Another approach to take into consideration is the possibility that a certain local community can benefit from an investment, which all participants can benefit from. Investors can be reimbursed for their investments and local citizens can benefit from access to renewable energy generation. Local communities, as a whole, can benefit from active participation in the reduction of greenhouse gases. Figure 3, illustrates an approach of the community-driven energy model.

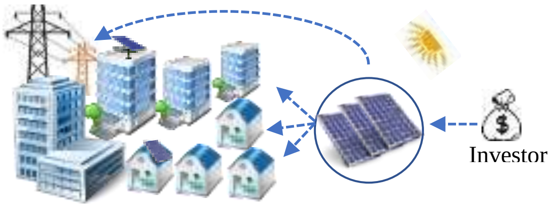

Fig.3. Community group (buy and sell)

Finally, if a lack of space in the top of the buildings to install solar PV panels is an issue, it may be possible to create an offsite shared solar approach, as depicted in Figure 4. This solution makes it possible for people to invest in solar energy together, and for that, allows multiple players (including the community residents) to directly benefit from the electricity produced by one solar array.

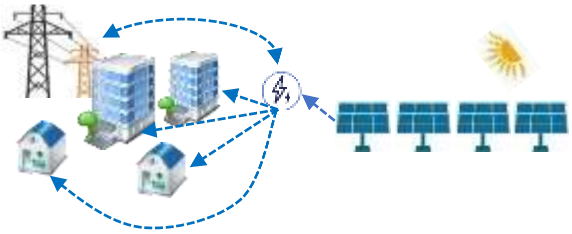

Fig.4. Offsite shared PV in energy community context

Customer demand aggregation may enhance the deployment of shared solar programs reducing technical and financial barriers and limitations. Thus, instead of a single PV array installation by the customer, acting alone, the shared solar models divide the costs among all of the participants, thus facilitating their participation. Investments are even safe for those who cannot stay in one place too long. If a customer moves, his or her solar share can be transferred to a new home within the same utility service territory or sold to someone else [12].

The siting flexibility can also be beneficial to participants since shared PV generation can be located on or off-site thanks to the possibility of having virtual net metering, which enables strategic PV panel placement on commercial and service rooftops of buildings, and municipal areas, contributing to the optimization of the power grid operation and encourage local economic development.

3. Shared PV Generation in buildings: an approach and optimization model

All over European Countries, households have taken the opportunity to produce a part of their electrical power, smoothing the load consumption peaks and reducing their electricity bill, apart from their direct contribution to mitigating carbon emissions. This opportunity is provided by the installation of rooftop PV panels on their facilities.

The regulatory aspects created by the European Parliament and of the Council, as well as, by the national legislation of each country, promoted to households the possibility to generate electricity from renewable sources, injecting the power directly in low voltage power networks (with a certain tariff per each produced kWh), also promote the self-consumption, and recently the shared renewable generation and the deployment of energy communities.

New models and approaches are required to explore the advantages of the shared renewable generation, in an apartment building context, with a special focus on solar PV technology.

A. Shared PV in collective buildings

In Portugal, typically, solar PV panels are installed in stand-alone houses. However, apartment buildings have a great potential to utilize solar PV systems. According to the building size and number of flats, the potential rooftop space available to install PV panels can vary significantly. This means that in small buildings (2-3 floors) and medium buildings (4-6 floors) the potential rooftop for PV energy production is likely to exceed common property (CP) demand as well as meet household load consumption demand.

The challenge to install solar PV panels in buildings is identified. PV generation systems among apartments of the same building might be used to sell electricity, for self-consumption or, even to supply offset apartment loads as well as common properties. Battery energy storage systems (BESS) could have an important role in managing electricity generation in hours in which there is less electricity consumption.

New models and business plans are required to explore the advantages of these new opportunities, presently enshrined in legislation.

Inspired by [5] and [12], it is possible to point out some approaches to take advantage of shared solar PV generation in a building context. Figure 5 shows the typical model for stand-alone self-generation and self-consumption having the opportunity to sell the excess power. Bidirectional meters are required for each unit load. While this solution avoids additional infrastructure requirements, the financial benefits for facility owners are limited. To take more advantage of solar PV generation, BESS can be used to smooth the electricity consumption during peak periods.

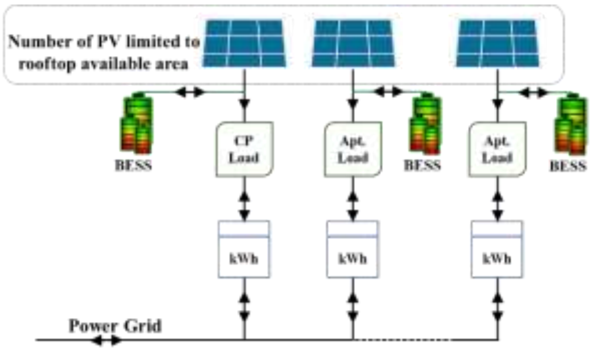

Fig.5. Individual solar PV generation system

Figure 6 depicts another solution based on the shared solar PV generation approach.

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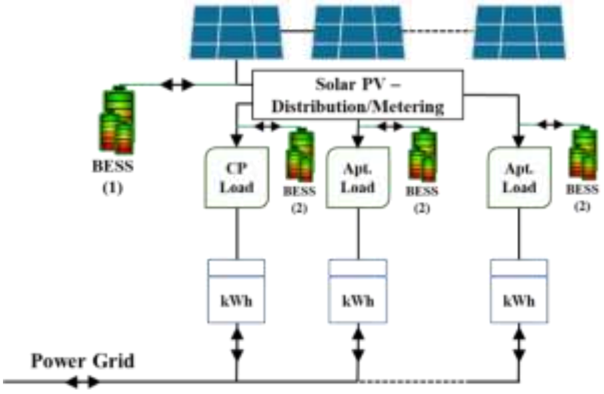

Fig.6. Shared solar PV generation system

Shared solar PV generation may contribute optimization of available rooftop space to install PV panels. Secondary metering is required to distribute among residents the on-site PV generation, while residents can continue to purchase their off-site generation from a certain electricity retailer. The residents can also have BESS to store the generated energy and use it during peak hours to smooth the resident consumption load profile. There are two ways to use BESS: as a centralized storage unit, marked (1) in Figure 6, which means that every resident can use that stored energy, or, as marked (2), using individual storage. In this case, the BESS is charged by the shared PV generation, and then each consumer can use the stored electrical energy accordingly to its consumption preference and load profile.

Figure 7, presents another solution for sharing the roofing resource to be managed by owners or by an aggregator. The aggregation of solar PV generation may open several business models as well as the participation in the electricity market, or the emerging and so-called local electricity markets.

The distribution of the solar PV generation throughout the building can be assured via an embedded power network, requiring an extra investment in proper infrastructure. The PV generation can be used (and charged by an aggregator or owner's corporation) for each resident.

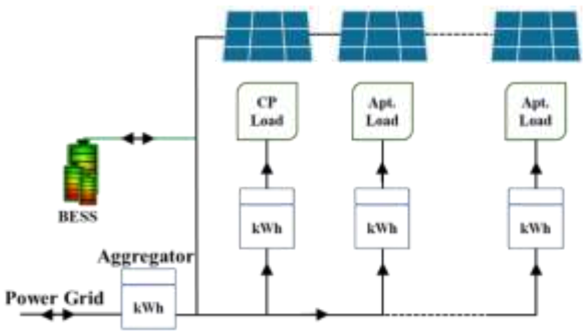

Fig.7. Embedded private power network

Besides selling on-site photovoltaic generation, the aggregator can also stimulate electricity demand aggregation throughout the building to reach advantageous agreements for the electricity demand purchase that can be sold to residents [5].

A centralized BESS can be used to optimize the management of the PV generation according to consumers' load profile, demand response programs, and charging schemes for electrical vehicles (EVs). Another potential of this approach is that it allows some degree of freedom in the apartment contracted power. Even though the legislation does not allow flexibility in the value of the contracted power of low voltage consumers, a third party can manage the building renewable generation, BESS, and EVs charging to enable flexibility in each single contracted power. In this case, an optimization problem is required to minimize the electricity consumption of the entire building.

B. Contracted Power flexibility in building context: An optimization approach proposal

Shared solar energy generation can open new business plans and new ways of commercial relationships between a set of end-consumers and an energy aggregator or energy supplier, as presented in Figure 7.

If those consumers were settled in a building, the building can be considered as a single client instead of several electricity consumers. Thus, it may have flexibility on the contracted power value of each end-consumer.

The increase of electrical vehicle (EVs) usage brings new challenges to both residents and aggregators concerning the management of the power available to charge EVs. In the near future, the possibility to consider the EVs discharge also brings new challenges and approaches to manage the duration and amount of energy that can be transferred from EVs to the building-embedded power network.

BESS may be useful to manage the PV generation and EVs discharges, to minimize the overall electricity consumption of the building.

Thus, to address these identified challenges, a Mixed Integer Linear Programming (MILP) is proposed to minimize the peak load power demand in a residential building (common property and households). The model takes into consideration the management of solar PV generation accordingly to the charging and discharging process of EVs scheduling, and considers the usage of BESS, taking into consideration the knowledge about consumers' typical load profile. The main idea is to consider the building as a single electricity customer, where an aggregator minimizes the contracted power value of the building taking into consideration the management of PV generation and the BESS/EVs charging/discharging process.

In this subsection, the objective function and constraints of the proposed mathematical formulation are presented, and the most important notation and parameters are shown in Table 1 [13].

Table 1. Nomenclature of the mathematical formulation.

Indices	
i	Index of time periods
j	Index of EVs
Parameters	
τ	The length of interval in each period i
P_g^i	Active power extracted from the grid in period i (kW)
c^i	Penalty factor based on the available PV versus the consumption in period i
P_{sb}^i	Active power related to the smart building load expected in period i (kW)
P_{pv}^i	Active power related to the photovoltaic generation foreseen in period i (kW)

P_{ch_evj}	Active power related to the charging process of the EV j (kW)
P_{dis_evj}	Active power related to the discharging process of the EV j (kW)
σ_j^i	Binary parameter based on the forecasted EVs' trips, which represents the connection of the EV j in period i
P_{ch_B}	Active power related to the charging process of the BESS (kW)
P_{dis_B}	Active power related to the discharging process of BESS (kW)
SOC_j^{max}	Maximum SOC that EV j can assume in period i
SOC_j^{min}	Minimum SOC that EV j can assume in period i
$SOC_j^{min\_final}$	Minimum SOC that EV j can assume at the end of the period
SOC_B^{max}	Maximum SOC that BESS can assume in period i
SOC_B^{min}	Minimum SOC that BESS can assume in period i
P_g^{max}	Maximum power that the grid can feed to the building (kW)
Variables	
α_j^i	Binary variable that represents the EV j charging process in period i
β_j^i	Binary variable that represents the EV j discharging process in period i
α_B^i	Binary variable that represents the BESS charging process in period i
β_B^i	Binary variable that represents the BESS discharging process in period i
SOC_j^i	SOC of the EV j at the start of period i
SOC_B^i	SOC of the BESS at the start of period i

Equation (1), presents the objective function, which intends to minimize the building energy consumption from an external power network.

$$\min: \sum_{i=1}^{I} P_g^i \cdot c^i \tag{1}$$

Equations (2) and (3) assure the system power balance. Equation (2) takes into consideration the building load consumption and also the CP consumption. It is also considered the PV generation and the charging/discharging process related to EVs and BESS usage.

$$P_g^i = P_{sb}^i - P_{pv}^i + \sum_{j=1}^{n} \left(P_{ch\_evj}^i \cdot \alpha_j^i - P_{dis\_evj}^i \cdot \beta_j^i\right). \cdot \sigma_j^i + P_{ch\_B}^i \cdot \alpha_B^i - P_{dis\_B}^i \cdot \beta_B^i \tag{2}$$

Equation (3) represents a cost function of the power availability for EVs and BESS charging and discharging process, in the period I. The most appropriate schedule to optimize the EVs/BESS charging/discharging process is achieved.

$$c^i = \frac{\left(P_{sb}^i - P_{pv}^i\right)}{\min\left(P_{sb} - P_{pv}\right)} \tag{3}$$

It is necessary to take into consideration a set of constraints to assure the model's effectiveness. The following constraints ensure that the resources do not violate their physical limits and they are not charging and discharging at the same time. Constraints related to the minimum battery state of charge (SOC) and the maximum power value to be consumed from the power grid were proposed. Equation (4) ensures that the physical limitations of the EVs batteries storage capacity are not violated.

$$SOC_j^{i+1} = SOC_j^i + \sigma_j^i.\left(P_{ch\_evj} \cdot \alpha_j^i - P_{dis\_evj} \cdot \beta_j^i\right) \cdot \tau \tag{4}$$

Equation (5) is proposed to assure the SOC maximum value of each EV battery that can be assumed in each period i and τ represents the interval of length in each period i.

$$SOC_j^i \leq SOC_j^{max}, \quad i = 0, \dots, I \tag{5}$$

The minimum SOC values of the EVs were also defined. Equations (6) and (7) represent the constraints for the minimum value of SOC_j^i at any period i and in the last period (i = I). Equation (8) was formulated to avoid the EVs charging/discharging process at the same time.

$$SOC_j^i \geq \sigma_j^i.SOC_j^{min}, (i = 1, 2, \dots, I-1), \tag{6}$$

$$SOC_j^I \geq SOC_j^{\min\_final}. \tag{7}$$

$$\alpha_j^i + \beta_j^i \leq \sigma_j^i \tag{8}$$

The formulation for BESS is similar to the approach for EVs constraints and is presented by equations (9), (10), (11), and (12).

$$SOC_B^{i+1} = SOC_B^i + \left(P_{ch\_B}^i \cdot \alpha_B^i - P_{dis\_B}^i \cdot \beta_B^i\right) \cdot \tau. \tag{9}$$

$$SOC_B^i \leq SOC_B^{max}, \qquad i = 0, \dots, I \tag{10}$$

$$SOC_B^i \geq SOC_B^{min}, \qquad i = 1, \dots, I \tag{11}$$

$$\alpha_B^i + \beta_B^i \leq 1. \tag{12}$$

Finally, equation (13) represents the maximum power value from the grid that can supply the building during each period i.

$$P_g^i \leq P_g^{max}, i = 1, \dots, I. \tag{13}$$

Using the proposed mathematical model formulation, and taking into consideration the use of real databases concerning PV Generation, CP and residents load consumption, and also the technical characteristics of the BESS and EVs batteries, it is intended, for future work, to obtain several scenarios (considering the use of BESS or only EVs charging/discharging process) aiming to smooth out the building load consumption and an analysis of the potential benefits gains for end-consumers.

4. Concluding remarks and future work

In this paper, an overview of conceptual solutions for the deployment of solar PV generation systems in buildings was addressed. It enhances the advantages of self-consumption by the promotion of shared PV generation. The way that energy can be accounted for and the organization of the consumers, as prosumers, was also addressed.

Single electricity consumers, collective consumers, and energy communities are facing great challenges supported by recent European and national legislation. In this scope, several approaches for shared PV generation in buildings and also in energy communities were conceptually explored, taking into consideration the possibility of new business plans. The use of battery energy storage systems can increase the management of shared PV generation. Some possible solutions were discussed and pointed out.

For future work, and supported by a proposed optimization model, it is intended to investigate several scenarios regarding the management of shared PV generation taking into consideration the use of BESS and EVs, to smooth out resident building electricity consumption.

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