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Assessing the Benefits of Renewable Energy Communities: A Portuguese Case Study

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Abstract. The new European legislation regarding self-consumption from local renewable energy sources, and the following Portuguese transposition, define new structures to the self-consumption process, namely the Storage Installation and the Production Installation. It also brings the concept of Renewable Energy Community (REC), defining how it can be formed and how to manage its energy consumption and generation. Regarding this management, there is the possibility to share the generated energy locally, among REC members, by the application of sharing coefficients. This paper analyses the benefits introduced to a group of buildings, in terms of electricity costs, when they operate as a REC. Additionally, it analyses the impact of battery storage systems on renewable energy sources self-consumption, when the referred buildings operate individually or as a REC.

Keywords: Renewable Energy Community, Self-Consumption, Energy Storage.

1 Introduction

According to Directive (EU) 2018/2001 of the European Parliament and of the Council on the promotion of the use of energy from renewable sources [1], the increase of renewable energy usage is one of the goals of the European Union energy policy. The increase of renewable energy sources also plays a role on the energy security framework, along with the environmental benefits. However, the natural intermittence of some technologies commercially available (e.g., solar Photovoltaic (PV) systems) and high reverse power flows might introduce problems during the operation of electrical grids [2]. Non-hydro renewables (geothermal, solar, wind, ocean, biofuel and waste) were responsible for up to 11% of all electricity generation in 2019 [3] but this figure is expected to increase to 40-70% by 2050.

Given the importance of the building sector, which is responsible for the consumption of 48% of all electricity generated [3] one of the innovations brought by Directive 2018/2001 refers to the possibility of aggregating buildings as a Renewable Energy Community (REC). Among other objectives, RECs aim to enable renewable energy sharing among its members with the overall goal of improving the development of the renewable energy market, while contributing to the promotion of energy efficiency at building and cluster levels, and to the decrease of energy poverty through electricity costs reduction. RECs are also a tool, as an added value, to increase both local acceptance of renewable energy sources, and citizen participation on energy transition [1]. Additionally, existing energy flexibility can be aggregated and used at community level to mitigate the referred challenges imposed to the operation of electric grids by the introduction of energy conversion systems based on renewable energy resources [4].

In this context, the contributions of this paper are twofold: firstly, a comparison with individual and collective self-consumption is conducted in order to analyse the impacts of both configurations on the electrical energy import and resulting electricity costs. The second major contribution refers to the assessment of the Storage Installation impact on both self-consumption configurations (individual and collective). Regarding the collective self-consumption, the recent published European and Portuguese legal framework are considered in this study, with special attention to the association of buildings into a renewable energy community and the energy sharing procedure among its members.

2 Relationship to Technological Innovation for Digitalization and Virtualization

The “World Energy Outlook 2021”, published by the International Energy Agency [5], states that there is a need to increase the capacity of distribution lines, to handle the growing distributed solar PV capacity, which is predicted to increase four-fold by 2030. To comply with this increasing share of distributed renewable energy sources into the distribution grids, there is a need to manage locally how this energy is used. The concept of Renewable Energy Community is created by the Directive 2018/2001 of the European Council [1] in order to address this need. However, for a proper energy management within the borders of a REC there is a need to virtualize the energy sharing process, since it is impossible to drive the generated energy to a given user when it is needed. Furthermore, REC members might be distant from each other, which makes unfeasible the physical management of the energy trading among them. In this case, the distribution grid is used, and grid fees are charged. These fees are virtually calculated, based on the net values of energy import and export of each community member. Thus, the energy sharing is made at energy meter level, and the result is charged to every REC member.

Through simulation, the case study presented in this paper addresses the impacts introduced by a REC on a group of real buildings in Évora, Portugal, in terms of electricity costs, when comparing to their individual operation. These buildings are, in fact, detached from each other and physically separated by hundreds of meters.

However, it is possible to manage the energy import, sharing and export of these buildings by virtualizing the process at energy meter level. Additionally, this paper aims to assess the impact introduced by Storage Installations (SIs) on PV self-consumption at building and community level. The presented case study is carried out under the scope of European POCITYF H2020 project [6], which, among other objectives, aims to create a REC that will integrate the referred buildings.

3 Renewable Energy Community

At European level, the concept of Renewable Energy Community is described by Directive 2018/2001 of the European Council [1]. This document defines a REC as a legal entity, formed by the association of electricity consumers, which has the main objective of providing environmental, economic, and social benefits to its members and to the surroundings entities, both private and public. Renewable Energy Communities have the rights to generate, store, use and export energy to the grid. They also have the right to share part of the generated energy among its members.

Considering the Portuguese context, the definition of Renewable Energy Communities has been updated by Decree-Law 15/2022 [7], which states that energy sharing among REC members must be conducted using sharing coefficients whose values are agreed by all members. The complete regulation of REC operation is described by Regulation 373/2021, published by the Portuguese Energy Services Regulatory Authority (ERSE) [8]. This regulatory document also brings two new concepts for the self-consumption topic: i) the Storage Installation, an electrical installation licensed on the terms of the Decree-Law 15/2022, for storage of renewable electrical energy, static or by using electric vehicles batteries, which can be installed on private network or in the public grid; and ii) the Production Installation (PI), an electrical installation licensed under the terms of the Decree-Law 15/2022, for production of renewable energy on one or more Units for Self-Consumption Production (USCP), which is connected to the public grid, directly or by a local network. Regarding the energy sharing coefficients, the Portuguese regulation [8] states that they must be sent to the distribution system operator prior to the start of the sharing process.

Studies on energy communities have been recently increasing, given the importance for meeting strategic objectives in terms of responding to the climate emergency by, for instance, promoting the use of renewable energy resources. Botsaris et al. [9] address the business case scenario and the market players involved in a virtual REC composed of different types of buildings in Greece. Results show that the community implementation on a low-income housing context must be followed by promotion schemes due to the initial cost of adapting existing buildings and installing new equipment. On another context, Ceglia et al. [10] analysed the environmental performance of a simulated REC composed of two office buildings, implemented considering European regional directives [1] together with the Italian legal framework. Results show that the share of consumed electricity which is locally generated rises to 79% when considering collective self-consumption. The user's intention to participate on a REC, assessed by the analysis of their attitude, the norms and the possible

behavioural control that might be perceived by them, is described in [11]. This survey shows that, when people are previously informed of the benefits related to a REC, both economic and environmental, their interest to participate increases.

One of the main features of a Renewable Energy Community refers to the energy sharing process. Under the Portuguese context, sharing is made by the definition of sharing coefficients (according to Decree-Law n° 15/2022 [7]), which can be static or time dependent. Static coefficients might have distinct values for different days (e.g., weekdays and weekends), while variable coefficients might follow any criteria, such as energy consumption and generation during a specific period. According to this second type, the sharing coefficients used in this case study vary throughout the day (15-min resolution) following the power needs of each member relative to the entire REC, as described by Eq. (1), where ESC_i refers to the value of the energy sharing coefficient attributed to member i at time-step n , Pd is the power demand and N is the number of REC members.

$$ESC_i(n) = \left(\frac{Pd_i(n)}{\sum_{j=1}^N Pd_j(n)} \right) \quad (1)$$

The literature also shows that the energy sharing process is normally associated with peer-to-peer energy transactions in microgrids with local energy sources. Liu et al. [12] developed an energy sharing model, to be used with a price-based demand response mechanism, applied to an energy community formed by residential, commercial and office buildings. Huty et al. [13] also applied an energy sharing model to a residential microgrid, on a community formed by 50 residences. However, in this case, along with the PV systems used as local energy source, electric vehicles are also an asset, which can play as loads, when charging, or as an energy source when discharging. The business model proposed by Fioriti et al. [14] takes into consideration rewards distribution within the community together with strategies to add or remove members, and a reward mechanism to a possible aggregator entity. They concluded that the grid dependence, when the community operates in a cooperative way, decrease by 54%. They also conclude that a collective implementation of local energy sources is cheaper than the individual purchasing of needed assets to turn self-consumption possible. Lastly, the increase of PV self-consumption by the community members is up to 46% when they operate collectively.

4 Case Study

This case study assesses the benefits introduced to a group of four public buildings by the implementation of a REC. These buildings are located in Évora, Portugal, and belong to the local municipality. Additionally, this case study addresses the impact of energy storage systems on PV self-consumption, when the referred buildings operate individually or as a REC. These buildings are used for distinct activities, resulting in different electricity needs, as presented in Fig. 1, which shows the normalized daily average demand profiles for 2019 (real data collected with 15-min resolution). In more detail, Building #1 is a multipurpose pavilion, used for concerts, sports tournaments and other events (see the increased power demand during the night due to shows),

Building #2 is a public market, Building #3 is a public school and Building #4 is the City Hall. The annual peak power demand, the electrical energy needed to comply with users' necessities, and the associated electricity costs are presented in Table 1. Currently, none of the buildings is equipped with PV systems although the installation is foreseen during the POCTIYF H2020 project, where these buildings will integrate a Positive Energy Block in Évora historic centre.

For this case study, two distinct scenarios are considered for the future PV systems installation. In the first one, the four buildings operate individually and therefore self-consumption is carried out at building level. In the second scenario, a REC is implemented in order to allow the collective self-consumption, as regulated by [8], where local generation, by the same Production Installations mentioned before, is shared among REC members according to the energy sharing coefficient described in Section 2 (Eq. 1). In both scenarios the impact of installing Storage Installations is assessed. These energy storage installations are controlled to only charge when PV surplus is available and to discharged whenever power demand is higher than generation. The overall power demand and generation (four buildings) is considered at community level.

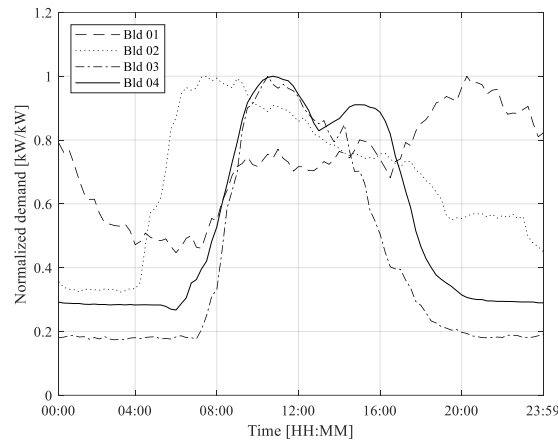


Fig. 1. Normalized daily average load diagram of the considered buildings.

Table 1. Buildings' energy related metrics.

Building	Peak power (kW)	Demand [kWh/y]	Cost [€/y]
#1	78	37,904	4,876.80
#2	21	33,289	4,305.70
#3	43	36,486	5,051.10
#4	136	236,350	32,064.00
Total	-	344,029	46,297.60

The PV production is estimated using real irradiance data acquired during 2019 from a local weather station. Fig. 2 presents the average daily profile of the global

horizontal irradiance (15-min resolution), which was computed by averaging the corresponding 365 daily profiles. Table 2 summarizes the considered PV peak power for each building and the associated yearly energy output. The rated power of the buildings to be installed, in the POCITYF project context, are a result of a survey conducted on the early stages of the project. The real values to be installed may differ from the ones used in this study. The generation profile of each building was obtained using the model described in [15] without modifying the inclination of the PV modules relative to the horizontal plan. Regarding the Storage Installations, it is assumed that each building uses the 10kWh/5kW system described in [17] when the individual self-consumption is carried out. For the scenario where the REC is formed, the SI is considered to be installed directly in the public grid, with the same total storage capacity as in the individual self-consumption scenario.

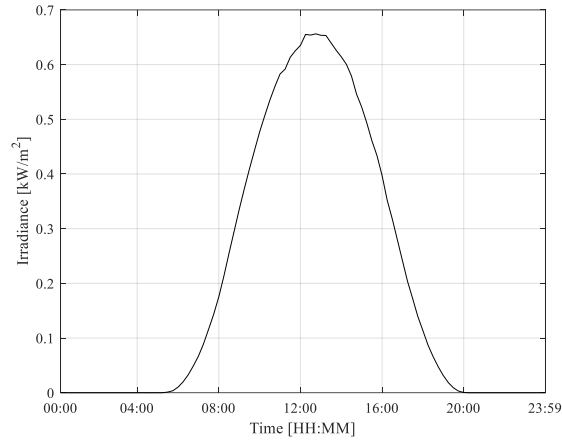


Fig. 2. Daily average global horizontal irradiance at the case study location.

Table 2. PV systems specifications.

Building	Rated power [kWp]	Generation [kWh/y]
#1	7.2	10,801
#2	15.7	23,552
#3	40.6	60,904
#4	85.5	128,260
Total	-	223,517

5 Results and Discussions

The results presented in this section focus on the energy imported from the distribution grid by each building and the corresponding costs, considering that PV generation is primarily used for self-consumption and that no revenue is received from injecting PV surplus into the grid. For both scenarios, energy is priced considering two tariffs. The

first one, with a value of 0.15 €/kWh, is observed from 08:00 to 22:00. The second one (0.09 €/kWh) is registered during the remaining period. The periods are based on a daily cycle billing, while the prices are adapted from the values considered for the Low-Voltage billing for 2019 [17].

5.1 Individual Self-Consumption (ISC)

When operating individually, buildings use their PV systems to satisfy part of the daily consumption profiles and therefore reduce energy imports from the grid. However, given the mismatch between demand and generation profiles, part of the generation is still exported to the grid. Table 2 presents the energy imported from the distribution grid by each building and the corresponding costs. This table also shows the impact of using a Storage Installation (10kWh/5kW) at each building. These SIs leads to a better performance regarding energy import and, consequentially, costs. Total energy imports and costs decreased by 4% and 5%, respectively, when comparing to a scenario without storage. However, this improvement is not equal among all buildings, since Building #2 and Building #3 have a better use of their SI due to the higher share of energy locally generated.

Table 3. Buildings' performance – Individual self-consumption.

Building	Import [kWh/y]			Cost [€/y]		
	w/o SI	w/ SI	Variation (%)	w/o SI	w/ SI	Variation (%)
#1	29,757	27,955	-6%	3,678.40	3,408.20	-8%
#2	20,748	18,482	-11%	2,473.20	2,133.30	-14%
#3	16,217	14,207	-12%	2,068.10	1,766.50	-15%
#4	140,090	137,800	-2%	17,890.00	17,547.00	-2%
Total	206,812	198,444	-4%	26,109.70	24,855.00	-5%

5.2 Collective Self-Consumption (CSC)

The main difference of this scenario to the previous one regards the use of the locally generated energy. When the buildings implement a REC and take advantage of collective self-consumption, the four generation and consumption profiles are added and seen as a single entity before sharing the PV generation to reduce the imports of each member. The total generation is therefore computed for each 15-min time-step and shared among REC members applying the sharing coefficient previously defined (Eq. 1). The SI, if considered, is seen as another generator when discharging and as a load when on charging, as defined in [8]. Table 4 shows the results obtained for the REC scenario (with and without energy storage systems).

Table 4. Buildings' performance – Collective self-consumption.

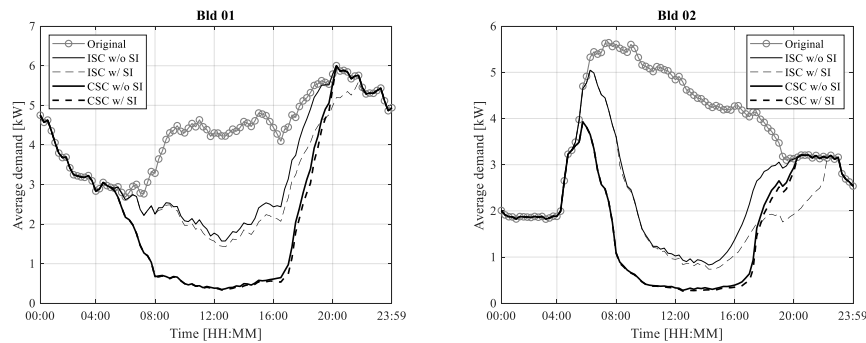
Building	Import [kWh/y]			Cost [€/y]		
	w/o SI	w/ SI	Variation (%)	w/o SI	w/ SI	Variation (%)
#1	22,165.00	21,761.00	-1.9%	2,591.00	2,530.30	-2.4%
#2	15,269.00	14,997.00	-1.8%	1,747.70	1,707.00	-2.4%
#3	11,201.00	10,981.00	-2.0%	1,324.30	1,291.20	-2.5%
#4	80,564.00	79,010.00	-2.0%	9,291.70	9,058.60	-2.5%
Total	129,199.00	126,749.00	-1.9%	14,954.70	14,587.10	-2.5%

The SIs have a positive impact on the energy import and associated costs. However, this impact is lower than on the individual self-consumption operation. On average, the SIs lead to a 1.9% improvement on the energy import and to a 2.4% cost reduction. However, even without them, the performance of the collective self-consumption operation is considerably better than the operation based on an individual self-consumption, with total imports and costs decreasing by 37% and 42%, respectively.

5.3 Discussion

As described in the previous sections, the collective self-consumption leads to a better performance comparing to the individual self-consumption process of each building considering both assessment metrics (i.e., energy import and cost). Additionally, total peak load also decreases when operating as a REC, which can have a significant impact on the energy bill due to its cost on the price formation. Results also show that energy storage devices have higher positive impact when considering the individual operation. The reason for this is related with the lower PV surplus of the entire community, which decreases the use of all storage systems.

In terms of grid interaction, Fig. 3 presents the daily average demand profiles for all buildings, considering their original operation (no PV) and the two scenarios (individual self-consumption and REC). This figure shows that the average peak load decreases for all building except Building #1, due to its peak demand during the evening. The impact of collective self-consumption is evident, reducing grid interaction in terms of energy and power for all buildings when the solar resource is available.



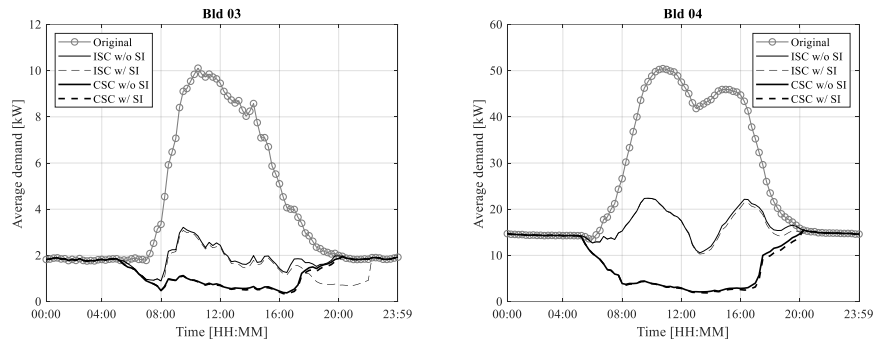


Fig. 3. Daily average demand profiles for all scenarios.

6 Conclusions and Future Work

This paper analyses the benefits of implementing a Renewable Energy Community (in terms of electrical energy imports and associated costs) on a group of four buildings from the municipality of Évora, Portugal. The considered case study also addresses the impact of including battery energy storage systems at building and community levels to increase PV self-consumption. The collected results shows that the electrical energy imports and costs are 36% and 41% lower, respectively, for the four buildings when they operate as a Renewable Energy Community (comparing to the individual operation). Previous results [18] also show that the installation of battery energy storage systems would not be profitable in any of the considered scenarios given the yearly annual savings and the required initial investment.

The work presented in this paper leaves open the opportunity to further study the impact of different types of energy sharing coefficients on REC members benefits. Additionally, further studies should be carried out regarding the possibility and feasibility of energy flexibility tools integration on a REC operation with energy sharing since there is a lack of studies joining energy flexibility concepts and energy sharing on a REC context.

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