Harnessing Solar Energy for Urban Regeneration: Advancing Energy Communities to Mitigate Poverty and Empower Social Neighbourhoods.

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Abstract. This paper investigates Renewable Energy Communities (RECs) as innovative instruments for urban regeneration, focusing on their dual role in advancing decarbonisation and mitigating energy poverty. Cascais Municipality, aligned with EU climate neutrality objectives, launched a pilot in Alcabideche integrating technical deployment with social engagement. The intervention included photovoltaic (PV) systems on five public buildings (two with storage) and five social housing blocks, complemented by three electric vehicle chargers. Preliminary monitoring indicates reductions in household electricity bills of up to 30%, contributing directly to alleviating energy poverty. To complement the technical implementation, structured surveys and focus groups were conducted with residents and local stakeholders. Findings reveal high levels of interest in participating in RECs, though concerns remain regarding information accessibility, trust in governance structures, and long-term benefits. Citizen engagement activities proved essential in overcoming these barriers, reinforcing social acceptance and community ownership. The initiative is supported by the WeGenerate project, which provides frameworks for replicating REC models across Europe, linking technological innovation with participatory governance. Results demonstrate that socially inclusive RECs can simultaneously enhance energy efficiency, reduce carbon emissions, and strengthen social cohesion, positioning them as critical enablers of equitable and resilient urban regeneration.

1 Introduction

Cascais Municipality is deeply committed to European and international goals for climate neutrality and sustainability, especially in sectors such as mobility, construction, agriculture, and waste management. To this end, the municipality is a signatory of the Covenant of Mayors, the EU Green Cities Agreement, and the EU Climate Change Adaptation Mission. Cascais promotes renewable energy generation and the electrification of sectors as central pillars of its 2050 decarbonisation roadmap. A key municipal priority is the development of local Renewable Energy Communities (RECs) in partnership with public and private stakeholders, with a particular focus on reducing energy poverty in social housing areas.

The study focuses on the neighbourhood of Alcabideche. The aim is to mitigate energy poverty and improve the comfort and liveability of neighbourhoods by promoting their inclusion in active Renewable Energy Communities (REC). To this end, Photovoltaic (PV) systems were installed in the rooftops of 5 public buildings managed by the municipality, 2 of them with batteries, in the rooftops of 5 social housing buildings and installing 3 Electric Vehicles' (VE) chargers, as there is only one public VE charger available in the area. The surplus of energy produced by these PVs will be shared and used by the REC participants.

In addition, to promote the creation of REC, through a dedicated urban digital tool that enables the simulation and visualisation of potential REC, and aiming to incorporate all the data from the buildings, their users and the energy production, consumption and flows, a web-based platform integrating a Digital Twin will be created to support data management/sharing and decision making. Making this information available together with a structured social engagement strategy implementation and working closely with the traget local population, will motivate citizens to collaborate with the central city planning by providing them showcases with the Digital Twin. In addition, social equality and cognitive change will be stimulated through local awareness workshops promoted by the

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municipality, that will also serve to recruit members to the REC.

1.1 Main problems and opportunities related to energy poverty

Energy poverty is aggravated by higher energy prices combined with low energy performance of building and appliances. In the case of Portugal, all these three factors are critical, and it is estimated that between 1.9 and 3 million people are in energy poverty (20-30% of the country's population).

Along with the poor construction quality of buildings, that only began to be controlled through an energy consumption class ranking in 2006 with the start of the Regulation on the Thermal Performance Characteristics of Buildings (RCCTE) program, the main identified problems that led to the growth in energy poverty in Portugal are the significant increase in electricity prices since 2008 reducing the real purchasing power of low income families and the growing usage of energy-intensive appliances and household equipment leading to the increase of electricity consumption.

Opportunities to mitigate energy poverty are, for example, the available platforms with information about energy efficiency in buildings and savings in electricity bills, the implementation of 50 "Citizen Energy Spaces" throughout the territory to advise and help the population regarding energy and energy efficiency-related issues. Also, the integration of renewable energy solutions, particularly solar energy, and the improvement of the energy efficiency of buildings, especially through targeted renovations in older properties with the Energy Efficiency in Buildings program of the "Environmental Fund" that finances household renovations and improvements.

1.2 Demo site description

Alcabideche is a heterogeneous urban environment (outlined in blue in Figure 1) that encompasses the the social neighbourhood called "Bairro de Alcabideche" (outlined in green), public schools, cultural amenities, housing a sports centre and a municipal swimming pool. With a total land area of 40 hectares and approximately 2800 residents, the site includes 333 residents in social housing (127 of whom receive government support). The area also hosts a school community exceeding 2500 individuals, around 1138 regular users of sports facilities, 50 workers in the local Parish Office, 30 daily users of a day-care centre, and 300 music school students. This demographic diversity provides a strong basis for REC implementation and participatory governance.

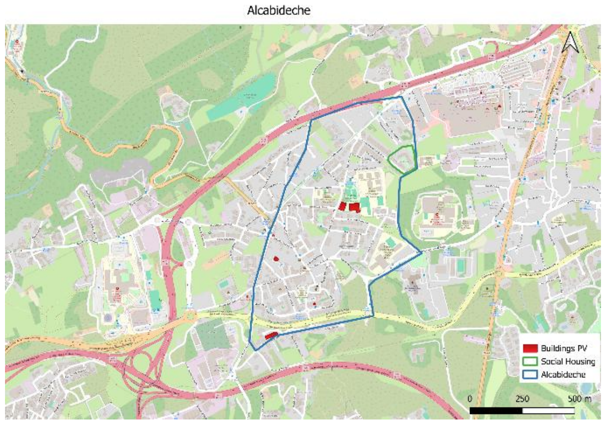

Fig. 1. Boundaries of the "Bairro de Alcabideche"

2 Social evaluation and engagement

2.1 Energy poverty assessment

The European Domestic Energy Poverty Index (EDPI) is a composite index that includes indicators as "ability to keep house warm in winter" and "ability to keep house cool in summer", which are highly dependent on climate conditions. Still, it is informative and can be useful for cross-country comparison. Figure 2 illustrates the ranking of the energy poverty level for the different European countries, considering this composite index, where Portugal's score in energy poverty is one of the highest [2].

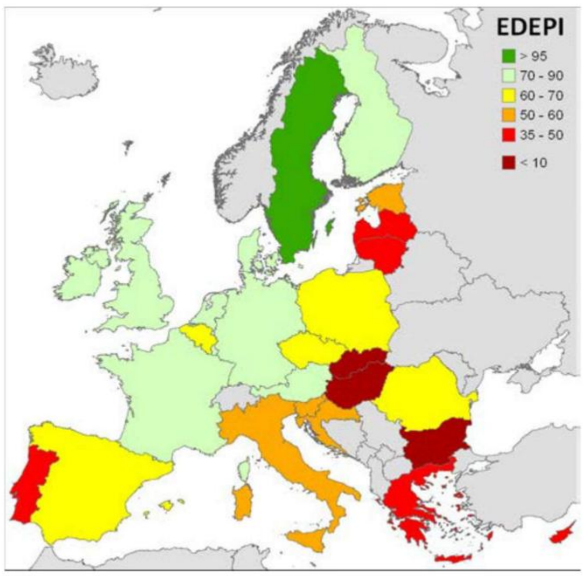

Fig. 2. Ranking of countries based on the EDEPI

In the Cascais demo the most appropriate indicators to characterize the energy poverty level of the social housing residents of the Alcabideche parish were defined and measured at the household level The selection of the relevant energy poverty indicators, which include the built environment quality and indoor comfort conditions, and energy literacy level was based on an extensive literature review and a critical analysis considering the specificities of the context. The data collection took place before the project's intervention and will be done again after the intervention and the creation of the REC. It started with the collection from available sources (national statistics and municipal databases), data on the built environment quality, and micro data at the household level was collected through a face-to-face survey that was preceded by an engagement campaign (flyers, condo sessions).

The survey included 559 valid responses, encompassing three population groups:

- 200 residents from local social housing estates;
- 302 users of public facilities (e.g., public health centres, sports centres);
- 49 residents of "Bairro de Alcabideche", the core area of intervention.

Presently, the survey results are being analysed to answer the different objectives: characterization of the citizens involved and their perceptions on community services and infrastructures as well as to assess their level of energy poverty and energy literacy for which indicators will be obtained. The preliminary findings are the following:

The survey revealed high vulnerability to energy poverty: 45% of households report poor insulation, and the average winter energy bill is €88. Thermal discomfort was significant, as 71% feel cool in summer, but only 60% feel warm in winter. Additionally, 39% reported cutting basic needs to pay energy bills, and 13% indicated health impacts due to thermal conditions. Energy literacy is low—40% don't check bills, 48% don't know their home's energy certification, and 90% want to learn more. Nevertheless, attitudes are pro-environmental: 71% try to live sustainably and many adopt efficient behaviours. Despite socioeconomic constraints, including low income, limited savings, and disabilities in 49 households, there is strong community inclusion (94%) and a sense of safety (73%). These findings informed the project's design, guiding interventions in technical retrofits, participatory governance, and energy awareness.

2.2 Social engagement strategy

The social engagement strategy of the Cascais Demo Site is central to the WeGenerate project and targets three main groups: (1) 127 residents receiving government housing support; (2) residents in the broader Alcabideche social housing area (approx. 2100); and (3) users and staff of municipal buildings where PV systems are installed (over 1000 individuals). To reach the target groups of community members, the demo will alsoengage with relevant municipal departments: - "Cascais Envolvente", which manages the social housing infrastructure

- "Cascais Próxima" which is the mobility department of the municipality, managing the public transportation "light mobility" infrastructure and EV chargers of the municipality, through "MobiCascais".
- Division of Social Intervention and Quality of Life, which works directly with community members and social housing residents specifically.

At the same time, the local parish, which has a more direct contact with all Alcabideche residents and the managers of the buildings that are part of the intervention, that is, those where the PV systems are installed, will also facilitate the contact with the residents.

The group (1) of community members is the one that will benefit more directly from the project's activities. This group of residents will have the chance to join the pilot energy community, which will include the extra energy produced in the solar PV systems installed in their buildings and in the public buildings. By actively involving these residents, the aim is to address social equity, ensuring that participant community members will benefit from energy savings and sustainability initiatives, thereby improving their quality of life and fostering a sense of community ownership in the energy transition.

The interaction with the three groups will be done through co-creation workshops and community meetings to promote sustainable energy use. Participants will be involved in the design of the digital twin platform. Therefore, it will be designed in a way that should be useful for them, contributing to engaging them in finding solutions that improve their livelihood regarding energy and what they would like to see improved.

As mentioned before, to enhance engagement through an inclusive governance model, a Digital Twin platform will be developed, providing a virtual representation of real energy consumption and potential savings. This tool will play a key role in the engagement strategy involving the different community groups and will be present in activities with community members (workshops, information sessions, communication through digital platforms). Regular updates and an interactive tool will empower participants to share and compare consumption data, increasing their energy literacy. Finally, the three community groups will be targeted by the energy literacy and awareness campaigns that will be developed.

3 Solar resource assessment

To evaluate the potential of solar energy production, a solar resource assessment was made, not only for the Alcabideche region, but for the whole Cascais municipality, since the project idea is to replicate this concept in other social housing neighbourhoods, first in Cascais, and later in other municipalities of the Lisbon metropolitan area.

The average yearly Global Horizontal Irradiation (GHI) at ground level and in buildings' rooftops was mapped for Cascais municipality considering the terrain's slope and the buildings' shape and height by using an urban digital terrain model (U-DTM). This methodology strongly reduces the computational effort to simulate groups of buildings; it simplifies the geometry of the urban mesh and allows to extend the area of simulation to a city scale. The GIS solar radiation analysis tools calculate insolation across a landscape, based on methods from the hemispherical viewshed algorithm developed by Rich et al. [3] and further developed by Fu and Rich [4]. The total amount of irradiation calculated for a particular location or area is given as global irradiation. The calculation of direct, diffuse, and global irradiation is repeated for every location on the topographic surface, producing irradiation maps for an entire geographic area. Figure 3 shows the resulting map.

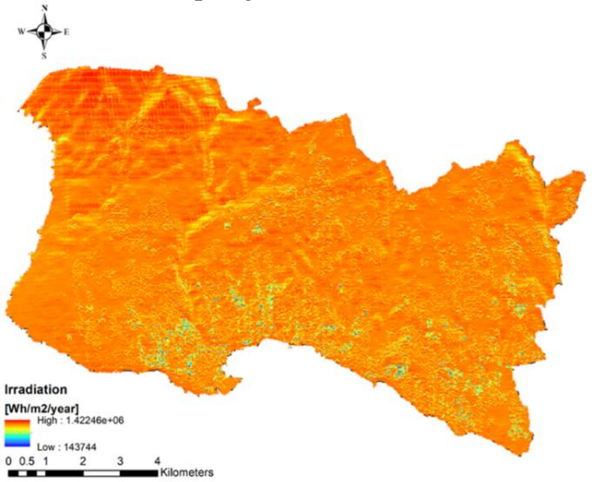

Fig. 3. Average GHI in Cascais municipality

The areas in light color in the map correspond to the minimum GHI, 144 kWh/m^2, and it is mainly due to the shading within the urban mesh. The darker areas correspond to higher GHI values, up to 1422 kWh/m^2, and relate to areas that are free of shading.

4 Social housing buildings energy assessment

The social housing management department of Cascais Municipality, “Cascais Envolvente”, shared the buildings’ energy certificates and their evaluation was undertaken. The social housing units are partially owned by the municipality, while the remaining units are privately owned.

Regarding Domestic Hot Water (DHW), 5 buildings have natural gas water heaters and 1 building has electric water heaters. For air renovation there is natural ventilation through window openings and mechanical exhaustion in the bathrooms and kitchens. The Energy Classes of the apartments are mainly C (23 Apt.) and D (20 Apt.). Figure 4 shows the primary energy needs and energy class distribution of the apartments in each building according to the analysed energy certificates.

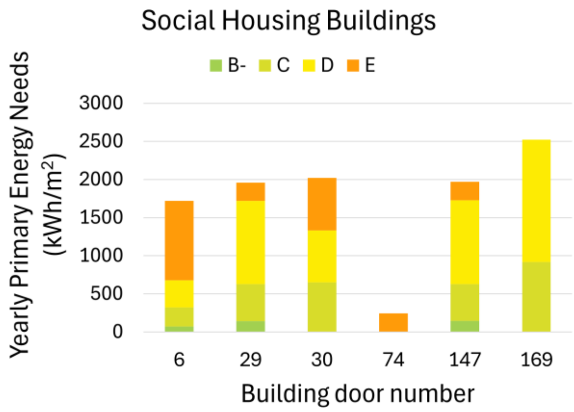

Fig.4. Yearly primary energy needs of the social housing buildings (needs per energy class)

Table 1 summarizes the primary energy needs of each apartment typology. Each floor has three typologies, T1, T2 and T3, which represent 1, 2 and 3 bedrooms. Typology T2 is highlighted to show that it has the highest energy needs.

Table 1. Average primary energy needs of each apartment typology

Typology*	Average Primary Energy Needs (kWh/m^2.year)
T1	151.9
T2	204.5
T3	184.8

As for the average energy needs on each building floor, Table 2 shows that the top floor of the buildings has the higher energy needs for heating and cooling.

Table 2. Average primary energy needs of each apartment

Floor	Average primary energy needs (kWh/m^2.year)	Average heating needs (no DHW) (kWh/m^2.year)	Average cooling needs (kWh/m^2.year)
Ground	221,8	70,2	0,6
1st	115,6	28,3	2,2
2nd	144,0	40,5	2,6
3rd	247,1	76,5	4

The information above shows the need for exterior insulation of the roof and walls. The buildings’ certificates indicate that the most relevant improvements to be made in the buildings are the exterior insulation and the replacement of windows with more efficient ones with high insulating window frames and at least double glass pane. The neighborhood buildings also need to have their roofs replaced because they are made of fiber cement. In addition to this pathology, and following a technical assessment on the ground, there was an urgent need for the façades to be refurbished. The buildings were dilapidated, with cracks and a lack of conservation, giving rise to various infiltrations inside the apartments. Presently the buildings are already renovated and small PV systems with 3 kWp were installed on their rooftops.

5 Planning of the REC

Within the buildings managed by the municipality, five key buildings were identified as suitable for the installation of PV systems, providing a practical foundation for the energy community. These buildings include the Municipal Swimming Pool, Sports Hall, Parish Office, Elderly Day-care Centre, and Music School.

An initial evaluation of the maximum PV power that could be installed in the rooftops was done, but due to the available funds, the municipality decided to initially install less power and within the project timeframe to upgrade the systems. Table 3 shows the comparison between potential and initial installed PV capacity.

Table 3. Summary of the capacity of the buildings with PV systems.

Building	Potential Capacity [kWp]	Initial Installed Capacity [kWp]
Parish Office	12,2	10,0
Municipal Swimming pool	66,6	27,0
Elderly Day-care Centre	2,2	2,0
Music School	13,3	1,5
Sports Hall	84,3	40,0

The project leverages these municipal buildings as anchor points for energy production. By installing PV systems on these rooftops, the buildings will act as primary energy producers within the energy community, contributing with a significant portion of the renewable energy consumed locally. However, the project doesn't stop at the municipal level - residents and businesses can also be integrated as prosumers, further increasing the community's capacity to produce and share renewable energy.

The energy produced by these installations will be:
- Consumed locally by the buildings themselves (self-consumption).
- Distributed across the community to cover the energy needs of other REC members.

5.1 Public buildings energy production

PV systems were already installed in the public buildings and their energy production along with the buildings' energy consumption have been monitored. These systems have been connected to the public grid and producing energy since August 2024. Figures 5-9 show the monthly energy balance of each building.

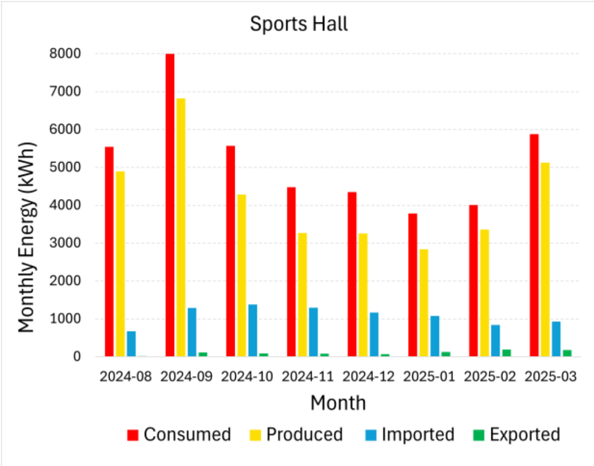

Fig. 5. Sports Hall monthly energy balance

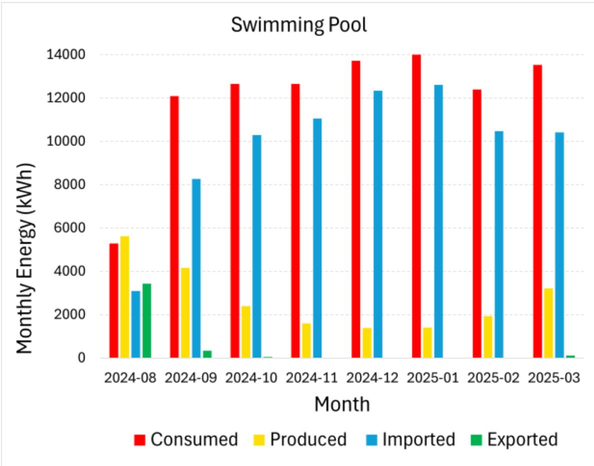

Fig. 6. Swimming pool monthly energy balance

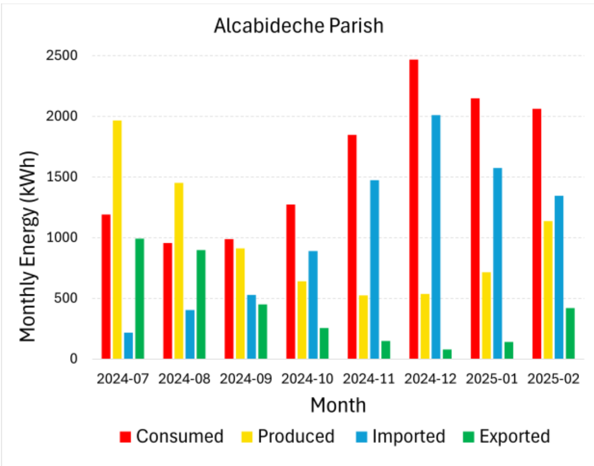

Fig. 7. Alcabideche's parish monthly energy balance

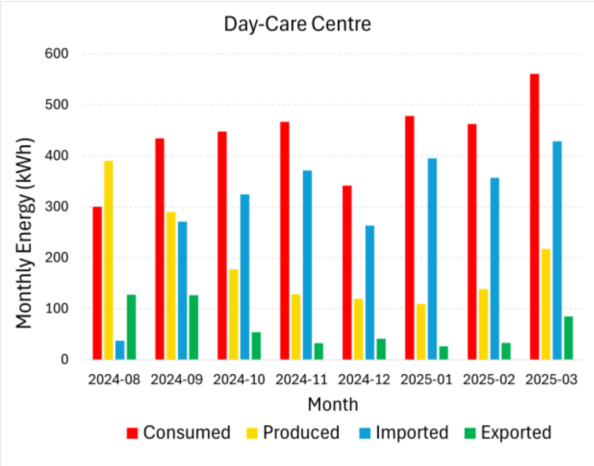

Fig. 8. Elderly day-care Centre monthly energy balance

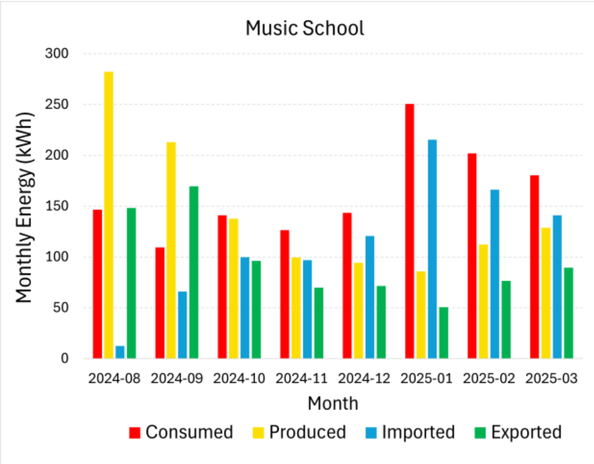

Fig. 9. Music school monthly energy balance

The Sports Hall and the Swimming Pool are the major producers and consumers with a small amount of surplus energy to share with the REC. These systems' PV capacity will be increased, for there is still enough space in their rooftops, to have more energy available for the REC members.

The five buildings total exported energy in the first 8 months of operation was 9 MWh that could have been share with the social housing buildings if the REC was already set up.

5.2 REC social nexus

To help clarify the social nexus behind the creation of this REC between the Municipality's buildings and the social neighbourhood, a scheme is presented in Figure 4 showing the energy flows (green and pink arrows) and the social connection between the users and residents (red connections) of public buildings with Photovoltaic (PV) systems (in red), the social housing (in orange) and the school (in blue). It is planned to also install PV systems in the school buildings' rooftops in the near future, still in WeGenerate's timeframe. However, the exact timing depends on the buildings' managers.

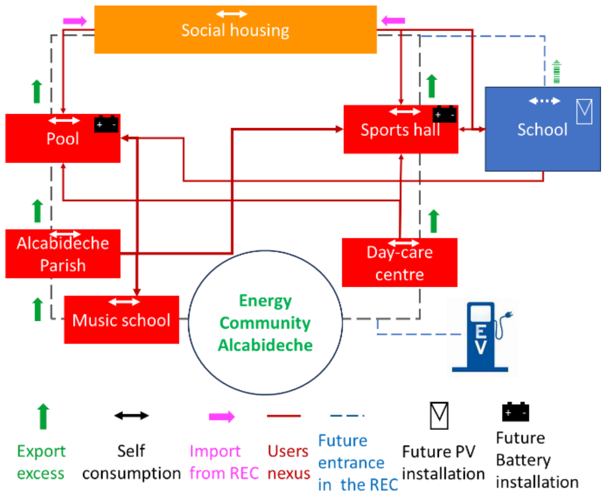

Fig. 4. "Bairro de Alcabideche" REC social nexus scheme

As future implementation, batteries will be installed in the two PV systems with higher capacity (sports-hall and swimming pool) and 3 Electric Vehicle (EV) chargers in the locations where they can become more beneficial to the citizens.

5.3 Creation of the REC

The planning of the energy community was done according to Portuguese legislation and the sharing scheme will be defined according to one of the possible schemes: i) Fixed Coefficients - the fixed coefficients associated with each participating installation, which can be differentiated in time and must be communicated in advance to the Distribution System Operator (DSO); ii) Coefficients Proportional to Consumption- energy is shared among the participating installations according to coefficients proportional to the consumption and injection measured in each 15-minute period, which the DSO is responsible for determining; iii) Hierarchical Sharing – a communication is made to the DSO in advance, informing the hierarchical structure to be considered in the self-consumption system, defining the priorities for each consumer or group of consumers; iv) Dynamic Sharing – the REC communicates to the DSO at a later date and within a period compatible with the monthly billing cycle for grid access and consumption readings, the shared energy or the energy sharing coefficients between each installation that injected energy into the grid, and each installation that received energy from the grid.

The next steps are the recruiting of members for the REC, which started with the community communication and engagement, and the in-person surveys followed by dedicated workshops to inform the neighborhood's community. When the structure and members of the REC are defined, permits will be requested to the responsible authorities, the Directorate-General for Energy and Geology (DGEG), to create the REC and the response should be received within a period of 4 months.

5.4 Designing the Cascais Digital Platform on REC promotion

In the context of the WeGenerate project, the Cascais Digital Platform on REC promotion will aim to raise awareness towards energy communities' creation, to uptake energy literacy and to lead to action from citizens. The current process for Digital Platform developments drives the uptake of the energy transition towards the decarbonisation of the building stock in Cascais Municipality.

The digital platform vision pursues generating an interactive public service to enable the energy transition to be stable and not depending on limited subsidies as well as beyond specific timeframes. Cascais Digital Platform for Active and Inclusive Energy Communities looks for generating dynamics and to establish robust mechanisms that are the basis of the energy transition through the decarbonization of the urban built environment.

The Cascais Digital platform for REC ambitions to become a user friendly tool able to portray the map of the Alcabideche neighbourhood on a web-based platform that allows citizens and practitioners to simulate potential energy communities to be created in the future as well as to visualize existing initiatives, with a special emphasis to uptake the energy poverty mitigation strategies such as collective self-consumption or social bonus on electricity [5]. Complementarily, it will incorporate all the data from the buildings, their users and the energy production, consumption and flows, in view to explore and showcase successful REC initiatives which can be expanded and replicated across Cascais municipality.

The Cascais Digital platform for REC will integrate several layers of data (open access) addressing target groups to explore and learn through dedicated features. As back-end to the Digital platform development, a calculation and visualisation engine in the form of a Urban Digital Twin will be developed to determine meaningful KPIs on energy, environmental and socio-economic aspects (such as to quantify the energy savings potential) to enable visualising/assessing scenarios for the creation of REC. Additionally, the Platform aims to allow orchestrating the network of facilitators from the administration, companies and neighbours in the areas under users' analyses.

Along the implementations, a fine tracking of performance will be done to assess the user experience, effectiveness and impact of the urban tool.

As background, it exists various initiatives at EU level that envision urban digital tools to uptake REC in specific territories, e.g. the *Comunitat Energetica* platform (Spain) [6], which seeks to respond to the need to increase renewable energy production by overcoming social barriers to setting up energy communities in the Catalonia Region (Spain), with the ultimate aim of offering environmental, social and economic benefits through reduced consumption and household energy costs while promoting decarbonisation and increasing social cohesion and community empowerment.

6 Conclusions and future work

The WeGenerate project demonstrates that the integration of social, technical, and digital innovation can drive an inclusive and just energy transition in vulnerable urban areas. The implementation of a Renewable Energy Community (REC) in Alcabideche showcases how coordinated renovation, community engagement, and renewable energy infrastructure can significantly address energy poverty while promoting social empowerment. Preliminary survey data reveal limited energy literacy but strong willingness among residents to participate in local solutions.

The Digital Twin platform offers a replicable and scalable tool for visualising and simulating REC scenarios, enabling stakeholder involvement from inception to implementation. By including site-specific data, such as solar potential and urban constraints, this platform fosters citizen and practitioner engagement in the co-creation of energy communities.

Future work will involve formalising the REC, expanding rooftop PV capacity, integrating schools, and assessing long-term impacts. Policy recommendations will emerge from this pilot to support broader REC adoption across Cascais and beyond, aligned with Portugal's decarbonisation and inclusion targets.

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