NOVA SCHOOL OF SCIENCE & TECHNOLOGY
DEPARTAMENT OF ELECTRICAL AND COMPUTER ENGINEERING

EVANDRO CESAR CAHINO FERREIRA
BSc in Renewable Energy Engineering

Renewable Energy Communities: Concepts, Approaches and the Case Study of Telheiras Neighborhood in Lisbon

MASTER IN RENEWABLE ENERGY ENGINEERING
NOVA University Lisbon
March, 2023

DEPARTAMENT OF ELECTRICAL AND
COMPUTER ENGINEERING

Renewable Energy Communities: Concepts, Approaches and the Case Study of Telheiras Neighborhood in Lisbon

EVANDRO CESAR CAHINO FERREIRA

BSc in Renewable Energy Engineering

Adviser: João Pedro Gouveia
PhD,Invited Assistant Researcher and Professor, NOVA School of Science and Technology, FCT-NOVA

Co-advisers: Miguel Macias Sequeira
MSc, NOVA School of Science and Technology, FCT-NOVA

Examination Committee:

Chair: João Murta Pina
Assistant Professor, NOVA School of Science and Technoogy, FCT-NOVA

Rapporteurs: Pedro Miguel Ribeiro Pereira
Assistant Professor, NOVA School of Science and Technoogy, FCT-NOVA

Adviser: João Pedro Gouveia,
Invited Assistant Researcher and Professor, NOVA School of Science and Technology, FCT-NOVA

MASTER IN RENEWABLE ENERGY ENGINEERING

NOVA University Lisbon
March, 2023

Renewable Energy Communities: Concepts, Approaches and Case Study of Telheiras Neighborhood in Lisbon.

This document was created with Microsoft Word text processor and the NOVAthesis Word template [1].

To my family and dear friends.

ACKNOWLEDGMENTS

First, I would like to thank God and my family, who have always supported me in my personal and academic life. Especially, my father Evandro, my mother Sônia, my sister Giulliane and my aunts Solange and Ana. Also, *in memoriam* of my grandmother Edy, who forged principles that I will always carry with me.

Special thanks to my advisor João Pedro Gouveia, for the attention, patience and knowledge provided during the preparation of this thesis and all the opportunities that were given to me, and the co-adviser Miguel Sequeira, for the attention and opportunity of integrating an implementation process of a renewable energy community. Also, I would like to thank all the participants of Telheiras Renewable Energy Community, who accepted me in this amazing project of sustainability and green energy.

Thanks to important friends who accompanied me through the best and most difficult times, namely Dirceu, Giulia, Geyse, Rodrigo, Murilo, Vanessa, Gabriel, Bárbara, Lora, Yury, Nicole, Arthur, Marie, Marina and Louise. I also would like to thank friends that I've made during my bachelor's degree, with whom I shared important moments of study and joy, namely Sarah, Lucas, Dallysson, Matheus, Amanda and João.

Lastly, I would like to thank special professors with whom I had the pleasure of learning the basics of electrical and mechanical engineering, namely Alberto, João, Gilberto, Raimundo, Flávia and Fabiano. They were definitely people who inspire me every day to be an ethical and dedicated engineer.

“Don't rush, because tomorrow anything can happen, including nothing. Don't rush. Happiness is never late - maybe tomorrow it will knock on your door".

(Flávio José)

Abstract

Climate change, strong dependence on non-renewable energy sources and alarming levels of global energy poverty: the current scenario highlights the profound need for an energy transition, emphasizing energy efficiency procedures and increasing the share of renewable energy sources in the global energy systems. However, this process should occur in a fair way, where the citizens should have an active voice in the decisions. Citizens will no longer be seen only as energy consumers, but increasingly, they will have the knowledge and foundation to be part of this transition, as well through distributed generation systems.

In this context, local collective energy initiatives play a key role in increasing energy citizenship, primarily through Renewable Energy Communities. Albeit it is a very broad and diverse concept, the expansion of these communities entails various economic, social, and financial benefits for the locals, in addition to potentially reducing energy poverty and increasing energy justice.

This dissertation aims to present a broad review of the concept of a Renewable Energy Community focused on the European and Portuguese context, and it interlinks with associated topics such as energy poverty, energy citizenship and distributed generation. In addition, it systematizes a set of study cases to uncover key activities, technologies, advantages and challenges and to explain how these organizations work to reduce energy poverty and increase citizen participation. In this context, a real-world study case is explored in detail through the Telheiras Renewable Energy Community development, where the implementation process was followed and is reported and key outputs include photovoltaic simulations carried out in six buildings of the community.

Keywords: Renewable energy community, energy transition, energy poverty, energy democracy, renewable energy, solar photovoltaic.

RESUMO

Mudanças climáticas, forte dependência de fontes não renováveis e níveis alarmantes de pobreza energética global: o cenário atual evidencia a profunda necessidade de uma transição energética, enfatizando práticas de eficiência energética e aumentando a participação de fontes renováveis na matriz. No entendo, este processo deve ocorrer de forma justa, onde os cidadãos devem ter voz ativa nas decisões associadas. O cidadão não será mais visto apenas como um consumidos de energia, mas, cada vez mais, terá conhecimento e fundamentos para fazer parte dessa transição, também por meio de sistemas de geração distribuída.

Neste contexto, as iniciativas coletivas locais de energia desempenham um papel fundamental no aumento da cidadania energética, especialmente através das Comunidades de Energia Renovável. Embora seja um conceito muito amplo e diverso, a expansão dessas comunidades traz diversos benefícios económicos, sociais e financeiros para os habitantes locais, além de potencialmente reduzir a pobreza energética e aumentar a justiça energética.

Esta dissertação tem como objetivo apresentar uma revisão ampla do conceito de Comunidades de Energia Renovável centrada no contexto europeu e português, e articula com temas associados como a pobreza energética, cidadania energética e geração distribuída. Além disso, sistematiza um conjunto de casos de estudo para revelar as principais atividades, tecnologias, vantagens e desafios e explicar as formas pelas quais essas organizações trabalham para reduzir a pobreza energética e aumentar a participação cidadã. Neste contexto, é explorado em detalhe um caso de estudo através da Comunidade de Energia Renovável de Telheiras, onde foi acompanhado e reportado o processo de implementação e os principais resultados incluem simulações fotovoltaicas realizadas em seis edifícios locais da comunidade.

Palavas chave: Comunidade de energia renovável, transição energética, pobreza energética, democracia energética, energia renovável, energia solar fotovoltaica.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

AcerBatalha	Batalha Renewable Energy Community Association.
BAPV	Building Adopted Photovoltaics.
BIPV	Building Integrated Photovoltaics.
CEC	Citizens Energy Community.
CFN	Climate-Friendly Neighborhood.
COME RES	Community Energy for the Uptake of Renewables in the Electricity Sector.
CREW	Community Renewable Energy Web.
CSC	Collective Self-Consumption.
DECIDE	Developing Energy Communities Through Informative and Collective Actions.
EPAH	Energy Poverty Advisory Hub.
EPUL	Public Urbanization Company of Lisbon.
EU	European Union.
GHG	Greenhouse Gases.
HAWT	Horizontal Axis Wind Turbine.
IoT	Internet of Things.
IPCC	Intergovernmental Panel on Climate Change.
LCED	Low Carbon Energy District.
NEWCOMERS	New Clen Energy Communities in a Changing European Energy System.
NIMBY	Not in My Backyard.
PED	Positive Energy District.
PEN	Positive Energy Neighborhood.
PV	Photovoltaic.
REC	Renewable Energy Community.

RES	Renewable Energy System.
RRP	Recuperation and Resilience Program.
SDG	Sustainable Development Goal.
UK	United Kingdom.
UNFCC	United Nations Framework Convention on Climate Change.
VAWT	Vertical Axis Wind Turbine.

1

INTRODUCTION

This initial chapter encompasses the context of this dissertation, the objectives and motivations of this study and its structure.

1.1 Context

The energy transition towards renewable energy sources, reduction of global warming effects, and achievement of sustainable development are some of the most important goals of this century. The search to achieve the well-known concept of sustainable development that meets the needs of the present without compromising the ability of future generations to meet their own needs, based on three main pillars - namely, social, economic, and ecological - is a complex process that involves many different players and approaches (Ruggerio, 2021).

In this scenario, the change in the world energy matrix, to increase the share of renewable energy sources and reduce the dependence on fossil fuels, is crucial. The constant increase of the planet's population and energy per capita demand, associated with the excessive burning of fossil fuels, leads to the depletion of natural resources, and an increase of the average global temperatures, due to the significant enlargement of carbon dioxide emissions, leading the world to an imminent energy crisis (Chevalier, 2009).

Analyzing how this energy is consumed is also a crucial factor: energy efficiency reduces carbon dioxide emissions as it reduces the demand for energy in different sectors (residential, industrial, commercial, and agricultural) (Zakari et al., 2022). According to the Dutch concept of Trias Energetica, reduction of energy demand is the first step towards sustainability, as it says that the first step is to minimize the energy demand and, only after that, use renewable energy sources for supply and fossil fuels as cleanly and efficiently as possible (Alavirad et al., 2022).

In this context, governments and associated institutions play a significant role in mitigating climate change. The first important step in agreements and directives took place in 1992 with the United Nations Framework Convention on Climate Change (UNFCCC), where the objective was "to stabilize greenhouse gas emissions in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame which allows ecosystems to adapt naturally and enables sustainable development" (UNFCC, 1992). This was the first time a document was signed aiming to reduce climate change, where developed and developing countries had different responsibilities (Legett, 2020).

Further, in 1998, the Kyoto Protocol was signed, obligating 37 developed countries in the UNFCCC to reduce greenhouse gas emissions by 5% below their 1990 levels, which entered into force in 2005 (UNFCC, 1998).

But the most significant toward reducing the effects of climate change took place in Paris, in 2015, where 196 countries signed the Paris Climate Agreement, as it can be considered the first agreement on climate change that firmly has a global scale (King, 2021). This document implies, among other goals, that the increase in the global average temperature must be well below 2ºC above pre-industrial levels and to pursue efforts to limit the temperature to rise to further than 1.5ºC. The countries must define their own emission goals in accordance with their capacity to do so (UNFCC, 2015).

To discuss the guidelines and paths to support the goals of the Paris Agreement, signers met in 2018, in Katowice (Poland), and elaborated a scientific-based document known as the Katowice Package (Legett, 2020). Also in this conference, a special report was published by the Intergovernmental Panel on Climate Change (IPCC), establishing that the present scenario (2018) would not meet the goals of the agreement and, to do that, a reduction of 45% in total emissions by 2030 and 100% by 2055 is needed, as well as, at least, 32% share of renewable energy sources in final energy consumption (IPCC, 2018).

Different approaches, methods, and lines of study have been developed to face the Paris Agreement goals, supported by governmental directives and laws. Even though the European Union (EU) is leading the governmental and institutional efforts, strategy development and production of scientific knowledge associated with the international climate policy, the region is not close to meet the climate targets of 2030 (Nikas et al., 2021).

In this context, an important package of 8 new directives was approved in 2019 - the Clean Energy for All Europeans Package. Based on five pillars - namely, energy performance in buildings, renewable energy, energy efficiency, governance regulation, and electricity market design - this package confirms the leadership of EU's policy framework towards clean energy and the Paris Agreement's goals. The Member States had 1-2 years to convert these eight new directives into national laws (European Commission, 2019).

A summary of the new directives from the Clean Energy for All Europeans Package is shown in Figure 1.1.

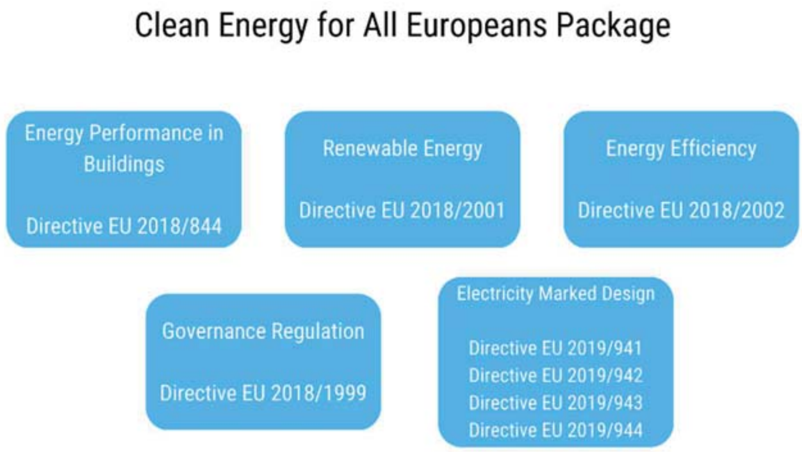

Figure 1.1 — Summary of the directives from the Clean Energy for All Europeans Package (2019).

Important changes are presented in these directives, where more rights and participation were given to the citizens in terms of energy generation and consumption, reinforcing the concept of a citizen who consumes and produces electricity via distributed generation onsite, through a more integrated energy market inside the block (European Commission, 2019). The "Directive on Common Rules for the Internal Market for Electricity" (EU 2019/944) and the "Regulation on the Internal Market for Electricity" (EU 2019/943) introduced the citizen as an active and important player in the energy transition. Also, the "Renewable Energy Directive" (EU 2018/2001) plays an important role as it establishes a common framework for the promotion of renewables, reinforcing the target of 32% share of renewable energy on the final energy consumption and imposing financial rules for supporting the development of renewable sources on electricity, transports, and heat and cooling sectors (Directive EU 2018/2001, 2018).

Another important mark was announced at the end of 2019: the European Green Deal is a set of policies and strategies promoted by the European Commission to contain the threat of climate change, imposing the ambitious goal to make Europe the first climate-neutral continent by 2050 (no net emissions of greenhouse gases). This package involves more than just energy generation and consumption, but also encompasses agriculture, food waste, and recycling, among other topics (European Commission, 2021).

At the moment, a set of proposals to revise EU legislation to meet the goal of a 55% reduction of emissions by 2030 is being done - the so-called Fit for 55 Package. Most of the directives presented in the Clean Energy for All Europeans Package are under revision, where topics as EU emissions trading system, emissions reduction targets, sustainable aviation fuel and renewable energy sources are analyzed aiming to achieve the respective goal for 2030 (Schlake et al., 2022).

However, the concept of a Renewable Energy Community appears only in July 2021, with the milestone of the revision of the "Renewable Energy Directive" (EU/2018/2001) - well known as RED II - which defines a REC as a citizen-driven energy action that contribute to the clean energy transition, advancing energy efficiency within local communities, where the goal is not financial profits, but benefits for the community itself (Revised Directive EU 2018/2001, 2021).

Therefore, citizen participation through collective actions regarding energy consumption and renewable-based generation is crucial to meet the ambitious goals of the next decades, where Renewable Energy Communities symbolize an important factor for the worldwide deep energy transition.

It is significant to point out that recent challenges are making even more difficult to meet all these goals, as the Covid-19 pandemic and conflicts on the European continent, as regulation reviews and new packages are needed to take account of these recent difficulties. In the scenario of the Russian invasion of Ukraine, the European Commission approved the REPowerEU as a plan to phase out the European dependence on Russian fossil fuels - especially natural gas - providing more energy security and enhancing the share of renewables in the matrix (Deng et al., 2022).

A timeline of the main agreements, directives, and packages regarding climate change in the European Union is presented in Figure 1.2.

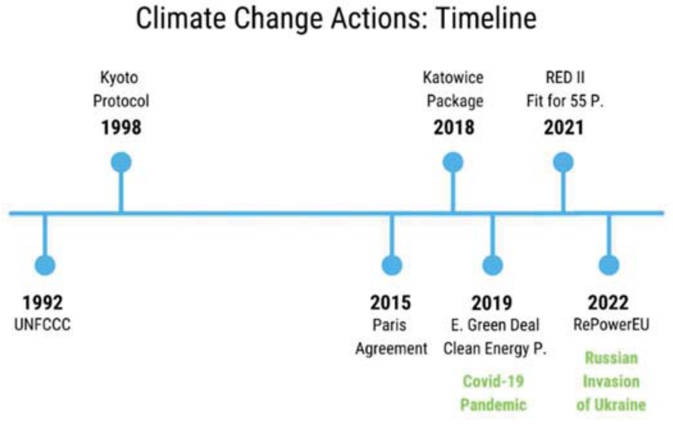

Figure 1.2 — Timeline of main actions regarding climate change (2022).

1.2 Objectives and Motivation

Renewable Energy Communities may enhance citizen participation in the energy transition: these local actions can play a key role in providing energy democracy and decentralization, where the needs of the individuals are considered in decisions about the electrical system. Therefore, RECs can also contribute to a fairer energy transition reducing energy poverty inside the community. Since it incorporates renewable energy generation, RECs contribute to increase the share of renewables in the final energy consumption matrix and decrease the effects of climate change through reducing the emissions associated with energy generation.

Wherefore, studying and analyzing concepts, approaches, forms of implementation and real cases of Renewable Energy Communities is an important step for spreading this knowledge and helping the development of new RECs worldwide as an important player on energy transition and actions regarding the climate goals of the next decades.

In relation to the Sustainable Development Goals (SDGs) of the 2030 Agenda, this dissertation is linked to the following objectives: 1 (No Poverty), 7 (Affordable and Clean Energy), 10 (Reduced Inequalities), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), 13 (Climate Action) and 17 (Partnership for Goals).

A summary of the associated SDGs can be seen in Figure 1.3.

Figure 1.3 — Summary of the SDGs linked to this dissertation (2022).

The main objective of this dissertation is to provide a complete study of Renewable Energy Communities while following the development of a real implementation process (REC in Telheiras, Lisbon).

To achieve this goal, secondary objectives include:

- Review of important concepts associated with Renewable Energy Communities, such as energy poverty, energy citizenship, prosumption and distributed generation, obtaining a brief review of each definition.
- Overview of RECs in the European Union, regulatory framework of the Member States, characteristics of these organizations and European projects aiming the development of the concept.
- Analysis of different types of RECs, their organization, structure, classification, and renewable energy source, resulting in a systematization - based on real cases - about how a Renewable Energy Community can de diverse and embracing.
- Analysis of the implementation of a REC (associated benefits, most important challenges, and barriers) through the support of development of the study case REC in Telheiras Neighborhood.

1.3 Structure

To achieve the objectives defined in the previous section, this dissertation is divided into seven chapters, where the literature review is presented, as well as the study case, results, and final conclusions.

The first chapter includes the introduction, where the context regarding climate change agreements and directives is presented. Also, the objectives and the motivation of this dissertation are listed.

The second chapter explains important concepts for comprehending RECs and their impact on the community and individuals: energy poverty, prosumption, and distributed generation.

The third chapter starts with the definition of a REC, followed by a broad overview of RECs in the European Union, where statistics and data about regulation and projects for developing these energy communities are shown. Also, characteristics and important aspects of the most common renewable energy systems applied to RECs - namely, solar photovoltaics and wind energy - are presented, as well as the main advantages and barriers/challenges of the implementation process of a REC. Finally, a classification regarding four main criteria is shown, with associated real cases of Renewable Energy Communities.

In the fourth chapter, the methodology of the analysis and development of the study case are presented, with a complete explanation of the methods and study process used for the present dissertation.

In the fifth chapter, the study case of Telheiras neighborhood is presented, starting with a general overview of the area and its pioneering in sustainability, as well as the creation process of a REC, its organizational structure, important partnerships, local energy poverty analysis, pilot project of the REC and its local communication and engagement plan.

The sixth chapter brings the results and discussion obtained through the study case, based on three main topics: photovoltaic systems sizing and simulations, systematizing/analysis of the REC Telheiras and comparison with other real cases and the challenges/next steps for the study case.

The seventh and last chapter brings the conclusions of the dissertation and opportunities for new studies and analysis associated with Renewable Energy Communities.

2

Initial Concepts

In this chapter, initial concepts that are important for the full comprehension of the energy transition process and Renewable Energy Communities will be presented and defined - namely, energy poverty, energy citizenship, prosumption and distributed generation - where it ends with definitions of a REC itself.

2.1 Energy Poverty

According to the WEC (2022), the main dimensions regarding energy analysis are based on three topics - the so-called World Energy Trilemma Index: energy security, environmental sustainability, and energy equity - which are graded and have a value based on a percentual scale on each dimension, where energy comparisons and analysis of evolution can be done worldwide. Energy security is linked to the capacity of a country to supply the energy demand now and in the future in a reliable way. Environmental sustainability is associated with the transition of the national energy system to reduce climate change impacts. Finally, energy equity is linked to the ability to provide access by all the population to affordable energy with righteous tariffs. A balance between these three dimensions must be done to meet a reliable, affordable, fair, and sustainable energy system. Figure 2.1 brings a diagram of the World Energy Trilemma Index.

Repeatedly, governments and authorities give much attention to the dimensions of energy security and environmental sustainability, but less effort has been attributed to energy equity, which may lead to energy poverty. The concept of energy poverty itself is much diverse and wide, where some differences in this definition are observed between developed and developing countries (Zhao et al., 2022).

World Energy Trilemma Index

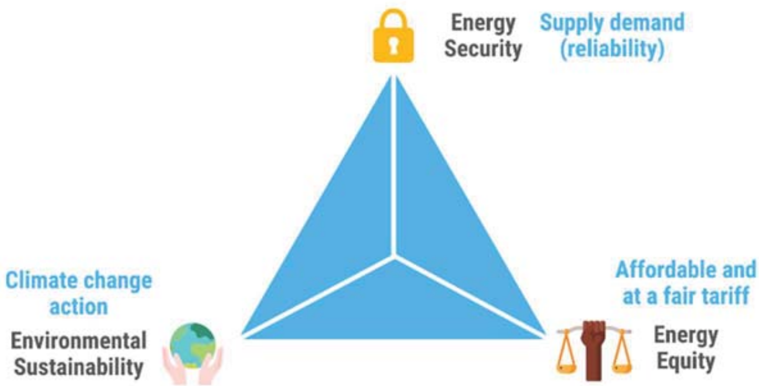

Figure 2.1 — World Energy Trilemma Index (2023).

The first definition of energy poverty was done in 1979, in a context of the historical petroleum crisis and the drastic increase in prices related to energy sources (Castaño-Rosa et al., 2018) but, in general, energy poverty definitions are related to the inability to consume energy services at a level that meets certain basic needs (González-Eguino, 2015). The concept of energy poverty in developed countries is linked to three main pillars:

a) High Energy Prices

Connection to the grid costs and energy tariffs needs to be affordable for general people for reducing energy poverty - in a simple way, if vulnerable citizens cannot afford the electricity prices and the costs associated with their connection to the electrical system, these persons will simply consume as little as possible or not even consume, leaving aside basic needs associated with cooking and cooling and heating systems (Brown et al., 2020).

The concept of energy affordability is associated to the ease with which consumers can pay for energy services. In the household environment, high energy prices and costs are associated with lower consumption or even disconnections/service interruptions - a vulnerable consumer can decide to disconnect and live without electricity for a period or find another alternative for supply due to an extreme enhance of energy costs (Jessel, Sawyer & Hernandéz, 2019). Increases in energy prices have also important effects on energy consumption, economic growth, and urbanization, where the variations of prices will affect the long-term development of a specific country or block (Wang et al., 2019).

Here, it is also important to refer that high energy prices are also an important pillar of energy poverty in developing countries.

b) Household low Income

A low household income will be translated as more difficult to pay for basic needs related with energy, such as energy bills and efficient equipment, where energy comfortable starts to be a problem associated with its affordability. In this scenario, the priority of the income will be destined to other basic needs, such as rent, food and water, where enhancing the costs with energy to promote a more comfortable environment is not an option (Igawa & Managi, 2022).

Especially in the European Union, costs associated with high rent values arising from strong migratory waves and high population concentration in urban centers, recent high inflation rates arising from the post Covid-19 pandemic scenario, enhancement of the energy costs due to the Russian invasion of Ukraine and low wage readjustment rates turns the income an important factor associated with energy poverty.

c) Low efficiency of buildings and equipment

Along with transportation and industry, buildings are one of the three main sectors in final energy consumption. Reducing energy consumption in a building is strongly associated with energy efficiency procedures and interventions, and architectural techniques in the project phase (Belussi et al., 2019). In a simple way, energy efficiency in the building sector is based on using less energy for operations, but not compromising the comfort of the occupants. In this context, many legislations and directives were created aiming to set targets and obligations for the construction sector, to increase the associated efficiency (Ruparathna, Hewage & Sadiq, 2016).

Especially in the European Union, old residential buildings represent a significant portion of the architectural landscape and patrimony of the cities, being truly marks of the historical development of the continent. However, this aging process is strongly linked to lower energy performances, where more energy is needed for basic operations, as heat and cooling systems and ventilation. Furthermore, in many cases, a complete retrofit is needed, where precarious housing conditions are evidenced (Marques et al., 2018). For a vulnerable consumer, this lower energy efficiency in the household environment leads to higher energy costs for basic operations (in comparison to another consumer who lives in a more efficient building), resulting in a decrease in energy consumption at the expense of the resident comfort.

The constant increase in equipment efficiency in a household environment is also an important topic associated with energy poverty. For the present time, the quality of an equipment is strongly associated with its efficiency and energy consumption, especially for the electric ones. This increase in efficiency occurs due to technological innovations resulted from massive investments in research and development made by large companies, which also increases the final price for the consumer (Fesenko et al., 2018).

In this context, two scenarios may occur: i) poorer families will only be able to buy old or second-hand vital equipment with considerably lower efficiencies, resulting in higher energy costs for basic needs, such as food storage and cooking, and enhancement of energy poverty; or ii) families who face income growth will start to buy more household appliances, but will not be able to buy the most efficient ones, where these new goods may be not much efficient equipment that is not crucial for living but represents a certain degree of comfort, also resulting in higher energy costs. These scenarios sometimes are referred as the paradox of energy efficiency and energy poverty in households (Simões & Leder, 2022).

The concept of energy poverty in developing countries is linked to three main pillars:

a) High Energy Prices (as previously mentioned).

b) Lack or insecurity in the energy supply

Energy poverty is associated with the total absence of choice, where the lack or deficiency in energy supply leads to extreme harmful consequences to the citizens, economies, and governments - a non-reliable energy system constraints the capacity of generating incomes of industrial and commercial sectors and causes inefficiency on public services, as the citizens will face not only household consumption problems, but troubles regarding financial inequalities, job offers and higher prices of goods, providing a vicious cycle (Adom et al., 2021).

Reliable access to electricity has an important linkage with the level of poverty in a country and its development, associated with devastating impacts on production and labor (significantly lower production efficiencies), education (deeply precarious educational systems that compromise the level of preparation and specialization of the youngest for the future in the labor market), medical (lack of reliability on medical infrastructure) and physical and mental health (efficient cooking systems, comfort provided through household cooling and heating, entertainment goods, access to information, among other factors) (Alam et al., 2018).

c) Energy sources availability

It is necessary to emphasize that primary energy sources are processed and, just after that, distributed and stored in different forms, such as electricity and heat. Commonly, wealthier countries have more diversity in energy sources than others, where various ways of using electricity for basic needs are presented, and the method of "processing" primary energy are realized - in some cases, like Qatar and Saudi Arabia, a huge part of their economy is based on energy sources like natural gas or crude oil. On the other hand, poorer countries have very limited options for energy use or do not have the technology methods or infrastructure to take advantage of their natural energy sources, where energy poverty is presented on basic attitudes as cooking only with wood, especially in rural areas - that is the case of some communities in African countries as Burkina Faso and Burundi (González-Eguino, 2015).

A summary of these pillars associated with energy poverty in developed and developing countries can be seen, respectively, in Figure 2.2 and Figure 2.3.

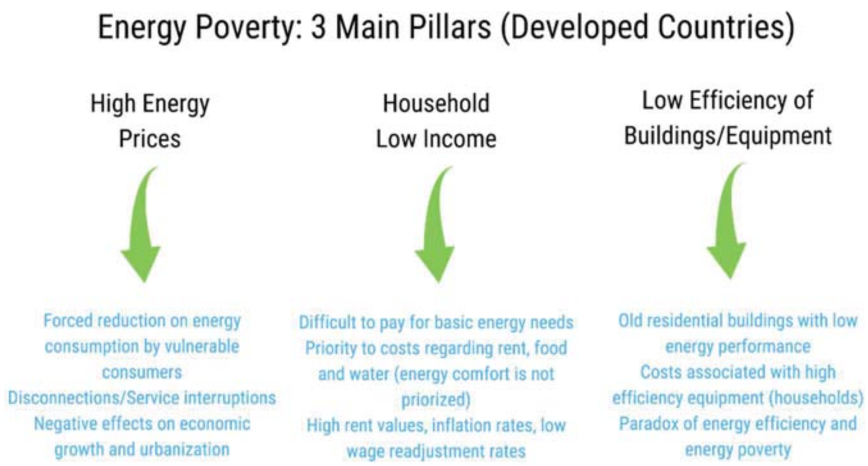

Figure 2.2 — Pillars of energy poverty (developed countries) (2023).

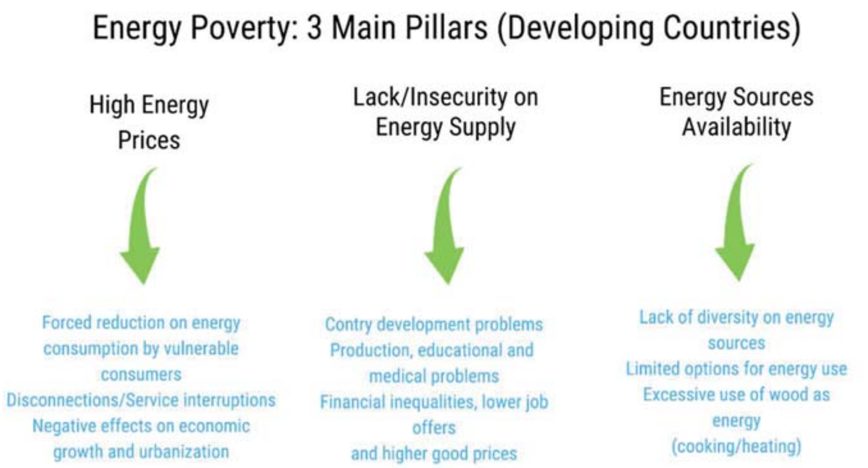

Figure 2.3 — Pillars of energy poverty (developing countries) (2023).

2.2 Energy Citizenship

Energy decentralization, democratization and citizen participation are crucial for the success of the energy transition. This process of seeing a citizen not only as a simple consumer but as an active player and decision-maker on energy consumption and generation was emphasized in the Clean Energy Package (2019), where more rights and power were given to citizens. It is also clear that a fair energy transition will only occur if the needs of the consumers are considered, where collective energy actions and organizations - such as Renewable Energy Communities - gain more importance (Wahlund & Palm, 2022).

The definition itself of energy citizenship is very broad and easily confused with energy democracy, involving decentralized generation, renewable energy systems, and energy efficiency. A pillar of this concept is the emphasis on energy literacy, where an energy citizen can act on small scale - such as households energy efficiency practices - or large scale - such as becoming part of activists’ groups associated with clean energy policies and democracy on energy transition (Ryghaug, Sjølsvold & Heidenrich, 2018).

According to Beauchampet & Walsh (2021), energy citizenship also highlights the increase of citizens' social and environmental responsibilities, as they respond to their way of energy consumption as starting to have an active role in the energy-related questions.

However, one of the most accepted definitions is that energy citizenship is "a view of the public that emphasizes awareness of responsibility for climate change, equity and justice (...) and the potential for (collective) energy actions" (Devine-Wright, 2007, p. 72).

There is an important link between energy citizenship and energy poverty. As this empowerment process depends on knowledge and information, social and economic inequalities can provide exclusion of some individuals from the energy transition - most of the times, these will be the ones who suffer the most from energy poverty and vulnerability (Lennon et al., 2020). However, if this process focuses in a collective way rather than on individuals, energy citizenship can give voice to the energy-poor by providing knowledge and supporting them to become active players in the transition, where energy poverty will be reduced through this social approach of citizenship (Sanz-Hernandéz, 2019).

DellaValle & Czako (2022) provide a concept that the citizens who face energy poverty have three levels of energetic empowerment to play a key role in the energy transition: a consumer, a consumer with needs and an energy citizen. An overview of this levels is presented in Figure 2.4.

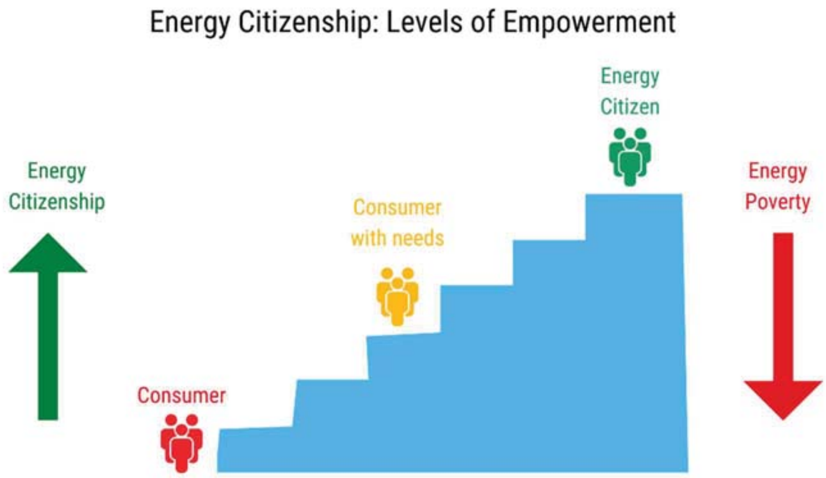

Figure 2.4 — Levels of energy citizenship (2023).

a) Consumer

Basically, a consumer is a citizen who consumes and pays for electricity. Here, empowerment can be done by simple measures that provide ways to make better consumption decisions, household energy efficiency measures and procedures, also with smarter investment choices (Coy, Malekpour & Saeri, 2022).

- **Empowerment channels examples:** energy advice by an external advisor, smart-meter based feedback and Energy Living Labs (laboratories to promote behavior change, give support to small enterprises regarding green energy and promote energy savings/efficiency) (Sahakian & Wilhite, 2014).

b) Consumer with needs

The consumer understands and recognizes his energy needs, where citizen participation is given through the insertion of these needs and interests in the energy system, which can be done by intermediate actors in positions of decision-making, representing consumers (Schwarz, 2020).

- **Empowerment channel examples:** tailored energy advice, training of energy actors, innovative financing, and business models.

c) Energy citizen

The last empowerment level is reached when citizens are exposed to mechanisms that enable them to become decision-makers in the energy transition, where they can participate, with knowledge, in social, economic, and technical changes (Berka & Creamer, 2018).

- **Empowerment channel examples:** individual and collective prosumption, energy citizenship dialogues.

2.3 Prosumption and Distributed Generation

The word "prosumption" itself means the union of energy production and consumption, meaning the scenario where a simple consumer starts to generate energy - mostly, through renewable energy sources - and becomes, at the same time, consumer, and producer of electricity. In this scenario, solar photovoltaic (PV) systems play a leading role, where the ease of the installation process, constant decrease in the average cost of equipment, low average payback times and an increasingly popular acceptance of this renewable energy source are the main reasons of this current trend on prosumption based on PV panels on rooftops (Bellekom, Arentsen & van Gorkum, 2016).

These microgeneration systems - also referred as distributed generation - are truly important for the energy transition, helping to enhance the share of renewables in the final energy consumption matrix, reducing emissions associated with energy generation, increasing energy security, and decreasing energy costs for householders and businesses (Reid & Ellsworth-Krebs, 2017). In addition, in many cases, becoming a prosumer can be the first step towards citizen insertion in the transition and increasing their energy citizenship (Kotilainen, 2020).

Distributed generation based on renewable energy systems has also an important link with energy poverty. In countries that have problems with generation and distribution of electricity, where energy supply is not reliable, the main sources are non-renewable, and a significant percentage of the households still does not have access to electricity, distributed renewable systems provide severe benefits in the social (enhancement of the comfort of the citizens provided by electrification and inclusion of these households in the energy transition), economic (lower energy costs associated with reduced payback times of the systems, government financing programs for the acquisition of equipment and creation of new local job opportunities related to installation, design, consulting and maintenance of these systems) and environmental (reduction of greenhouse gas emission, increase share of renewables in the matrix and decrease in the use of fossil energy sources) fields. A practical case is presented in South Africa, where investments in renewable microgeneration systems are a pillar of the actual energy policies (Baruah & Enweremadu, 2019).

Hanke & Lowitzsch (2020) present an intrinsic relation between prosumership, energy poverty, energy efficiency, and energy collective schemes, such as Renewable Energy Communities, which can be seen in Figure 2.5.

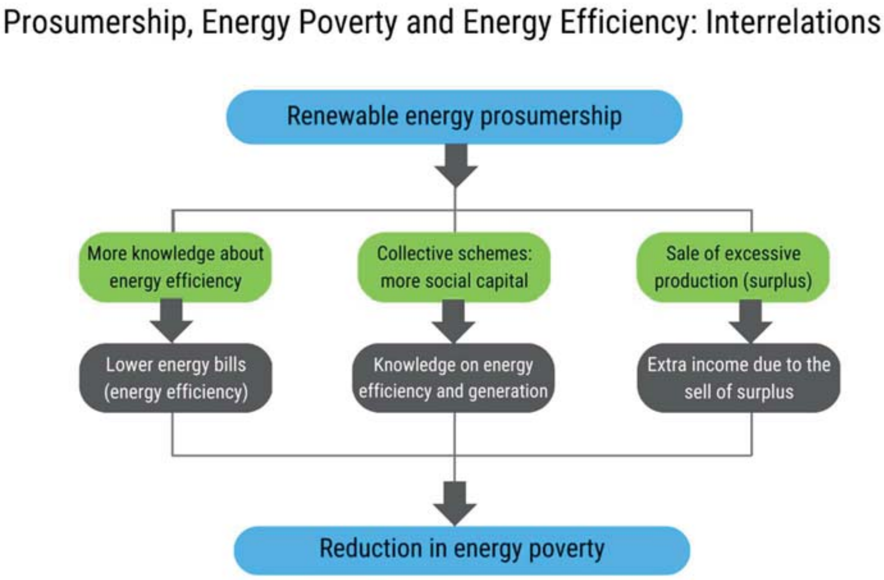

Figure 2.5 — Interrelations between renewable prosumership, energy efficiency, and energy poverty (Adapted from Hanke & Lowitzsch, 2020).

Renewable energy prosumership can lead to three important events: enhancement of knowledge about energy efficiency among households, creation of collective generation schemes among local citizens and sale of excessive production to the grid (on-grid systems depending on the electrical system regulation and operational structure). Then, as householders have more consciousness about energy efficiency procedures, they will face lower consumption and cheaper energy bills, leading to lower costs with energy and reduction of energy poverty. Collective generation schemes also enhance the knowledge about energy efficiency and generation, therefore also leading to reduction of energy poverty. Finally, the sale of excessive production creates an extra income for prosumers, where more capital may be available for possible energy investments and improvements in habitations, likewise providing reduction in energy poverty (Hanke & Lowitzsch, 2020).

The main advantages of renewable distributed generation are:

a) Reduction of greenhouse gas emission

The leading driver of climate change is the high level of greenhouse gas (GHG) emissions from the energy sector. As most of the distributed generation systems are based on renewable energy sources - more commonly, solar photovoltaics - enhancing the number of prosumers also means reducing the emissions associated with energy generation (Khodayar, Feizi & Vafamehr, 2019). Further, in a context of ambitious goals provided by recent climate change international agreements, enabling and encouraging this type of systems can become a pillar of energetic politics for reducing greenhouse gas emissions. A real case can be seen in Brazil, where investments and an impressive increase in the installed power of microgeneration, especially photovoltaics, has been one of the bases for the country to reduce its GHG emissions (Lima et al., 2020).

b) Lower ohmic losses in the distribution grid

Whenever electric current is conducted through a conducting wire of a certain resistance, energy dissipation in the form of heat, commonly called ohmic losses, will occur, where these losses vary quadratically with the value of the electric current and are directly proportional to the resistance. Also, this electrical resistance is directly proportional to the length of the conducting wire. So, as electrical power can be seen as voltage times current, transmission and distribution grids always seek to enhance the value of the voltage and decrease the value of the current, to maintain the same value of power and reduce ohmic losses (Sultana et al., 2016). As distributed generation promotes a severe reduction in the distance between energy generation and consumption - these two processes are placed on the same site - the generated current will have to be conducted through a wire of significantly smaller length, where the resistance seen will also be smaller and, consequently, the ohmic losses will also be reduced (Stieneker & De Doncker, 2016).

c) Higher energy security and affordability

The opposite of distributed generation are the centralized generation systems, where huge installed capacities, based or not on renewable energies, are installed in key locations for transmission and distribution where, in most cases, the place of consumption has a significant distance from the generation site. Distributed generation increases the security of energy supply due to the fact that the vast number of microgeneration sites promotes a decrease in extreme dependence on centralized systems, where technical and operational faults could be a huge problem for local energy supply. Also, prosumers face lower energy costs and tariffs, enhancing energy affordability and helping to reduce energy poverty (Strachan & Farrel, 2006).

d) Energy generation sources diversification

As distributed generation can be seen not only as PV systems, but as small wind turbines (microturbines) and micro biomass systems for electrical generation, the enhancement of the number of distributed generation sites maximizes the diversity of energy sources in the matrix, promoting lower dependence on a specific source that has patterns of peak energy generation, dependency factors and operational characteristics. An adequate mix of energy sources, with maximum share as possible of renewables, promotes greater security of energy supply and enhances grid reliability (Ellsworth-Krebs, 2016).

A summary of the advantages of prosumption and distributed generation can be seen in Figure 2.6.

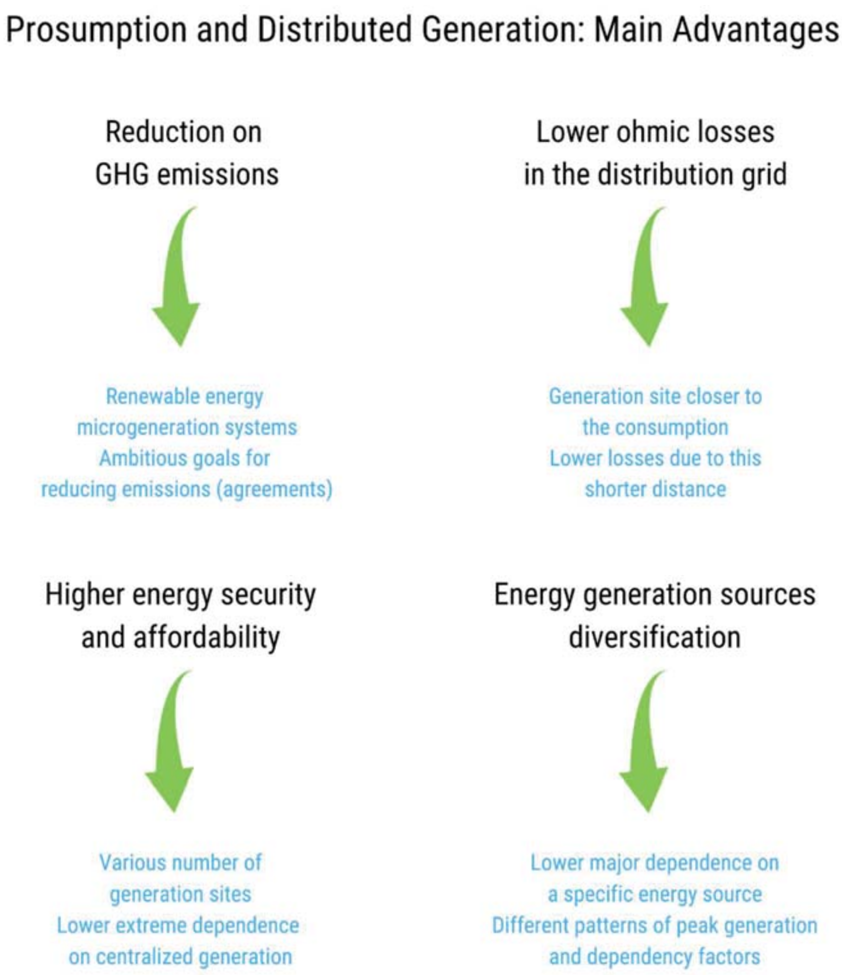

Figure 2.6 — Prosumption and distributed generation: main advantages (2023).

3

METHODOLOGY

In this chapter, the methodology defined to elaborate the work of this dissertation will be presented, focusing on the Study Case that will be introduced in the next chapter. Flowcharts will be shown to systematize the structure of different methodological steps.

After a comprehensive study and review of the existing literature about energy poverty, energy citizenship, prosumership, distributed generation and renewable energy communities, a global analysis of these initial concepts and the RECs is done, in order to completely understand these entities, common characteristics and associated advantages and challenges/barriers of this implementation process.

Then, focus was given to the Portuguese case, especially the Study Case of REC Telheiras. First, a study of the current framework regarding the Portuguese regulation of climate change and Renewable Energy Communities is done, highlighting targets, methods and the evolution of these laws and legislations about these energy entities. Also, some examples of existing Portuguese RECs are presented, as well as other cases of RECs that are waiting for the licensing process and still are in the implementation process.

After that, the Study Case is introduced, beginning with a presentation of the characteristics of the location and the historical pioneering of Telheiras in sustainability questions. Then, the Telheiras REC itself is presented, with a timeline of the creation of this entity, important partnerships, organizational and financial schemes of operation and other details about this action led by the residents.

A complete follow up of the meetings, events and internal questions of this REC was done, aiming to help and act towards the development and the progress of the entity. As the selected renewable energy system for the REC was PVs, a complete and detailed analysis of selected buildings, shading analysis, PV sizing and simulation is done, also with a budget and financial analysis of these systems. A systematization and analysis of this process of implementation and comparisons with other real cases of operating RECs is done, where the discussion ends with an evaluation of the biggest challenges for this energy entity and its next steps.

This methodology process can be divided into two stages: Stage 1 - Literature Review and Stage 2 - Study Case.

a) Stage 1 - Literature Review

Aiming to understand the importance of a REC and its impact in the energy transition and the community, the first step is to provide a study about the important conceptual background regarding topics as energy poverty, energy citizenship, prosumership and distributed generation. Therefore, a literature review associated with these concepts, aiming to understand the definitions, causes and impacts on the society, is done, through relevant peer-reviewed scientific papers and articles about these topics.

After that, this bibliography review starts to properly focus on Renewable Energy Communities. Initially, through the analysis of the definitions of these communities on European directives and on recent articles, this concept is provided. Then, with the objective to show the state of art of these projects on the EU, a review of different articles regarding characteristics, statistics, and data about operating RECs and associated regulatory framework is done, aiming to obtain a complete overview and present the current European projects for supporting the development of these communities.

A literature review about the most common renewable energy sources used in RECs and the respective main advantages and challenges/barriers of process is also done. Specially, by providing a study of the current bibliography regarding definitions of solar PVs and wind energy associated with criteria as applicability, modularity, installation process, need for specific natural conditions and density of installed power per generation unit. Following, an assessment of operational forms, important players for the implementation of a REC and main difficulties and benefits associated with this process is performed.

Finally, this literature review focused on systematizing existing Renewable Energy Communities, aiming to understand and search for ways to classify similar operational schemes, objectives and characteristics of these organizations and providing real examples for each selected criteria.

This literature review feeds a deep discussion about how a REC can reduce energy poverty and enhance energy citizenship in community, providing examples of how to do so and the expected impacts.

A flowchart regarding the Stage 1 is presented in Figure 3.1.

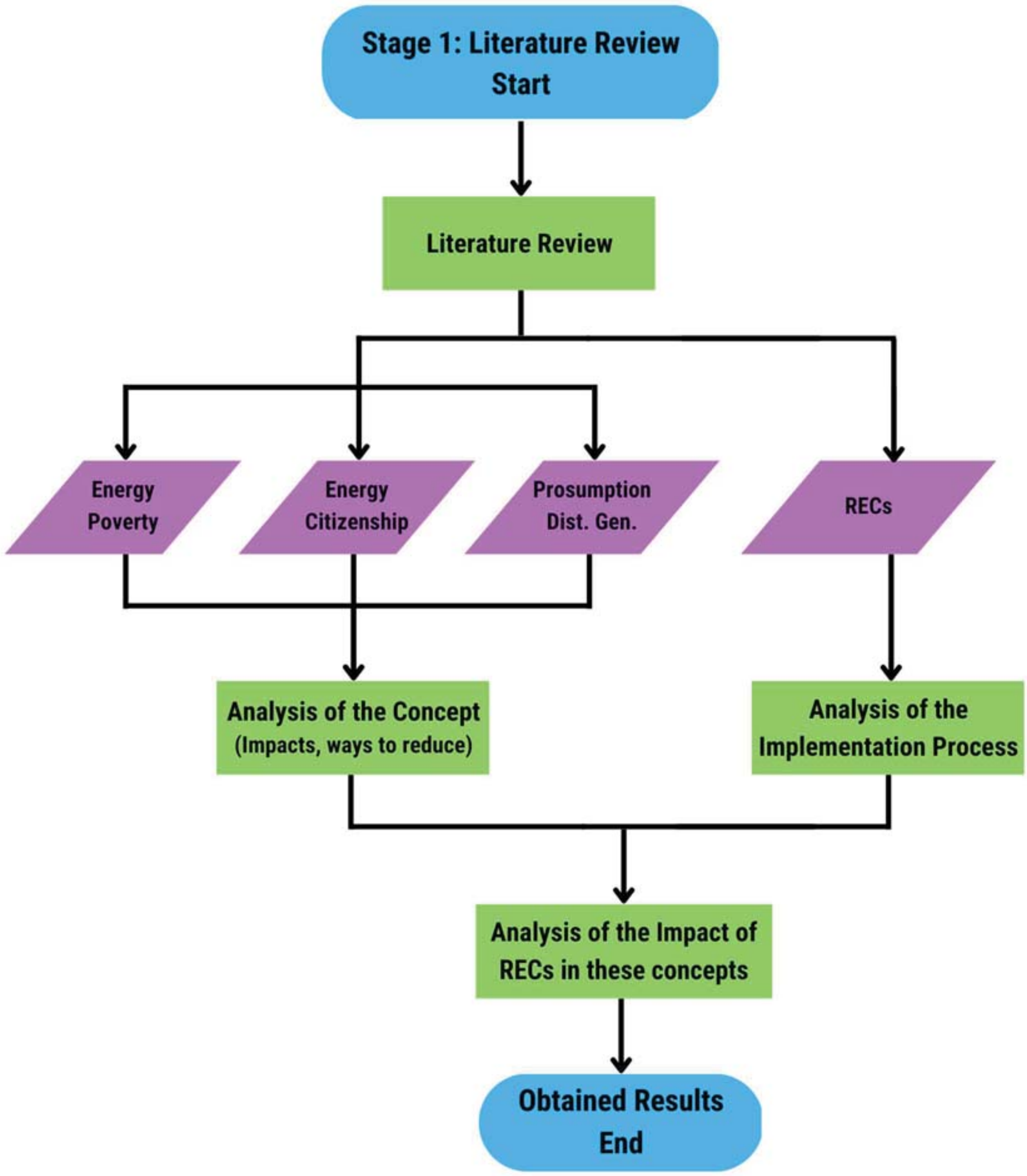

Table 3.1 - Methodology - Flowchart for Stage 1 (2022).

b) Stage 2 - Study Case

This second part of the dissertation starts with an analysis of the Portuguese regulation regarding climate action and Renewable Energy Communities and climate action, through the study of different directives and national laws. In addition, an assessment of the status quo of RECs in the country is performed and important projects of current and future energy communities.

Then, a complete timeline of the development of REC Telheiras is presented, through analyzing intern documents of *Parceria Local Telheiras* and *Grupo Telheiras Sustentável* and through the attendance of meetings and internal discussions about the project. An analysis of the characteristics of the location and the neighborhood is done as a case study. After that, the implementation process of REC Telheiras was analyzed, focusing on documents provided by *Parceria Local Telheiras,* Lumiar Civil Parish, EPAH and Coopérnico and the meetings of the working group.

Since REC Telheiras had only one basic and simple PV sizing for only one building of the neighborhood, a complete shading analysis, PV sizing and simulation through a specific PV software (HelioScope) was done for six buildings, selected according to the administrative availability of the associated roof area to become part of the REC and receive PV modules. This PV analysis started through visits to the selected buildings and analysis of the roof area through views on Google Maps. Then, the evaluation of the roof areas that are adequate for PV generation is done, through a shading analysis of all the rooftop areas of the buildings. After that, the PV sizing and simulation is done, where the obtained results present the PV potential of each building in order to be utilized for the generation of REC Telheiras.

Another important analysis was done regarding the main barriers and challenges associated with the implementation process of the study case, through the evaluation of the documents and analysis of the meetings and current scenario of the project, and feedback from local participants. Then, REC Telheiras was classified regarding the criteria presented on Stage 1 and compared with RECs with similar operational schemes.

Figure 3.2 brings a flowchart of the Stage 2 of the dissertation.

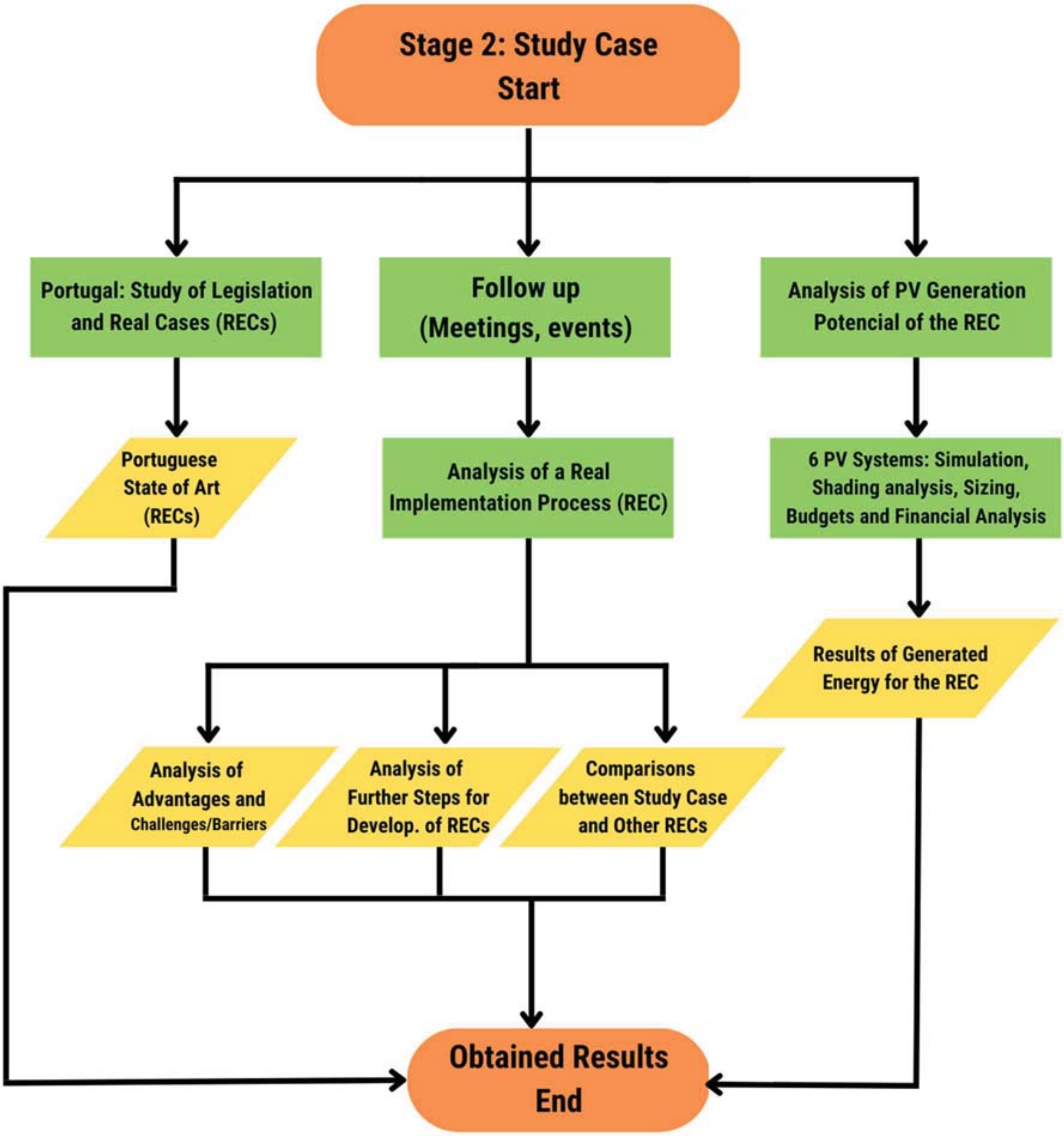

Table 3.2 - Methodology - Flowchart for Stage 2 (2022).

4

RENEWABLE ENERGY COMMUNITIES

In this chapter, the definition of Renewable Energy Communities (RECs) will be presented, as well as an overview of the state of the art at an European level. Then, the European projects for the development of RECs, renewable energy systems and the implementation process of these energy entities will be presented. Finally, a classification of RECs and real cases will be shown, as well as their forms of operation and characteristics.

4.1 Definition

According to the Revised Renewable Energy Directive (EU (2018/2001), July 2021), RED II, the definition of a Renewable Energy Community combines open participation of the citizens or investors of the respective area close to or within the renewable energy projects, which ones have the power to control, in an autonomous way, the entity (European Commission, 2018). A REC involves more than just consumption and generation of electricity: its most important purposes are associated with the community's social and economic aspects, such as helping the decarbonization, reducing energy poverty and enabling sustainable community growth (Cielo et al., 2021).

However, the most accepted definition of a REC is presented in the Renewable Energy Communities Repository (2023), as it says that it is "a legal entity that, in accordance with the applicable national law, is based on open and voluntary participation, autonomous, effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; the shareholders or members of which are natural persons, small and medium-sized enterprises or local authorities, including municipalities".

A REC is allowed to produce, consume, store, sell and share among the community's members the renewable-based generated energy (European Commission, 2018). Financial benefits can be presented, such as selling the surplus energy to the grid, lower energy costs as the result of onsite and distributed generation and land rent for implementation of renewable energy systems, such as photovoltaics installed on ground-fixed structures and wind turbines. Also, it is known that the investment made by the EU to reduce emissions according to the Paris Agreement and 2030 climate goals it is not sufficient to achieve those objectives, so this scheme based on collective investment plays a key role to help in this situation (Pons-Seres de Brauwer, 2020).

Since the promotion of the concept through the RED II, it has been a great challenge for EU Member States to incorporate national regulations and laws for the promotion of RECs, to reduce local energy poverty and increase energy justice of its citizens. Also, the heterogeneity associated with the different organizational and structural forms and a very broad definition of a Renewable Energy Community provided by RED II are important factors for governments while developing regulatory framework associated with these organizations (Heldeweg & Saintier, 2020).

Another important factor is the diversity of similar concepts, which can easily cause confusion between the definitions and hinders the regulation process of these entities. Some examples are Positive Energy Districts (PEDs), Climate-Friendly Neighborhoods (CFNs), Positive Energy Neighborhoods (PENs), Low Carbon Energy District (LCEDs), among others. One of the concepts most easily confused with REC is the Citizens Energy Community (CEC) - introduced in the Recast Electricity Directive, these organizations are very similar to a Renewable Energy Community, but, here, energy generation is not obligatory, even though most of the times is presented and based on renewable energy sources (Brozovski, 2021).

4.2 Overview: European Union

In this section, an overview of the regulatory framework in the European Union will be presented, also with an analysis of statistics and data regarding RECs cases and local projects for the development of the concept.

In this context of regulations allowing the constitution of RECs, these projects have rapidly increased over the past years, especially in the European Union, where the combination of national regulations, community awareness and support projects are the three pillars of the advancement of this type of energy entities.

Being the global leader of the concept, the EU needs to have a different approach when analyzing the roll-out of Renewable Energy Communities, since it is not just a single country, but a block of 27 Member States with sensible differences and characteristics. This implies that each EU Member needs to design a framework to support RECs and to make them competitive with other types of existing organizations (Compile, 2022).

The scenario regarding the development of national approaches and regulatory frameworks in most of EU Member States on May 2022 is presented in Table 4.1.

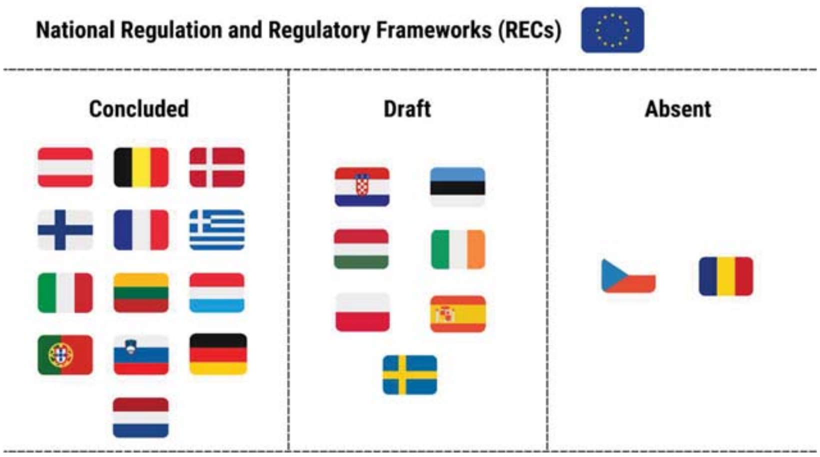

Table 4.1 — National regulatory framework regarding RECs - May 2022 (Adapted from Compile, 2022).

It is crucial to recall that there are deep differences among the Member States in many aspects: social, economic, technical, regulatory, and cultural. For example, a report made by the JRC (2020), presents that, in Europe, there are over 3,500 Renewable Energy Communities led by citizens. In this scenario, due to cultural traditions of collective participation, citizen engagement and activity markable in northern European countries, Germany, Denmark, the Netherlands, and Sweden have the largest amount of this type of REC, as presented in Table 4.2.

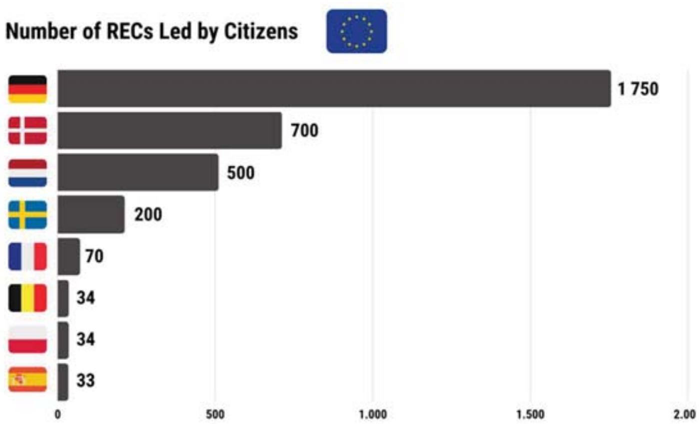

Table 4.2 — Number of RECs led by citizens in EU (Adapted from Joint Research Centre, 2020).

Also, in the same report by JRC (2020), 24 study cases were analyzed - 3 from Belgium, 3 from France, 3 from Germany, 3 from Poland, 3 from Sweden, 2 from Denmark, 2 from the Netherlands, 2 from Spain and 3 from the United Kingdom (although UK is no longer an EU Member State, its relevance in the REC scenario justifies its presence in this study).

Regarding the type of renewable energy associated with the community, solar energy emerges from the other sources as the most applied - even though RECs situated in countries such as Spain and France (south region) face more favorable conditions of solar radiation, the policies and legal frameworks associated with PV energy in northern countries, as Germany, Belgium, and the Netherlands, make the solar energy common also in these Member States' RECs (Joint Research Centre, 2020).

Communities associated with wind energy are especially found in Denmark and Sweden, where conditions of annual average wind speed - on or off-shore - and their historical technological developments in wind turbines provides propitious conditions for this renewable energy source integration (Joint Research Centre, 2020).

RECs linked to biomass energy vary in many ways - heat and power, usage of agricultural residues, biogas application - depending, most of the time, on conditions of supply, needs of the community and local organizational structure (Joint Research Centre, 2020).

A summary of the types of renewables in those 24 RECs can be seen in Table 4.3.

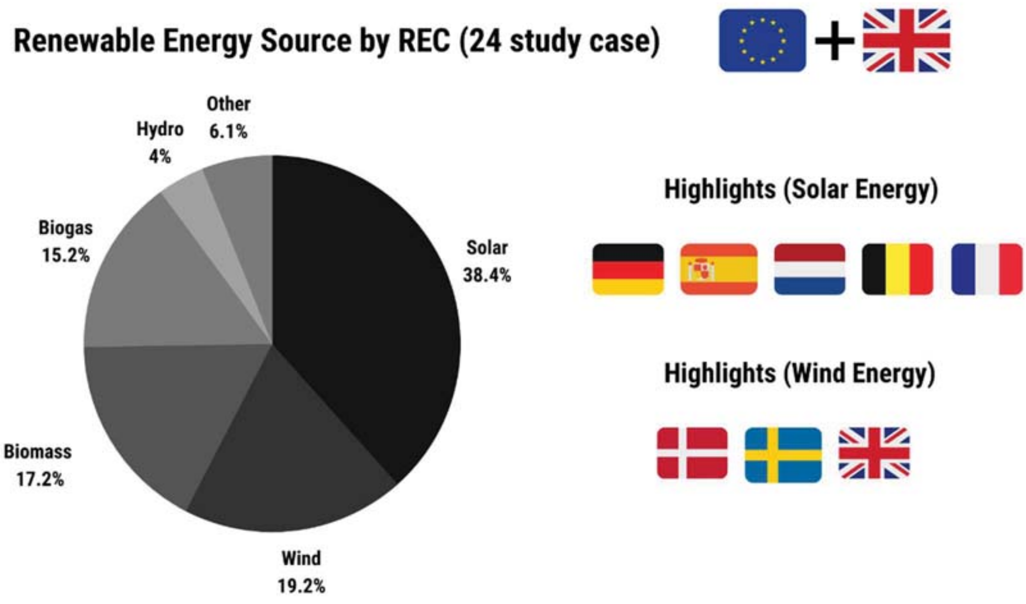

Table 4.3 — Renewable energy source by REC - 24 Study cases (Adapted from Joint Research Centre, 2020).

Hanke, Guyet & Feenstra (2021) provides data from 71 European RECs through an online survey - more specifically, 51 German, 10 French, 6 Dutch, 1 Belgian, 1 Portuguese, 1 Irish and 1 Turkish RECs (although Turkey is not an EU Member State, as it is only one Renewable Energy Community in a sample space of 71 case studies, the Turkish case will also be utilized). One of the most important questions asked in the survey is about the organization's main motivation: on 85% of the cases, one of the primary purposes of the REC is to promote renewable energies and in 46% of the cases, it is the creation of regional value. Also, 46% of the cases identified one of the main purposes as having ownership of the energy supply. A summary of these answers and their percentage of cases can be seen in Table 4.4.

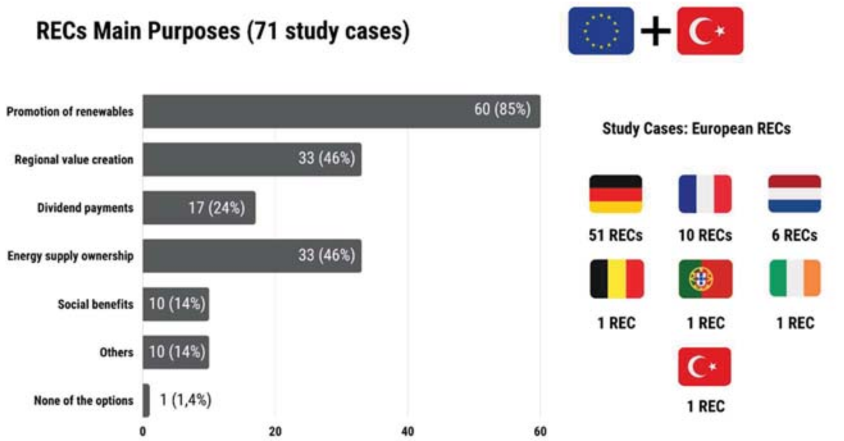

Table 4.4 — Main purposes of RECs - 71 Study cases (Adapted from Hanke, Guyet & Feenstra, 2021).

In addition, another important question in the survey is regarding the type of activities realized on the Renewable Energy Community: 54% of the cases have renewable energy electricity, 23% have renewable energy heating systems and 21% of the cases include electric mobility. These results prove how diverse and broad the concept of a REC can be (Hanke, Guyet & Feenstra, 2021). A summary of these answers is presented in Table 4.5.

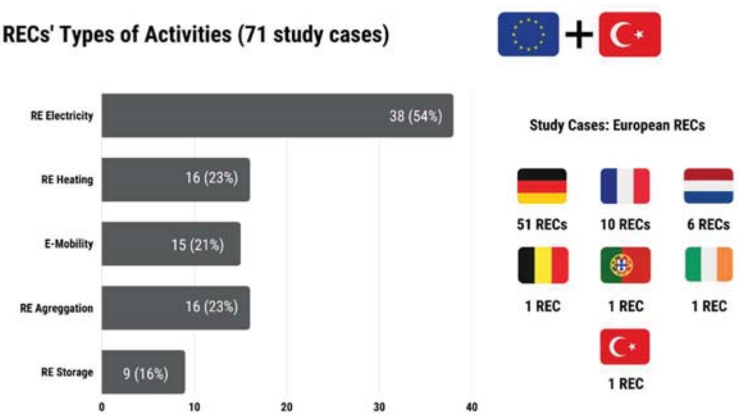

Table 4.5 — Main activities of RECs - 71 Study cases (Adapted from Hanke, Guyet & Feenstra, 2021).

4.3 European Projects

In this context, the European Union has been developing many different projects to provide tools to enhance the number of RECs in the block, helping with technical and regulatory knowledge, presenting existing business and operational models, and providing platforms to exchange ideas and concepts with success cases. In this topic, five EU projects will be presented: NEWCOMERS, COME RES, eCREW, DECIDE and Up-Stairs.

a) NEWCOMERS

Enhancing from locally-led citizen initiatives to virtual communities, municipalities or commercial-drive initiatives, the NEWCOMERS project (New Clean Energy Communities In a Changing European Energy System) aims to explore, study and evaluate different types of RECs, delivering practical recommendations about how EU - as well as national and local governments - can support new clean energy communities, in order to enhance their benefits among citizens and the European Union itself, aiming to meet the European challenge of decarbonization. NEWCOMERS has eight partners from six countries (Germany, Italy, the Netherlands, Slovenia, Sweden, and United Kingdom) and evolves ten energy communities, where one of its major objectives is to stimulate interaction, learning and innovation (NEWCOMERS, 2022).

The main study cases of RECs of NEWCOMERS projects are presented in Table 4.6.

b) COME RES

The COME RES Project (Community Energy for the Uptake of the Renewables in the Electricity Sector) has the objective to enhance the share of renewable energy sources in the electrical energy matrix, focusing on advancing RECs in nine European countries - namely, Belgium, Germany, Italy, Latvia, the Netherlands, Norway, Poland, Portugal, and Spain), via a multidisciplinary approach to support the development of these communities. The project focuses on areas of these countries with a promising future in the development of these communities or which develop are already in an advanced stage (COME RES, 2022).

Other import aspect of COME RES Project is the Country Stakeholder Desks, which are places located in these nine countries where dialogues, roundtables and discussions related to the development of RECs happen, aiming to find solutions and enhance the number of RECs in the country (COME RES, 2022). Table 4.7 brings an overview of the existing Country Stakeholder Desks.

Newcomers RECs Study Cases newcomers EXPLORING NEW ENERGY COMMUNITIES

Project	Location	Purpose
Dalby Solby	Malmö	Cooperative house association Shares in local wind turbines, solar thermal collectors and PV generation Installation of LED lightning
Energy Local Clubs	Bethesda 1st Club	Cooperative of local generators and suppliers 100 households acessing electricity from a local hydro generation plant More Clubs developed in many other UK cities
ERiC	Sicilia	Facilitates the creation of citizen purchasing groups for solar PV systems (lower tariff costs by negociations) Independent and transparent advise on product choices and devices (eletricity consumption)
GEN-1 Jesenice	Jesenice	Project between energy supplier and group of residences (apartment block in Jesenice) 2 PV systems for common areas of the building and a heat pump
Buurtmolen Herbaijum	Herbaijum	Place-based REC Joint investment in a local wind turbine Reduced energy taxes and tariffs for members
Project Z	North Rine Westphalia	Pilot project: trial to local energy trading (retail privately generated renewable electricity within a defined area) Blockchain techonologies: capture and process data on electricity (generated, consumed and traded)
SO EN	Messina	Place-based REC in abandoned low-income neighbourhood Provide electricity from renewables to socially disadvantaged citizens Micro-grid: PV power plant + storage linked to 6 residences
sonnen Community	Virtual	Virtual REC: members declaring "independece" All electricity needs through a combination of self-consumption and community supply (virtual power plant) Decentralized and privately-owned storage units of members
Buurtmolen Tzum	Tzum	Facilitate the installation and use of a wind turbine to benefit the local community Cooperative will enable members to acess a tax break on their electricity bills (local citizens)
Energ. Coop. Zuiderlicht	Amsterdam	Matching empty roof spaces with households willing to invest in PV energy Investor members and consumers members

Table 4.6 — Study Cases Newcomers (RECs) (2022).

Come RES Stakeholder Desks

Country	Location of Stakeholder Desks
BE	Limburg, West-Flanders, East-Flanders, Antwerp, Flemish-Brabant
DE	Thuringia, Schleswig-Holstein
IT	Apulia, Piedmont
NL	North-Brabant, Zeeland, Rijsenhout, Etten-Leur, Woerden
PL	Warmia-Masuria, Lower Silesia, Pomerania
PT	North Region, Lisbon
ES	Balearic and Canary Islands, Valencia, Catalonia
LV* NO*	

*whole country

Table 4.7 — Come RES Stakeholder Desks (2022).

c) eCREW

Operating in Germany, Spain, and Turkey, eCREW Project coordinates and supports the development of forms of household collective partnership for energy consumption, generation, and management through the so-called Community Renewable Energy Webs (CREWs). The basic principles of these organizations are renewable microgeneration, battery storage and enhancement of energy efficiency. Currently, this project encompasses 240,000 households arranged in 200 CREWs and totalizing 13 GWh/year of energy savings, where eCREW approaches new members through partnerships with three energy companies (one in each country member) (eCREW, 2022). A summary of some existing CREWs is presented in Table 4.8.

d) DECIDE

The DECIDE Project (Developing Energy Communities through Informative anD collEctive actions) has the main objective to analyze and have deep knowledge about the implementation of Renewable Energy Communities and energy efficiency services, also analyzing forms of communication and interaction to encourage energy actions and citizen participation in the energy transition and providing knowledge exchange among European energy projects. Operating in Austria, Belgium, Estonia, France, Germany, Greece, and the Netherlands, this project is based on 9 pilot projects and aims to be a mark for the enhancement of RECs in the European Union (DECIDE, 2022).

A summary of the 9 pilot projects can be seen in Table 4.9.

Existing CREWs - eCREW Project

Country	Light Company	Data
ES	Alginet Distribución Energia Eléctrica	~1000 households ~580kWh/y saved per household (130€/y) ~140 GHG tons/y saved per household
TR	Uluğ Enerji Dağıtım ve Perakende Satış Hizmetleri	~5000 households ~330kWh/y saved per household (34€/y) ~140 GHG tons/y saved per household
DE	Stadtwerk Haßfurt GmbH	75-125 households ~500kWh/y saved per household (160€/y) ~200 GHG tons/y saved per household

Table 4.8 — Some existing CREWs (eCREW Project) (2022).

e) Up-Stairs Project

The Up-Stairs Project aims to accelerate the implementation of Renewable Energy Communities through the so-called One-Stop-Shops - locals where support for development of collective energy actions with the cooperation of the local households is provided. Facilitating citizen participation in the energy transition, the main objective of this project is to enhance the creation of RECs and collective actions in 5 pilot regions - namely, cities in Austria, Bulgaria, Germany, Ireland, and Spain. Different One-Stop-Shops have different main topics, such as advice to citizens on energy efficiency and microgeneration, implementation of RECs, and so on. Actual data presents 66 million euros triggered and 10,000 consumers engaged, also with important publications regarding the experience with the existing One-Stop-Shops and events for support and development of new Renewable Energy Communities around the European Union (Up-Stairs, 2022).

A summary of the existing 5 One-Stop-Shops (pilot regions) and their main motifs is presented in Table 4.10.

Pilots - RECs in DECIDE Project

Country(ies)	REC	Details of the REC
AT	OurPower	Peer-to-Peer marketplace of renewable energy generation Small rooftop PVs, wind turbines, hydropower/biomass plants
BE	ThermoVault	Software/Hardware solutions for residential thermal appliances Most cost-effective solution Renewables integration
BE, FR, DE, NL	ENBRO	Solutions to reduce energy bills (residential, industrial, comercial, public) Energy brokage, guidance, advice, development and structuring of solutions
EE	TREA	Experts on energy efficiency, energy planning, sustainable transport, energy renovation and energy communities Development of Estonian energy transition
DE	Elektrizitätswerke Hindelang e.G. (EWH)	Renewable electricity supply of the village of Hindenlang Generation from local sources 330 citizens and the municipality as part of the community
EL	HERON	Largest independent electricity retailer Real-time power meters for consumption and electricity prosumers Comsumption and local renewable production
EL	DomX	Retrofit solution for the automation of legacy gas-based heating systems Improve heating efficiency, smart and remote control

Table 4.9 — Pilot Projects (DECIDE Project) (2022).

Pilots Regions - Up-Stairs Project

Country	Location	Topic of the One-Stop-Shop
IE	City of Cork	Advice to citizens on energy upgrades to their homes
ES	Barcelona	Support service for energy transition and implementation of Energy Communities
DE	Brunnthal	Support service for the establishment of Energy Communities
AT	Region of Upper Austria	Support service for the establishment of Energy Communities
BG	Asenovgrad	Advice on energy refurbishment and the use of renewables in private households

Table 4.10 — Existing One-Stop-Shops - Pilot Regions (Up-Stairs Project) (2022).

An overview of all the presented projects (NEWCOMERS, COME RES, eCREW, DECIDE and Up-Stairs) and their target countries can be seen in Table 4.11.

EU Projects - Support and Develop New RECs

newcomers – Exploring new energy communities	DE - IT - NL - SI - SE
COME RES	BE - DE - IT - LV - NL - PL - PT - ES
eCREW	DE - ES - TR
DECIDE	AT - BE - DE - EE - FR - NL
UP-STAIRS – Uplifting Energy Communities	AT - BG - DE - ES - IE

Table 4.11 - Five EU Projects for development and support new RECs (2022).

4.4 Renewable Energy Generation

Many different renewable energy systems can be implemented for Renewable Energy Communities. Choosing the best one for each case can determine the success - or not - of the whole identity since clean energy generation is one of the most important pillars of implementing a REC. A review of the most common renewable energy systems for Renewable Energy Communities - namely solar PV and wind energy - regarding five criteria (applicability, modularity, installation process, need for specific natural conditions and density of installed power per generation unit) is presented in this section of the dissertation.

4.4.1. Solar Photovoltaics

Significant growth in added capacity in recent years, substantial and constant decreases in the prices of the components and a developed worldwide market: solar photovoltaics is advancing in strides in this century. Connected (on-grid) or isolated (off-grid) systems are widely presented nowadays in different sectors, regions, and applications (Comello, 2018).

The most common ways of implementing a PV system are ground-mounted, Building Adopted Photovoltaics (BAPV), Building Integrated Photovoltaics (BIPV), carport structures and, on a lower scale, floating systems. Ground-mounted systems are based on PV modules installed in structures fixed to the ground and include most of the large-scale PV plants (Peters, 2017). On the other hand, BAPV and BIPV concepts concern with buildings and constructions: in a BAPV system, PV modules are attached to the building envelope, most commonly on structures installed on building's roofs; in a BIPV system, the PV modules are integrated into the building envelope as they substitute one or more construction elements, where can be applied in the façade, rooftop, or shading elements (Kumar, 2019). Another form of PV implementation is through the so-called carport structures, which use the space of the covered car parking places for installing PV modules and, in many cases, can be associated with electric car charging points (Riakhi, 2021). Another approach is the floating system, which consists of an "off-shore" PV power plant, but nowadays it is not as common as the other types of PV systems (Ranjbaran et al., 2019).

a) Applicability

Photovoltaic systems, especially in the forms of BIPV and BAPV, are easily incorporated in cities and districts, where the easiest is the BAPV on rooftops. According to the urban density of the area, namely the density of skyscrapers and buildings, the efficiency of the PV generation can decline, as those constructions will probably promote temporary or permanent shading, even though an individual analysis of each scenario is required (Li et al., 2019). An example of a BIPV system can be seen in Figure 4.1.

Figure 4.1 - Example of BIPV system applied to the roof (spaced PV cells allowing the passage of natural light) - Gare de Perpignan, France (Révolution Énergétique, 2022).

b) Modularity

PV systems are easy to modulate: if an on-grid system was installed with a string inverter, it is easy to connect more PV modules if they are all the same (brand, model, and specifications) and if fit well with the inverter sizing. This modularity becomes even higher when using microinverters because the modules can have different parameters as new microinverters will also be added to the system (Deshpande, 2017).

c) Installation Process

The process of installing a PV system depends on the form of implementation (ground-mounted, BAPV, BIPV, carport or floating). Installations associated with BAPVs (most of the time, on rooftops) are the quicker ones, as the fixation of metallic profiles and their respective structures of module's fixation is the lengthiest process. Ground systems require a slightly more complex installation process - foundation concrete blocks are needed to fix the poles of the metallic structure for PV modules - being an installation step unique for ground mounted systems (although it is not a complex, costly and lengthy process) (Leccisi, 2016). The BIPV systems, in fact, are more complex because involve construction elements and components, beyond the fact that this type of PV system needs to be planned and sized, in the project phase, among engineers and architects (Ghosh, 2020). An example of a ground-mounted PV system is presented in Figure 4.2.

Figure 4.2 - Example of ground-mounted PV system (Solar Electric Supply, 2022).

d) Need for Specific Natural Conditions

The photovoltaic conversion process is based on, under incident radiation, the creation of charge carriers, subsequent separation and collection, and generation of an electric current on a semiconductor (Zhang et al., 2019). In the case of PV solar cells, the conversion occurs under incident solar radiation, so this type of generation is intermittent and depends on the sunlight and shading. Under shading conditions, the PV generation will not be null, but, since diffuse radiation is much less energetic than direct radiation, the PV generation will face a drastic reduction (Teo et al., 2018).

e) Density of Installed Power per Generation Unit

Many technologies have been developed to increase the efficiency of PV modules (basic unit generation of photovoltaics), especially on mono-crystalline silicon solar cells, such as PERC cells, half-cell modules, bifacial cells/modules, among other possible solutions (Mesquita et al., 2019). Though these technologies mean evolution and progress in the PV industry - especially the commercial ones - PV modules have peak power much lower than generation units associated with other renewable energies, such as wind energy (wind turbines have nominal installed power ranging from kW to MW).

Evaluating all the concepts and important topics associated with PV generation, it becomes evident why most of the Renewable Energy Communities are based on those systems. The most important reason is regarding the high modularity degree associated with a relatively easy installation of the systems - it fits perfectly with the distribution generation concept, enhancing the development of smart cities and energy management. On the other hand, the fact that the peak of PV generation does not match the peak consumption, and that there is no generation during the night or significantly lower generation during hazy/rainy days can make the power system supply unreliable, where solutions as storage systems and energy flexibility procedures can be needed. Also, constant evolutions of PV technology, such as inverters technologies, cells arrangement and modules peak power contribute to increasing the participation of PV systems in RECs (Nolden, Barnes & Nicholls, 2020).

A summary of PV systems regarding the presented criteria is presented in Table 4.12.

Renewable Energy Generation
Solar Photovoltaics

Applicability	Although shading problems, it is easy to incorporate
Modularity	Easy to modulate, especially with microinverters
Installation Process	For BAPV, carports and ground systems, easy and quick process
Need for Specific Natural Conditions	Cloudy and rainy days / Regions with low irradiance levels
Density of Installed Power / Gener. Unit	Relatively low peak power per PV module (lower than 1kWp/unit)

Table 4.12 - PV systems - Summary of the presented criteria (2022).

4.4.2. Wind Energy

Wind energy has a significant participation in the energy generation matrix, especially in countries as China, Denmark, Portugal, Brazil, and Ireland. The installed capacity of the turbines has increased significantly in the recent years, where these systems face constant advances and new technologies (Son & Ma, 2017).

The main classification regarding wind turbines is associated with the orientation of their rotor axis: a Horizontal Axis Wind Turbine (HAWT) has its rotor axis oriented, actively or passively, parallel to the wind direction. On the other hand, a Vertical Axis Wind Turbine (VAWT) has an omnidirectional operation (does not depend on the wind orientation) (Porté-Agel, Bastankhah & Shamsoddin, 2020). Another important classification is associated with the location of the turbines: onshore turbines are located and fixed on the ground, while offshore turbines are located on the high seas and fixed through different structures suitable for the marine environment. Although offshore wind turbines face higher average wind speeds, the marine environment and the technology associated with the fixation structures increases their costs, while the onshore ones are cheaper and operates with lower average wind speeds (Li et al., 2020). An example of offshore wind turbines can be seen in Figure 4.3.

Figure 4.3 - Example of offshore wind farm (The American Clean Power Association, 2022).

With the increase of interest in distributed generation, a significant development of horizontal axis wind microturbines started in this decade, where these generation units have nominal power from 100W to several kW. Thus, these miniatures bring numerous benefits through the application of wind energy in distributed generation, where the dependence on PV systems in this type of generation is reduced and makes possible to take advantage, on a smaller scale and in a simpler way, of the available wind resource. However, these microturbines are still not widely applied, where more development in control systems and lower prices are needed to them to be more widely used (Chudzik, 2023).

a) Applicability

Onshore HAWTs are not easily incorporated in urban areas, due to the need of land usage, perturbation on average wind speed caused by the presence of buildings and skyscrapers and local resistance problems due to noise, aesthetic and public safety concerns. This becomes even a bigger problem when considering offshore turbines: the need to be a coastal zone and higher costs for implementation make the implementation of this type of wind turbine even more difficult in a Renewable Energy Community. Although, for RECs in rural areas, onshore HAWTs can be applied in a relatively simple way (Schaffarczyk, 2020).

Vertical axis wind turbines are easily incorporated in urban areas, as they operate with wind from any direction and are relatively simple to design and install. However, the installed capacity of this type of turbine is significantly lower than the values for HAWTs, making this application not suitable for situations where a larger amount of generated energy is demanded (Kumar, Raahemifar & Fung, 2018).

b) Modularity

The fact that the wind turbine itself encompasses all the necessary components for energy conversions processes makes wind energy to have a high degree of modularity, where the addition of more turbines in a wind farm can be done in a simple way. One of the only limitations is the distance between turbines, since too proximity between these towers can affect the average speed of the wind that reaches the blades, thus reducing the energy generation (Rezamand et al., 2020).

This modularity becomes even higher with VAWTs, as its relatively reduced size and dimensions turns even easier to add more turbines on a specific site (Kumar, Raahemifar & Fung, 2018).

c) Installation Process

For onshore wind turbines, the installation process must be seen as having different steps of infrastructure, civil and electrical works. Clearing of terrain, access roads for equipment transport, concrete foundation for the towers, proper electrical installations for connection of the turbines in the grid: all these needed steps make the installation process complex and costly, where detailed prior planning and an elaborate schedule of work must be carried out prior to the start of the process (Sovacool et al., 2017).

For offshore wind turbines, the difficulties during the installation process become much bigger, where this phase is totally crucial for the success of the operation. The aggressive marine environment, high distances for cables to make the connection to the grid and the complex fixation structures for these HAWTs are the main pillars of these difficulties, where the costs are even higher than the ones for onshore turbines (Jiang, 2021).

d) Need for Specific Natural Conditions

One of the most important phases of implementing a wind farm is the previous studies about wind speeds and occurrence frequencies. It is important that the site where the wind turbines will be placed experiments high average wind speeds and that these values occur repeatedly. Statistical distributions have been used for analyzing these values, as the Weibull distribution is the one that has been implemented the most in these studies. A badly performed wind study or its non-existence is a critical factor for the failure of a wind project (Wang, Hu & Ma, 2016).

e) Density of Installed Power per Generation Unit

HAWTs have relatively huge nominal power per generation unit, especially when compared to PV modules. Ranging from kW to MW, the enlargement of the rotor diameter and height of the tower results in constant new models with higher nominal power, especially with recent developments in offshore wind turbines (higher average wind speeds). Modern control systems also play a major role in the advance of wind energy, where modern wind turbines have complex systems for enhancement of their efficiency and energy generation (Asim et al., 2022).

A summary of wind turbines regarding the presented criteria is presented in Table 4.13.

Renewable Energy Generation
Wind Energy

Applicability	Easy for VAWTs, but complex for HAWTs in urban areas
Modularity	Easy to modulate (addition of new turbines)
Installation Process	Civil, electrical and logistics works are needed
Need for Specific Natural Conditions	Wind studies are required (high average wind speed and frequency)
Density of Installed Power / Gener. Unit	From kW to MW per wind turbine (especially for offshore ones)

Table 4.13 - Wind energy - Summary of the presented criteria (2022).

4.5 Implementation Process

The recent creation and large scale spread of the concept are associated with important factors as the increase of distributed generation based on renewable energy sources (prosumption), development of associated regulatory framework, innovations on business models related to the energy market, application of IoT and Blockchain technologies in energy services, need for security and reliability on energy supply and urgency in decarbonizing the economy, where important challenges and barriers for the worldwide development of RECs are presented (Di Silvestri et al., 2021).

According to Gjorgievski (2021), a Renewable Energy Community has three types of major players - namely, consumer, energy service provider and initiator - where they all interact with each other for the functioning of the REC. In a simple way, the consumer/prosumer is the beneficiary (energy or another commodity), provided by another player by joining the REC. The energy service provider is responsible for the services associated with energy, such as transmission, distribution, generation (centralized generation) and supply, owning (in an individual or collective way) and using the electrical infrastructure. A prosumer is also an energy service provider, due to the fact that shares responsibility for the energy generation and can also sell the surplus to the grid. Finally, the initiator deals with the organization and coordination of the REC itself, being crucial for the implementation and maintenance processes.

Figure 4.4 presents a scheme of these major players and their interactions.

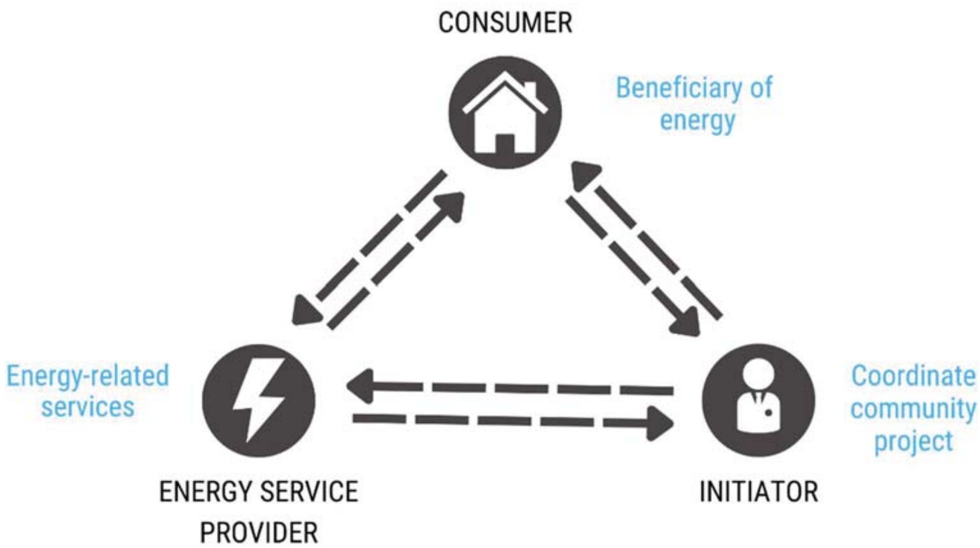

Figure 4.4 - Major players on a REC (Adapted from Gjorgievski, 2021).

Even though the major players and their respective roles can be listed, the concept of Renewable Energy Community is very wide ad can have many different operational forms, which depend on the objectives of the REC, organization, and its strategies to meet its purposes (Seyfang, 2013).

In this process of implementation of a REC, an important partner can be seen as a great facilitator: the local government. Working together with the municipalities is a "two way street", where both entities have much benefits associated with the promotion of these local organizations - many cities are still having problems to put in practice energy actions regarding energy efficiency and renewable energy generation in the local community, as well as local groups that aims to create a Renewable Energy Community face problems associated with motivation, voluntary work and the need for leadership and proactivity from citizens. Therefore, some of the ways that municipalities can act to help in this implementation process are presented: (REScoop.eu, 2023)

- **Providing favorable regulations to the development of citizens local energy actions**: less bureaucracy associated with this process, subsidies, favorable land-use regulation.

- **Enhancement of knowledge regarding energy:** share of knowledge associated with energy efficiency and renewable energy sources with the community, events and fairs about sustainability and action on climate change.

- **Financing projects:** the initial capital for the creation of the pilot project can be a significant barrier for its development, where the municipality can act to help in this first step.

- **Municipality as a direct member:** the municipality itself can become a member of the REC, without taking full control of the organization. Here, the municipality can contribute with sites and land for renewable energy generation (for example, roofs of buildings owned by the local government for the installation of PV modules), promote events, meetings and external partnerships for the REC and help in the possibility of this energy organization to reach new activities and fields of action, such as electric mobility and collective energy storage.

There are many advantages and challenges/barriers associated with the implementation of a REC. A review of the most important ones will be presented in the next topics.

4.5.1. Main Advantages

One of the most important contributions of a Renewable Energy Community is the fact that its implementation enhances the acceptance of renewable energy systems and alternative energies by putting citizens in decision-making situations on energy issues and increasing the awareness of the need for an urgent and deep energy transition. Furthermore, creating a REC improves energy decentralization and democratization through generation schemes as prosumption, facilitating the creation of a "sense of community" among the citizens and involved members/organizations (Hanke, 2021).

Historically, households are considered a target group hard to reach or persuade - even more when the topic in question is not widely known by the public. Not all citizens are aware of the situation regarding the urgent need for an energy transition, severe climate change and alternative and renewable energy sources. Through the active participation of the population in local energy politics, decisions and discussions, RECs can be considered a strategy to improve energy efficiency and conscious consumption in the household environment, also helping the citizens to acquire a more sustainable lifestyle through the dissemination of energy-saving expertise at the community level (Coehen & Hoppe, 2022).

Another important advantage of a REC is associated with energy poverty and vulnerable consumers. As previously mentioned, energy poverty can be defined as the inability of citizens to have adequate access to energy sources that lead, most of the time, to problems with excessive heat or cold inside homes, difficulties associated with basic food manipulation, among other facts. Some reasons to explain the importance of analyzing and finding ways to reduce energy poverty rely on the fact that it has a strong association with absolute poverty, malnutrition and poor diets, economic development, gender inequality and health problems (Hamed & Peric, 2020).

Also, the energy transition towards a matrix based on renewable sources and enhancement of energy efficiency needs to meet all the citizens, with no exclusions, as it is the only way to avoid more climate change effects soon. The implementation of a Renewable Energy Community may create a complete scheme that leads to reduction of energy poverty and increase of energy justice for vulnerable consumers - the so-called energy democratization - as it is based on three pillars: knowledge about energy efficiency and renewable sources, prosumption and energy management (Hanke & Lowitzsch, 2020).

a) Knowledge

To transform a citizen into an active decision-maker on energy questions, the Renewable Energy Community association needs to provide knowledge about energy efficiency and renewable energy generation to its members. Achieving energy efficiency in the household environment involves behavioral (personal attitudes and habits that consume energy in a non-efficient way) and financial aspects (tariffs, taxes, peak hours of consumption), where reliable information can lead to lower energy consumption.

Therefore, the citizens will start to consume less energy by applying simple energy efficiency procedures in their homes, leading to lower energy bills. Also, all this knowledge provided through the REC association can lead to the creation of small local business associated with renewable energy systems (project, installation, maintenance, consultancy) and energy services (technical services associated with electricity, energy management and electrical installations), which can be translated into creation of local financial, economic, and social value for the local citizens (Ebrahimigharehbaghi et al., 2019).

Also, the community will face empowerment (transformation of normal citizens into energy citizens) since its members will lead its energy decisions - so, most of the time, the REC will opt for paths that favor the community itself and its members, in a collectively way. The transformation of regular citizens into active players on the energy transition also enhances the knowledge about the electric system and the grid (Azarova et al., 2019).

b) Prosumption

Prosumer is strongly dependent on politics and energy regulations (especially the on-grid systems). In some cases, the surplus - generated amount minus consumed amount - can be sold to the energy company, where the prosumer receives money directly for this excess energy. Also, in other scenarios, this surplus can be consumed, as an energy credit, in a defined period by the prosumer, which leads to almost full use of the energy generated by microgeneration, thus reducing the payback time of the systems, and increasing the attractiveness of distributed generation. This creation of an extra income and/or faster return on investment leads to reduction of energy poverty as more capital will be available for improving energy use and increasing energy comfort in households (Ellsworth-Krebs, 2016).

In addition, a consumer who becomes a prosumer also increases his level of energy citizenship, where he becomes a more active player in the transition and has greater knowledge about his energy needs, also enhancing the energy democratization (Berka & Creamer, 2018).

Also, as previously mentioned, microgeneration systems are, most of the times, based on renewable sources - especially solar PVs - as the enhancement of prosumers provided by the implementation of a REC will conduct to lower greenhouse gas emissions and a larger share of renewable energy in the final energy consumption matrix.

c) Energy Management

Applying concepts of energy flexibility inside a Renewable Energy Community can lead to lower expenses - avoiding excessive consumption or increasing generation during peak hours can lead to lower energy costs in these periods. Another important aspect is monitoring and analyzing energy consumption profiles of the members of the REC, to identify patterns and possible faults, leading to increased energy efficiency. Also, energy storage can be used to supply part of the consumption during peak hours, avoiding energy consumption from the grid and higher energy tariffs during these hours (Li, 2021).

Other important advantage of a REC is associated with concepts as Smart City and flexible power systems. A Smart City can be defined as an urban area able to manage and control its connected devices in a reliable and affordable way. It can be amplified to concepts as energy storage, monitoring, analysis, and control in a smart way, using technologies like IoT (Camero & Alba, 2019).

Interrelations among buildings and houses associated with generation and consumption, storage of energy to provide a more reliable electrical power system based on renewable energies, monitoring consumption/generation and the instant fluxes of energy through smart meters and controllers and concepts such as smart mobility, governance and living are easier to apply and implement on RECs because of its level of integration and relation among members, buildings/houses, power plants and the electrical system itself (Simões et al., 2021).

Table 4.14 summarizes the main advantages and benefits provided by the implementation of a Renewable Energy Community.

Table 4.14 - Implementation of a REC - Main advantages (2022).

4.5.2. Main Challenges and Barriers

Important challenges and barriers regarding the implementation of a Renewable Energy Community are associated with the current policies and regulatory framework. The RED II (Revised Renewable Energy Directive) was a milestone for introducing the concept of a REC at an European level, but the governance and regulatory system of implementing these communities is left to the Member States, which have different regulations and policies about RECs.

The difficulty to define, in a common way, energy citizenship and energy democratization leads to ambiguity in developing the respective regulation. Also, a Renewable Energy Community can be implemented in many different ways, with various organizational structures, major players, financial organization, and forms of interaction with the electrical system and the grid, all dependent on how the concept will be developed in each scenario. It is hard to classify these communities in a common way in all the EU Member States (many other concepts similar to RECs have been developed and can cause confusion), in order to have similar policies and regulations for Renewable Energy Communities in the whole block. Also, it is necessary to mention that different Member States have different regulations and laws for distributed generation, on-grid systems, and their communication with the grid, prosumership and tariff systems (Heldeweg & Saintier, 2020).

Another important challenge regarding RECs is the need of energy justice in the transition. Sovacool et al. (2017) defines energy justice as "a global energy system that fairly distributes both the benefits and burdens of energy services, and one that contributes to a more representative and inclusive energy decision-making". Injustices regarding energy questions are related to aspects like social class, race, ethnicity, age, gender, or economic inequalities. The REC concept must be applied in order to achieve, as much as possible, fairness in the energy transition - any group, region or citizen should be able to benefit from these communities. This culminates in a great challenge due to the difficulties related to the implementation of the concept, especially in scenarios of totally isolated communities, regions with an average low level of education and areas with severe problems, among other aspects (Hanke, Guyet & Feenstra, 2021).

Technical and environmental barriers also represent a key role in Renewable Energy Communities. Technical challenges are linked, most of the time, to limitations of the electrical grid: topics regarding the intermittency of renewable energy generation - most cases, associated with solar PV and wind energy - low energy efficiency of the final users, the mismatch between peaks of energy consumption and generation or even problems associated with the lack of reliability on local energy supply or access to the grid (electrification problems) (Koirala et al., 2016). On the other hand, environmental challenges are more associated with land usage, especially for the installation of renewable energy systems that will be responsible for the distributed generation of the community and the waste provided by its implementation (van Zalk & Behrens, 2018).

Internal aspects can also be, in some cases, challenging for implementing a Renewable Energy Community - high costs of implementation due to the necessity of electrical grid infrastructure, design, acquisition and installation of renewable energy and storage systems, monitoring/analysis energy equipment and data processing/management - might be a challenge for the creation of a REC and can be aggravated in cases of lack of finance to run the project. Also, sometimes the lack of initiative of local members to accept or start the project can be translated into an important internal challenge. Even the lack of the concept of what a Renewable Energy Community is - by the population, local and national government entities, and potential investors in the energy sector - results in a barrier to its implementation (Koirala et al., 2018).

Another important aspect that needs to be mentioned is the concept of NIMBYism (Not In My BackYard). For some authors, this line of thought is based on selfishness and ignorance of the citizens, and the motto "renewable energy projects are good until the moment they are located close to my house" (Petrova, 2016), but renewable energy systems do have an impact in a residential zone, especially when the local community is not involved and consulted before the execution of the project, where this can lead to complete rejection and/or boycott of these systems by the locals.

It is a fact that public acceptance is a barrier for most of the new technologies, but although some of these citizens have proper knowledge of energy and climate problems, they put in the foreground the negative aspects of having renewable generation plants close to their residential areas. The biggest problem is that NIMBYism, most of the time, is defined by the lack of theoretical basis, real study cases, and conceptual models - even though the impacts provided by these renewable energy systems exist and must be considered, the positive aspects of this type of generation is much larger and considerable, especially when considering the current scenario regarding the urgency for a clean energy transition and the climate change situation (Wolsink, 2000).

Some renewable energy sources - as wind turbines and centralized PV generation - face more problems with this concept than others - as distributed PV generation. In the suburbs of New England Town (Massachusetts, USA), for example, a 2MW ground-mounted solar project faces this type of problem with the local community based on themes, such as loss of community local control, distrust of the project owners due to lack of connection with the citizens and desire of keeping this residential area esthetical aspects and zoning (O'Neil, 2021). Another case is the implementation of wind turbines in small Israeli cities (country with a society not used to wind energy, which has a complex terrain, high populational density, and important religious areas). NIMBYism is presented in this case with topics such as visual impacts, noise intensity and bird deaths (Peri, Becker & Tal, 2020).

A review of the main challenges and barriers associated with the implementation process of a REC is shown in Table 4.15.

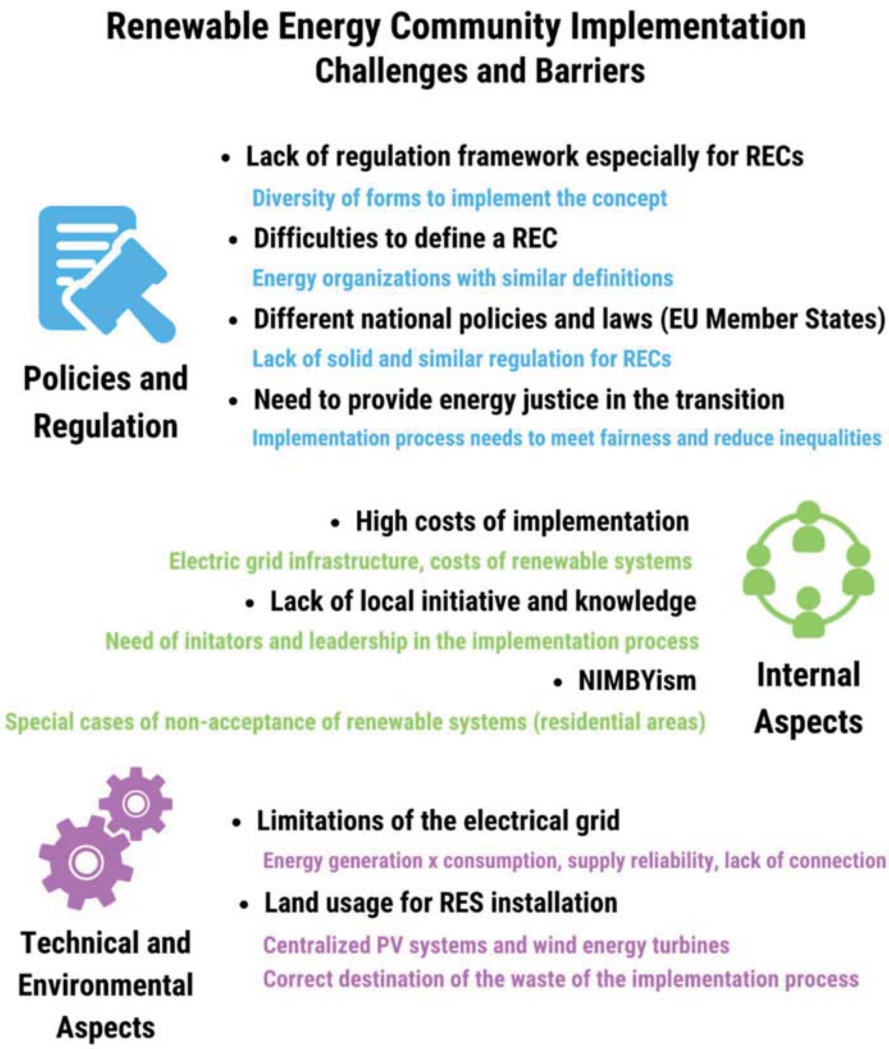

Table 4.15 - Implementation of a REC - Main challenges and barriers (2022).

4.6 Classifications and Real Cases

Many classifications of RECs have been made with different criteria by many studies. To categorize a Renewable Energy Community, is common to analyze three aspects: organizational structure, interplay between major players and financial questions associated with its implementation and operation. In this topic, four main categories of RECs in the literature - namely location, purpose, organization, and associated activities - are presented and linked to existing real cases.

4.6.1 Location

The classification of Renewable Energy Communities associated with the correspondence between the community and a specific area can be drawn between place-based and non-place-based REC. A place-based REC is an energy community that is directly associated with a specific territory, while a non-place-based REC has not this connection with a portion of land. The boundaries and extension of a place-based REC can vary from tower blocks and grouping of houses to city districts, where the members have similar aspects (social, local). A non-place-based REC can have members of different locations and realities, and it does not necessarily require ownership of equipment or land (Moroni et al., 2018).

A real case of a place-based REC is the Sola-Re, created in 2011 and located in Recklinghäusen (Germany). This Renewable Energy Community was founded since the citizens decided to exploit the potential of many public roof surfaces in the city for electricity generation through photovoltaic conversion. The city of Recklinghäusen itself supports the initiative by the lease of the roof surface for PV modules - even the major, personally, invested in the REC. The total PV plant is divided into three systems, which can generate a total of 195,000kWh per year (supplying around 60 households on an annual basis). The founding of the project was totally done by own capital resources, where citizens could participate with the minimum investment of 500 euros. Three companies and an association were created to run the project, where the members of the companies - 70 to 80 citizens on each one - finance and consume the generated energy, while the association is responsible for the construction and maintenance of the three PV systems (Enercommunities, 2022).

Figure 4.5 brings a view of one of the PV plants of Sola-Re, installed in the rooftop of the City Hall of Recklinghäusen.

Figure 4.5 - Recklinghäusen Solaranlage Stadthaus A, one of the three PV plants of Sola-Re - City Hall of Recklinghäusen (Recklinghäuser Zeitung, 2022).

Another example of a place-based REC, now using wind energy instead of photovoltaics, is the Gorran Highlanes, which also started in 2011 in Saint Gorran, United Kingdom. Around 100 citizen members invested, together, 80,000 pounds to build two 80kW wind turbines in the city, where the generated energy is shared among the members. The Gorran Highlanes project is part of the Community Power Cornwall Initiative, which has the mission to promote conditions to collective-owned renewable systems (Moroni et al., 2019). Figure 4.6 brings a view of some members of this REC and one of the wind turbines.

Solardachbörse is a German non-place-based REC, consisting of an online portal that makes the connection between supply - in this case, people who want to rent out their roofs for PV systems - and demand - in this case, those who do not have or want more roof space for investments in PV energy - where members can choose among the type of roofs, maximum rent amount and minimum area. At the end of 2018, 22,000m² were rented and became operational PV systems via this platform (Steinhausen, 2011).

Figure 4.6 - Community Power Cornwall (Community Power Cornwall, 2022).

4.6.2 Purpose

According to the number of purposes of the community, two types of Renewable Energy Communities can be listed: single-purpose and multi-purpose. A single-purpose REC consists of an entity, with settled rules and relations among players, only for purposes associated with energy production and consumption/purchase. On the other hand, a multi-purpose REC shares other types of goods and services beyond energy (Moroni et al., 2018).

Beyond the examples of Sola-Re, Community Power Cornwall and Solardachbörse, another single-purpose REC is the Comunità Solare Locale, which started in 2014 in Casalecchio di Reno (northern Italy). The idea of the community started with a research group at Bologna University, and it began with 23 family members (until 2018, there were 80 members). The main objective of the community is to identify and make available, by local entities and public buildings/spaces roofs for shared PV systems installation, where the members share the generated energy (Centro Per la Comunità Solare, 2022). Figure 4.7 brings an overview of a community action of Comunità Solare Locale and some of its members.

Figure 4.7 - Community action of Comunità Solare (Comunità Solare Locale, 2022).

On the other hand, The Samsø Project is an example of a multi-purpose REC. Starting in 1997 and placed on Samsø Island (Denmark), the concept of the project involves multiple associations working together for shared goals, such as energy transition and local development of the island. The main plan of the project is to achieve the complete independence of the island based on the local population's decisions and founding. In the energy field, the project promotes the complete dissemination of renewable energy systems, based on eleven on-shore wind turbines and ten off-shore ones, totalizing 23MW of installed power. In 2007, The Samsø Project started to encompass other aspects, such as independent communication infrastructure and solutions regarding mobility, waste, and agriculture (Sperling, 2017). Figure 4.8 brings a view of the offshore wind turbines associated with this REC.

Figure 4.8 - Samsø Project - Off-shore wind turbines (VisitSamsø, 2022).

4.6.3 Organization

Regarding the organization, there are three types of RECs: centralized, decentralized and distributed. This classification is connected directly to the planning and governance mode - members and other main players and their roles in the operation of the REC (Gjorgievski, 2021).

A centralized REC is the one where households and businesses, in a collective way, own or participate in energy projects, being the most common type of Renewable Energy Community. Basically, they are initiatives started on a community scale where the governance, decision-making, organization, and implementation are done also at a community level (Gui, 2018). Most of the time, it is also linked to experimental learning, extreme citizen empowerment (energy citizenship) and social development (Rowse, 2014). An example is the Hepburn Wind Project, started in 2011 and regarding a 4.1MW wind farm (two wind turbines) located in Daylesford (Australia). The community is led by a cooperative, where each member has a vote in energetic decisions (Holmes, 2014). Figure 4.9 brings a view of some of the members of this REC and one of the two wind turbines.

Figure 4.9 - Hepburn Wind Project (Flora & Fauna, 2022).

On the other hand, a distributed REC is the one where the households and businesses own or participate in energy projects individually, and they are connected via an entity - virtual or not - sharing the same rules. Here, most of the members are not directly connected and they make individual investments/decisions according to their own preferences but are controlled by a legal entity designed for this purpose (Gui, 2018). Western Australia (WA) Peer-to-Peer Trading Trial is an example of distributed Renewable Energy Community, consisting of an association of 10 households and about 20 people at Busselton (Australia), trading energy in a peer-to-peer way (digital mode with no centralized server, where each computer realizes the function of client and server) with the local grid company. Through a blockchain-based software, citizens can buy excess generated energy from PV power plants in the city directly from the member that own these systems or portions of PV plants (Vorrath, 2016).

The last type of classification regarding organization is the decentralized REC, which is based on the concept of self-sufficiency: in this type of Renewable Energy Community, the households, businesses or even municipalities generate and consume energy locally, in a self-sufficient way, and can or cannot be connected to the electrical grid (on-grid or off-grid) where, like the distributed REC, most of the members are not connected directly with each other (Wellman, 2005). Many municipalities around Europe are organizing decentralized RECs, such as Michałowo (Poland), Magliano Alpi (Italy), Ellhöft, Westre and neighboring villages in Schleswig-Holstein (Germany), Eeklo (Belgium), among other examples (Hinsch, Rothballer & Russel, 2022). Figure 4.10 presents a view of a PV system associated with the municipality of Magliano Alpi (Italy).

Figure 4.10 - Decentralized REC - Municipality of Magliano Alpi (Italia Che Chambia, 20222).

4.6.4 Activity

Based on the type of activities that are implemented, there are three main types of Renewable Energy Communities: promotion of home energy services, development of collective energy generation and development of collective energy management. Here, it is important to mention that different types of activities can be presented at the same time in a REC.

The activities can be based on an association of members who wants to promote home energy practices regarding consumption and generation, in order to increase energy efficiency/generation and reduce energy bills. Civic attitudes inside homes made by households make a considerable impact in the community total energy consumption and generation, where the importance of making energy "visible", highlighted, managed, stored, and discussed by normal citizens helps to create an energy concern that is crucial to a REC operation (Hargreaves, Nye & Burgess, 2010). This activity is done through the promotion of technical and non-technical knowledge about these practices to the members, creating the notion of how important renewable energy systems and energy efficiency are. For example, constant decreases of PV modules prices led to the creation of community associations to collective purchase of PV systems and creation of RECs, such as Duurzame Energie Haaren (Haaren - the Netherlands) and Morgen Groene Energie (Nuenen - the Netherlands) (van der Schoor et al., 2016). Figure 4.11 brings a view of one of the Duurzame Energie Haren PV plants.

Figure 4.11 - One of Duurzame Energie Haaren PV plants: Zonneweide Glimmen (Duurzame Haaren, 2022).

Collective energy generation can be seen as the "step forward" from home energy practices and distributed generation in the Renewable Energy Community. Large solar PV plants, wind farms or biomass facilities can be installed, and the members of the community have portions of the generated energy, but do not own or are responsible for the generation units and their operation, maintenance, or monitoring. The founding of the project needs to be designed to promote equality among the members, which are responsible for the costs - there is not a large investor for the whole generation system. Also, to do this operational scheme, it is important that the local electrical grid have adequate and reliable infrastructure (Smith et al., 2016). An example can be the cooperative Escozon (Heeten - the Netherlands), focusing on supporting local initiatives on RECs through the development of sustainable renewable energy-based power plants, where the generation - most of the time, provided by PV plants - is shared among the local members of the community (Escozon, 2020).

The third activity is another evolution for a REC: energy management. It is crucial for an optimized system involving energy generation and consumption to monitor, analyze and make improvements in the forms that this energy is reaching its final use. Concepts such as energy monitorization, energy storage systems, microgrids, evaluation of energy quality and usage of Internet of Things (IoT) technology in power systems can be utilized to maximize the entire efficiency of energy consumption/generation in a Renewable Energy Community, and it must be done in a collectively way, with transparency and side by side with the community members, reaching - among other benefits - financial rewards by avoiding losses, preventing failures and increasing the reliability on the REC's energy system (Hirsch, Parag & Guerrero, 2018). The Samsø Project itself is an example of a Renewable Energy Community that uses many concepts of energy management. Figure 4.12 presents one of the PV plants of Escozon REC.

Figure 4.12 - A Escozon PV power plant (Escozon, 2022).

A summary of all the presented projects and their classifications according to the showed criteria can be found in Table 4.16.

REC Classification Location, Purpose, Organization, Activity

Criteria	Classification	Real Cases
Location	Place-Based	Sola-Re (DE), Gorran Highlanes (UK)
	Non-Place-Based	Solardachbörse (DE)
Purpose	Single-Purpose	Comunità Solare Locale (IT)
	Multi-Purpose	Samsø Project (DK)
Organization	Centralized	Hepburn Wind project (AU)
	Distributed	Western Australia Peer-to-Peer Trading (AU)
	Decentralized	Michałowo (PO), Magliano Alpi (IT), Eeklo (BE)
Activity	Promotion of Home Energy Practices	Duurzame Energie Haaren (NL) Morgen Groene Energie (NL)
	Collective Energy Generation	Cooperative Escozon Heeten (NL)
	Collective Energy Management	Samsø Project (DK)

Table 4.16 - RECs classification - A summary (2022).

5

STUDY CASE: TELHEIRAS RENEWABLE ENERGY COMMUNITY (LISBON, PORTUGAL)

In this chapter, the study case of a Renewable Energy Community in Telheiras neighborhood, located in Lisbon, Portugal, will be presented. First, an overview of the recent Portuguese legislation regarding climate action and RECs will be presented, as well as an introduction of the characteristics of the location of the Study Case. Then, the history of projects and pioneering spirit of Telheiras in topics related to sustainability will be shown, as well as information about the REC itself, such as its development, associated renewable energy source and the current status of the organization.

5.1 Overview: Portugal

As a Member State of the European Union, Portugal has developed different regulations and laws regarding climate change and energy transition in the recent years.

One of the most important recent steps was the *Roteiro para Neutralidade Carbónica 2050* (Roadmap for Carbon Neutrality 2050), signed on July 1, 2019, being the first national document where Portugal firms the commitment to become carbon neutral by 2050 (carbon neutrality means a scenario where the emissions and captures are equal, turning the carbon balance neutral). Acting in four principal pillars - namely, energy, transports, residues, and agriculture/forests/use of the soil - the main objective of this document is to identify, analyze and propose paths, through viable ways (economic and social), to reach this main goal aligned with the Paris Agreement (Diário da República, 2019). To achieve this objective, the electric sector plays a key role, where renewable energy sources, distributed generation, energy efficiency procedures and local energy actions are important parts of this process.

Specifically, regarding the current decade, the most important national document associated with energy and climate politics is the *Plano Nacional Energia e Clima 2021-2030* (National Energy and Climate Plan 2021-2030), approved on 10 July, 2020, where a complete characterization of the current status and the definition of specific targets for each sector of the economy - especially those associated with emissions reductions - for the decade. This national plan is totally aligned with the goal of complete decarbonization by 2050, where the principal pillar is the increase of energy efficiency in different sectors (buildings, industry, agriculture, use of the soil), where other important aspects are also linked this plan, such as enhancement of the share of renewables in the final consumption matrix, energy supply security and interconnections and sustainable mobility (Diário da República, 2020). Becausee this document was approved after the beginning of the Coronavirus pandemic, it also reflects and takes into account a scenario of reaction and resumption of climate commitments in a context of extreme instability and provoked changes.

Another milestone was the *Lei de Bases do Clima* (Climate Bases Law) - approved in the last day of December 2021, this law presents the guiding principles of the Portuguese climate policy and governance for the next years, aligned with the goal of carbon neutrality by 2050 and a possibility to reach that by 2045. Here, different sectors of the economy are involved, where it entered into force on February 1. The most important difference between *Roteiro Neutralidade Carbónica 2050* and *Lei de Bases do Clima* is that the last one is, in fact, a law, where obligations regarding climate action in a structural scale were stablished, while the first document focus more on defining ways and paths for the decarbonization, as well as technologies and progressions to achieve this main goal (Assembleia da República, 2021).

A timeline of these three important Portuguese documents is presented in Figure 5.1.

Regarding Renewable Energy Communities, important recent regulations with a view to accelerate the development these energy organizations in the country were created, where one of the most important ones is the *Decreto-Lei nº15/2022* (Ordinance nº 15/2022), published on January 14, 2022. Here, the Portuguese definition of a REC is provided, also with important rights to guarantee the citizen participation in those organizations and forms of the electrical national system to incorporate those entities (Diário da República, 2022).

Also, in *Decreto-Lei nº 30A-2022* (Ordinance nº 30A-2022), published on April 18, 2022, the promotion of RECs is done, in an exceptional and temporary way, through the reduction of bureaucracy and greater speed in the process of regularization of distributed generation systems - based on renewable energy sources - with the electric grid (Diário da República, 2022).

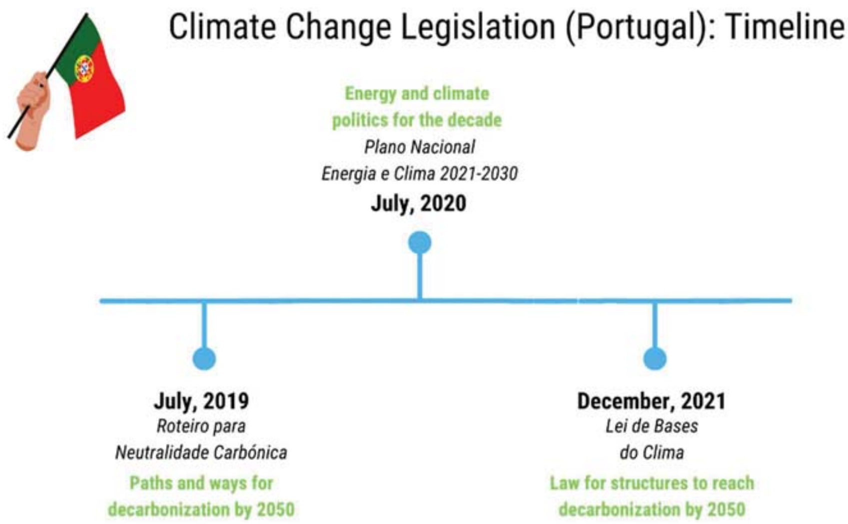

Figure 5.1 - Portuguese milestones regarding climate action (2023).

Another important step for the development of Portuguese RECs was the *Decreto-Lei nº 72/2022* (Ordinate nº 72/2022), published on October 19, 2022. Here, even more ease was provided for approving and operating electro-producing centers of renewable energy sources, leaded by the scenario of Russian invasion of Ukraine and urgent necessity of increase of national energy supply security/reliability and participation of renewable energy sources in the matrix (Diário da República, 2022).

As previously mentioned, one of the main initial obstacles to the implementation of a REC is related to the initial capital needed to organize and launch the organizational. Therefore, governmental financing schemes that act to mitigate this financial barrier are crucial to spread these energy organizations in a national scale.

An example of these actions can be seen in Portugal, through the *Investimento de Apoio à concretização de Comunidades de Energia Renovável e Autoconsumo Coletivo* (Investment to Support the implementation of Renewable Energy Communities and Collective Self-Consumption), program founded by the European Union under the Portuguese *Programa de Recuperação e Resiliência* (Recovery and Resilience Program). Here, the main goals are to enhance energy efficiency (at least, 30% reduction of primary energy consumption on the participant buildings) and increase the capacity in self-consumption and/or Renewable Energy Communities (residential, central public administration and services sectors) by, at least, 93MW. The maximum value given to each collective self-consumption or REC project is 500.00,00 euros and the total allocation of the program is 30 million euros (10 million euros for residential sector, 10 million euros for central public administration and 10 million euros for the service sector). The deadline for submitting applications was extended several times and runs from 14th of June 2022 until 17th of February 2023 or until the total amount is reached, where it is made through an online platform (Fundo Ambiental, 2023). Figure 5.2 brings a scheme of this Portuguese financial project.

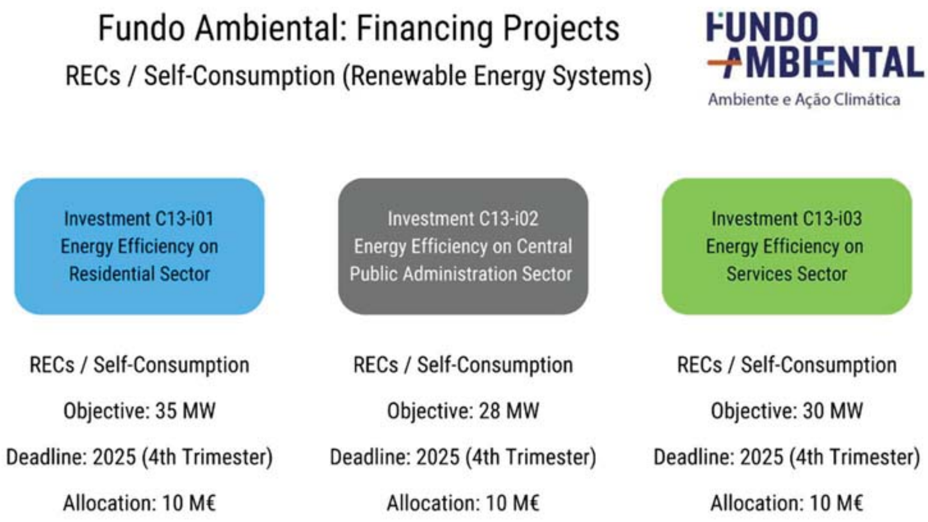

Figure 5.2 - *Fundo Ambiental* - Financing Programs (2023).

However, the number of Portuguese RECs and Collective Self-Consumption (CSC) organizations are not increasing rapidly. According to Environmental and Climate Action Ministry, by 20 January 2023, Portugal has only four RECs/CSCs in total operation and 372 licensing processes for these energy organizations, evidencing that the number of communities aiming to create a REC is increasing, but the national reality is still far from northern European countries as the Netherlands and Germany, where many RECs are already operating (Público, 2023).

The first Renewable Energy Community launched in Portugal in the summer of 2021 and was created in a small town close to the border with Spain - Miranda do Douro. In this REC, a local site of a catholic brotherhood whose mission is to care for and support the sick and disabled (Santa Casa da Misericórdia de Miranda do Douro) is responsible for solar PV systems on different rooftops in order to reduce its costs with electrical energy. This project is provided by the company Cleanwatts, which aims to support the creation of a hundred RECs in small Portuguese villages (Sapo, 2021). In Figure 5.3, one of the PV systems associated with this REC is presented. Another example of a Portuguese project of REC is the AcerBatalha (*Associação da Comunidade de Energia Renovável da Batalha* - Batalha Renewable Energy Community Association), located in the city of Batalha (center of Portugal). This REC involves many associations and companies, as well as the City Hall, the renewable generation is based on PV modules on rooftops of 25 public and commercial buildings associated with energy storage units (Câmara Municipal da Batalha, 2023).

Figure 5.3 - One of the PV systems of the REC in Miranda do Douro (2023).

Among these 372 licensing processes, some important projects of RECs in different regions of the country can be found. In the extreme south part of Portugal - the touristic region of Algarve - a pilot project of a REC in Culatra's Island has been promoted, based on new forms of energy consumption by households through energy management systems associated with renewable energy generation and the implementation of a new model of circular economy, where the profits and costs of this renewable generation will be distributed in order to promote the development of the local community. The whole project has the support of Algarve University and the local resident's association (Culatra 2030, 2023). Figure 5.4 brings a view of one the existing PV plants near the island docks.

Figure 5.4 - Existing PV plant in the docks of Culatra's Island (Culatra Project, 2023).

5.2 Telheiras Neighborhood

Located in the Lumiar Civil Parish (with also a small area in the Carnide Civil Parish) Telheiras is a neighborhood of the north part of Lisbon, capital of Portugal. Its urbanization was planned in the 1970's, by EPUL (Public Urbanization Company of Lisbon), were many parks, green areas, and important connections with other parts of the city through three different expressways can be seen. The neighborhood is considered mostly residential, where most of the residents belong to an upper-middle social class and are graduated (Contumélias, 2008).

Most of the buildings in this neighborhood are symmetrical and residential, with shops on the ground floor, where commerce associated with general retail, offices, food services and health/beauty are the most presented in the location (Sequeira & Joanaz de Melo, 2020). A view of the area of this neighborhood is presented in Figure 5.5.

According to the maps from Solargis (2023), Portugal - and especially Lisbon and the south region of the country - presents a propitious scenario for PV generation, where high values of average global irradiance are presented. This explains the wide use of PV systems in this country, being one of the pillars for the fulfillment of the Portuguese goals of decarbonization. The map of global horizontal irradiation for Portugal can be seen in Figure 5.6, where the districts of Lisbon, Setubal, Evora, Beja and Faro present the highest values. Also, a view that presents the symmetry of the buildings in Telheiras can be seen in Figure 5.7.

Figure 5.5 - Map of Lisbon - Telheiras (Sequeira & Mameri, 2022).

Figure 5.6 - Map of global horizontal irradiation - Portugal (Solargis, 2023).

Figure 5.7 - Evidence of the symmetry of the buildings in the central area of Telheiras (2023).

5.3 Telheiras' Pioneering in Sustainability

First, it is important to mention that Telheiras neighborhood plays a pioneering role in sustainable practices, environmental concern, and energy efficiency procedures, with a very united and organized community. It can be seen by the *Parceria Local Telheiras* (Local Partnership of Telheiras) an informal network of around 20 formal entities and informal groups created in 2013, ranging from local organizations of parents of students from schools in the neighborhood and the local association of residents, to the Lumiar Civil Parish and the local Public Security Police entity. The *Associação Viver* Telheiras is the formal entity that manages the work of *Parceria Local* Telheiras. A view of the entities and organizations that are part of the Parceria Local de Telheiras is presented in Figure 5.8.

Figure 5.8 - Parceria Local de Telheiras - Entities and organizations (Sequeira & Mameri, 2022).

In this context, one important step took place in 2018, where a working group about sustainability was created - *Grupo Pegada Ecológica* (Ecological Footprint Group), also known as *Grupo Telheiras Sustentável* (Sustainable Telheiras Group) - with objectives regarding enhancing local sustainability and environmental concern. Important entities of *Parceria Local Telheiras* were also integrating this new group, such as, for example, the Lumiar Civil Parish itself. This can be seen as an important first step for all the existing projects regarding sustainability, energy efficiency and renewable energy generation in Telheiras.

In 2018, Telheiras neighborhood became a pilot-case on project Municipalities in Transition. This project has the objective of reuniting scenarios of collaboration between citizens and local public administration entities regarding sustainability, actions on climate change, community resilience and reduction of inequalities, in order to identify existing local sustainability actions and enhance their impact in the community, recognize new initiatives of programs and actions for enhancing the local sustainable development and share all this framework with other cases around the world (Municipalities in Transition, 2023). Among around 80 candidates around the world, the neighborhood of Telheiras was one of the six pilot cases selected. Figure 5.9 brings an overview of all the selected pilot cases for the Municipalities in Transition project.

Figure 5.9 - Municipalities in Transition - Selected pilot cases (2023).

In 2020, *Grupo Telheiras Sustentável* was opened to general citizens, facing many voluntary associations, and launched the "Networked Ideas" process - a project where the citizens could show their ideas of projects that they would like to be carried out in the community (Sequeira & Mameri, 2022). The first stage of this process occurred during a neighborhood festival, where the locals could write their ideas for the community in papers that were fixed in a structure in a central location of Telheiras (Figure 5.10). This first stage was also complemented with an online survey. In the second stage, the group systematized all the ideas according to its key stakeholder for implementation: local partnerships (type 1), local partnerships and local authorities (type 2), and local authorities (type 3), where distinct approaches were done for each typology. The principal ideas and approaches were:

a) Type 1 Ideas - Local Partnerships (29 Ideas)

As these ideas only concerns for local partnerships that are led by the citizens of the neighborhood, a more hands-on approach is required. Here, the pilot project was the

Biodiverse Telheiras, where volunteers were responsible for building shelters in the region for birds, bats, and pollinators, contributing to the local ecosystems.

Figure 5.10 - Networked Ideas - First stage (Parceria Local de Telheiras, 2020).

After this pilot idea, an online open call for volunteers began to start other groups from the Networked Ideas action, such as: Made-In Lumiar Brand (valorization of local handcraft products through the creation of a local brand) and Neighborhood Cleanups and Waste Reduction (call for the citizens to clean the public spaces of the neighborhood and promote the reduction of waste production by local households). The idea of a Renewable Energy Community in Telheiras began here, as a Type 1 Idea.

b) Type 2 Ideas - Local partnerships plus local authorities (14 Ideas)

Since this type of idea requires not only actions provided by the citizens, it was necessary to select among in order to contact the local authorities and focus on the most approved ones by the locals. To do so, an online public pool was done, where two selected ideas went to selection to Lisbon's participatory budget. Only one idea was selected: ReCoopera, a program that aims to create an interactive space of theoretical and practical knowledge sharing among the residents of Telheiras, where the concept "do-it-yourself" promotes a creative environment and the empowerment of the citizens.

c) Type 3 Ideas - Local authorities (15 Ideas)

This type of idea is the only one that the locals do not have any independence or ability to promote them entirely by themselves. Therefore, those 15 ideas were forwarded to the authorities, expecting to be executed by those.

A summary of the Networked Ideas action can be seen in Figure 5.11.

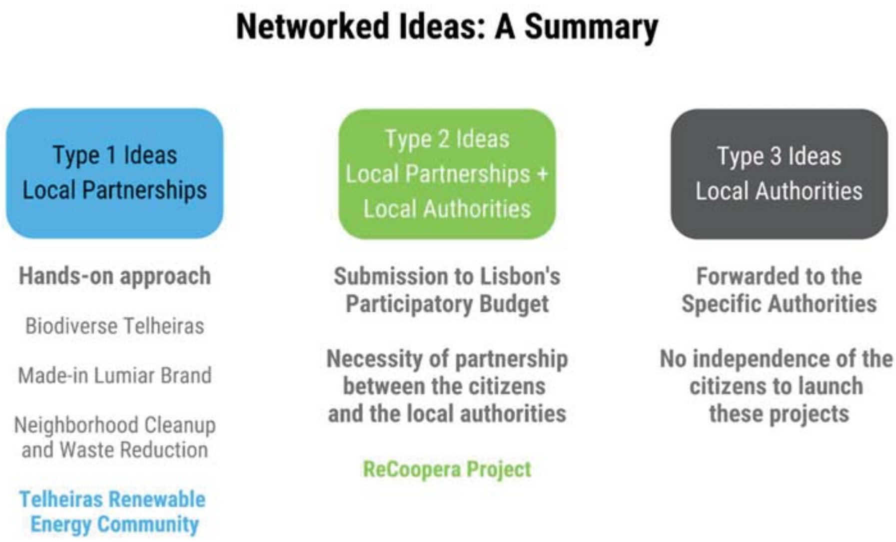

Figure 5.11 - Networked Ideas - A Summary (2023).

This brief context showcases that Telheiras is already a "sustainable" neighborhood, with community engagement for a better future regarding environmental, social, and economic questions.

5.4. Telheiras Renewable Energy Community

In this section, the creation, operational forms, and organizational structure of Telheiras REC will be presented, being the study case of this dissertation. Finally, the current status of development of the project will be shown, linking to the work presented in the results section.

5.4.1. Creation Process

As previously mentioned, the initial idea of a Renewable Energy Community in Telheiras appeared in 2020, with the local action Networked Ideas as one of the Type 1 ideas. However, it is important to mention that previous work in the topic of energy efficiency was performed in Telheiras, namely a master's thesis in Environmental Engineering at FCT-NOVA (Sequeira, 2016) and an associated published article (Sequeira & Joanaz de Melo, 2020), where, with these studies, a start for the energy analysis of the locality was done.

In September 2021, at a local festival, *Grupo Telheiras Sustentável* started the discussion to put into practice some of the ideas from the action Networked Ideas, where the discussions about a REC in Telheiras started. The main pillars about the implementation process of this energy organization were: who (which persons/entities could be involved), with who (which natural actors should also be involved), what (what do we imagine that could be done), for what (what are the objectives of this action), how (what is necessary for put in practice) and where (in which sites could it happen). This session counted with the participation of one expert from Lisboa E-Nova - Lisbon's Environmental and Energy Agency. A photography of this meeting can be seen in Figure 5.12, as well as the original paper that was filled with these pillars and their respective answers in Figure 5.13.

Figure 5.12 - Meeting at a local festival - Initial discussions regarding the implementation of a REC in Telheiras (Parceria Local de Telheiras, 2021).

This initial idea of the REC was formulated as "Let's produce our own renewable energy in Telheiras and share it among neighbors" and was based on three levels:

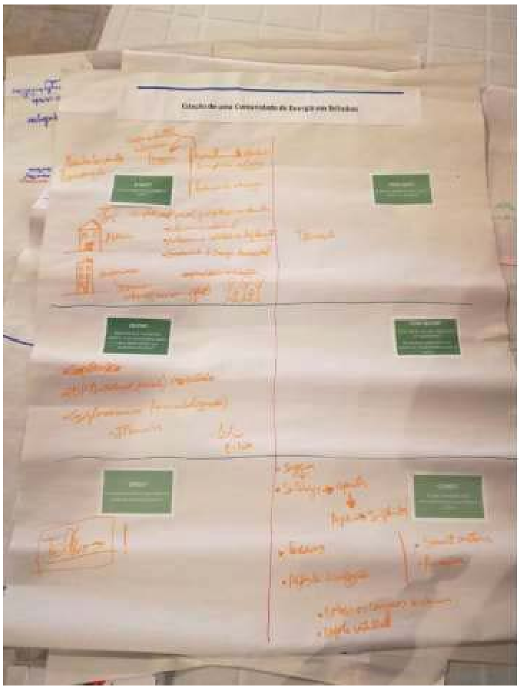

Figure 5.13 - Original paper filled at Telheiras Festival - Answers for the six main questions (Parceria Local de Telheiras, 2021).

- Communication and raising awareness about energy efficiency, energy poverty and renewable energy systems among residents and local organizations.
- Facilitate contact with companies in the electricity sector, suppliers, and other important players, also supporting families, condominiums, and local businesses.
- Develop and invest in local projects to improve energy performance and energy production through renewable sources.

A summary of the answers and results obtained in this meeting is shown in Figure 5.14.

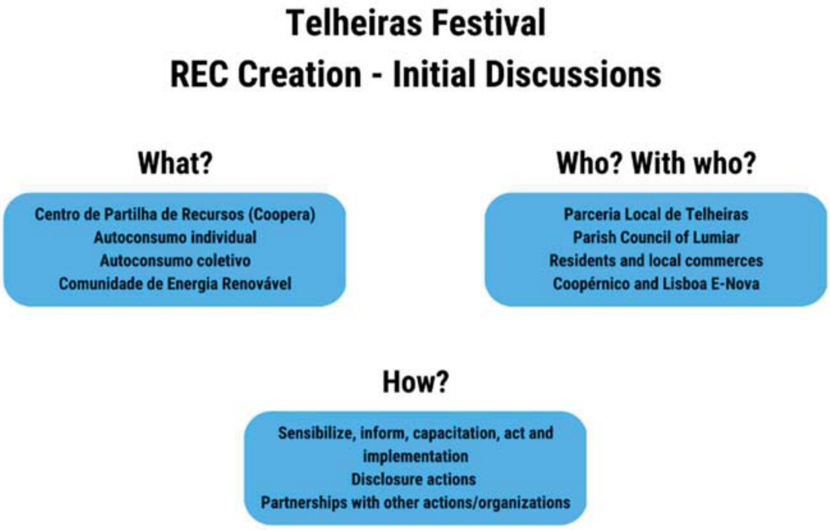

Figure 5.14 - Summary of the answers to main questions about the implementation process of the REC (2023).

After this big initial step, a voluntary working group to realize this REC implementation process was created in November 2021. One of the first actions of this group was the organization of a public session in February 2022, with the topic "Renewable Energy Communities: What? How? And in Telheiras?", which increased the local acceptance and knowledge about RECs and gathered new volunteers to the group. This session counted with the participation of the *Parceria Local de Telheiras*, the Lumiar Civil Parish, Coopérnico (cooperative that acts with the development of these local citizen organizations), and FCT-NOVA (Figure 5.15). So, in 2022, several other actions began to be carried out to get the project off the ground.

Figure 5.15 - Public session in Telheiras about the development of a REC (Parceria Local de Telheiras, 2022).

5.4.2 Pilot Project: Structure

A game changer partner for the Telheiras REC has been the Energy Poverty Advisory Hub (EPAH) - focused o the reduction of energy poverty and enhancement of energy citizenship in the transition, this EU initiative provides support, training with experts and research results through a collaborative environment of stakeholders, municipalities, and authorities for sharing and providing measures for the reduction of energy poverty. Technical support is given after the evaluation of applications and requests for support from municipalities and civil parishes across the EU, where tailored technical assistance is given to chosen local authorities and which supported by expert institutions for developing the local projects (EPAH, 2023).

In the case of Telheiras, the Renewable Energy Community development was selected to be part of the first roster of the EPAH supported technical assistance projects, where the chosen institution to help this development and the implementation process was Coopérnico - Renewable Energy Cooperative. The original poster of Telheiras' candidacy to participate in EPAH, as a partner with the Lumiar Civil Parish, is shown in Figure 5.16.

Figure 5.16 - Telheiras' project overview - Original poster (EPAH, 2022).

After selected, the workplan for the support provided by EPAH was developed and based on three main pillars:

a) Energy poverty analysis in Lumiar

To classify and understand the characteristics of energy poverty in the parish of Lumiar, aiming to obtain a diagnosis of vulnerability, a complete study was developed in September 2022, in partnership with the experts from CENSE (Center for Environmental and Sustainability Research) from FCT-NOVA. The methodology relies on two components of analysis: calculation of the thermal discomfort gap and calculation of the adaptive capacity of the population. The first one is associated with comparisons between the theoretical final energy consumption for heating and cooling and the effective consumption, and the last is linked to the vulnerability of the population to the consequences of energy poverty, measured through social economic aspects of the residents such as average income, age, unemployment index, state of the buildings and education degree. Then, combining these two parameters, an index of vulnerability to energy poverty was calculated for the winter and the summer, ranging from 1 (best scenario) to 20 (most vulnerable situation) (Palma & Gouveia, 2022). The two resulting maps for Lisbon are presented in Figure 5.17 and 5.18.

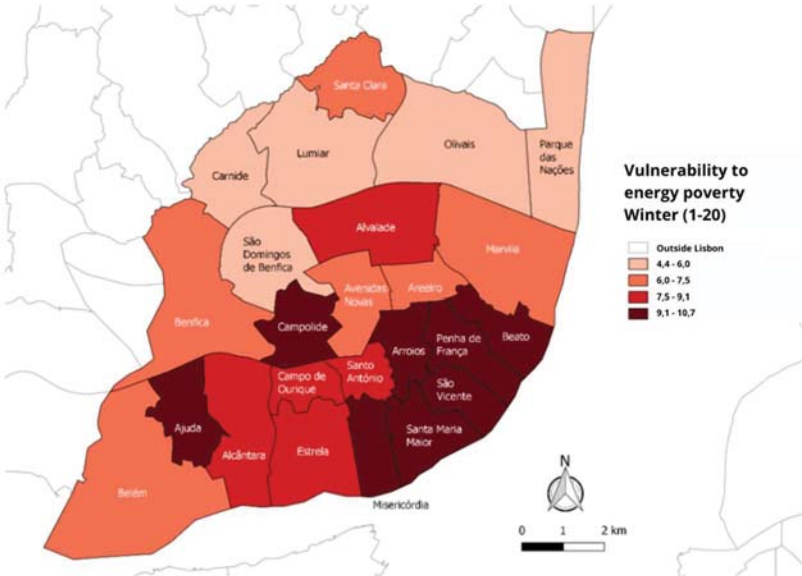

Figure 5.17 - Vulnerability to energy poverty in Winter - Lisbon (Adapted from Palma & Gouveia, 2022).

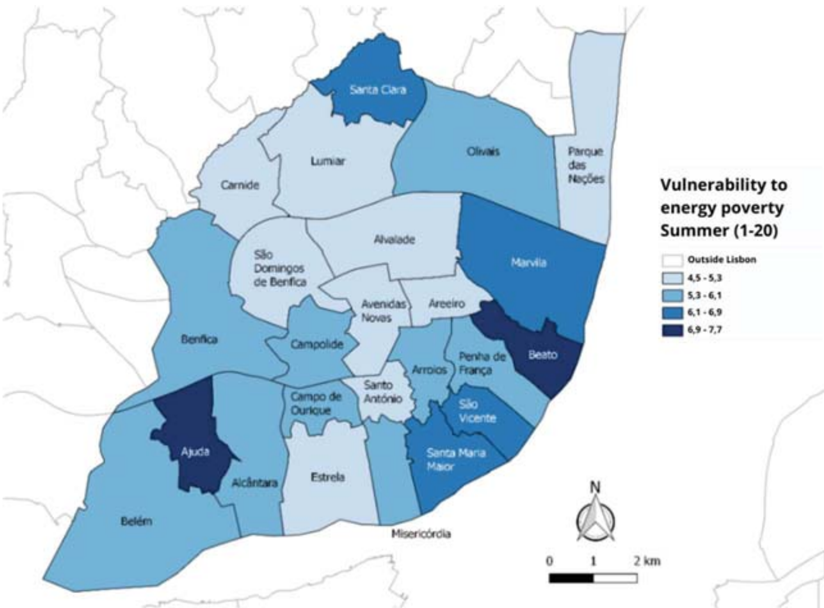

Figure 5.18 - Vulnerability to energy poverty in Summer - Lisbon (Adapted from Palma & Gouveia, 2022).

The obtained results show that the Lumiar civil parish is one of the less vulnerable civil parishes in the country regarding energy poverty, ranked in position #3,089 in winter and #3,086 in summer, among 3,092 Portuguese parishes. Inside Lisbon, Lumiar is the least vulnerable parish in winter and the fourth less vulnerable in summer, while still presenting significant energy performance gaps for both summer and winter. One of the reasons is that this parish is in the last severe climate area in winter and its residents have a high index of ownership of heating equipment (Palma & Gouveia, 2022). However, energy poverty is an endemic problem in Portugal. Using an average value for a territory may lead to neglecting vulnerable communities that can be better identified and supported through local-scale action.

This study was important for the development of the REC because it is necessary to make a diagnosis of the situation through a complete characterization of the location regarding these topics - energy consumption, energy poverty - in order to tackle energy related problems and enhance energy justice, in a local scale.

b) Design of the pilot project of the REC and development of the financing scheme

One of the most important parts of the implementation process of a REC is the definition of the structure and operational model. In Telheiras, two options for the pilot project were defined in a partnership between the *Parceria Local de Telheiras*, Civil Parish of Lumiar, Coopérnico, and EPAH through CENSE, FCT-NOVA team. Herein, two stages of the REC were studied: the installation stage and the operating stage (Parceria Local de Telheiras & Coopérnico, 2023).

Due to favorable conditions of solar irradiation, ease, modularity, and speed in the installation process and the available rooftop area, the chosen renewable energy system for both options were solar photovoltaics in the form of BAPVs on rooftops.

- Option 1: Original concept by *Grupo Telheiras Sustentável*

- Management of the REC: *Parceria Local Telheiras* (Local Partnership of Telheiras).
- Formal legal structure of the REC: *Associação Viver Telheiras*, filed together with the Lumiar Civil Parish.

<u>Installation Stage</u>

Stakeholders invest a variable amount of money to be members of the REC, aiming to obtain financial profits and helping with the development of the neighborhood. These investors are not obligatory residents of Telheiras. Then, a contract with the investor and the *Associação Viver Telheiras* is made. Social members could be involved, being members who do not need to invest to be part of the community or may invest symbolic values but do consume electricity. Not all the investor members become consumers of the REC. With a certain amount of capital, it becomes possible to purchase and pay for the PV system, also guaranteeing the maintenance cost for the first year of operation. Then, the *Associação Viver Telheiras* licenses the REC with the responsible entity (*Direção-Geral de Energia e Geologia* - Directorate-General for Energy and Geology), as a Collective Self-Consumption Management Entity (CSME) and identifies the members/consumers of the REC through the energy meter identifier number with an associated sharing coefficient and an internal regulation of the entity. In this model, the sharing coefficient would be dynamic and proportional to the consumption of each participant at each moment in time. A scheme of the installation stage of Option 1 can be seen in Figure 5.19.

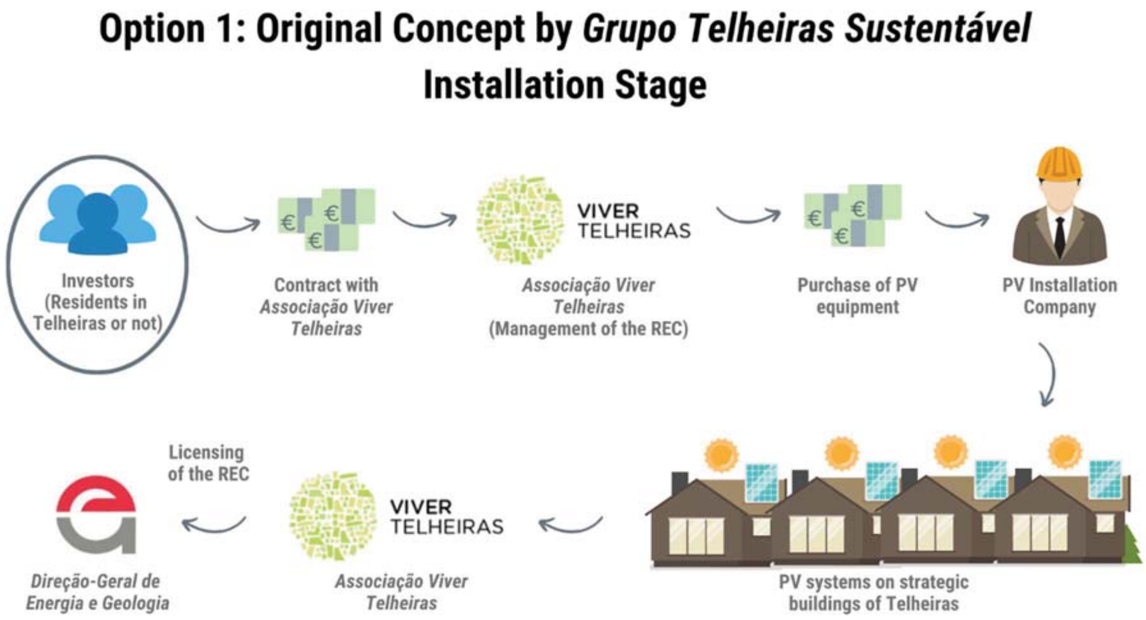

Figure 5.19 - Option 1: Installation stage of the REC in Telheiras (2023).

<u>Operation Stage</u>

Monthly, *Associação Viver Telheiras* receive information from the grid operator that manages the electrical system about the total amount of generated electricity by the PV systems and the amount that was "delivered and consumed" by each member, measured through smart meters every 15 minutes. Then, an energy bill is sent by *Associação Viver Telheiras* to its members (monthly, quarterly or semiannually) that includes an energy tariff (euros per kWh) lower than the one that members would pay for the conventional way of consumption (electric provider), taxes and the grid access fee. The adjustment of the energy tariff aims to pay the investors of the community, taxes, operational costs, and maintenance. After reaching the pay-back time of the initial investment, the tariff will be reduced (only operational and maintenance costs). Then, members of the REC pay those bills to the *Associação Viver Telheiras*, benefiting from those reduced tariffs and helping the energy transition (renewable energy generation). Smaller tariffs could be provided for energy-poor participants. Annually, this organization gives back to its investors a fraction of the initial investment until they receive the total invested amount.

A scheme of the operation stage of Option 1 can be seen in Figure 5.20.

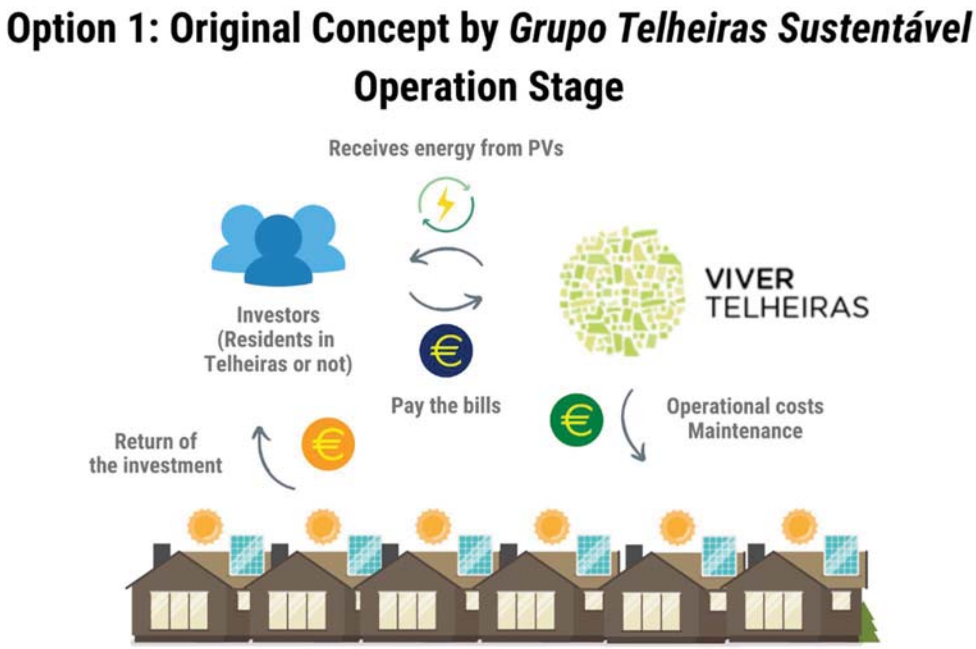

Figure 5.20 - Option 1: Operation stage of the REC in Telheiras (2023).

- Option 2: Optimized concept (supported by Coopérnico)

- Management of the REC: *Parceria Local Telheiras* (Local Partnership of Telheiras), filed together with the Lumiar Civil Parish.
- Formal legal structure of the REC: *Associação Viver Telheiras.*

<u>Installation Stage</u>

Investors pay a fixed initial amount to the *Associação Viver Telheiras* to become members of the REC or, alternatively, a variable amount according to differences in the consumption. All members need to be within a 2km range a PV system from the REC. A defined quantity of social members is admitted inside this entity, where the initial amount can be paid by the Lumiar Civil Parish, as a donation or even by an external entity. All the members of the REC have a fixed sharing coefficient of the generated energy. With a certain amount of capital, it becomes possible to purchase and pay for the PV system, also guaranteeing the maintenance cost for the first year of operation. Then, the *Associação Viver Telheiras* licenses the REC with the responsible entity (*Direção-Geral de Energia e Geologia* - Directorate-General for Energy and Geology), as a Collective Self-Consumption Management Entity (CSME) and identifies the members/consumers of the REC through the energy meter identifier number with an associated sharing coefficient and an internal regulation of the entity.

A scheme of the installation stage of Option 2 can be seen in Figure 5.21.

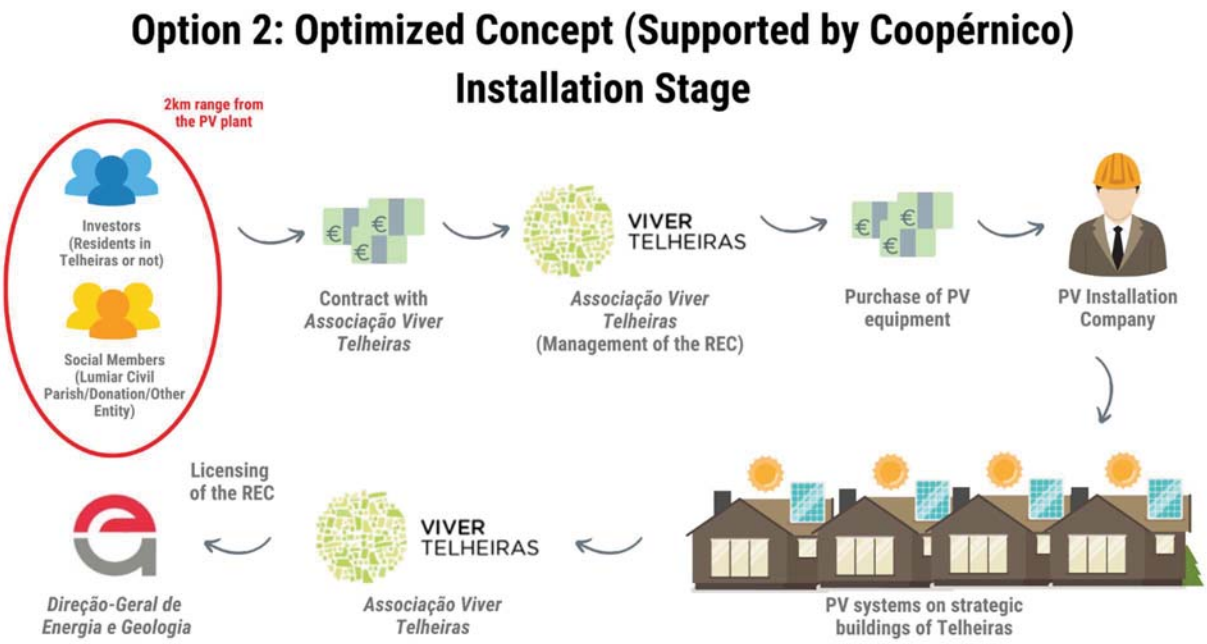

Figure 5.21 - Option 2: Installation stage of the REC in Telheiras (2023).

Operation Stage

The generated electricity through the PV modules will be distributed among the members according to the fixed sharing coefficient. Quarterly, the *Associação Viver Telheiras* receives data from the entity that manages the electric system but, since each member has already paid - or, in the case of the social members, other person/entity or the Lumiar Civil Parish paid for him/her - it has the right to consume energy according to the coefficient without another costs and, due to that, taxes are not paid (optimization of the payback time). Energy that is not used by the members can be sold by the *Associação Viver Telheiras*, where this income is used for the REC itself. Using fixed sharing coefficients turns the management of the energy distribution among members easier and more efficient. Finally, the costs of operation and maintenance are paid as a fee by the members to the association.

A scheme of the operation stage of Option 2 can be seen in Figure 5.22.

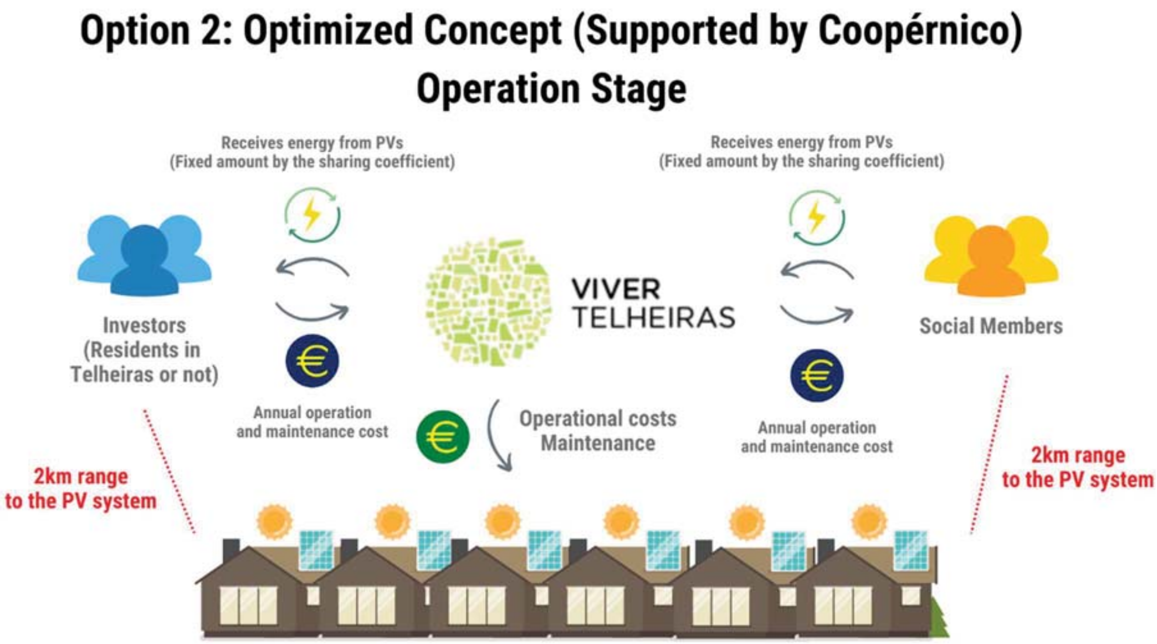

Figure 5.22 - Option 2: Operation stage of the REC in Telheiras (2023).

For both options, a financial analysis was made by *Parceria Local Telheiras* and Coopérnico, analyzing the financing forms, return of the investment and payback time of the PV systems. In both options, the members will have an active vote in managing the REC through being associated of *Associação Viver Telheiras*, presenting a real case of energy citizenship.

The optimized concept provided by Coopérnico brings many advantages, such as presenting an investment that is distributed similarly among participants, investors and consumers as only one player in the REC, clarification of the insertion of social members, simplification of processes and less burden on *Associação Viver Telheiras* by not having to emit invoices or pay loans and the enabling the possibility to transfer the position in the community to someone else. Also, the original concept has crucial disadvantages, as the necessity to make contracts with each investor and the fact that the associated investment is too low and with a low return to be a competitive financial asset.

b) Local communication and engagement plan

In a partnership with *Associação Viver Telheiras* and Coopérnico, a local communication and engagement plan is being developed, in order to enhance the acceptance of the process of creation of a REC in the neighborhood and renewable energy systems, as well as promoting and attracting new possible future members of this entity. Most of the times, this was done through participation of the member of *Grupo Telheiras Sustentável* in local events and festivals and in other meetings/events regarding energy efficiency, sustainability, and renewable energy sources.

Figures 5.23 to 5.25 brings some photographs of those events and festivals.

Figure 5.23 - Presentation about REC Telheiras (2022).

Figure 5.24 - Presentation about REC Telheiras - Telheiras Festival 2022 (2022).

Figure 5.25 - Apresentation about REC Telheiras - Telheiras Magusto Festival 2022 (2022).

5.4.3. Partners

In this context, the pilot project for implementing REC Telheiras is being promoted by *Parceria Local Telheiras* and the Lumiar Civil Parish with the technical support of Coopérnico and FCT-NOVA in the scope of EPAH. These are the important partners of this process of implementing this energy organization.

The Lumiar Civil Parish is the main beneficiary of EPAH's support and is acting in order to promote the creation of this energy organization, recognizing the opportunity to enhance the citizen participation in the transition and the acceptance of renewable energy sources in the region. Also, the Lumiar Civil Parish successfully requested the approval of the installation of PV modules to Lisbon Municipality in two of its buildings and will, probably, also be an effective member of the REC.

FCT-NOVA contributed actively with academic work and research about energy efficiency, energy poverty and Renewable Energy Communities, always linked with this specific project and acting actively in meetings and the development of the pilot project. The present dissertation itself was done with an active participation in this development process, discussions and meetings with partners and presence in important events and festivals for promote the local communication associated with the creation of this energy organization.

Figure 5.26 shows the kick-off meeting in October 2022 with all partners: *Parceria Local Telheiras*, Lumiar Civil Parish, Coopérnico, FCT-NOVA and EPAH.

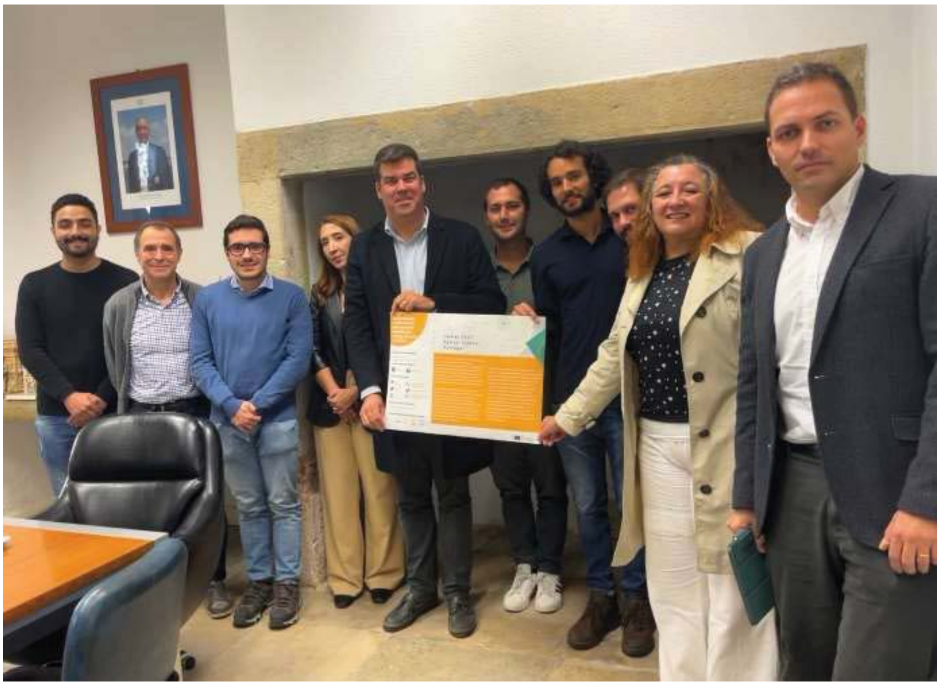

Figure 5.26 - Meeting with representants of Coopérnico, Lumiar Civil Parish, *Grupo Telheiras Sustentável* and EPAH (2022).

6

RESULTS AND DISCUSSION

In this chapter, the results obtained in the literature review and analysis/development of the Study Case will be presented, as well as a discussion about these themes and results. To do so, this chapter will be organized in six sections: impact of RECs on energy poverty, impact of RECs on energy citizenship, photovoltaic simulations for REC Telheiras, analysis of the implementation process of REC Telheiras and comparisons betweeen the Study Case and existing RECs.

6.1 Impact of RECs on Energy Poverty

The creation of a Renewable Energy Community has several local positive impacts. In this scenario, these energy organizations may reduce energy poverty, but, since a REC can be implemented and operated in many different ways, having different purposes, type of members and objectives, it is not right to say, with complete certainty, that this will occur. One important aspect is that the REC may reach the energy vulnerable ones (citizens who suffer the most about energy poverty), what can be translated as a bigger challenge, since those citizens, most of the time, are the ones that have lesser knowledge about these energy actions, urgency of the energy transition and climate change effects, as well as lower available capital for investing to become members of a REC.

However, most of the RECs do reduce energy poverty, being able to act in all the pillars of this concept (developed and developing countries). Depending on the form of operation and the structure of the REC, some examples can be presented, such as:

- **Profits from the distributed generation after reaching the payback time of the system:** since those renewable energy systems have a relative long lifetime - for example, most of the PV modules manufacturers guarantee 80% of the initial generation after 25 years of operation - after reaching the payback time most of the generated energy will be seen only as a profit, since the members, according to stipulated sharing coefficients or fixed fractions, will consume this generated energy after receiving back the initial invested amount in the form of lower energy bills. Also, this value that now is not paid to the electric service provider can be used to buy more efficient electric equipment and invest in possible renovations of houses, commerce, and buildings, providing more comfort and reducing energy consumption through higher energy efficiency.

- **Sell of the surplus energy to the grid:** through on-grid renewable energy systems and possible contracts with the service provider, a REC can sell the surplus of the generated energy to the grid, where this extra income can be used to pay for energy fees (access fee and other ones associated with the electric grid) and costs associated with operation and maintenance of the renewable systems of the REC. Also, this amount can be saved for a certain quantity of months and then used to promote events and workshops about energy efficiency procedures to the members, resulting in lower energy consumption in the household environment.

- **Partnerships with the municipalities that are interested in enhancing the share of renewable energy generation and increasing the number of prosumers:** this leads to higher energy security and reliability, as well as the fact that this increased citizen participation in the transition and greater sustainability practices are important political aspects. Here, the municipality can promote lower energy tariffs through subsides with the local energy provider or even being a member of the REC itself, where more actions inside the community towards energy equity can be done through these local governmental institutions.

- **Energy storage systems:** in scenarios of lack or high level of insecurity in energy supply, a REC can promote energy storage systems connected to renewable energy generation, being able to operate in a total or almost completely isolated way. Since this collective investment on batteries and generation equipment is way lower than the costs associated with electric grid extension procedures and does not only depend on authorities and governments, this solution can be seen as the opportunity for more citizens to have electricity in their homes or enhance the reliability on the energy supply, being able to use this energy for basic needs (cooking and cooling/heating systems) and change from traditional fuels (wood, agricultural waste and animal waste) to electricity. This leads to a substantial enhancement of life quality and reduction of absolute poverty. Also, energy storage systems can be used for energy flexibility practices, where during peak hours, the energy demand will be supplied by the batteries, while they will recharge during the other period of the day, avoiding consumption from the grid during the hours when the tariffs are significantly higher.

It is important to highlight that this reduction on energy poverty is crucial for a fair and more equal energy transition, as part of the population is more vulnerable to the impacts of this concept (factors as age and state of health can aggravate these negative impacts).

Figure 6.1 brings a summary of these examples of how a Renewable Energy Community can act to reduce energy poverty among its members.

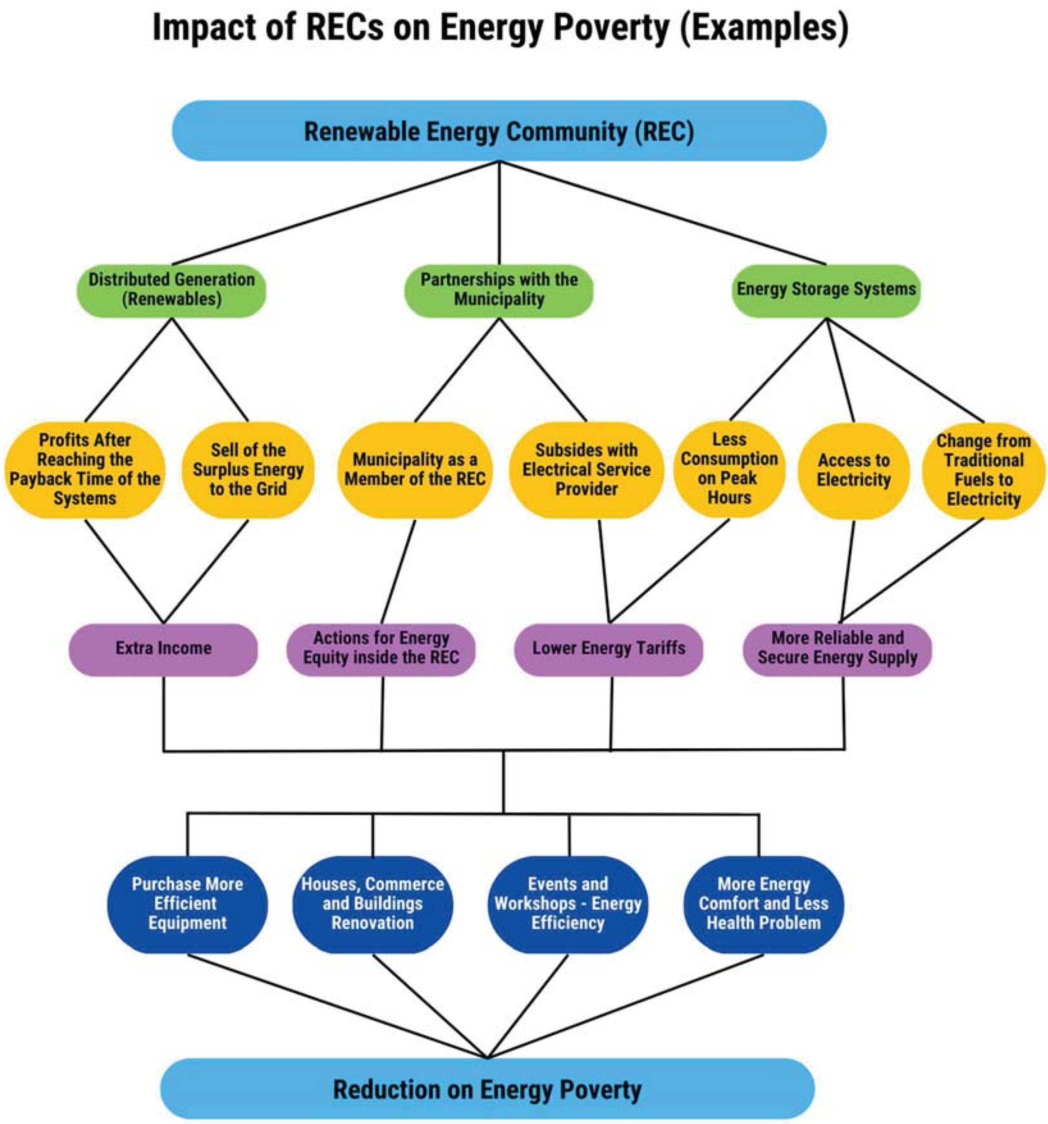

Figure 6.1 - Examples of how RECs can act to reduce energy poverty (2023).

6.2 Impact of RECs on Energy Citizenship

Similar to energy poverty, the impact of a Renewable Energy Community on the level of energy citizenship of its members depends strongly on the structure and operating characteristics of this energy entity. Some RECs are managed by specific organizations and entities, also with stakeholders and investors that are not citizens or individuals, and some RECs were created from local citizen actions and formed only by local residents - this sensible differences impact strongly on how of this entity will affect the energy citizenship of its members, where it is clear that the last ones will provide more empowerment of the members, since the energy-related decisions and governance of the REC will be done through individual members and a citizen-led organization for management of the entity.

Climbing the ladder of energy empowerment means putting the citizens in an active position in the energy transition, where these individuals recognize their importance and responsibility for the questions related to climate change and energy demand/supply. However, different members of a REC have different levels of knowledge regarding energy consumption, generation, and efficiency. In this concept, a REC can act on different forms to enhance the energy citizenship of its members, such as:

- **Enhancement of energy literacy:** the REC can provide sessions, workshops, and events to present and discuss simple energy efficiency procedures in a household environment, leading to lower energy consumption and higher energy consciousness. Here, the focus may not only be on costs and energy bills, but also focusing on the importance that everyone has in the energy transition and in the action regarding climate change. It is also important to provide information for the members regarding their energy needs, aiming to explain how their basic energy needs in households can be supplied in an efficient and intelligent way and providing knowledge about energy consumption associated to basic home appliances. Through this process, members will understand how and why they consume the actual amount of energy in their homes, also knowing how they can consume less with the same comfort and life quality.

- **Increase on the acceptance of renewables:** in many situations, renewable energy systems are not a topic that the public have knowledge about the conversion processes, equipment, and associated benefits - some people have never seen a PV module or wind turbine and does not even know how these systems can provide electric energy. The REC can act in this link between renewable energy systems and the citizens, providing information about the mechanisms and process associated with energy conversion (with a general easy-to-understand language) and making these systems and their benefits closer to the community. This will lead to more acceptance about renewables, where the REC may also face an increase of the acceptance and in the number of its members. This share of knowledge provided by the REC can also foster the creation of local companies in renewable energy, electricity services and energy efficiency, as well as the increase in demand by individuals for training courses in installation, design, and maintenance of those systems, creating local economic development.

- **Raise awareness about citizen participation in the transition:** many recent directives and regulation regarding climate action and energy transition highlight the importance of the participation of the citizens in this process. The REC itself is a proof of it, but this entity can also act enhancing the consciousness of the citizens about the importance of local actions by all the individuals and how this will affect the energy transition and economy decarbonization. Putting the members in a position of decision-makers on local energy questions make them understand their importance in this scenario of climate change, where this can also lead to more acceptance and participation in the REC.

Figure 6.2 brings a summary of these examples of how a Renewable Energy Community can act to enhance energy citizenship among its members.

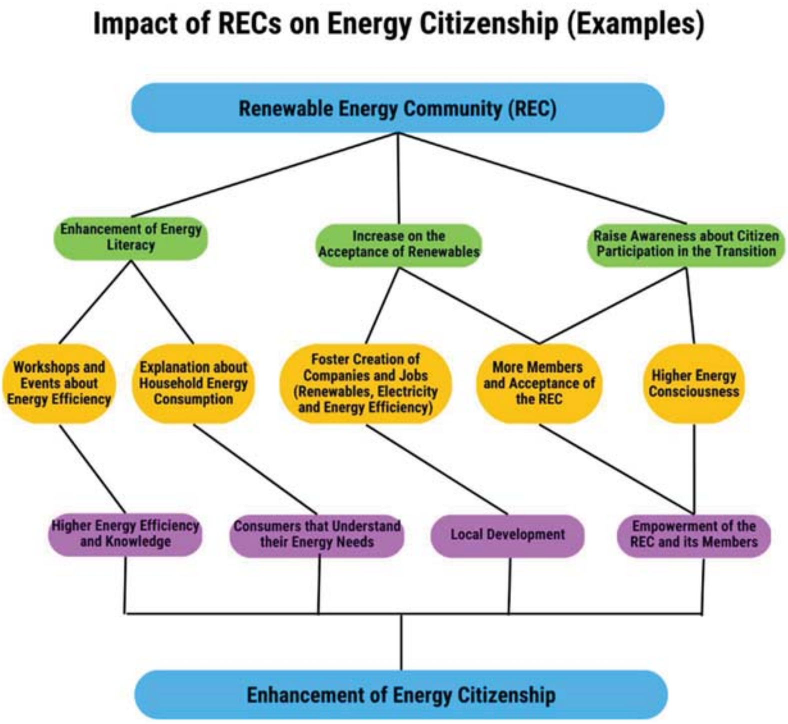

Figure 6.2 - Examples of how RECs can act to enhance energy citizenship (2023).

6.3 Photovoltaic Simulations - REC Telheiras

Before the start of the present dissertation, it was already decided that the type of renewable energy generation for REC Telheiras was PV systems. However, there was only one preliminary analysis of PV generation in a specific building of the neighborhood, made by Coopérnico, with a low level of detail. Therefore, a complete PV simulation, sizing and shadow analysis was done in six specific buildings of the neighborhood - namely, Lagar of São Vicente's Farm, Mira Rio School and Telheiras Church (here, will be considered as only one building), Telheiras EB1 School, Orlando Ribeiro Library Auditorium, Lumiar Civil Parish Headquarters and Alto da Faia Multisport Gym.

All of the six PV simulations started with a complete shadow analysis according to the surrounding area, constructive elements of the building and level differences between different roof areas. Then, defined optimized areas of the roofs for installing PV modules were defined and the maximum number of modules was defined to this area. After that, using a specific PV software - HelioScope - the amounted of annual generated energy was obtained. A budget estimation was done for each system, where an approximation done by *Coopérnico* was used (1,000 euros per installed and operation kW of PV system).

The results of these PV simulations will be presented individually for each building in the next sections of this dissertation.

6.3.1 Lagar of São Vicente's Farm

The old Lagar of São Vicente's Farm is a building owned by Lisbon Municipality that nowadays is managed by the Lumiar Civil Parish and commonly used by *Parceria Local Telheiras* for local events and meetings, being a hub in Telheiras of this civil parish. This building is in a central area of Telheiras, close to a metro station and two important gardens of the neighborhood. Figure 6.3 shows a photo of this building.

First, it is important to emphasize that only a specific roof area of this building was analyzed, since the other parts of the roof are much older and may need repair works soon. Figure 6.4 emphasizes this area that can receive PV modules.

<u>Shading analysis</u>

After analyzing the surroundings of this building and, specifically, the area that is prepared to receive the PV system, it becomes clear that there are no higher buildings or trees close to this building, where the only shading element is the chimney present in the building itself. Here, this element was not measured, but, for safety reasons, a height of 1.2m was estimated (certainly this chimney is shorter, but it is better to assume this worst scenario in order to obtain results with more reliability).

Figure 6.3 - Lagar of São Vicente's Farm (2023).

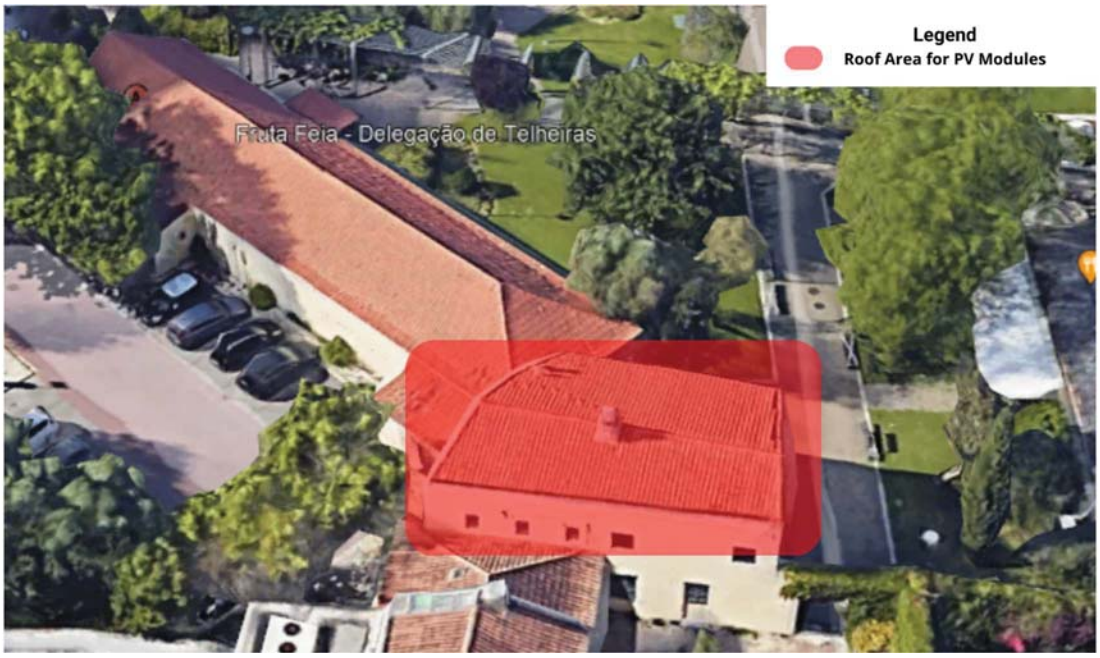

Figure 6.4 - Lagar of São Vicente's Farm - Area for PV modules (Google Earth, 2023).

So, for maximizing the PV generation and avoid shading caused by the chimney, only the south part of the roof will be used and an area too close to the chimney is avoided. Then, the area used for installing PV modules is presented in Figure 6.5, with estimated area of 54.3m² and estimated slope of 18.4º (this value was estimated according to the dimensions of this roof area).

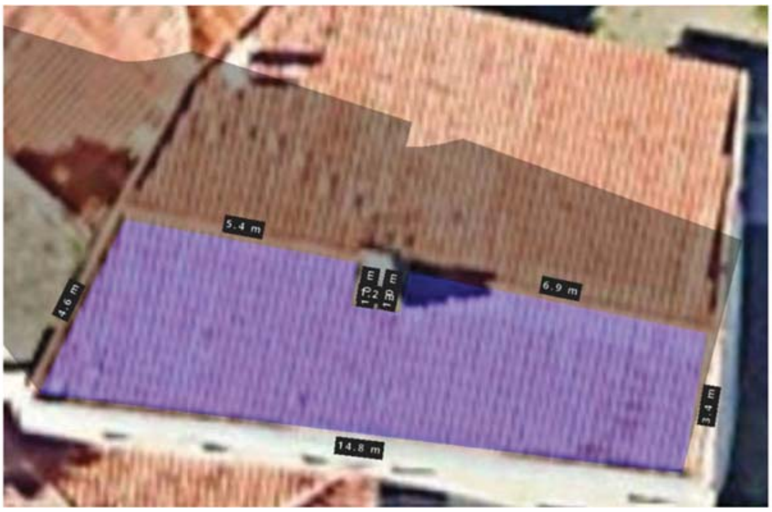

Figure 6.5 - Lagar of São Vicente's Farm - Area for PV modules after shading and generation analysis (HelioScope,2023).

PV Sizing

Before sizing the PV system in this defined area, due to its different dimensions, an analysis of the preferred orientation of the modules was done - namely, portrait or landscape orientation. Here, with the landscape orientation it was possible to install more PV modules than the portrait orientation and, due to that, landscape orientation was selected. This comparison can be seen in Figure 6.6.

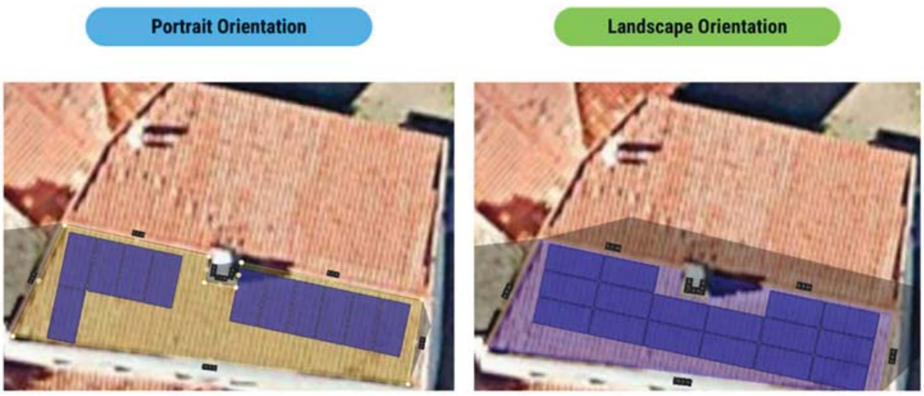

Figure 6.6 - Lagar of São Vicente's Farm - Analysis of orientation of PV modules (HelioScope, 2023).

So, with the selected orientation, the defined PV system parameters are:

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 16 modules.
- **Total installed power:** 7.36kWp.
- **Frequency inverter:** Sungrow SG-7.0 7kW (good relation between price and market availability), with a factor of 1.05 of oversizing.
- **Number of frequency inverters:** unique inverter.

PV Simulation

Before executing the simulation of the system, an analysis of the effect of the possible shading due to the presence of the chimney was done, as the results are presented in Figure 6.7. It can be seen that modules M1, M2, M3 and M4 will suffer a low incidence of shading during the year. One of the forms to avoid this aspect to affect the whole generation of the system is to divide the system into two strings (S1 and S2), where the modules that may suffer more with shading must be in the same string. This division of strings is shown in Figure 6.8.

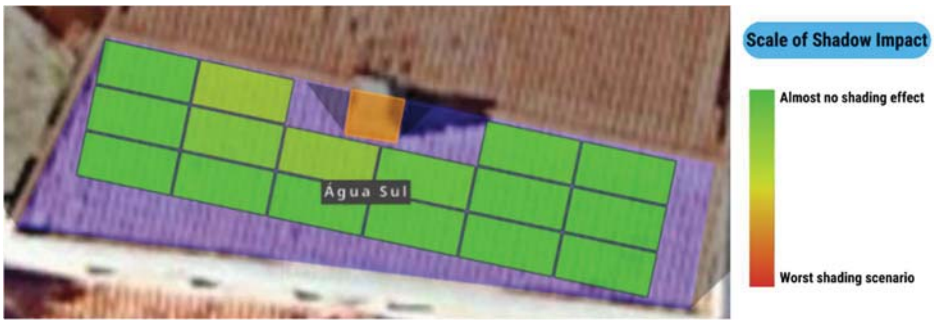

Figure 6.7 - Lagar of São Vicente's Farm - Shading effect on PV modules - Part A (HelioScope, 2023).

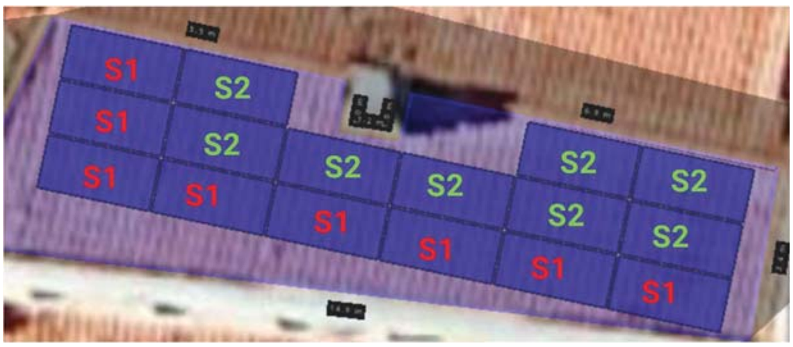

Figure 6.8 - Lagar of São Vicente's Farm - Shading effect on PV modules - Part B (HelioScope, 2023).

After this division, the simulation was done, where the results and parameters are presented in Figure 6.9.

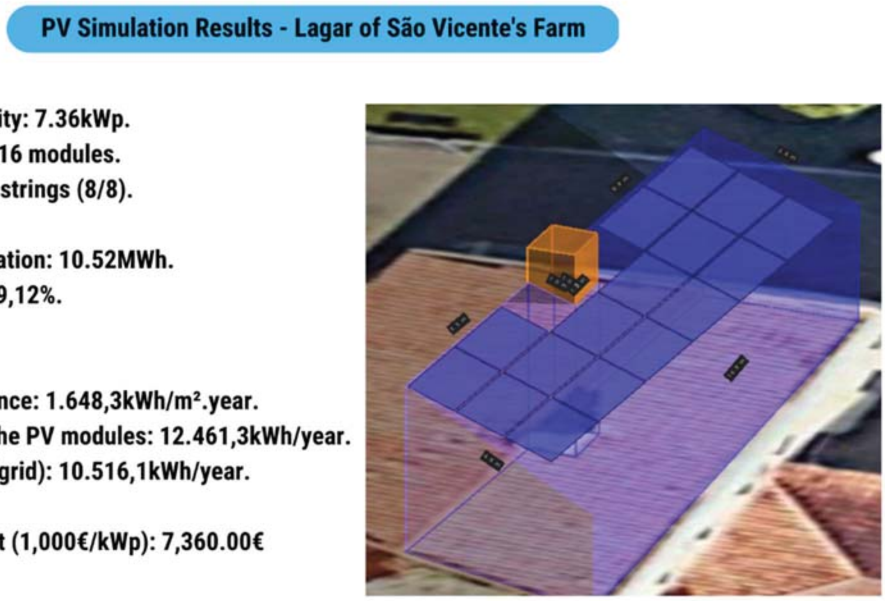

Figure 6.9 - Lagar of São Vicente's Farm - PV Simulation (HelioScope, 2023).

6.3.2 Mira Rio School and Telheiras Church

Opened in 2017, the Mira Rio School is a modern private school located in Telheiras, with a large roof open central area and a geminated building to the Telheiras Church. Due to this reason, the analysis and simulation will be done as only one building. The selection of this building was done due to its conditions and to provide REC Telheiras with an alternative beyong public buildings. Figure 6.10 brings a view of the entrance of this school.

Figure 6.10 - Mira Rio School entrance (2023).

Roof/Shading Analysis

Due to the large roof area with different orientations and characteristics, the first action in this building was to analyze, separately, each roof area. Here, they will be denoted as A1 to A7, as presented in Figure 6.11.

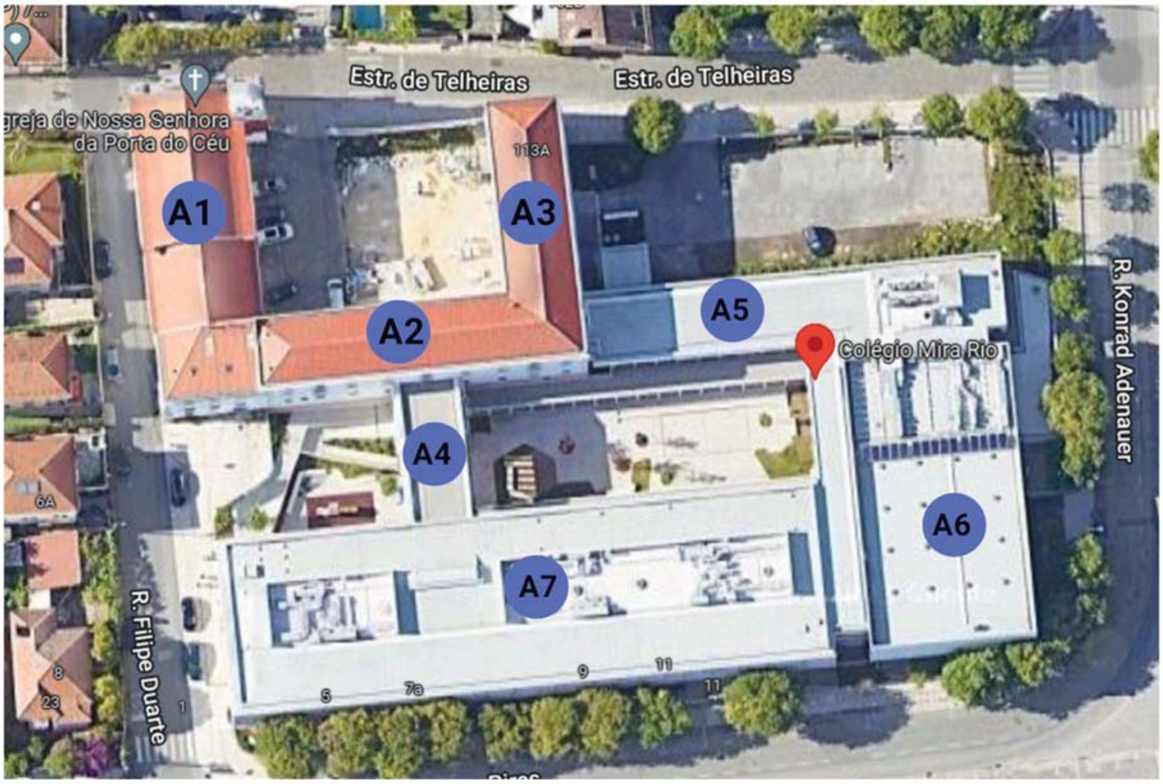

Figure 6.11 - Mira Rio School and Telheiras Church - Area division (Adapted from Google Maps, 2023).

a) Roof Area A1

This roof area has orientations east and west, where a difference level is presented between the south and the north part of this area (Figure 6.12). Since this area is the closest to the façade of the church, there is an architectural element higher than this northern part of A1. Also, there is the tower of the church, that represents a significative shadow element for this area.

Therefore, to avoid as much as possible the shading of the façade element and the tower of the church, a really small area with west orientation will be used for PV modules fixation, where installing a PV system in this area is not attractive from both economic and technical analysis. So, A1 will not receive PV modules, since there are more attractive areas on this building to be utilized for PV generation.

Figure 6.12 - Mira Rio School and Telheiras Church - Area A1 (Google Maps, 2023).

b) Roof Area A2

This roof area has a large fraction with an optimized orientation for PV generation (south), without any shading elements or close higher roof areas (Figure 6.13). So, this area will be utilized for the PV generation. The system of area A2 will be denoted as System 2 (S2).

Figure 6.13 - Mira Rio School and Telheiras Church - Area A2 (Google Maps, 2023).

c) Roof Area A3

This roof area has orientations west and east, with a not large total area (Figure 6.14) This site could be used for PV generation, but, in the specific case of this building, there are more interesting areas to use for PV modules. So, this area will not be used for PV generation.

Figure 6.14 - Mira Rio School and Telheiras Church - Area A3 (Google Maps, 2023).

d) Roof Area A4

This area can be seen as a connection between two parts of the building, with high differences of level and a small available area (Figure 6.15). Here, since this area is a flat slab, the PV structure needed is similar to the ground-mounted systems, where problems associated with self-shading of different rows of modules can occur, especially in small areas as A4. So, due to these reasons, this area will not be used for PV generation.

Figure 6.15 - Mira Rio School and Telheiras Church - Area A4 (Google Maps, 2023).

e) Roof Area A5

Like A4, area A5 suffers from a high-level difference in its west side and has not large dimensions (Figure 6.16). Ground-mounted structures will also be needed, where problems with self-shading will definitely occur in a significant way. So, this area will not be used for PV generation.

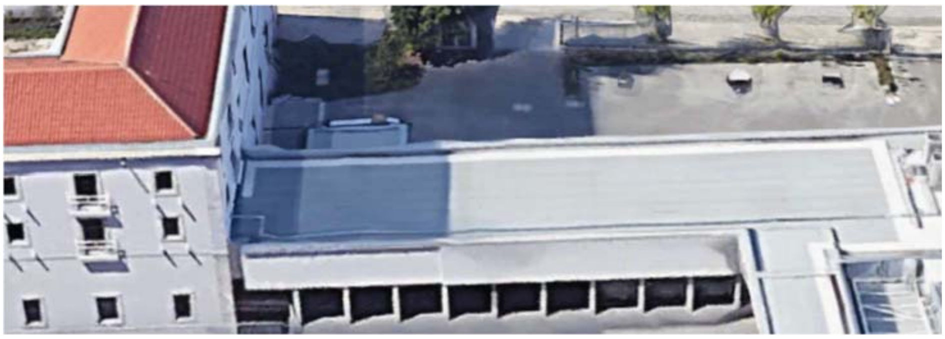

Figure 6.16 - Mira Rio School and Telheiras Church - Area A5 (Google Maps, 2023).

f) Roof Area A6

A6 has a large area for PV modules fixation, with also an easy access for maintenance. There are some flat plate collectors already installed for preparation of hot water (Figure 6.17). Here, the possibility of south orientation with ground-mounted structures and the large dimensions (possibility to avoid self-shading) are also benefit for PV generation. The only attention points are the parapets, where can be shading elements - a centralized distribution of the modules can solve this possible problem. So, PV modules will be installed in A6 as System 6.

Figure 6.17 - Mira Rio School and Telheiras Church - Area A6 (Google Maps, 2023).

g) Roof Area A7

A7 is a large area interesting for PV generation, especially its southern fraction (Figure 6.18). Here, ground-mounted structures in a single row of PV modules facing south will be an adequate solution, also with an easy access to maintenance and far from the equipment located in this roof area. So, A7 will be used for PV generation and will be denoted by System 7.

Figure 6.18 - Mira Rio School and Telheiras Church - Area A7 (Google Maps, 2023).

A summary of the areas that will be and will not be used for PV generation is presented in Figure 6.19.

Figure 6.19 - Mira Rio School and Telheiras Church - Roof Areas Evaluation (Adapted from Google Maps, 2023).

PV Sizing

The PV sizing will be done individually for each system (S2, S6 and S7). Figures 6.20 to 6.22 present a view of each designed system, as the results will be presented individually.

a) System S2 (Area A2)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 28 modules.
- **Total installed power:** 12.88kWp.
- **Frequency inverter:** Sungrow SG-10 10kW (good relation between price and market availability), with a factor of 1.29 of oversizing.
- **Number of frequency inverters:** unique inverter.

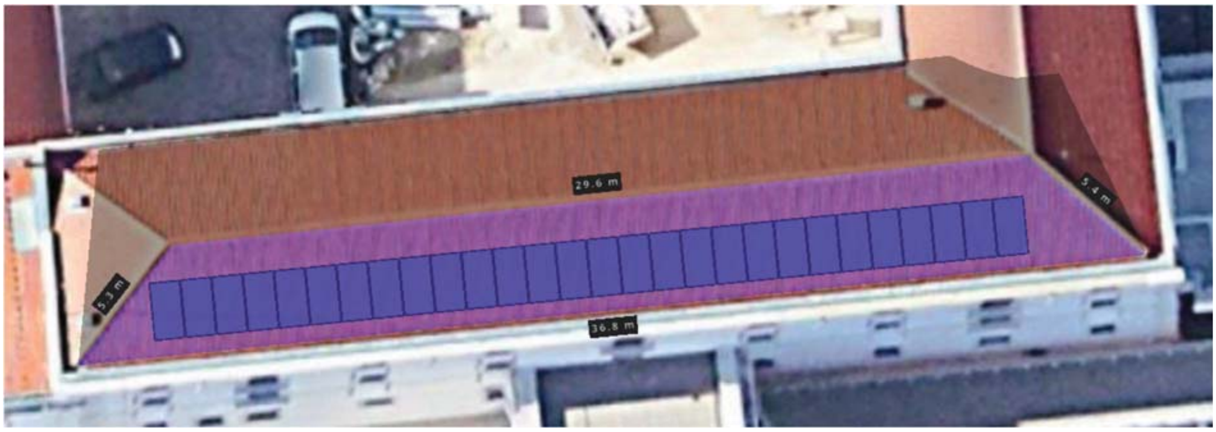

Figure 6.20 - Mira Rio School and Telheiras Church - S2 - A2 PV Sizing (HelioScope, 2023).

b) System S6 (Area A6)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 48 modules.
- **Total installed power:** 22.08kWp.
- **Frequency inverter:** Sungrow SG-20 20kW (good relation between price and market availability), with a factor of 1.10 of oversizing.
- **Number of frequency inverters:** unique inverter.

- **Special characteristics:** centralization of the modules in order to avoid shading caused by the parapets. Modules with 30º of inclination (similar to Lisbon latitude - maximize generation).

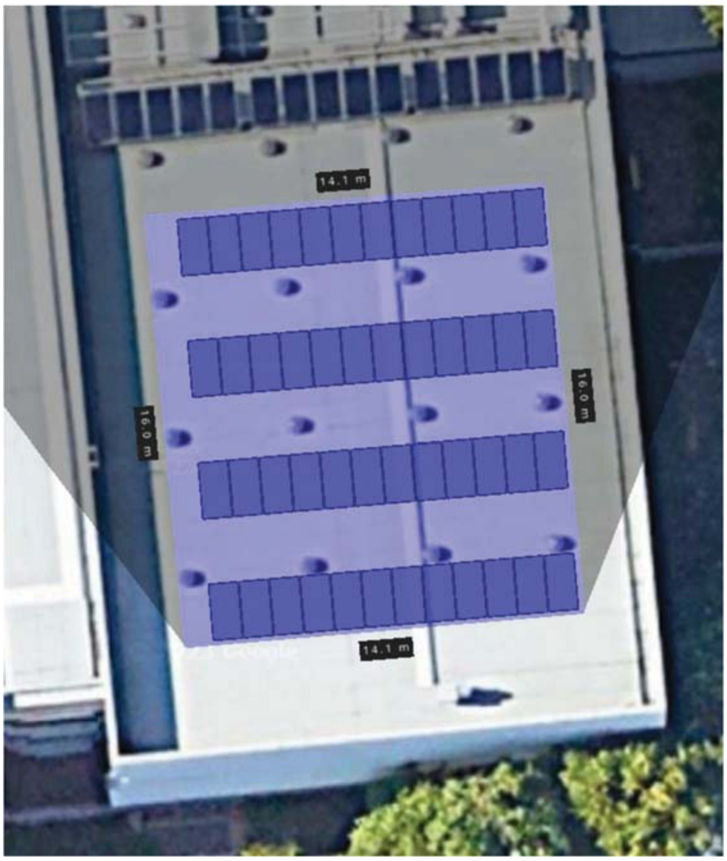

Figure 6.21 - Mira Rio School and Telheiras Church - S6 - A6 PV Sizing (HelioScope, 2023).

b) System S7 (Area A7)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 55 modules.
- **Total installed power:** 25.30kWp.
- **Frequency inverter:** Sungrow 25CX 25kW (good relation between price and market availability), with a factor of 1.01 of oversizing.
- **Number of frequency inverters:** unique inverter.
- **Special characteristics:** unique row of PV modules where, in the middle, there is a passage for maintenance. Modules with 30º of inclination (similar to Lisbon latitude - maximize generation).

Figure 6.22 - Mira Rio School and Telheiras Church - S7 - A7 PV Sizing (HelioScope, 2023).

PV Simulation

The simulation of these three systems will be done separately, where the results are presented in Figures 6.23 to 6.25.

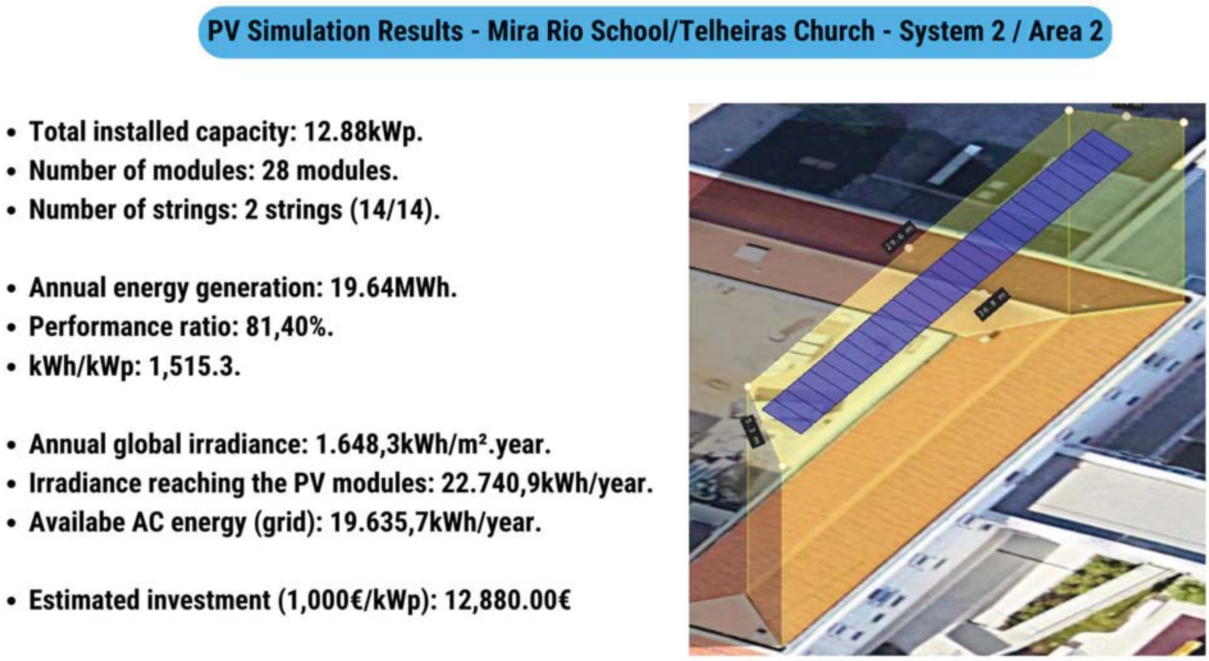

Figure 6.23 - Mira Rio School and Telheiras Church - S2 - A2 PV Simulation (HelioScope, 2023).

PV Simulation Results - Mira Rio School/Telheiras Church - System 6 / Area 6

- **Total installed capacity: 22.08kWp.**
- **Number of modules: 48 modules.**
- **Number of strings: 4 strings (12/12/12/12).**

- **Annual energy generation: 35.06MWh.**
- **Performance ratio: 83,40%.**
- **kWh/kWp: 1,588.1.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 39.014,4kWh/year.**
- **Availabe AC energy (grid): 35.064,2kWh/year.**

- **Estimated investment (1,000€/kWp): 22,080.00€**

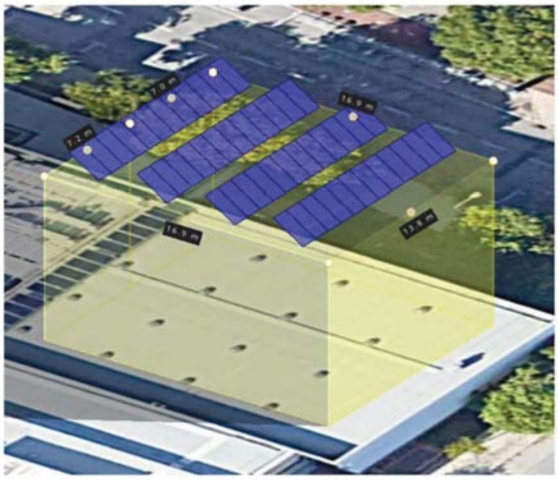

Figure 6.24 - Mira Rio School and Telheiras Church - S6 - A6 PV Simulation (HelioScope, 2023).

PV Simulation Results - Mira Rio School/Telheiras Church - System 7 / Area 7

- **Total installed capacity: 25.03kWp.**
- **Number of modules: 55 modules.**
- **Number of strings: 5 strings (11/11/11/11/11).**

- **Annual energy generation: 41.07MWh.**
- **Performance ratio: 85,10%.**
- **kWh/kWp: 1,623.4.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 45.805,2kWh/year.**
- **Availabe AC energy (grid): 41.072,6kWh/year.**

- **Estimated investment (1,000€/kWp): 25,030.00€**

Figure 6.25 - Mira Rio School and Telheiras Church - S7 - A7 PV Simulation (HelioScope, 2023).

6.3.3 Telheiras EB1 School

Telheiras EB1 School is one of the public schools of the neighborhood. Recently renovated, this building has also a large area of roofs with different orientations, slopes, and characteristics. It should be noted that the view of this building is still not updated in Google Maps, thus the roofs may have changed slightly. However, the recent renovation did not alter the area and configuration of the building. Primary schools are owned by the Lisbon Municipality but managed by the Civil Parishes. Figure 6.26 brings a view of the entrance of the school.

Figure 6.26 - View of Telheiras EB1 School (2023).

<u>Roof/Shading Analysis</u>

A similar process that was done for analyzing roof areas of Mira Rio School/Telheiras Church will be done in Telheiras EB1 School. Here, they will be denoted as A1 to A9, as shown in Figure 6.27.

Figure 6.27 - Telheiras EB1 School - Area Division (Adapted from Google Maps, 2023).

a) Roof Area A1

This roof area is flat with fiber cement tiles, with significant dimensions and no near shading elements. This area should be utilized to PV generation, but ground-mounted structures to promote an adequate inclination of the modules should not be used - these structures are not adapted for fiber cement tiles, where the fixation may not be adequate, and the security of the system might be affected. Figure 6.28 shows this roof area, as the system of this location will be denoted as System 1 (S1).

Figure 6.28 - Telheiras EB1 School - Area A1 (Google Maps, 2023).

b) Roof Area A2

This roof area is also covered with fiber cement tiles, but now the roof is not flat. A2 is a really small area that faces a certain level of shading due to A1 so, due to these reasons, roof area A2 should not be used for PV generation, as it is not economically and technically interesting for this purpose. Figure 6.29 brings a view of A2.

Figure 6.29 - Telheiras EB1 School - Area A2 (Google Maps, 2023).

c) Roof Area A3

Like A1, A3 is a roof area of flat fiber cement tiles. Although this area has significant dimensions, A2 promotes shading effects on a significant part of this roof area and there is another area with a different level on the south part of A3, also promoting shading effects. Due to these reasons and combined with the fact that is a flat roof area, PV modules should not be installed to this roof area. Figure 6.30 presents a view of roof area A3.

Figure 6.30 - Telheiras EB1 School - Area A3 (Google Maps, 2023).

d) Roof Area A4

Another roof area with flat fiber cement tiles, also with significant dimensions, but now there are no shading elements or differences of level in the surroundings. Only a three, in the south part, might promote a certain level of shading, but the extreme region of this area can be avoided. So, A4 will be utilized for PV generation and its system will be denoted as System 4 (S4). Figure 6.31 brings a view of this roof area.

Figure 6.31 - Telheiras EB1 School - Area A4 (Google Maps, 2023).

e) Roof Area A5

Area A5 has a significant slope and high parapets, as can be seen as a shading element. Also, it is one of the smallest roof areas of the building where, when avoiding the shading effect from the parapets, almost none of the area will be available for PV modules. So, A5 will not be used for PV generation. Figure 6.32 brings a view of area A5.

Figure 6.32 - Telheiras EB1 School - Area A5 (Google Maps, 2023).

f) Roof Area A6

This is another roof area with flat fiber cement tiles, without differences of level with the surroundings and with a relatively large area. The parapets and the three in the south part of this area can promote shading, where this fraction of A6 must be avoided. The rest of this roof area will be used for PV generation, denoted by System 6 (S6). Figure 6.33 brings a view of area A6.

Figure 6.33 - Telheiras EB1 School - Area A6 (Google Maps, 2023).

g) Roof Area A7

This area is extremely close to a three, where most of the area will face constant shading during the entire year. Although A7 has significant dimensions, this area should be totally avoided for PV generation. Figure 6.34 presents a view of this roof area.

Figure 6.34 - Telheiras EB1 School - Area A7 (Google Maps, 2023).

h) Roof Area A8

Roof area A8 suffers from the same problem of area A7: proximity with a three (Figure 6.35). Even though some part of the west region could be used for PV generation, these modules may also face intense problems with shading in certain months. So, A8 will not be utilized for PV generation.

Figure 6.35 - Telheiras EB1 School - Area A8 (Google Maps, 2023).

i) Roof Area A9

This roof area has a considerable slope and no differences of level in the surroundings. With significant dimensions, the only possible shading elements are two three located close to the south part of this area. A9 should be used for PV generation (denotated by System 9 (S9)), just avoiding the extreme south fraction of this roof area. Figure 6.36 brings a view of this area.

Figure 6.36 - Telheiras EB1 School - Area A9 (Google Maps, 2023).

A summary of the areas that will be and will not be used for PV generation is presented in Figure 6.37.

Figure 6.37 - Telheiras EB1 School - Roof Areas Evaluation (Adapted from Google Maps, 2023).

PV Sizing

The PV sizing will be done individually for each system (S1, S4, S6 and S9). Figures 6.38 to 6.41 present a view of each designed system, as the results will be presented individually.

a) System S1 (Area A1)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 35 modules.
- **Total installed power:** 16.10kWp.
- **Frequency inverter:** Sungrow SG-15 15kW (good relation between price and market availability), with a factor of 1.07 of oversizing.
- **Number of frequency inverters:** unique inverter.

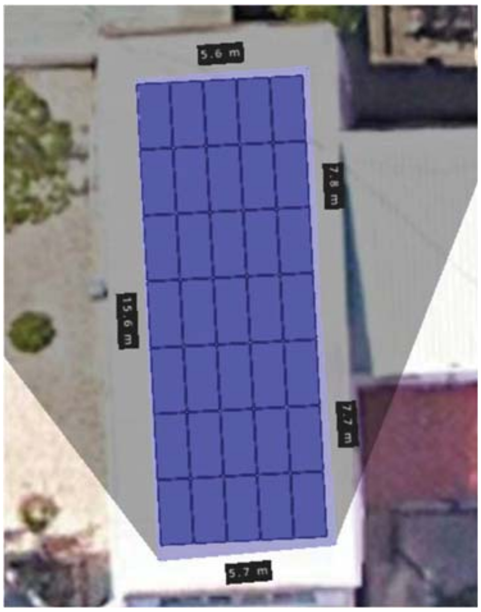

Figure 6.38 - Telheiras EB1 School - S1 - A1 PV Sizing (HelioScope, 2023).

b) System S4 (Area A4)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 20 modules.

- **Total installed power:** 9.20kWp.
- **Frequency inverter:** Sungrow SG-8KTL-M 8kW (good relation between price and market availability), with a factor of 1.125 of oversizing.
- **Number of frequency inverters:** unique inverter.

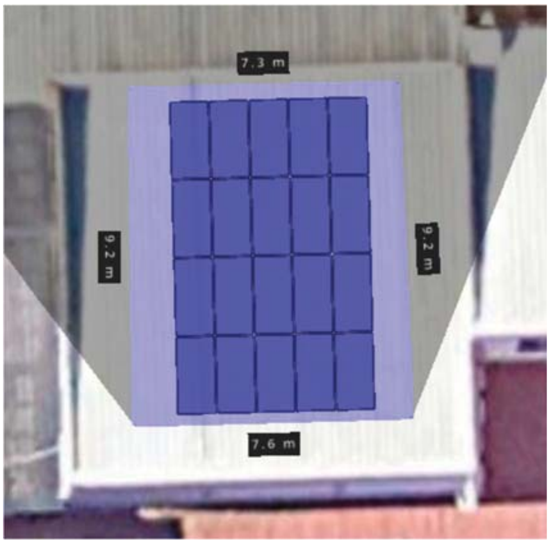

Figure 6.39 - Telheiras EB1 School - S4 - A4 PV Sizing (HelioScope, 2023).

c) System S6 (Area A6)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 11 modules.
- **Total installed power:** 5.06kWp.
- **Frequency inverter:** Sungrow SG-5KTL-M 5kW (good relation between price and market availability), with a factor of 1.01 of oversizing.
- **Number of frequency inverters:** unique inverter.

d) System S9 (Area A9)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 16 modules.
- **Total installed power:** 7.36kWp.

- **Frequency inverter:** Sungrow SG-8KTL-M 8kW (good relation between price and market availability), with a factor of 0.92 of oversizing.
- **Number of frequency inverters:** unique inverter.

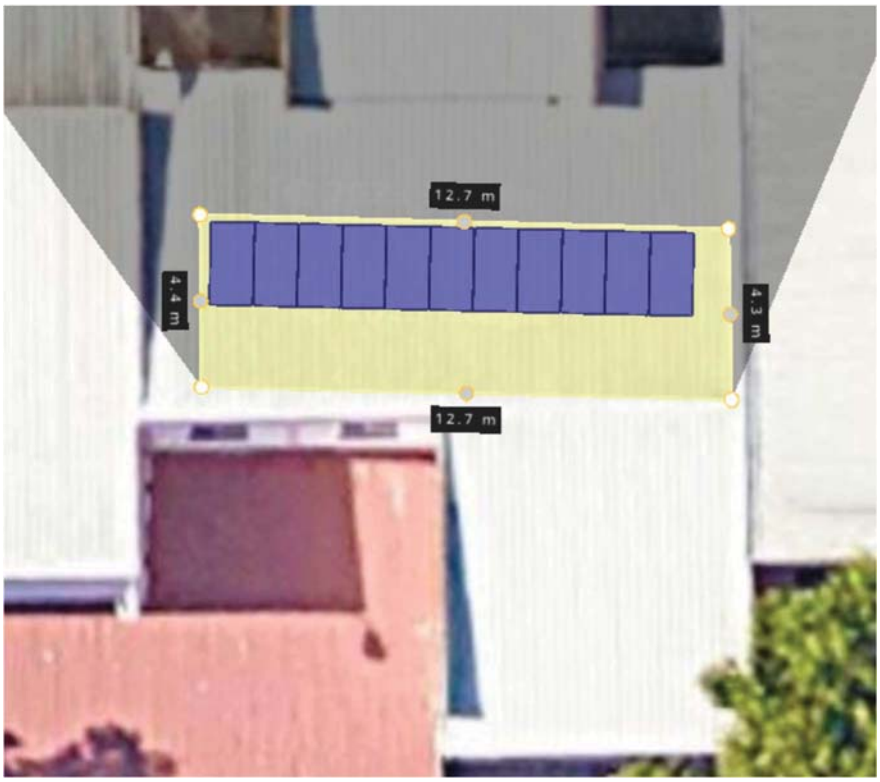

Figure 6.40 - Telheiras EB1 School - S6 - A6 PV Sizing (HelioScope, 2023).

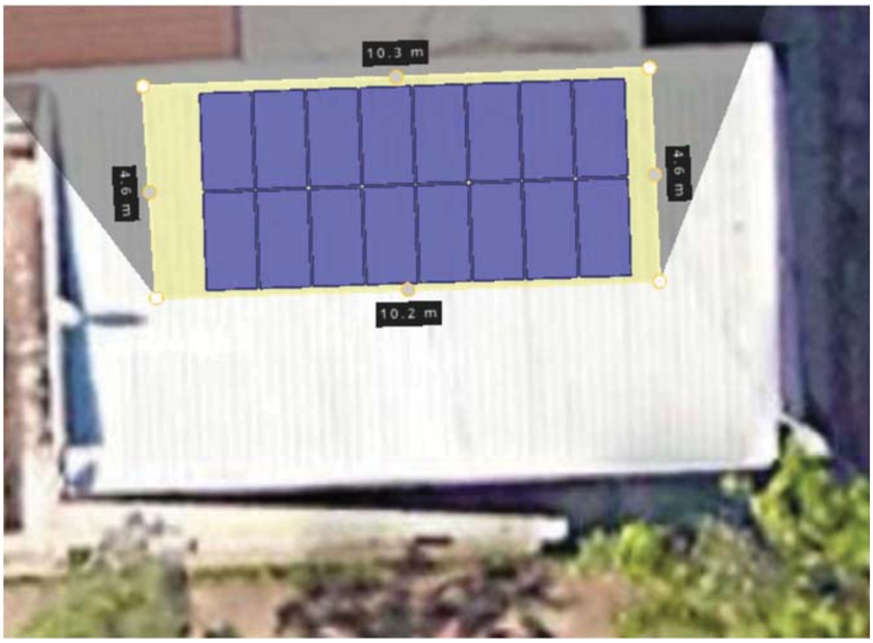

Figure 6.41 - Telheiras EB1 School - S9 - A9 PV Sizing (HelioScope, 2023).

PV Simulation

The simulation of these four systems will be done separately, where the results are presented in Figures 6.42 to 6.45.

PV Simulation Results - Telheiras EB1 School - System 1 / Area 1

- **Total installed capacity: 16.10kWp.**
- **Number of modules: 35 modules.**
- **Number of strings: 3 strings (12/12/11).**

- **Annual energy generation: 21.59MWh.**
- **Performance ratio: 81,80%.**
- **kWh/kWp: 1,341.3.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 24.813,6kWh/year.**
- **Availabe AC energy (grid): 21.594,8kWh/year.**

- **Estimated investment (1,000€/kWp): 16,100.00€**

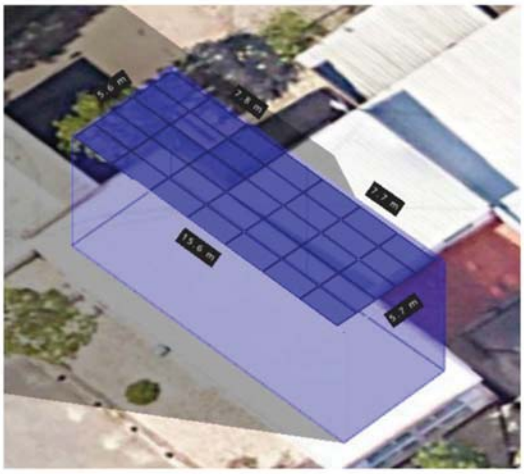

Figure 6.42 - Telheiras EB1 School - S1 - A1 PV Simulation (HelioScope, 2023).

PV Simulation Results - Telheiras EB1 School - System 4 / Area 4

- **Total installed capacity: 9.20kWp.**
- **Number of modules: 20 modules.**
- **Number of strings: 2 strings (10/10).**

- **Annual energy generation: 12.35MWh.**
- **Performance ratio: 81,80%.**
- **kWh/kWp: 1,342.1.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 14.178,3kWh/year.**
- **Availabe AC energy (grid): 12.347,3kWh/year.**

- **Estimated investment (1,000€/kWp): 9,200.00€**

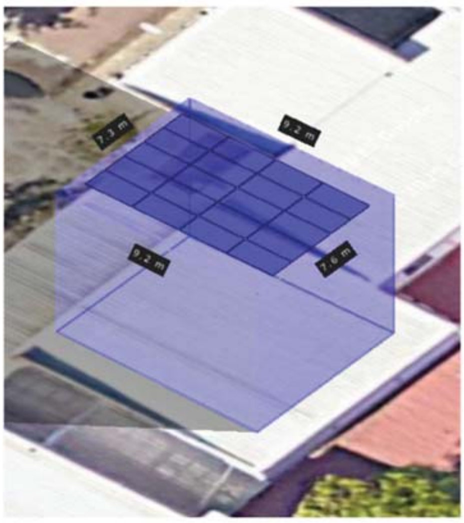

Figure 6.43 - Telheiras EB1 School - S4 - A4 PV Simulation (HelioScope, 2023).

PV Simulation Results - Telheiras EB1 School - System 6 / Area 6

- **Total installed capacity: 5.06kWp.**
- **Number of modules: 11 modules.**
- **Number of strings: unique strings.**

- **Annual energy generation: 7.32MWh.**
- **Performance ratio: 78,70%.**
- **kWh/kWp: 1,446.7.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 8.818,2kWh/year.**
- **Availabe AC energy (grid): 7.320,2kWh/year.**

- **Estimated investment (1,000€/kWp): 5,060.00€**

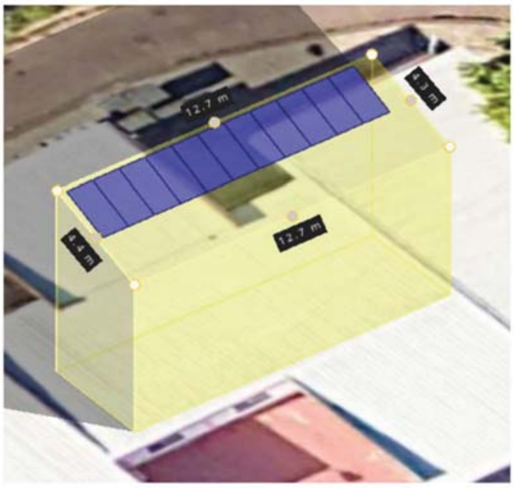

Figure 6.44 - Telheiras EB1 School - S6 - A6 PV Simulation (HelioScope, 2023).

PV Simulation Results - Telheiras EB1 School - System 9 / Area 9

- **Total installed capacity: 7.36kWp.**
- **Number of modules: 16 modules.**
- **Number of strings: 2 strings (8/8).**

- **Annual energy generation: 11.29MWh.**
- **Performance ratio: 82,70%.**
- **kWh/kWp: 1,553.5.**

- **Annual global irradiance: 1.648,3kWh/m².year.**
- **Irradiance reaching the PV modules: 12.931,1kWh/year.**
- **Availabe AC energy (grid): 11.286,8kWh/year.**

- **Estimated investment (1,000€/kWp): 7,360.00€**

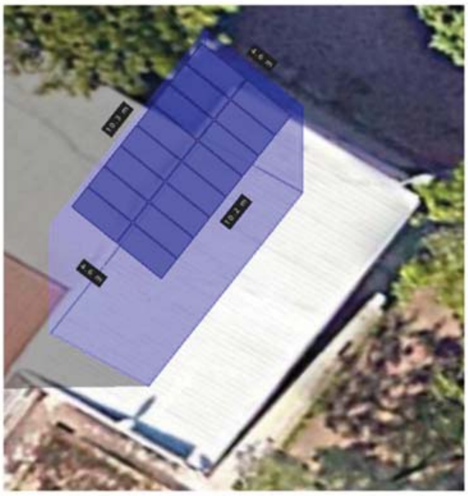

Figure 6.45 - Telheiras EB1 School - S9 - A9 PV Simulation (HelioScope, 2023).

6.3.4 Orlando Ribeiro Library Auditorium

Situated in a central location in Telheiras, close to Lagar of São Vicente's Farm, the Orlando Ribeiro Library is a library from the Municipal Chamber of Lisbon, being a place of culture, knowledge and leisure for the residents in Telheiras. During conversations with the Lumiar

Civil Parish, it was established that the only possibility for a PV system in the roof of this building it was on the part of the auditorium, due to legislative and administrative facts (the other parts of the roof are owned and managed by the Lisbon Municipality which will renovate them soon). A view of the entrance of this library can be found in Figure 6.46.

Figure 6.46 - View of the entrance of Orlando Ribeiro Library (2023).

As presented in Figure 6.47, this roof area has many difficulties regarding PV generation. First, there is a high building in the western part of the roof, which will promote an extreme scenario of shading during the whole year. Also, the central area of this roof is almost completely filled with outdoor units of heating, colling and air treatment equipment, where there is no space for PV modules. In the eastern part (ceramic roof tiles area), a really small area for PV modules is presented. Due to all these factors, PV generation in this roof area should be avoided, in order to prevent PV systems with really low performance ration.

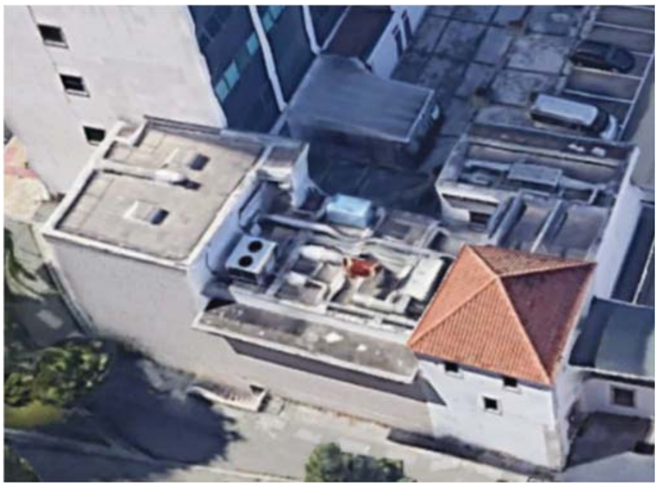
Figure 6.47 - View of the roof area of the Auditorium of Orlando Ribeiro Library (2023).

6.3.5 Lumiar Civil Parish Headquarters

Located in a central site of the Lumiar Parish, close to an important institute for graduation in Lisbon (Superior Institute of Education and Sciences of Lisbon), the Lumiar Civil Parish Headquarters is an historic building with various roof areas with different orientations and slopes. It is owned by the Lisbon Municipality and managed by the Lumiar Civil Parish. Figure 6.48 brings a view of this building.

Figure 6.48 - View of the Lumiar Civil Parish Headquarters (2023).

<u>Roof/Shading Analysis</u>

A similar process that was done for analyzing roof areas of Telheiras EB1 School. Here, they will be denoted as A1 to A6, as shown in Figure 6.49.

Figure 6.49 - View of the Lumiar Civil Parish Headquarters - Roof areas (2023).

a) Roof Area A1

This roof area has significant dimensions, but an orientation almost directly to the north (lower PV energy generation for locations in the south hemisphere). No shading elements are presented, where there is also a small fraction of the area with orientation west/east. Since this building has a large total roof area and aiming to avoid installing PV modules with north orientation, area A1 will not be used for PV generation. Figure 6.50 brings a view of this roof area.

Figure 6.50 - Lumiar Civil Parish Headquarters - Area A1 (Google Maps, 2023).

b) Roof Area A2

With fractions with orientations west and east, this roof area faces a high level of shading due to a high building located on the other side of the street. So, even though A2 has significant dimensions, this roof area should be avoided for PV generation. Figure 6.51 show this roof area and the building that cause this shading scenario.

Figure 6.51 - Lumiar Civil Parish Headquarters - Area A2 (Google Maps, 2023).

c) Roof Area A3

This area has significant dimensions with orientations north and south, where almost no shading effect is presented - only a three, as high as this roof area, can cause small shading in a little fraction of this area. So, roof area A3 will be used for PV generation, especially the south-oriented part, denotated by System 3 (S3). Figure 6.52 shows this roof area.

Figure 6.52 - Lumiar Civil Parish Headquarters - Area A3 (Google Maps, 2023).

d) Roof Area A4

Even though this roof area is significantly smaller than the others, area A4 has no problems with shading and a south-oriented fraction. So, roof area A4 will be used for PV generation, denotated by System 4 (S4). Figure 6.53 brings a view of roof area A4.

Figure 6.53 - Lumiar Civil Parish Headquarters - Area A4 (Google Maps, 2023).

e) Roof Area A5 and A6

Area A5 has significant dimensions and fractions with south and north orientations, but the presence of a building close to this area symbolizes a scenario of constant shading effects, where installing PV modules in this portion of the roof area will provide a PV system with significant low performance ratio. Then, roof area A5 will not be utilized for PV generation.The same situation occurs for roof area A6, where PV modules will not be installed. Both roof areas also can be seen in Figure 6.54.

Figure 6.54 - Lumiar Civil Parish Headquarters - Area A5 and A6 (Google Maps, 2023).

A summary of the areas that will be and will not be used for PV generation is presented in Figure 6.55.

Figure 6.55 - Lumiar Civil Parish Headquarters - Roof Area Evaluation (Adapted from Google Maps, 2023).

PV Sizing

The PV sizing will be done individually for each system (S3 and S4). Figures 6.56 and 6.57 present a view of each designed system, as the results will be presented individually.

a) System S3 (Area A3)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 30 modules.
- **Total installed power:** 13.80kWp.
- **Frequency inverter:** Sungrow SG-12 12kW (good relation between price and market availability), with a factor of 1.15 of oversizing.
- **Number of frequency inverters:** unique inverter.

Figure 6.56 - Lumiar Civil Parish Headquarters - S3 - A3 PV Sizing (HelioScope, 2023).

b) System S4 (Area A4)

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 5 modules.
- **Total installed power:** 2.30kWp.

- **Frequency inverter:** SMA SunnyBoy 2kW (good relation between price and market availability), with a factor of 1.15 of oversizing.
- **Number of frequency inverters:** unique inverter.

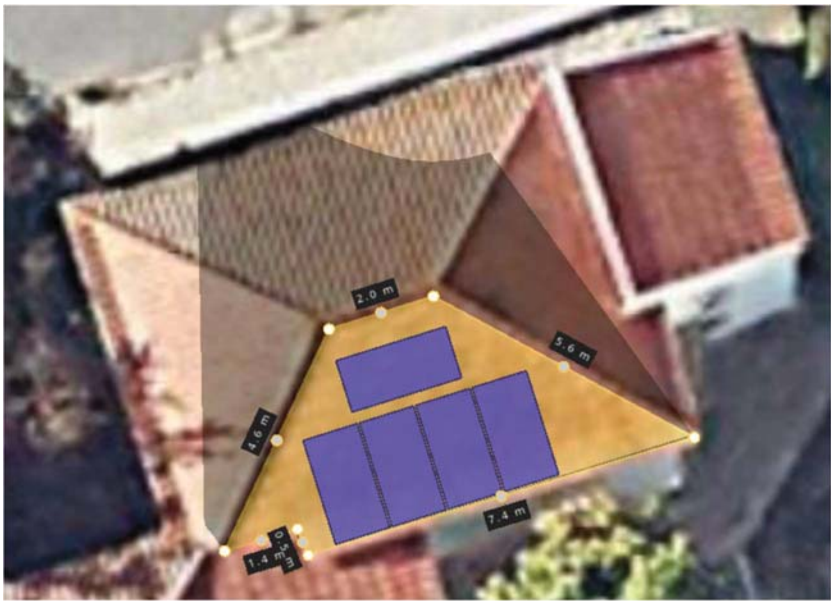

Figure 6.57 - Lumiar Civil Parish Headquarters - S4 - A4 PV Sizing (HelioScope, 2023).

PV Simulation

The simulation of these four systems will be done separately, where the results are presented in Figures 6.58 and 6.59.

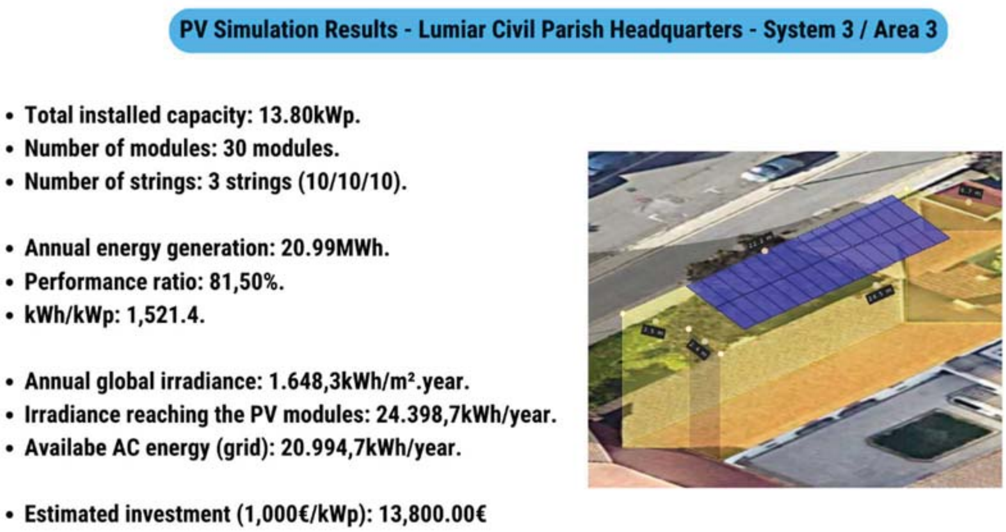

Figure 6.58 - Lumiar Civil Parish Headquarters - S3 - A3 PV Simulation (HelioScope, 2023).

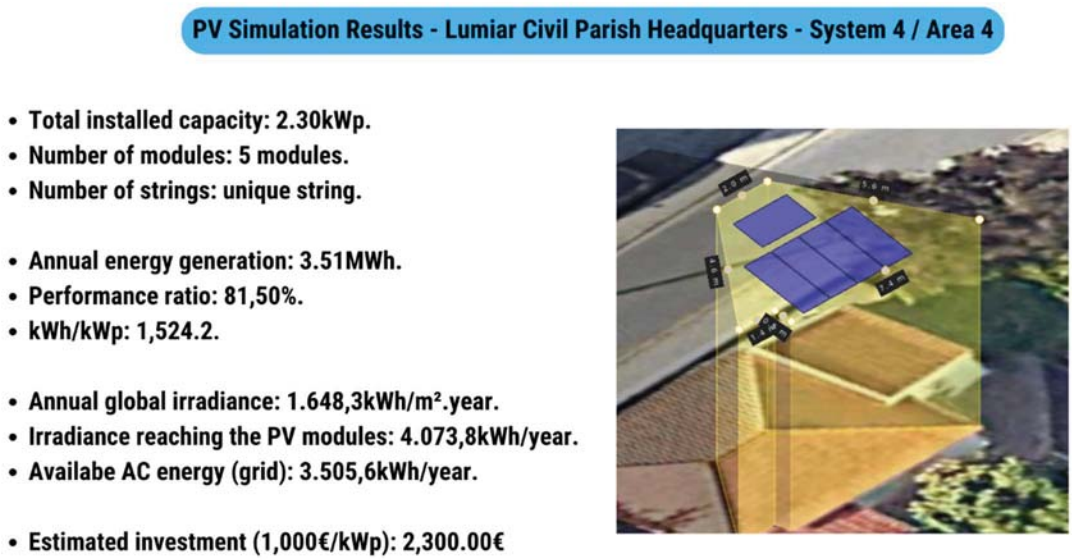

Figure 6.59 - Lumiar Civil Parish Headquarters - S4 - A4 PV Simulation (HelioScope, 2023).

6.3.6 Alto da Faia Multisport Gym

The Alto da Faia Multisport Gym is a public gymnasium for the practice of sports by citizens and residents of Telheiras and Lumiar, owned by Lisbon Municipality and managed by the Lumiar Civil Parish. With a large roof area with south and north orientation, this building should have priority when selecting the areas for installation of PV modules.

<u>Shading analysis</u>

One of the biggest advantages of this gymnasium is that there are no shading effects - there are no buildings, threes higher than the roof level or other constructive element in the surroundings. This, associated with a large roof area, leads to an adequate scenario for PV generation. Figure 6.60 brings a view of Alto da Faia Multisport Gym.

Figure 6.60 - View of Alto da Faia Multisport Gym (Google Maps, 2023).

PV Sizing

In this building, the PV sizing will result in a system of large scale. Since the Telheiras REC is still in a pilot project phase, this system might be oversized for the actual scenario of the energy entity, but this building should have priority for the PV generation. One possible scenario is starting the installation with a smaller PV system, but leaving done an infrastructure (cabling, conduits and other components) for future extensions.

So, the characteristics and parameters of the sized PV system are presented (Figure 6.61):

- **PV module:** Trina Solar TallMax 460Wp Monocrystalline (good relation between efficiency, dimensions, solar cell technology and market availability).
- **Number of PV modules:** 156 modules.
- **Total installed power:** 117.76kWp.
- **Frequency inverter:** Sungrow CX50 50kW (good relation between price and market availability), with a factor of 1.18 of oversizing.
- **Number of frequency inverters:** two inverters (one for the south-oriented area and other for the north-oriented area).

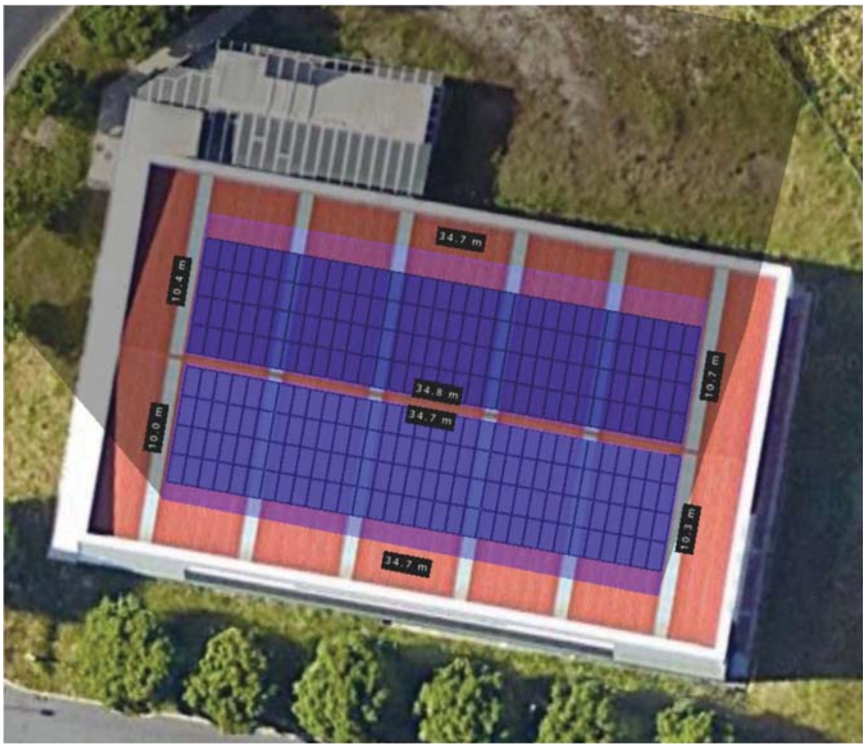

Figure 6.61 - Alto da Faia Multisport Gym - PV System (HelioScope, 2023).

PV Simulation

The simulation results of this PV system are presented in Figure 6.62.

PV Simulation Results - Alto da Faia Multisport Gym

- **Total installed capacity: 117.80kWp.**
- **Number of modules: 256 modules.**
- **Number of strings/inverter: 6 strings (18/18/18/18/18/18).**

- **Annual energy generation: 168.80MWh.**
- **Performance ratio: 81,30%.**
- **kWh/kWp: 1,443.0.**

- **Annual global irradiance: 1.772,1kWh/m².year.**
- **Irradiance reaching the PV modules: 195.032,5kWh/year.**
- **Availabe AC energy (grid): 168.755,6kWh/year.**

- **Estimated investment (1,000€/kWp): 117,800.00€**

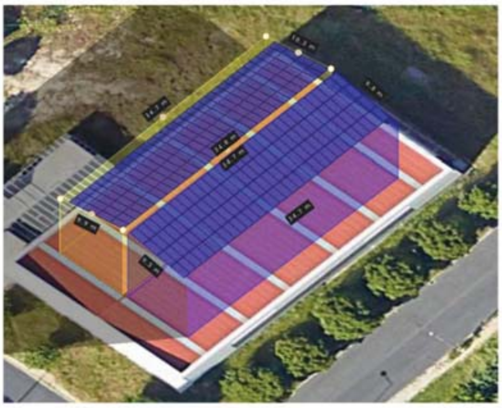

Figure 6.62 - Alto da Faia Multisport Gym - PV Simulation (HelioScope, 2023).

6.3.7 PV Simulations - Summary of the Results

A summary of all the results obtained through the PV simulation and analysis of these six buildings is presented in Figure 6.63. This can be seen as the PV potential of these buildings, in order to contribute with REC Telheiras' renewable energy generation.

As this community is currently in a pilot project phase and the REC is not licensed yet, this total energy generation is too large for this moment of the project. So, after evaluating each of those buildings, the choice and definition of the roofs that will receive PV modules first needs to follow some criteria, namely:

- **Permission from the responsible entities for installing the system:** since those buildings are owned by the Lisbon Municipality and managed by the Lumiar Civil Parish, that is a local governmental organization, priority should be given to those roofs that are first approved to receive PV modules. Recently, two buildings were approved for the PV installation for the REC:

Lagar of São Vicente's Farm and the Lumiar Civil Parish Headquarters. Therefore, these must be the buildings to receive first the PV systems.

- **Adequate conditions for these systems:** buildings with adequate roof area for PV installation with significant dimensions should be prioritized, where higher energy production will be expected, as well as an easy installation process. In this context, Alto da Faia Multisport Gym and Mira Rio School/Telheiras Church have more favorable conditions to receive systems with larger installed capacities. If not all the PV potential is needed in this pilot project, part of the roof area can be used, and the infrastructure can be done for future expansions of the systems.

- **Location of the buildings:** according to the Portuguese law, low-voltage generation sites must be in a 2km range from the members of the REC. So, choosing wisely the buildings which will receive these PV systems can enhance the covered area for larger member participation. So, spatially distributed buildings, such as the Alto da Faia Multisport Gym and Lagar of São Vicente's Farm, should be utilized, since they are not located in the same central part of Telheiras and can provide a larger area for new members of the REC.

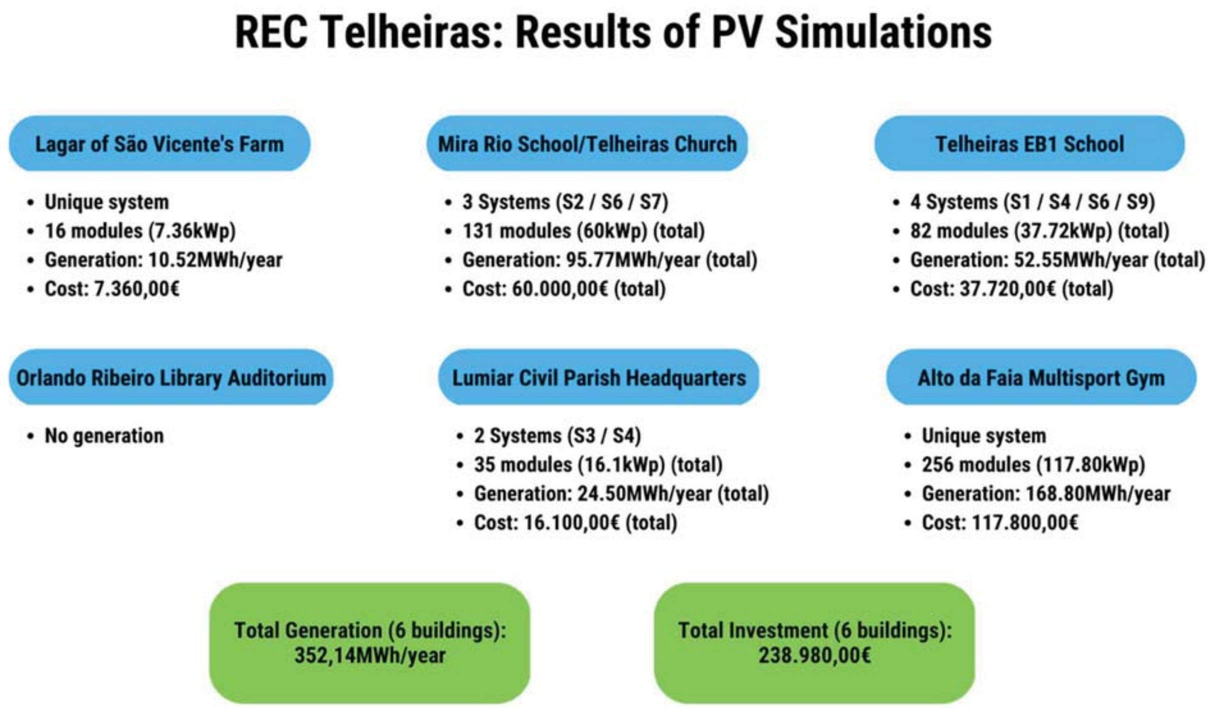

Figure 6.63 - REC Telheiras - Summary of PV Simulations (2023).

So, due to all these criteria and results, the buildings that should be prioritized are:

- Lagar of São Vicente's Farm and Lumiar Civil Parish Headquartes (already approved).
- Alto da Faia Multisport Gym and Mira Rio School/Telheiras Church (location and higher available roof area).

6.4 Analysis of the Implementation Process - REC Telheiras

Although Telheiras neighborhood has a pioneering role in sustainable actions and strong community engagement, the process of implementing a REC in this neighborhood faces several important barriers and challenges, as the main ones are:

a) Lack of knowledge about RECs by local governmental authorities and citizens

Since a formal definition of the concept of a Renewable Energy Community is recent and it is not a daily theme of the population and local authorities, many people do not know what this energy entity means, its purposes and ways of implementation. The fact that countries from the south part of Europe, as Portugal, still do not have a large number of operating and licensed RECs contributes for that, where the impact of these organizations is not felt by the majority of the national population. This also impacts the local governmental authorities, where the lack of a considerable number of citizen-led energy actions and energy related organizations make these entities unfamiliar with the processes necessary for the creation and regularization of a REC, which translates into greater difficulties and bureaucracy in the implementation process.

Due to this, a well-designed communication plan is crucial for the success of this process, providing information and presenting the concept, as well as the associated benefits for the community and its members, and also with a specific and well defined approach for local authorities and governmental organizations, aiming to facilitate and speed up this implementation process of a REC.

In the specific case of REC Telheiras, many meetings between *Grupo Telheiras Sustentável* and the Lumiar Civil Parish, with the presence of experts from the Energy Poverty Advisory Hub, Coopérnico and FCT-NOVA, were vital to advance this partnership with this local entity, where the concept of a Renewable Energy Community was presented, with associated benefits for the community, forms of operation and financial schemes. All this process made the Lumiar Civil Parish to become a partner in this implementation process, also willing to be a member of the REC in this pilot project.

Regarding the residents of Telheiras, different participations in local events and festivals, as well as the distribution of informative material (flyers) regarding this implementation process were really important for spreading what a REC is and its benefits, also enhancing the number of citizens that desire to be part of this energy organization or even become part of the group that is leading its creation. The fact that this action is led by residents of the neighborhood also enhances the acceptance and participation of the locals, where family and friends of those who are already engaged in the implementation of the REC end up being influenced and motivated to support the creation of this organization, also becoming potential future members.

b) Maintaining engagement and proactivity of the citizens involved in the process of creation

The group responsible for the implementation process of a REC in Telheiras - *Grupo Telheiras Sustentável* - started discussing this energy organization in an event in September 2021. By now (March 2023), the Renewable Energy Community is still not operating and licensed - it is a fact that this process does take a long time to start the operation, since many important factors, decisions and processes are involved with different players, but, for citizens that participate with voluntary work on this process, it can be a demotivating factor. Regarding this voluntary work, other important aspects are the lack of time of the participants and other priorities, where this affect presence and work inside this working group.

The motivation increases after important marks for the development of the REC, but in quieter moments and when it is necessary to wait for decisions by local authorities this motivation decreases drastically. This impacts the frequency of participation in internal meetings, individual contribution - most often intellectual - to making important decisions, and participation in events and festivals to enhance the acceptance of the project.

In the specific case of Telheiras, this barrier is solved by a constant and solid leadership figure in the process of creating the community, always seeking to increase and maintain the engagement of the REC development team and encouraging participation in meetings and events. Also, the sustainable background of the neighborhood helps in this context, where the residents have experienced the impact of citizen-led actions in the community and the importance of the resident participation in developing the area.

c) Authorization for the use of roof area of public buildings for PV systems

Since different public buildings have different management entities, characteristics, uses and historical aspects, receiving authorization to use those roof areas was one of the most significant barriers for REC Telheiras. Many meetings and conversations with different local authorities were done, with the presentation of the project, the PV potential of the building and the associated legislation to operate these systems. This process is bureaucratic and slow, since many different persons and entities need to approve the use of a single roof area of PV generation for the REC. This slowness combined with the fact that, so far, this process needs to be repeated for six different buildings, makes the implementation process of this REC even more difficult. Also, as previously mentioned, the local authorities' lack of knowledge about RECs makes theses conversations even more difficult.

In this scenario, the partnership with the Lumiar Civil Parish is crucial, where which makes the dialogues with other entities easier and more effective. Also, the participation of the experts of EPAH, Coopérnico and FCT-NOVA helps to obtain a positive decision about these roof areas, since they can clearly explain the associated benefits and the PV potential of these sites.

d) Slow process of licensing (*Direção-Geral de Energia e Geologia*)

As mentioned in previous sections, many Portuguese RECs for a long time to obtain the operating license from *Direção-Geral de Energia e Geologia*, where this process is needed to launch the community. As REC Telheiras has not even submitted the candidacy for obtaining this document, a long time is expected to obtain the license and properly start the operation of this REC, as this can be seen as an important barrier for launching REC Telheiras.

e) Elaborating a financing scheme, especially considering social members

Another challenge to Telheiras REC is to develop a financing scheme that fits with the organizational structure of the pilot project and consider the social members (energy-poor households that cannot invest in the community but will be benefitted by this organization becoming active members of it). In this situation, Coopérnico is supporting the development of this scheme, where the members will have a proper way of participating in the REC and this entity will provide energy poverty reduction specially for the most vulnerable ones.

6.5 Comparisons with Other RECs - REC Telheiras

Regarding the classification presented in Section 3.6 of this dissertation, at this moment, REC Telheiras can be classified as:

- **Location:** place-based REC.
- **Purpose**: single-purpose REC.
- **Organization:** centralized REC.
- **Activity:** development of collective energy generation.

Among all the existing RECs shown in Section 3.6, the most similar to REC Telheiras is the German Sola-Re. Both RECs grew from citizen-led actions regarding PV energy generation on roof areas of public buildings. Also, both of them have important partnerships with local entities (Lumiar Civil Parish in REC Telheiras, and the City Hall of Recklinghäusen in Sola-Re), where these entities also want to become (case of Lumiar Civil Parish) or are members of the REC (case of City Hall of Recklinghäusen).

These similarities with a twelve-year-old REC show that the scheme associated with REC Telheiras is operational and feasible, where communications and exchange of knowledge and experiences with Sola-Re can be an important factor to speed up the process of implementation of this energy organization in Telheiras.

7

Conclusions and Further Steps

With this dissertation, is possible to conclude the important role of Renewable Energy Communities in reducing energy poverty and enhancing energy citizenship. It is crucial that the citizens participate actively in the current energy transition, where they have an important contribution to meet the climate goals of the Paris Agreement and complete decarbonization by 2050. Other similar citizen-led energy organizations also should be enhanced and promoted by local governments and institutions, where their contributions are also important for a fairer and more democratic energy transition.

The leadership of the European Union - especially the northern European countries of this block - in RECs is visible, with many existing cases and others in the implementation process. Also, European projects play a main role in helping the launch of new and innovative cases of RECs in different Member States. North America and Oceania also have some examples of existing RECs. Still tthese energy entities should reach all the continents in order to promote a globally fair energy transition, where all the countries should be able to create citizen-led energy actions. For this, a regulatory framework regarding the development of this concept is necessary, where these countries can be inspired by the current scenario of EU and adapt their directives and laws to the existing reality.

The process of implementing a REC needs to be facilitated by the local governments, making it easier and faster. Also, barriers associated with a lack of knowledge and acceptance of renewable energy systems and/or energy organizations should be diminished by promoting programs and events that explain to the citizens and local stakeholders the benefits of these topics and the importance of acting in climate change related aspects.

Specifically in Portugal, it is crucial that the licensing process by *Direção-Geral de Energia e Geology* becomes faster and easier, as this is one of the most significant barriers for a large enhancement of the number of Portuguese RECs. Also, recently signed national laws aiming to turn easier to launch a REC shows the tendency of the government to promote these energy entities, as these authorities know the importance of these local actions.

Telheiras REC should become a model case for other RECs in Lisbon and Portugal since it has an advanced situation regarding the development of the project and an existing operational scheme for the pilot project (RECs as Sola-Re operates in a very similar way than REC Telheiras' pilot project). The PV potential of the six selected buildings can, easily, supply the pilot project and further extensions of the REC, but suffers from bureaucracy and problems for obtaining the authorization to use these roof areas of local public buildings.

Necessary further steps for REC Telheiras are to advance in the financial scheme and submit the candidacy to obtain the operating license as soon as possible. Also, the urgent validation and confirmation of the structural scheme for the pilot project is needed, in order to put into practice the actions needed to launch it. Exchange of ideas and experiences and a partnership with RECs that operate in a similar way is also essential, as Sola-Re, where this contact can speed up the launching and enhance the success of the implementation process.

References

Adom, P. K., Amuakwa-Mensah, F., Agradi, M. P., & Nsabimana, A. (2021). Energy poverty, development outcomes, and transition to green energy. Renewable Energy, 178, 1337–1352. https://doi.org/10.1016/j.renene.2021.06.120.

Alam, M. S., Miah, M. D., Hammoudeh, S., & Tiwari, A. K. (2018). The nexus between access to electricity and labour productivity in developing countries. Energy Policy, 122, 715–726. https://doi.org/10.1016/j.enpol.2018.08.009.

Alavirad, S., Mohammadi, S., Hoes, P.-J., Xu, L., & Hensen, J. L. M. (2022). Future-Proof Energy-Retrofit strategy for an existing Dutch neighborhood. Energy and Buildings, 260(111914), 111914. https://doi.org/10.1016/j.enbuild.2022.111914.

Asim, T., Islam, S. Z., Hemmati, A., & Khalid, M. S. U. (2022). A review of recent advancements in offshore wind turbine technology. Energies, 15(2), 579. https://doi.org/10.3390/en15020579.

Baruah, D. C., & Enweremadu, C. C. (2019). Prospects of decentralized renewable energy to improve energy access: A resource-inventory-based analysis of South Africa. Renewable and Sustainable Energy Reviews, 103, 328–341. https://doi.org/10.1016/j.rser.2019.01.006.

Beauchampet, I., & Walsh, B. (2021). Energy citizenship in the Netherlands: The complexities of public engagement in a large-scale energy transition. Energy Research & Social Science, 76(102056), 102056. https://doi.org/10.1016/j.erss.2021.102056.

Bellekom, S., Arentsen, M., & van Gorkum, K. (2016). Prosumption and the distribution and supply of electricity. Energy, Sustainability and Society, 6(1). https://doi.org/10.1186/s13705-016-0087-7.

Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Fanciulli, C., Ghellere, M., Guazzi, G., Meroni, I., Salamone, F., Scamoni, F., & Scrosati, C. (2019). A review of performance of zero energy buildings and energy efficiency solutions. Journal of Building Engineering, 25(100772), 100772. https://doi.org/10.1016/j.jobe.2019.100772

Berka, A. L., & Creamer, E. (2018). Taking stock of the local impacts of community owned renewable energy: A review and research agenda. Renewable and Sustainable Energy Reviews, 82, 3400–3419. https://doi.org/10.1016/j.rser.2017.10.050.

Brown, M., Soni, A., Lapsa, M., & Southworth, K. (2020). Low-income energy affordability: Conclusions from A literature review. Office of Scientific and Technical Information (OSTI).

Brozovski, J., Gustavsen, A., & Gaitani, N. (2021). Zero Emission Neighbourhoods and Positive Energy Districts – A State-of-Art Review. Sustainable Cities and Society, 72(103013), 103013. https://doi.org/10.1016/j.scs.2021.103013.

Câmara Municipal da Batalha (2023). AcerBatalha Submete Candidatura Superior a Meio Milhão de Euros para Produção de Energia Limpa. Available at https://www.cm-batalha.pt/noticias/acerbatalha-submete-candidatura-superior-a-meio-milhao-de-euros-para-producao-de-energia-limpa.

Camero, A., & Alba, E. (2019). Smart City and information technology: A review. Cities (London, England), 93, 84–94. https://doi.org/10.1016/j.cities.2019.04.014.

Castaño-Rosa, R., Solís-Guzmán, J., Rubio-Bellido, C., & Marrero, M. (2019). Towards a multiple-indicator approach to energy poverty in the European Union: A review. Energy and Buildings, 193, 36–48. https://doi.org/10.1016/j.enbuild.2019.03.039

Chevalier, J.-M. (2009). The new energy crisis. Em The New Energy Crisis (p. 6–59). Palgrave Macmillan UK. https://doi.org/10.1057/9780230242234_2

Chudzik, S. (2023). Wind microturbine with adjustable blade pitch angle. Energies, 16(2), 945. https://doi.org/10.3390/en16020945.

Cielo, A., Margiaria, P., Lazzeroni, P., Mariuzzo, I., & Repetto, M. (2021). Renewable Energy Communities business models under the 2020 Italian regulation. Journal of Cleaner Production, 316(128217), 128217. https://doi.org/10.1016/j.jclepro.2021.128217.

Coenen, F. H. J. M., & Hoppe, T. (2022). Renewable energy communities as a new actor in home energy savings. Urban Planning, 7(2), 108–122. https://doi.org/10.17645/up.v7i2.5088.

Comello, S., Reichelstein, S., & Sahoo, A. (2018). The road ahead for solar PV power. Renewable and Sustainable Energy Reviews, 92, 744–756. https://doi.org/10.1016/j.rser.2018.04.098.

Contumélias, M. M. D. S. (2008). Uma aldeia na cidade: Telheiras, o que é hoje e como se produz um bairro?.

Compile (2022). Compile Project - Home. Available at https://www.compile-project.eu/.

Coy, D., Malekpour, S., & Saeri, A. K. (2022). From little things, big things grow: Facilitating community empowerment in the energy transformation. Energy Research & Social Science, 84(102353), 102353. https://doi.org/10.1016/j.erss.2021.102353.

Culatra Project (2023). Comunidade de Energia Renovável. Available at https://www.culatra2030.pt/comunidade-energetica-renovavel/.

DellaValle, N., & Czako, V. (2022). Empowering energy citizenship among the energy poor. Energy Research & Social Science, 89(102654), 102654. https://doi.org/10.1016/j.erss.2022.102654.

Deng, M., Leippold, M., Wagner, A. F., & Wang, Q. (2022). Stock prices and the Russia-Ukraine war: Sanctions, energy and ESG. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4080181.

Deshpande, S., & Bhasme, N. R. (2017). A review of topologies of inverter for grid connected PV systems. 2017 Innovations in Power and Advanced Computing Technologies (i-PACT), 1–6.

Devine-Wright, P. (2007). Governing technology for sustainability, Earthscan, London; Sterling, VA.

Di Silvestre, M. L., Ippolito, M. G., Sanseverino, E. R., Sciumè, G., & Vasile, A. (2021). Energy self-consumers and renewable energy communities in Italy: New actors of the electric power systems. Renewable and Sustainable Energy Reviews, 151(111565), 111565. https://doi.org/10.1016/j.rser.2021.111565.

Diário da República (2019). Lei nº 123/2019, 18 de Outubro. Assembleia da República, p.3-53.

Diário da República (2020). Resolução do Conselho de Ministros nº 53/2020, 10 de Julho, p.2-128.

Diário da República (2022). Decreto-Lei nº 15/2022, 14 de Janeiro. Presidência do Conselho de Ministros, p.3-185.

Diário da República (2022). Decreto-Lei nº 30-A/2022, 18 de Abril. Presidência do Conselho de Ministros, p.2-6.

Diário da República (2022). Decreto-Lei nº 72/2022, 19 de Outubro. Presidência do Conselho de Ministros, p.15-20.

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance.)

Energy Communities Repository (2023). Obtained on January 9, 2023, from https://energy-communities-repository.ec.europa.eu/energy-communities_en.

Energy Poverty Advisory Hub (2023). The Leading EU Initiative on Local Action Against Energy Poverty. Available at https://energy-poverty.ec.europa.eu/index_en.

European Commission (2019). Clean Energy for All Europeans Package. https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en.

European Commission (2021). European Green Deal: delivering on our targets, Publications Office of the European Union. https://data.europa.eu/doi/10.2775/373022.

Escozon. (2020). Escozon. https://www.escozon.nl.

Fundo Ambiental (2022). C13-i01; 02; 03 - Apoio à concretização de Comunidades de Energia Renovável e Autoconsumo Coletivo. Support for the implementation of Renewable Energy Communities and Collective Self-Consumption. Fundoambiental.pt. Obtained on January 19,

2023. Available at https://www.fundoambiental.pt/apoios-prr/c13-eficiencia-energetica-em-edificios/c13-i01-02-03-apoio-a-concretizacao-de-comunidades-de-energia-renovavel-e-autoconsumo-coletivo.aspx

Ghosh, A. (2020). Potential of building integrated and attached/applied photovoltaic (BIPV/BAPV) for adaptive less energy-hungry building's skin: A comprehensive review. Journal of Cleaner Production, 276(123343), 123343. https://doi.org/10.1016/j.jclepro.2020.123343.

Gjorgievski, V. Z., Cundeva, S., & Georghiou, G. E. (2021). Social arrangements, technical designs and impacts of energy communities: A review. Renewable Energy, 169, 1138–1156. https://doi.org/10.1016/j.renene.2021.01.078.

González-Eguino, M. (2015). Energy poverty: An overview. Renewable and Sustainable Energy Reviews, 47, 377–385. https://doi.org/10.1016/j.rser.2015.03.013.

Gui, E. M., Diesendorf, M., & MacGill, I. (2017). Distributed energy infrastructure paradigm: Community microgrids in a new institutional economics context. Renewable and Sustainable Energy Reviews, 72, 1355–1365. https://doi.org/10.1016/j.rser.2016.10.047.

Gui, E. M., & MacGill, I. (2018). Typology of future clean energy communities: An exploratory structure, opportunities, and challenges. Energy Research & Social Science, 35, 94–107. https://doi.org/10.1016/j.erss.2017.10.019.

Hamed, T. A., & Peric, K. (2020). The role of renewable energy resources in alleviating energy poverty in Palestine. Renewable Energy Focus, 35, 97–107. https://doi.org/10.1016/j.ref.2020.09.006.

Hanke, F., & Lowitzsch, J. (2020). Empowering vulnerable consumers to join renewable energy communities—towards an inclusive design of the clean energy package. Energies, 13(7), 1615. https://doi.org/10.3390/en13071615.

Hanke, F., Guyet, R., & Feenstra, M. (2021). Do renewable energy communities deliver energy justice? Exploring insights from 71 European cases. Energy Research & Social Science, 80(102244), 102244. https://doi.org/10.1016/j.erss.2021.102244.

Hargreaves, T., Nye, M., & Burgess, J. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy, 38(10), 6111–6119. https://doi.org/10.1016/j.enpol.2010.05.068.

Heldeweg, M. A., & Saintier, S. (2020). Renewable energy communities as 'socio-legal institutions': A normative frame for energy decentralization? Renewable and Sustainable Energy Reviews, 119(109518), 109518. https://doi.org/10.1016/j.rser.2019.109518.

Hinsch, A., Rothballer, C., & Russell, L. (2022). Come-res.eu. Obtido 12 de julho de 2022, https://come-res.eu/fileadmin/user_upload/Resources/Factsheets_policybriefs/COME-RES-factsheet-2-ENG.pdf.

Hirsch, A., Parag, Y., & Guerrero, J. (2018). Microgrids: A review of technologies, key drivers, and outstanding issues. Renewable and Sustainable Energy Reviews, 90, 402–411. https://doi.org/10.1016/j.rser.2018.03.040.

Holmes, S. (2014). Opportunities for communities amidst the energy challenge: Hepburn wind. Proceedings of the Royal Society of Victoria. Melbourne, 126, 8. https://www.proquest.com/openview/d49c8ad45551109cdd97c2431fe20ad4/1?pq-origsite=gscholar&cbl=1256339.

Igawa, M., & Managi, S. (2022). Energy poverty and income inequality: An economic analysis of 37 countries. Applied Energy, 306(118076), 118076. https://doi.org/10.1016/j.apenergy.2021.118076.

Intergovernmental Panel on Climate Change (2018). Global warming of 1.5°C — Summary for Policymakers. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Working Group I Technical Support Unit.

Iwata, H., & Okada, K. (2014). Greenhouse gas emissions and the role of the Kyoto Protocol. Environmental Economics and Policy Studies, 16(4), 325–342. https://doi.org/10.1007/s10018-012-0047-1.

Jessel, S., Sawyer, S., & Hernández, D. (2019). Energy, poverty, and health in climate change: a comprehensive review of an emerging literature. Frontiers in public health, 357. https://doi.org/10.3389/fpubh.2019.00357

Jiang, Z. (2021). Installation of offshore wind turbines: A technical review. Renewable and Sustainable Energy Reviews, 139(110576), 110576. https://doi.org/10.1016/j.rser.2020.110576.

Khodayar, M. E., Feizi, M. R., & Vafamehr, A. (2019). Solar photovoltaic generation: Benefits and operation challenges in distribution networks. Electricity Journal, 32(4), 50–57. https://doi.org/10.1016/j.tej.2019.03.004

King, L. C., & van den Bergh, J. C. J. M. (2021). Potential carbon leakage under the Paris Agreement. Climatic Change, 165(3–4). https://doi.org/10.1007/s10584-021-03082-4.

Koirala, B. P., Koliou, E., Friege, J., Hakvoort, R. A., & Herder, P. M. (2016). Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. Renewable and Sustainable Energy Reviews, 56, 722–744. https://doi.org/10.1016/j.rser.2015.11.080.

Koirala, B. P., Araghi, Y., Kroesen, M., Ghorbani, A., Hakvoort, R. A., & Herder, P. M. (2018). Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. Energy research & social science, 38, 33–40. https://doi.org/10.1016/j.erss.2018.01.009.

Kotilainen, K. (2020). Energy prosumers' role in the sustainable energy system. Em Encyclopedia of the UN Sustainable Development Goals (pp. 1–14). Springer International Publishing.

Kumar, R., Raahemifar, K., & Fung, A. S. (2018). A critical review of vertical axis wind turbines for urban applications. Renewable and Sustainable Energy Reviews, 89, 281–291. https://doi.org/10.1016/j.rser.2018.03.033.

Kumar, N. M., Sudhakar, K., & Samykano, M. (2019). Performance comparison of BAPV and BIPV systems with c-Si, CIS and CdTe photovoltaic technologies under tropical weather conditions. Case Studies in Thermal Engineering, 13(100374), 100374. https://doi.org/10.1016/j.csite.2018.100374.

Kyoto Protocol to the United Nations Framework Convention on Climate Change. FCCC/CP/1997/L.7/Add.1. 10 dez. 1997. Available at <http://unfcc.int/cop4/l07a01.pdf>. Visited in June 10, 2022.

Leccisi, E., Raugei, M., & Fthenakis, V. (2016). The energy and environmental performance of ground-mounted photovoltaic systems—A timely update. Energies, 9(8), 622. https://doi.org/10.3390/en9080622.

Leggett, J. A. (2020). The United Nations framework convention on climate change, the Kyoto protocol, and the Paris agreement: A summary. Everycrsreport.com. https://www.everycrsreport.com/files/20200129_R46204_d496a7f6b79412253cfb14eb1e7c21c3124dfcf4.pdf.

Lennon, B., Dunphy, N., Gaffney, C., Revez, A., Mullally, G., & O'Connor, P. (2020). Citizen or consumer? Reconsidering energy citizenship. Journal of Environmental Policy & Planning, 22(2), 184–197. https://doi.org/10.1080/1523908x.2019.1680277

Li, X., Peng, J., Li, N., Wu, Y., Fang, Y., Li, T., Wang, M., & Wang, C. (2019). Optimal design of photovoltaic shading systems for multi-story buildings. Journal of Cleaner Production, 220, 1024–1038. https://doi.org/10.1016/j.jclepro.2019.01.246.

Li, Y., Huang, X., Tee, K. F., Li, Q., & Wu, X.-P. (2020). Comparative study of onshore and offshore wind characteristics and wind energy potentials: A case study for southeast coastal region of China. Sustainable Energy Technologies and Assessments, 39(100711), 100711. https://doi.org/10.1016/j.seta.2020.100711.

Li, H., Wang, Z., Hong, T., & Piette, M. A. (2021). Energy flexibility of residential buildings: A systematic review of characterization and quantification methods and applications. Advances in Applied Energy, 3(100054), 100054. https://doi.org/10.1016/j.adapen.2021.100054

Lima, M. A., Mendes, L. F. R., Mothé, G. A., Linhares, F. G., de Castro, M. P. P., da Silva, M. G., & Sthel, M. S. (2020). Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil. Environmental Development, 33(100504), 100504. https://doi.org/10.1016/j.envdev.2020.100504.

Lindholm, O., Rehman, H. ur & Reda, F. (2021). Positioning Positive Energy Districts in European Cities. Buildings, 11(1), 19. https://doi.org/10.3390/buildings11010019.

Manganaro, V. (202). E-DRIVER - Centro Per le Comunità Solari. Centro Per le Comunità Solari. https://comunitasolare.eu/edriver/.

Marques, R., Lamego, P., Lourenço, P. B., & Sousa, M. L. (2018). Efficiency and cost-benefit analysis of seismic strengthening techniques for old residential buildings in Lisbon. Journal of Earthquake Engineering, 22(9), 1590–1625. https://doi.org/10.1080/13632469.2017.1286616

Mesquita, D. de B., Lucas de S. Silva, J., Moreira, H. S., Kitayama, M., & Villalva, M. G. (2019). A review and analysis of technologies applied in PV modules. 2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America), 1–6.

Mohammed, Y. S., Bashir, N., & Mustafa, M. W. (2015). Overuse of wood-based bioenergy in selected sub-Saharan Africa countries: review of unconstructive challenges and suggestions. Journal of cleaner production, 96, 501–519. https://doi.org/10.1016/j.jclepro.2014.04.014

Moroni, S., Alberti, V., Antoniucci, V., & Bisello, A. (2018). Energy communities in a distributed-energy scenario: Four different kinds of community arrangements. Smart and Sustainable Planning for Cities and Regions (p. 429–437). Springer International Publishing.

Moroni, S., Alberti, V., Antoniucci, V., & Bisello, A. (2019). Energy communities in the transition to a low-carbon future: A taxonomical approach and some policy dilemmas. Journal of Environmental Management, 236, 45–53. https://doi.org/10.1016/j.jenvman.2019.01.095.

Municipalities in Transition (2023). The Pilots. Available at https://municipalitiesintransition.org/the-pilots/.

Nikas, A., Gambhir, A., Trutnevyte, E., Koasidis, K., Lund, H., Thellufsen, J. Z., Mayer, D., Zachmann, G., Miguel, L. J., Ferreras-Alonso, N., Sognnaes, I., Peters, G. P., Colombo, E., Howells, M., Hawkes, A., van den Broek, M., Van de Ven, D. J., Gonzalez-Eguino, M., Flamos, A., & Doukas, H. (2021). Perspective of comprehensive and comprehensible multi-model energy and climate science in Europe. Energy (Oxford, England), 215(119153), 119153. https://doi.org/10.1016/j.energy.2020.119153.

Nolden, C., Barnes, J., & Nicholls, J. (2020). Community energy business model evolution: A review of solar photovoltaic developments in England. Renewable and Sustainable Energy Reviews, 122(109722), 109722. https://doi.org/10.1016/j.rser.2020.109722.

Palma, P., & Gouveia, J.P. (2022). Diagnóstico de Vulnerabilidade à Pobreza Energética da Freguesia do Lumiar, Lisboa. Energy Poverty Advisory Hub.

Parceria Local Telheiras & Coopérnico (2023). Description and comparison of two financial and operational models for the pilot energy community. Draft version (23/01/2023). Energy Poverty Advisory Hub.

Peters, L., & Madlener, R. (2017). Economic evaluation of maintenance strategies for ground-mounted solar photovoltaic plants. Applied energy, 199, 264–280. https://doi.org/10.1016/j.apenergy.2017.04.060.

Pons-Seres de Brauwer, C., & Cohen, J. J. (2020). Analysing the potential of citizen-financed community renewable energy to drive Europe's low-carbon energy transition. Renewable and Sustainable Energy Reviews, 133(110300), 110300. https://doi.org/10.1016/j.rser.2020.110300.

Porté-Agel, F., Bastankhah, M., & Shamsoddin, S. (2020). Wind-turbine and wind-farm flows: A review. Boundary - Layer Meteorology, 174(1), 1–59. https://doi.org/10.1007/s10546-019-00473-0

Público (2023). Portugal Ainda Não Chegou a uma Mão-Cheia de Comunidades de Energia Renovável. Available at https://www.publico.pt/2023/02/05/azul/noticia/portugal-nao-chegou-maocheia-comunidades-energia-renovavel-2036970.

Ranjbaran, P., Yousefi, H., Gharehpetian, G. B., & Astaraei, F. R. (2019). A review on floating photovoltaic (FPV) power generation units. Renewable and Sustainable Energy Reviews, 110, 332–347. https://doi.org/10.1016/j.rser.2019.05.015.

Reid, L., & Ellsworth-Krebs, K. (2017). Practicing energy prosumption: Using unsolicited online data to reveal the everyday realities of solar thermal panels in the United Kingdom. Energy Research & Social Science, 34, 191–199. https://doi.org/10.1016/j.erss.2017.07.010.

Renewable energy – recast to 2030 (RED II). (2021). EU Science Hub. https://joint-research-centre.ec.europa.eu/welcome-jec-website/reference-regulatory-framework/renewable-energy-recast-2030-red-ii_en.

Rescoop.eu (2023). Community Energy - A Practical Guide to Reclaiming Power. Available at https://www.rescoop.eu/toolbox/community-energy-a-practical-guide-to-reclaiming-power

Rezamand, M., Kordestani, M., Carriveau, R., Ting, D. S.-K., Orchard, M. E., & Saif, M. (2020). Critical wind turbine components prognostics: A comprehensive review. IEEE transactions on instrumentation and measurement, 69(12), 9306–9328. https://doi.org/10.1109/tim.2020.3030165.

Riakhi, F.-E., & Khaldoun, A. (2021). PV sizing of a grid connected solar carport system linked to charging stations and its economic analysis (A case study). 2021 9th International Renewable and Sustainable Energy Conference (IRSEC), 1–6.

Rosen, C., & Madlener, R. (2016). Regulatory options for local reserve energy markets: Implications for prosumers, utilities, and other stakeholders. Energy Journal, 37(01). https://doi.org/10.5547/01956574.37.si2.cros.

Roteiro para Neutralidade Carbónica (2019). Resolução do Conselho de Ministros nº 107/2019, 1 de Julho, p.3208-3299.

Rowse, T. (2014). Local energy governance in Vermont: an analysis of energy system transition strategies and actor capacity.

Ruggerio, C. A. (2021). Sustainability and sustainable development: A review of principles and definitions. The Science of the Total Environment, 786(147481), 147481. https://doi.org/10.1016/j.scitotenv.2021.147481.

Ruparathna, R., Hewage, K., & Sadiq, R. (2016). Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings. Renewable and Sustainable Energy Reviews, 53, 1032–1045. https://doi.org/10.1016/j.rser.2015.09.084

Ryghaug, M., Skjølsvold, T. M., & Heidenreich, S. (2018). Creating energy citizenship through material participation. Social Studies of Science, 48(2), 283–303. https://doi.org/10.1177/0306312718770286

Sapo (2021). Primeira Comunidade de Energia Nasce em Miranda do Douro. Governo quer Mais, para Ajudar a Baixar a Fatura da Luz. Available at https://eco.sapo.pt/2021/08/24/primeira-comunidade-de-energia-nasce-em-miranda-do-douro-governo-quer-mais-para-ajudar-a-baixar-fatura-da-luz/.

Sahakian, M., & Wilhite, H. (2014). Making practice theory practicable: Towards more sustainable forms of consumption. Journal of Consumer Culture, 14(1), 25–44. https://doi.org/10.1177/1469540513505607

Sanz-Hernández, A. (2019). Social engagement and socio-genesis of energy poverty as a problem in Spain. Energy Policy, 124, 286–296. https://doi.org/10.1016/j.enpol.2018.10.001.

Sequeira, M.M., and Mameri, D. (2022). Can communities lead the way for socio-ecological urban transformations? The empiric experience of the "network of ideas" process in the Telheiras neighborhood, Portugal. International Sustainable Development Research Society Conference (ISDRS 2022), Sweden.

Schaffarczyk, A. P. (2020). Introduction to wind Turbine Aerodynamics. Springer Nature.

Schlacke, S., Wentzien, H., Thierjung, E.-M., & Köster, M. (2022). Implementing the EU Climate Law via the 'Fit for 55' package. Oxford Open Energy, 1(1), oiab002. https://doi.org/10.1093/ooenergy/oiab002.

Schoor, T. van der, van Lente, H., Scholtens, B., & Peine, A. (2016). Challenging obduracy: How local communities transform the energy system. Energy Research & Social Science, 13, 94–105. https://doi.org/10.1016/j.erss.2015.12.009.

Schwarz, L. (2020). Empowered but powerless? Reassessing the citizens' power dynamics of the German energy transition. Energy Research & Social Science, 63(101405), 101405. https://doi.org/10.1016/j.erss.2019.101405.

Sequeira, M., & Joanaz de Melo, J. (2020). Energy saving potential in the small business service sector: case study Telheiras neighborhood, Portugal. Energy Efficiency, 13(4), 551–569. https://doi.org/10.1007/s12053-020-09842-y.

SET Plan documents. (2018). SETIS - SET Plan Information System. 13 de julho de 2022, from https://setis.ec.europa.eu/implementing-actions/set-plan-documents_en.

Seyfang, G., Park, J. J., & Smith, A. (2013). A thousand flowers blooming? An examination of community energy in the UK. Energy Policy, 61, 977–989. https://doi.org/10.1016/j.enpol.2013.06.030.

Simões, M. G., Farret, F. A., Khajeh, H., Shahparasti, M., & Laaksonen, H. (2021). Future renewable energy communities based flexible power systems. Applied Sciences, 12(1), 121. https://doi.org/10.3390/app12010121

Simões, G. M. F., & Leder, S. M. (2022). Energy poverty: The paradox between low income and increasing household energy consumption in Brazil. Energy and Buildings, 268(112234), 112234. https://doi.org/10.1016/j.enbuild.2022.112234

Smith, A., Hargreaves, T., Hielscher, S., Martiskainen, M., & Seyfang, G. (2016). Making the most of community energies: Three perspectives on grassroots innovation. Environment & Planning A, 48(2), 407–432. https://doi.org/10.1177/0308518x15597908.

Sperling, K. (2017). How does a pioneer community energy project succeed in practice? The case of the Samsø Renewable Energy Island. Renewable and Sustainable Energy Reviews, 71, 884–897. https://doi.org/10.1016/j.rser.2016.12.116.

Solar community energy project in Recklinghausen. (sem data). Enercommunities.Eu. Obtido 12 de julho de 2022, de http://enercommunities.eu/course/solar-community-energy-project-in-recklinghausen/.

Son, J.-Y., & Ma, K. (2017). Wind Energy Systems. Proceedings of the IEEE. Institute of Electrical and Electronics Engineers, 105(11), 2116–2131. https://doi.org/10.1109/jproc.2017.2695485.

Sovacool, B. K., Enevoldsen, P., Koch, C., & Barthelmie, R. J. (2017). Cost performance and risk in the construction of offshore and onshore wind farms: Construction risk for wind farms. Wind Energy, 20(5), 891–908. https://doi.org/10.1002/we.2069.

Sovacool, B. K., Burke, M., Baker, L., Kotikalapudi, C. K., & Wlokas, H. (2017). New frontiers and conceptual frameworks for energy justice. Energy Policy, 105, 677–691. https://doi.org/10.1016/j.enpol.2017.03.005.

Steinhausen, K. (sem data). The Solarservice Bremen -a Web-GIS based information service for solar energy for the city of Bremen. Enviroinfo.eu. 12 de julho de 2022, from http://enviroinfo.eu/sites/default/files/pdfs/vol7233/0568.pdf.

Stieneker, M., & De Doncker, R. W. (2016). Medium-voltage DC distribution grids in urban areas. 2016 IEEE 7th International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 1–7.

Strachan, N., & Farrell, A. (2006). Emissions from distributed vs. centralized generation: The importance of system performance. Energy Policy, 34(17), 2677–2689. https://doi.org/10.1016/j.enpol.2005.03.015.

Sultana, U., Khairuddin, A. B., Aman, M. M., Mokhtar, A. S., & Zareen, N. (2016). A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system. Renewable and Sustainable Energy Reviews, 63, 363–378. https://doi.org/10.1016/j.rser.2016.05.056.

Teo, J., Tan, R., Mok, V., Ramachandaramurthy, V., & Tan, C. (2018). Impact of partial shading on the P-V characteristics and the maximum power of a photovoltaic string. Energies, 11(7), 1860. https://doi.org/10.3390/en11071860.

United Nations Framework Convention on Climate Change (1992). New York. <https://treaties.un.org/pages/ViewDetailsIII.aspx?src=TREATY&mtdsg_no=XXVII-7&chapter=27&Temp=mtdsg3&clang=_en>.

United Nations / Framework Convention on Climate Change (2015). Adoption of the Paris Agreement, 21st Conference of the Parties, Paris: United Nations.

van der Kroon, B., Brouwer, R., & van Beukering, P. J. H. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. Renewable and Sustainable Energy Reviews, 20, 504–513. https://doi.org/10.1016/j.rser.2012.11.045.

van Zalk, J., & Behrens, P. (2018). The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S. Energy Policy, 123, 83–91. https://doi.org/10.1016/j.enpol.2018.08.023.

Verkade, N., & Höffken, J. (2019). Collective energy practices: A practice-based approach to civic energy communities and the energy system. Sustainability, 11(11), 3230. https://doi.org/10.3390/su11113230.

Vorrath, S. (2016). Bitcoin-inspired peer-to-peer solar trading trial kicks off in Perth. RenewEconomy. http://reneweconomy.com.au/bitcoin-inspired-peer-to-peer-solar-trading-trial-kicks-off-in-perth-29362/.

Wahlund, M., & Palm, J. (2022). The role of energy democracy and energy citizenship for participatory energy transitions: A comprehensive review. Energy Research & Social Science, 87(102482), 102482. https://doi.org/10.1016/j.erss.2021.102482.

Wang, J., Hu, J., & Ma, K. (2016). Wind speed probability distribution estimation and wind energy assessment. Renewable and Sustainable Energy Reviews, 60, 881–899. https://doi.org/10.1016/j.rser.2016.01.057.

Wang, Q., Su, M., Li, R., & Ponce, P. (2019). The effects of energy prices, urbanization and economic growth on energy consumption per capita in 186 countries. Journal of Cleaner Production, 225, 1017–1032. https://doi.org/10.1016/j.jclepro.2019.04.008.

Wellman, B. (2005). Community: From neighborhood to network. Communications of the ACM, 48(10), 53–55. https://doi.org/10.1145/1089107.1089137.

World Energy Council (2022). World Energy Trilemma Index. Available at https://www.worldenergy.org/transition-toolkit/world-energy-trilemma-index.

Zakari, A., Khan, I., Tan, D., Alvarado, R., & Dagar, V. (2022). Energy efficiency and sustainable development goals (SDGs). Energy (Oxford, England), 239(122365), 122365. https://doi.org/10.1016/j.energy.2021.122365.

Zhang, Y. J., Ideue, T., Onga, M., Qin, F., Suzuki, R., Zak, A., Tenne, R., Smet, J. H., & Iwasa, Y. (2019). Enhanced intrinsic photovoltaic effect in tungsten disulfide nanotubes. Nature, 570(7761), 349–353. https://doi.org/10.1038/s41586-019-1303-3.

Zhao, J., Dong, K., Dong, X., & Shahbaz, M. (2022). How renewable energy alleviate energy poverty? A global analysis. Renewable Energy, 186, 299–311. https://doi.org/10.1016/j.renene.2022.01.005.

2023 EVANDRO FERREIRA RENEWABLE ENERGY COMMUNITIES: CONCEPTS, APPROACHES AND THE CASE STUDY OF TELHEIRAS NEIGHBORHOOD IN LISBON

NOVA SCHOOL OF SCIENCE & TECHNOLOGY