level charging or discharging is subsequently applied only to the residual energy imbalance, using the battery state of charge resulting from the individual operation. The first strategy concerns the coordinated discharge of batteries during community deficit periods. This condition occurs when the total residual electricity demand of the *REC* exceeds the simultaneous surplus energy available from the members. The residual community deficit is calculated as:

$$E_{def,REC} = max\left(\sum_{i=1}^{n} E_{def,i}^{final} - \sum_{i=1}^{n} E_{sur,i}^{final}, 0\right) \quad (13)$$

When a positive community deficit occurs, the batteries of the members with sufficient available charge can discharge energy to the grid in order to cover part of the *REC* demand. The theoretical discharge contribution assigned to each available battery $E_{q,dis}$ is calculated as:

$$E_{q,dis} = \frac{E_{def,REC}}{N_{bat,act}} \tag{14}$$

where $N_{bat,act}$ is the number of active batteries available for discharge at time step. The actual discharge of each battery is constrained by the theoretical assigned share, the previous state of charge and the maximum discharge power:

$$E_{dis,REC,i} = min\left(E_{q,dis}, SoC_{i,h-1}, P_{bat,i}^{max}\right) \tag{15}$$

The energy effectively shared through coordinated battery discharge is then:

$$E_{sh,dis} = min\left(E_{def,REC}, \sum_{i=1}^{n} E_{dis,REC,i}\right) \tag{16}$$

The second strategy concerns the coordinated charging of batteries during community surplus periods. This condition occurs when the total surplus energy injected into the grid by *REC* members exceeds the simultaneous total deficit. The residual community surplus is calculated as:

$$E_{sur,REC} = max\left(\sum_{i=1}^{n} E_{sur,i}^{final} - \sum_{i=1}^{n} E_{def,i}^{final}, 0\right) \tag{17}$$

When a positive community surplus is available, the model distributes this energy among the batteries that are not fully charged. The theoretical charging share for each available battery is:

$$E_{q,ch} = \frac{E_{sur,REC}}{N_{bat,ch}} \tag{18}$$

where $N_{bat,ch}$ is the number of batteries available for charging at each time step. The actual charging energy is limited by the theoretical share, residual storage capacity and maximum charging power:

$$E_{ch,REC,i} = min\left(E_{q,ch}, C_{bat,i} - SoC_{i,h-1}, P_{bat,i}^{max} \cdot f_{SoC}\right) \tag{19}$$

The energy effectively shared through coordinated battery charging is calculated as:

$$E_{sh,ch} = min\left(E_{sur,REC}, \sum_{i=1}^{n} E_{ch,REC,i}\right) \tag{20}$$

The combined implementation of coordinated discharge and coordinated charge allows the model to dynamically update the battery state of charge and the final grid exchange profiles of all *REC* members at each time step.

3. Economic assessment

After the annual energy flows were calculated, an economic assessment over a ten-year period was performed. The aim of this analysis was not to perform a conventional investment profitability assessment, but rather to compare the overall economic performance of the different

REC scenarios over a ten-year analysis period. Since the analysed scenarios involve different investment structures, including a reference case without local generation or storage investments, the comparison was based on the cumulative net economic cost, therefore other investment-specific indicators were not considered. The initial investment cost was estimated using specific unit costs for the main technologies considered in the analysis. The photovoltaic system cost, including modules, inverter and mounting structures, was assumed equal to 2000 €/kWp [21]. The battery investment cost was assumed equal to 800 €/kWh of nominal capacity [22], while the biogas cogeneration unit was assigned a specific cost of 8000 €/kW of installed electric power [23]. For each member, the total initial investment was calculated as:

$$I_i = SC_{PV} \cdot P_{PV,i} + SC_{bat} \cdot C_{bat,i} + SC_{bio} \cdot P_{bio,i} \quad (21)$$

where I_i is the investment cost of member i, SC_{PV} is the specific photovoltaic cost [€/kWp], $P_{PV,i}$ is the installed photovoltaic power [kWp], SC_{bat} is the specific battery cost [€/kWh], $C_{bat,i}$ is the installed battery capacity [kWh], SC_{bio} is the specific biogas plant cost [€/kW], and $P_{bio,i}$ is the installed biogas electric power [kW]. The annual economic balance of each member was calculated by considering electricity purchase costs and revenues from electricity sold to the grid. The electricity purchase price from the grid was assumed to be 0.30 €/kWh, whereas the selling price of exported electricity was set at 0.10 €/kWh. The incentive for shared energy was assumed to be 0.09 €/kWh, in line with the values adopted by Basilico et al. [24]. For this preliminary comparative assessment, constant electricity purchase and selling prices were assumed over the entire simulation period. Therefore, hourly market price variability and zonal electricity prices were not considered. Shared energy and the corresponding incentive were evaluated at the aggregate REC level. At each hourly time step, shared energy was calculated as the minimum between the total electricity injected into and withdrawn from the grid by all REC members, as defined in Eq. (11). Coordinated battery operation modifies these aggregate grid exchanges and, consequently, the total amount of incentivized shared energy. No specific allocation of the resulting incentive among individual members was assumed in the present analysis. The annual net electricity cost of each member, excluding the shared-energy incentive, was calculated as:

$$C_{el,i} = p_{buy} \sum_{h=1}^{8760} E_{def,i}^{final} - p_{sell} \sum_{h=1}^{8760} E_{sur,i}^{final} \quad (22)$$

where p_{buy} is the electricity purchase tariff [€/kWh], p_{sell} is the electricity selling tariff [€/kWh], $E_{def,i}^{final}$ is the final electricity withdrawal from the grid, and $E_{sur,i}^{final}$ is the final electricity injection into the grid.

The total annual revenue associated with shared energy was instead calculated at the REC level as:

$$R_{sh,REC} = p_{sh} \sum_{h=1}^{8760} E_{sh} \quad (23)$$

where E_{sh} is the shared energy of the overall REC at time step, as defined in Eq. (11), and p_{sh} is the shared-energy incentive [€/kWh]. Accordingly, the annual net economic cost of the REC was calculated as:

$$C_{REC} = \sum_{i=1}^{n} C_{el,i} - R_{sh,REC} \quad (24)$$

This formulation accounts for the economic benefit generated by shared energy at community level without assuming any specific redistribution of the corresponding incentive among individual members. For each configuration, the cumulative net economic cost over the ten-year period was obtained by combining the initial investment cost, when applicable, with the annual net economic cost of the REC. Lower cumulative values therefore indicate a more economically favourable configuration under the assumptions adopted in this study. This economic framework allows the comparison of different REC configurations by evaluating how photovoltaic generation, battery storage, biogas production and coordinated energy management influence both the energy shared within the community and the economic performance of its members.

4. Results

This section summarizes the amount of energy consumed, produced, and shared by the members of the REC, as well as the resulting cash flows. The results are compared with alternative scenarios in which: the members do not own any energy production system; the members own production systems and batteries but do not participate in the REC; the members participate in the REC, but the storage systems are operated individually and do not exchange energy with the grid to maximize shared energy ("without storage sharing"); and, finally, the members participate in the REC and use the storage systems according to the strategy described in Section 2.6, with the aim of maximizing shared energy without excessively penalizing individual members ("with storage sharing"). It can be observed that, although the total self-produced energy is higher than the total electricity consumption, it can cover only a limited share of the individual self-consumption. Therefore, sharing this energy with other REC members is essential, both from an environmental perspective, since it is entirely produced from renewable sources, and from an economic perspective. Furthermore, the coordinated use of battery storage allows a significantly higher amount of energy to be shared within the community, thereby increasing the overall economic benefit for REC members. The main annual energy results for the analysed configurations are summarized in Table 1.

Table 1. Annual energy balance of the analysed REC configurations

Parameter	Energy
Total electricity consumption of REC members	481,120.49 kWh
Total electricity production from all generation units	519,940.09 kWh
Total self-consumed energy, no REC	307,099.58 kWh
Total shared energy in the REC, without storage sharing	95,707.67 kWh
Total shared energy in the REC, with storage sharing	129,372.23 kWh

The corresponding economic results over the ten-year analysis period are reported in Table 2.

Table 2. Economic results

10 years cash flow for the 4 scenarios	Value
No power plants, no REC	1,443,361€
Power plants, no REC	1,003,626 €
Power plants, REC, without storage sharing	917,489 €
Power plants, REC, with storage sharing	811,863 €

5. Discussion and Conclusions

In this work, a REC composed of four real consumption profiles was modelled and evaluated from both energy and economic perspectives. The analysed community includes three members equipped with photovoltaic systems and battery storage, and one dairy farm equipped with a biogas cogeneration unit. The results show that, although the total annual renewable electricity production is higher than the total electricity consumption of the REC members, only part of this energy can be directly self-consumed by individual users. This highlights the importance of energy sharing within the REC, which allows a larger share of locally produced renewable electricity to be used by the community. One distinctive aspect of this study is the inclusion of a farm with a biogas power plant. Unlike photovoltaic systems, the biogas unit provides a more stable and dispatchable renewable generation profile, thus increasing the availability of energy that can be shared within the community. In particular, the biogas unit could provide approximately 53.1% of the REC's total annual electricity consumption, even in the absence of batteries. This suggests that the agricultural sector can play an important role in the development of RECs, especially when locally available biomass residues are used for renewable bioenergy production. A second relevant aspect is the evaluation of coordinated battery operation. The results show that shared energy increases from 95,707.67 kWh in the REC configuration without storage sharing to 129,372.23 kWh when the coordinated storage strategy is applied. This confirms that battery storage can provide benefits not only for individual self-consumption, but also for the whole community by improving the temporal matching between renewable generation and demand. From an economic point of view, the REC configuration with coordinated storage operation provides the best performance among the analysed scenarios. The ten-year cash flow decreases from 1,443,361 € in the case without production plants and REC participation to 811,863 € in the case with REC participation and coordinated storage management. Therefore, the proposed REC structure can improve both the use of renewable energy and the economic performance of its members. Finally, the increasing penetration of photovoltaic energy may lead in the future to progressively lower, or even negative, electricity export prices during periods of high renewable generation. In this context, strategies aimed at maximizing local energy sharing, including the coordinated use of batteries, may become increasingly important to preserve the value of renewable electricity. In conclusion, this preliminary study shows that a REC integrating photovoltaic systems, battery storage, and biogas generation can be both sustainable and economically attractive. The Excel-based model developed in this work can also be used to economically evaluate other REC configurations by modifying the input data, such as load profiles and the size of generation and storage systems.

Acknowledgement

The authors would like to thank Enerplan S.p.A. for its collaboration in the analysis of typical energy consumption profiles.

References

[1] Ruggiero S, Busch H, Hansen T and Isakovic A 2021 Context and agency in urban community energy initiatives: an analysis of six case studies from the Baltic Sea Region Energy Policy 148 111956 (doi:10.1016/j.enpol.2020.111956)
[2] Cavana G, Becchio C and Bottero M 2025 Feasibility and evolution studies on renewable energy communities in cities Renew. Sustain. Energy Rev. 213 115477 (doi:10.1016/j.rser.2025.115477)
[3] Mehta P and Tiefenbeck V 2022 Solar PV sharing in urban energy communities: impact of community configurations on profitability, autonomy and the electric grid Sustain. Cities Soc. 87 104178 (doi:10.1016/j.scs.2022.104178)
[4] Ancona M A et al 2022 Comparative analysis of renewable energy community designs for district heating networks: case study of Corticella (Italy) Energies 15 5248 (doi:10.3390/en15145248)
[5] Kazmi H, Munné-Collado Í, Mehmood F, Syed T A and Driesen J 2021 Towards data-driven energy communities: a review of open-source datasets, models and tools Renew. Sustain. Energy Rev. 148 111290 (doi:10.1016/j.rser.2021.111290)
[6] Bauwens T, Schraven D, Drewing E, Radtke J, Holstenkamp L, Gotchev B and Yildiz Ö 2022 Conceptualizing community in energy systems: a systematic review of 183 definitions Renew. Sustain. Energy Rev. 156 111999 (doi:10.1016/j.rser.2021.111999)
[7] Yaqoot M, Diwan P and Kandpal T C 2016 Review of barriers to the dissemination of decentralized renewable energy systems Renew. Sustain. Energy Rev. 58 477–490 (doi:10.1016/j.rser.2015.12.224)
[8] Wu Y, Wu Y, Cimen H, Vasquez J C and Guerrero J M 2022 Towards collective energy community: potential roles of microgrid and blockchain to go beyond P2P energy trading Appl. Energy 314 119003 (doi:10.1016/j.apenergy.2022.119003)
[9] Zwickl-Bernhard S and Auer H 2021 Citizen participation in low-carbon energy systems: energy communities and its impact on the electricity demand on neighborhood and national level Energies 14 305 (doi:10.3390/en14020305)
[10] Ryszawska B, Rozwadowska M, Ulatowska R, Pierzchała M and Szymański P 2021 The power of co-creation in the energy transition—DART model in citizen energy communities projects Energies 14 5266 (doi:10.3390/en14175266)
[11] DeWaters J, Powers S and Graham M 2007 Developing an energy literacy scale ASEE Annual Conference and Exposition, Conference Proceedings (doi:10.18260/1-2--2076)
[12] Barabino E, Fioriti D, Guerrazzi E, Mariuzzo I, Poli D, Raugi M, Razaei E, Schito E and Thomopulos D 2023 Energy communities: a review on trends, energy system modelling, business models, and optimisation objectives Sustain. Energy Grids Netw. 36 101187 (doi:10.1016/j.segan.2023.101187)
[13] European Parliament and Council 2018 Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources Off. J. Eur. Union L 328 82–209
[14] Gržanić M, Capuder T, Zhang N and Huang W 2022 Prosumers as active market participants: a systematic review of evolution of opportunities, models and challenges Renew. Sustain. Energy Rev. 154 111859 (doi:10.1016/j.rser.2021.111859)
[15] Zatti M, Moncecchi M, Gabba M, Chiesa A, Bovera F and Merlo M 2021 Energy communities design optimization in the Italian framework Appl. Sci. 11 5218 (doi:10.3390/app11115218)
[16] Lazaroiu A C, Roscia M, Lazaroiu G C and Siano P 2025 Review of energy communities: definitions, regulations, topologies, and technologies Smart Cities 8 8 (doi:10.3390/smartcities8010008)
[17] European Commission, Joint Research Centre n.d. Photovoltaic Geographical Information System (PVGIS) Available at: https://re.jrc.ec.europa.eu/pvg_tools/en/
[18] Alshahrani, A.; Omer, S.; Su, Y. An Investigation into the Potential of Hosting Capacity and the Frequency Stability of a Regional Grid with Increasing Penetration Level of Large-Scale PV Systems. Electronics 2021, 10, 1254. (doi.org/10.3390/electronics10111254)
[19] Faruhaan A, Go YI. Energy storage sizing and enhanced dispatch strategy with temperature and safety considerations: A techno-economic analysis. Energy Storage. 2021; 3(6):e260. (doi.org/10.1002/est2.260)
[20] Miserocchi L, Franco A, Puglia M, Pavesi J, Allesina G and Tartarini P 2025 Assessing on-site renewable energy potential for Parmigiano Reggiano production Int. J. Energy Prod. Manag. 10 384–393 (doi:10.56578/ijepm100303)
[21] Koskela J, Rautiainen A and Järventausta P 2019 Using electrical energy storage in residential buildings—sizing of battery and photovoltaic panels based on electricity cost optimization Appl. Energy 239 1175–1189 (doi:10.1016/j.apenergy.2019.02.021)

[22] Worighi I, Geury T, El Baghdadi M, Van Mierlo J, Hegazy O and Maach A 2019 Optimal design of hybrid PV-battery system in residential buildings: end-user economics, and PV penetration Appl. Sci. 9 1022 (doi:10.3390/app9051022)
[23] Balussou D 2023 An analysis of current and future electricity production from biogas in Germany Karlsruhe Institute of Technology (doi:10.5445/KSP/1000122103)
[24] Basilico P, Biancardi A, D'Adamo I, Gastaldi M and Stornelli V 2025 Socioeconomic dimensions of renewable energy communities: pathways to collective well-being Utilities Policy 96 102000 (doi:10.1016/j.jup.2025.102000)

IOP Conference Series

Declaration of use of generative AI

Please include a completed version of this template as an appendix to any submitted work that has involved the use of generative AI (GenAI) technology (further information on GenAI and assessment).

Acknowledge

Please tick the box to confirm the statement and fill in the name of the AI system you have used.

[X] I acknowledge the use of *OpenAI GPT-5.5 Thinking https://chatgpt.com/,* to generate materials for background research and self-study in the drafting of this assessment, or that were included within my final assessment in modified form.

Describe

Please provide a short summary of how you used generative AI in your assignment. You may wish to include the following information:

- *What prompts did you use?*
- *What outputs did you generate?*
- *How did you use/adapt/develop the outputs?*

Summary:

OpenAI GPT-5.5 Thinking was used solely to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Evidence

Please provide the outputs that you generated by copying & pasting below or by providing a screenshot.

Generative AI system: OpenAI GPT-5.5 Thinking.

Prompt: "Improve the grammar in this paragraph."

Output: Paragraph grammar improved.

Declaration

I confirm that no content created by generative AI technology has been presented as my own work.

Full name: Marco Puglia

Date: 02/09/2026