Instituto Superior
de Engenharia
Politécnico de Coimbra

DEPARTMENT OF ELECTRICAL ENGINEERING

Renewable Energy Communities – the contribution from the demand side

Project Report to fulfill the Master's degree in Electrical Engineering

Specialization in Automation and Communications in Energy Systems

Author

Manoel Melo Feijão Júnior

Supervisors

Professor Coordinator PhD Cristina Isabel Ferreira Figueiras Faustino Agreira

Prof. Adj. MSc Rui José Oliveira Nóbrega Pestana

Coimbra, December 2023

INSTITUTO POLITÉCNICO
DE COIMBRA

INSTITUTO SUPERIOR
DE ENGENHARIA
DE COIMBRA

ABSTRACT

With this project it is intended to assess Renewable Energy communities (REC), in terms of laws and regulations by the competent authority Energy Services Regulatory Authority (ERSE).

It was conducted an analysis of the legal framework governing all self-consumers, not only RECs, evaluating the rights and responsibilities, and it was assessed the impacts RECs and RES cause on the electrical system, on the environment and on society. It was explained the procedure to deploy an Production Unit for Self-Consumption (UPAC), in terms of licensing by Directorate-General for Energy and Geology (DGEG), which depends on the power to be installed. The operational issues of RECs on relation to the distance of the UPAC and the consumer facility but also on the energy sharing model between them.

It was performed an analysis on the component due to payment when a prosumer realizes this activity through the public grid.

Proposition of a practical case, with a simulation to Instituto Superior de Engenharia de Coimbra (ISEC) become a prosumer and share its surplus in a REC, showing the energy yield and performing an economic and environmental analysis.

Keywords: REC, REDII, Energy Transition, Renewable Energies, UPAC.

RESUMO

Com este projeto, pretende-se fazer um enquadramento em torno das Comunidades de Energia Renovável (CER), em termos de leis e regulamentos da Entidade Reguladora dos Serviços Energéticos (ERSE).

Foi realizada uma análise da estrutura legal que rege todos os autoconsumidores, não apenas as CER, avaliando os direitos e responsabilidades e analisando os impactos que as CER e as Fontes de Energia Renovável causam no sistema elétrico, no meio ambiente e na sociedade. Foi explicado o procedimento para instalar uma Unidade de Produção para Autoconsumo (UPAC), em termos de licenciamento pela Direção Geral de Energia e Geologia (DGEG), que depende da potência a ser instalada. Foram abordadas questões operacionais das CER nomeadamente em relação à distância entre a UPAC e as instalações consumidoras, bem como ao modelo de partilha de energia entre eles.

Foi realizada uma análise da componente a pagar quando um auto-consumidor realiza essa atividade através da rede pública.

Foi proposta uma situação prática, com uma simulação para que o Instituto Superior de Engenharia de Coimbra (ISEC) se torne um auto-consumidor e disponibilize o seu excedente em uma CER, mostrando a produção de energia e realizando uma análise económica e ambiental.

Palavras-Chave: CER, REDII, Transição Energética, Energias Renováveis, UPAC.

ACKNOWLEDGMENTS

In the first place I would like to thank the Polytechnic Institute of Coimbra and also the Polytechnic Institute of Lisbon, highlighting the Coimbra Institute of Engineering (ISEC) for providing a quality education throughout the years that I have been studying here, with a specific mention to the Electrical Engineering Department and its teachers. The same way I have to thank Lisbon Institute of Engineering (ISEL) for the cooperation with the institution I study, making this project possible.

I would like to express my heartfelt gratitude to my supervisors Professor Coordinator PhD Cristina Isabel Ferreira Figueiras Faustino Agreira and Prof. Adj. MSc Rui José Oliveira Nóbrega Pestana, that readily accepted to guide me on this difficult journey and above all, their strong presence along the development of this project.

I would like to thank Eng. Miguel Coelho (ISEC) for the help and to provide data for this project.

I am deeply appreciative of my family for their unending encouragement and understanding during this academic pursuit. I extend my thanks to my friends that also encouraged me to successfully accomplish my academic path.

To all, my sincere thanks.

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ACRONYMS

AT	High Voltage
BT	Low Voltage
BTE	Low voltage Especial
BTN	Low Voltage Normal
CAE	Energy acquisition contract
CCGT	Combined Cycle Gas Turbine
CESE	Extraordinary Contribution Electric System
CIEG	Costs of General Economic Interest
DEC	Cicil Engineering Department
DEE	Electrical Engineering Department
DEIS	Informatics Engineering Department
DEM	Mechanical Engineering Department
DEQ	Chemistry Engineering Department
DFM	Physics and Mathematics Department
DGEG	Directorate-General for Energy and Geology
DSO	Distribution System Operator
EGAC	Manager Entity of Self consumption
ERSE	Energy Services Regulatory Authority
EU	European Union
ECs	Energy Communities
GHG	Green House Gas
HVAC	Heating Ventilating and Air Conditioning
IEA	International Energy Agency

ISEC	Instituto Superior de Engenharia de Coimbra
ISP	Tax on Petroleum Products
LCOE	Levelized Cost of Electricity
MAT	Very High Voltage
MT	Medium Voltage
NGO	Non-governmental Organization
OLMC	Merchant Change Logistics Operation
PNEC 2030	Plano Nacional Energia e Clima
PRE	Special Regime Production
PRR	Recovery and Resilience Plan
PV	Photovoltaic
REC	Renewable Energy Community
REDII	Revised Renewable Energy Directive
RES	Renewable Energy Source
RESP	Electrical Grid for Public Service
RNC 2050	Roteiro para a Neutralidade Carbónica 2050
RND	National Distribution Network
RNT	National Transportation Network
SEN	National Electric System
STC	Standard Test Conditions
TSO	Transportation System Operator
UPAC	Self-consumption Production Unit
VPP	Virtual Power Plant

SYMBOLS

A	Ampere
CO_2	Carbon Dioxide
GW	Gigawatt
kV	Kilovolt
kVA	Kilovolt Ampere
kVAr	Kilovolt Ampere Reactive
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt Peak
MWh	Megawatt Hour
V	Volt

1 INTRODUCTION

It is known that modern society is highly dependent on energy to perform most of its activities and struggles with the lack of electricity in two ways: first when it isn't available for those who never face a rupture in supply and second, for those whom electricity has never been available. This combined with the goal to become carbon neutral by 2050 is leading society to adopt all forms of Renewable Energy Sources (RES) and abandon fossil fuels. This massive challenge is named energy transition.

The energy transition, in turn, creates the need for solid and effective laws and recommendations to hasten the penetration of sustainable energy sources, with major importance to wind and solar, because despite the significant efforts in policy making by some countries and the European Union (EU), the global pace still has to increase 60% of the current level to be in line with the International Energy Agency (IEA) Net Zero by 2050 Scenario. Comparing to 2022, projections indicate that cumulative PV capacity will be almost three times higher in 2027, totalizing 2350 GW, and will surpass hydropower in 2024, natural gas in 2026 and coal in 2027, becoming the world's largest installed capacity for electricity production [1].

As the rhythm is still not desired and new regulations keep emerging, it is important to assess the existing backbone structure that will guide the way to the final target. This document specifically focuses on actions that strike on Renewable Energy Communities (RECs), being expected they will have a key role on the future electric system.

The present regulation started with the Paris agreement, signed in 2015 by the European Union and its member states, including Portugal, and served as driving force to the development of further framework in benefit to RES, such as the Clean Energy for all Europeans package, the Revised Renewable Energy Directive (REDII), Revised Internal Market in Electricity Directive or Fit for 55 package. Another driving force urged the need for more ambitious targets, the war in EU border led to REPowerEU plan, that aims to reduce the dependency of fossil fuels.

In the same line, countries have 1-2 years to convert new directives into national law, meaning that for example, Portugal, had this time to convert the 2018/2001 directive into national law, but in reality Portuguese Government issued the Decree-law 15/2022, of January 14, only partially transposing the directive, but introducing significant changes on the organization and operation of the electrical system [2]. Additionally, Portugal has its own ambitious goals when it comes to climate and energy questions, set by "Plano Nacional de Energia e clima 2030" or "Roteiro para a Neutralidade Carbónica 2050" and despite there is still a long way to get there, Portugal is already setting records, being able to be supplied only by renewable energies sources during days when the right conditions are met.

1.1 Document structure

This document has as final purpose to analyze the resulting framework and impacts caused by the directives and laws mentioned above, for the implementation and operation of a REC in Portugal, walking through the Portuguese Government laws and the national regulatory entity regulations, the licensing process and operational questions. On top of that, a technical-economic assessment is also proposed.

In chapter 1, it was assessed the capacity growth projection in installed renewable energy sources that countries need to achieve to become carbon neutral, in order to reduce the impact human lives are causing on the planet, with special attention to the European Union countries. Also it was shown the agreements and targets the EU is bound and most importantly the Portuguese plans.

In chapter 2, it is given an vision on every important theoretical aspect about RECs, with an analysis about the rhetoric "the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits" stated on Revised Renewable Energy Directive (REDII) [3]. The measures taken and how each stakeholder benefits from a successful deployment of a REC. Finally, the future challenges that RES will bring to the electrical system, by changing the current demand management to a supply driven model and the measures that will need to be addressed to overcome this question.

In chapter 3, it is analyzed the structure of the electricity tariff applied to consumers, i.e., supplied by the public grid, both on liberalized and regulated market. It is described how the grid access tariff varies depending on the voltage self-consumer is supplied by the Self-Consumption Production Unit (UPAC) and what prosumers are obligated to pay when using the Public Service Electrical Grid (RESP).

In chapter 4, it is made the characterization of the chosen place to theoretically deploy a photovoltaic power plant to serve a REC, in geographic and in electrical terms. For the design of the UPAC, the consumption and orientation are also analyzed in this chapter. With the consumption data, after some adjustments, a consumption profile is drawn, in order to simulate on PVsyst software. It is proposed four simulations with different characteristics.

In chapter 5, it is presented the results from the simulations. The results include the electricity yield, an economic and environmental evaluation of the system to understand the impact a REC can have.

Finally, in chapter 6, it is presented the conclusions of this document and suggestions for future works are given.

2 RENEWABLE ENERGY COMMUNITY

A Renewable Energy Community (REC) is a legal person (a cooperative, an association, a foundation), which has as its main goal to allow, mainly to its members, the consumption of electricity from renewable sources, providing environmental, social and economic benefits to the local community. It is able to provide independence from power supply companies but also decentralize the electrical system to increase its resilience. Besides the production of electricity, a REC is allowed to consume, store, buy and sell green electricity to members and non-members of the community, so when comparing to other companies of the sector, a community has a wider operating range, as it may work as a distribution and as a production company, under the same legal name, with the difference that the financial profits isn't the reason that RECs work for.

The design of the framework for RECs was potentialized by the need for faster deployment of renewable energy production and concrete solutions to the energy transition, so it has an intrinsic characteristic which allows a diverse nature of investments, from private or public companies, local city councils and individual or legal persons, with the possibility of not being a member, just an investor. With this opening to third parties' investments, the RECs allow its members to have access to clean electricity, even though they haven't contributed with investment to the power plant(s).

The access for new members and the exit of the existing ones, must be free of unexplained or discriminatory reasons, as long as the legal responsibilities are fulfilled.

Once again, a REC may sell electricity to consumers that aren't members, but under the condition that they are located within the imposed distance limits. And may access all electric markets, including the market for ancillary services.

2.1 Impacts

As written in Revised Renewable Energy Directive (REDII), "the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits" [4]. In this statement, it is present the three pillars that are essential and mandatory in order to put together a Renewable Energy Community:

- Environmental
- Economic
- Social

The first and the second topics are naturally the ones society know better, since these impacts are always linked to renewable energy sources and the electrical system is witnessing an unprecedent speed of deployment, mostly of photovoltaic farms, giving the opportunity to create discussion about this subject.

The social impact, which is considered to be the most important criteria, or else people would invest only for themselves, causing a similar impact, is normally forgotten in the other types of prosumption. With the framework of a REC, by the way and purpose it is designed, the social benefit is highlighted.

As will be pointed out, Renewable Energy Sources and Communities don't represent only benefits, they also bring burdens and negative impacts for the electric system, for the society and for the environment. As for the economic impact, it is mostly benefits, especially for the members and consumers.

2.1.1 Environmental

Prosumption will perform a major role in the future of the energy system, helping to reach a more sustainable model.

When compared to the current system, based mostly on fossil fuel sources, renewable energies (except biofuels) used by any prosumption forms, are contributing positively to the environment in many ways.

Those contributions are easily assessed, well defined and extensively studied. Some benefits brought by any form of prosumption are:

- Reduce the production from fossil fuels
- Tend to increase in efficiency or lower consumption
- Reduction of GHG emissions
- Climate-neutral energy system
- Reduce the air pollution

Even considering the impacts of design, manufacturing and installation of the equipment needed for the renewable energy production, the benefits are greater following this path, as for example, regarding to climate-neutral energy topic, the system is virtually active, in other words, by not emitting carbon dioxide during operation, the production process become almost insignificant, since the amount not emitted is considered spared and is much higher.

Reduce the production from the current main fossil source, natural gas, which in Portugal, for 2022 represented 30% of primary energy source of electricity, adopting a green and decentralized system, has a variety of positive environmental reductions with direct association, such as, emission of Greenhouse gases, air pollution, and others indirectly, like the need of more transportation infrastructure, thus, the inherent problems of its construction, for example the occupation of more land [5].

Additionally, when compared to large scale renewable energy power plants, prosumption projects may also present some cons. The most relevant related to this topic might be efficiency, that due to some reasons, such as maintenance or ideal location/orientation, consumer-owned systems tend to be lower, causing indirect environmental burdens.

Reducing the dependency on fossil fuels itself can also be considered an environmental benefit.

Referring to photovoltaic panels, when deployed on existing buildings, the requirement of additional land is non-existent, and with that, there isn't the need to disturb the landscape and ecosystems. In opposition to that, self-consumers normally deploy only the power needed, since the regulation determines that and the price of further surplus of electricity sold isn't appealing, underusing potential space, however with REC framework this issue can be minimized.

2.1.2 Economic

Although RECs aren't expected to be working for financial revenues, the monetary aspect is the main driver for investing in PV systems, as found in a study for the European Commission in 2018, since the communities need to be self-sufficient and financially sustainable [6].

There are a lot of economic benefits for prosumers and for RECs, as a whole and for their members, being the most obvious and direct, the lower electricity cost and the possibility of selling the excess, generating a monetary income. A lower energy price in the present days is a very important support to many families, as society is facing historically high energy prices and an inflated market.

The need to finance some RECs, open access to a new type of investment, either from private or public investors, debt or equity based, and with a very low risk, in such a way that there are companies willing to do the whole upfront investment of the power plant and create a REC, and in other case also gather members for a structure similar to a REC. In both cases, to start a new community, the rooftop or space for installation is in charge of one member, with limitations like the area required for and who can become the producer [7] [8]. In the other hand, it is possible to see that there is a strong concern with low-income households and institutions with social nature in this type of investments, with good examples, like the Coopérnico cooperative [9]. Also, a public institution set the example, with public investment in "Comunidade de Energia Renovável – Agra do Amial" [10].

A decentralized system reduces the need for transmitting power over long distances, thereby, it is said that the investment on transportation grid may reduce. In reality the expansion and maintenance of this network has to be done, either by security reasons or to receive energy from elsewhere in Europe, in case of production shortage nationally or to maximize the production of renewable energy from other places across Europe. Also, the investment in distribution networks has to continue or even increase, as the power required on this grid is rising due to the diffuse production and the increasing demand for electricity caused by the electrification of the automobile sector.

Focusing on small enterprises and in public institutions, with lower prices of electricity, the first one can become more competitive and the second is able to reduce their huge bills, as public spaces are known for it.

2.1.3 Social

Renewable energy communities (RECs) are expected to bring a lot of positive social impacts to the local community and for its members as it helps to tackle energy poverty by allowing vulnerable households to become a member, it enables an active participation of the citizens on the transition to a low-carbon society for those interested and other benefits. But since RECs still represent a small number of households, compared to the traditional system, and only with the Directive 2018/2001 from the European Union (EU) these initiatives started to be more disseminated, causing that the social impacts aren't yet fully understood.

Nevertheless, there are a lot of studies to assess the social impact of RECs but focusing mainly on the benefits and mostly on northern Europe where these initiatives are more common.

Through a review on the existing studies, M. Bielig et al. in a critical review, verify that the assessment of social impacts, are not clear as they seem, as it is difficult or lacks research to evaluate some of them, unlike environmental and economics.

In this article, the authors divided the social impacts in four categories:

- Energy justice
- Energy democracy
- Community empowerment
- Social capital

Where energy justice is considered the equitable distribution of the energy system consequences or benefits, representation and inclusion of all society groups in the decision-making process and the creation of jobs.

Energy democracy refers to the participation and the quality of access, the change in power structures, social inclusion and shared ownership.

Community empowerment is related to the ability that RECs have to enhance the community resources and skills, by developing the knowledge in energy related fields, socio-organizational, social cohesion, confidence, and somehow political. Changes in power structures and shared ownership are also considered.

Social capital focuses on the community trust and social identification with it and also on the formation of relationships within the community, meaning the creation of a social network. Social cohesion, skill development and community confidence are referred as well.

Being the categories explained, it is important and interesting to see that some of the topics within one category overlap to another. It is also important to say that the categories might include other topics not mentioned, as they are very wide.

Within the review of the existing literature related to the measurement of social impacts of the RECs, done by M. Bielig et al., the conclusion shows that there is still the need of improvement on social level, to fully achieve the role that they are expected to have and keeping in mind the shallow way The Renewable Energy Directive (REDII) refers to it.

For the energy justice, the conclusion reached by [11], enlighten that some of the studies demonstrated greater participation in decision-making, the potential for job creation and reduction of energy poverty while others showed perceived injustice in terms of distribution of benefits and burdens. The authors also conclude that there is a variety of evidence that the goals for equal access and inclusion of energy poor and vulnerable households on RECs, were often not met, as the survey's results used by the different authors on the subject, report that more than 50% of RECs are not addressed to underrepresented groups or are mostly male representative.

Related to energy democracy, there are good results shown by the surveys, as the key definition of REC is based on shared ownership, leading to a democratic decision-making process. Yet, almost 30% of those surveyed feel that the decisions made were not perceived as democratic and there are reports where irregular vote-count or "shortcuts" in decision making happened. Again, the representation of different social groups was not even, mostly being male. Just like all democracy, there are people who don't want or don't have the time to be active participants in the process or simply don't mind what decisions are taken. Apart from the decisions, while members, people feel the existence of a sense of community.

Regarding community empowerment, it is safe to say that RECs provide means to promote social cohesion and help the development of knowledge and skills, mainly related to energy.

For the social capital, as it is related to community trust and social identification, reckon that there are a small amount of studies on this category, but overall, from the studies found, they show a positive tendency: Energy Communities (ECs) have the potential to strengthen the social network and lead to more community trust and identification [11]. Topics like skill development, despite all community learn something, the leaders of the project are the ones who learn the most because they have to know about the subject to make decisions, that way not promoting social cohesion.

The REDII establishes that one of the main objectives of a REC is to bring social benefits, besides environmental and economic, to its members and for the local community where it is deployed. These last two benefits are easier to evaluate as they are mostly numerical, however, the first one is hard to evaluate. On top of that, there isn't a standard pattern or indicators to help evaluate all projects the same way, meaning that every REC is different and provides different amounts, form or feeling of social benefits.

The social pillar must be present to allow the deployment of the community, but unlike the other two pillars, if it isn't evident that the REC will bring social benefits, the members are still willing to continue participating as long as it brings more benefits than burdens or they are not harmed. Still, by principle a democratic entity, all members are allowed to leave the REC without any objection, as long as they fulfill the responsibilities they are obligated to.

For the deployment of a REC, the social benefit might be intrinsic within the economic pillar, as the economy might be linked to social impact, for example allowing vulnerable households to have an ease on energy bills and that way the community fulfill the social requirement.

Continuous monitoring of the social pillar still doesn't exist as it would be needed lots of human resources and members might have the feeling of continuous policing of outside entities and their freedom attacked in some form. The vast majority of the data and the surveys conducted regarding the social impact of energy communities rely on the will of different authors interested in the combination of the fields, energy communities and social study.

There are lots of examples of the positive role across the Europe and Portugal included, with projects that seek to involve energy poor families, charity institutions or NGOs and even projects designed mostly for families that live in social neighborhood, as already mentioned, thus reducing their effort to pay the electricity bill, as on the category of social impacts, the inclusion of energy-poor families is the most important mission.

Further exploration of the existent literature, it is found that the creation of jobs locally, haven't yet been quantified. It is mentioned that REC enhances citizens support of development of RES in large-scale, either because they understand that it is more beneficial the clean energy than the disturbance and the visual impact on the landscape or because they own a share of the existing plant.

2.2 Licensing

In order to guarantee the reliability and well-functioning of the National Electric System (SEN), it is essential to know all interconnection points between the production units and the Electrical Grid for Public Service (RESP) as well as the impact they will have on it, based on the maximum power output. It is also important to assure that there are rules and procedures to properly install an UPAC, reducing the probability of occurring accidents or damage on the grid and even on the power plant to be installed.

2.2.1 DGEG's licensing

It is up to Directorate-General for Energy and Geology (DGEG) to inform the global manager of SEN of all electricity production plants that will interact with the system, and it is up to the owner/promoter of the project to inform DGEG about his intentions.

Since all production units impact differently on the grid, to give opportunity to all citizens or companies to be able to produce electricity from renewable energy sources, according to the limits imposed by the grid and by the responsible from the government, there are different procedures, thus different amount of information to provide to DGEG, which is dependent on the power to be installed. The procedures are [12]:

- Exemption from prior control.
- Prior communication.
- Prior registration and exploitation certificate.
- Production license and exploitation license.

On the first point, when the power of the Self-consumption Production Unit (UPAC) is up to 700W, and it is not predictable the injection of the surplus on the Electrical Grid for Public Service (RESP), it is not necessary to inform DGEG of the installation and it can be done whenever the owner decide to.

It is necessary realize the prior communication process to DGEG when the power plant ranges from 700W up to 30kW. When it isn't expected the injection of electricity to the grid, it isn't required the intervention of the RESP operator and the process begins with the registration on the platform, then submitting the instructional documents, to automatically be allowed to proceed to the installation of the plant.

The process required by the third subject is applied to UPACs with power over 30kW and equal or under 1MW and also to autonomous power storage facilities with power up to 1MW.

Finally, on the fourth point, the production of electricity from renewable sources to self-consumption or to fully inject on the RESP and the power is over 1MW.

Table 2.1 – Licensing procedures

Exemption from prior control	Prior communication	Prior registration and exploitation certificate	Production license and exploitation license
Power ≤ 700W	>700W and ≤30kW	>30kW and ≤1MW	>1MW

For power plants with power under 700W, the installation may be done by a non-professional person. To power over that, it is mandatory to be done by a certified technician or entity, unless the equipment doesn't need an installation and in that case the power must be lower than 1500W. After the installation of the power plant by a certified technician or entity, it takes place, by an inspection entity, the verification if the site complies with the applicable legal and regulatory standards, filling out the form on the DGEG´s portal.

In these prior control procedures, the licensing entity, DGEG, emits on its platform the following documents, which depends on the type or power of the project:

- Proof of existence of a prior communication that enables the deployment or the re-equipment of the UPAC. In this last case, it is allowed an over equipment up to 20% of the initial licensed power.
- Proof of prior registration that enables the installation of the power plant, the UPAC or the storage facility.
- Exploitation certificate that enables the power plant, the UPAC or the storage facility to start operating.
- Production license that allows the facility to produce electricity for self-consumption by an UPAC or to allow the facility to store electricity.
- Exploitation license that allows the promoter of the site to start the industrial exploitation of an electroproduction center, an UPAC or a storage facility.

Putting aside the industrial production and focusing on self-consuming, these documents are issued in the name of:

- In the case of individual self-consumption, to the prosumer itself.
- In the case of collective self-consumption, to the manager entity of collective self-consumption (EGAC) or to the REC or to the condo, represented by its manager.

When it is expected to take place injection of electricity to the grid, and it exceeds:

- 50% of the contracted power of the user installation(s) with a Normal Low Voltage (BTN - Power purchased ≤ 41,4 kVA) consumption profile and 50% of the requested power of the user installation(s) for other consumption profiles.
- 30 kVA, when connected to the low voltage distribution network or 100 kVA, when connected to the National Distribution Network (RND) or to National Transportation Network (RNT).

In both cases, the process is not automatic and DGEG will require the pronunciation of the Distribution System Operator (DSO), the Transportation System Operator (TSO) and/or the global manager of the SEN. Additionally, the process that automatically allows the installation, exempting the intervention of a third part, referred above, is only valid until the RESP injection capacity, set by a member of the government to UPACs, is exhausted.

2.2.2 Licensing of urban operations by the municipality

To protect the historical heritage, the installation of photovoltaic panels or wind turbines in one of the areas mentioned below, are subject to an administrative licensing emitted by the city council, if approved. These areas are:

- Classified properties or in the process of being classified
- Properties integrated in sets or classified sites or in the process of being classified
- Properties located in protection zones for classified properties or in the process of being classified

As read in the Decree-law No. 72/2022, of October 19, for an UPAC outside any of these areas, and with power under 1MW is exempted from prior control for urban operations, that means that the applicant is required just to communicate in advance to the city council and declare to have knowledge of the applicable legal rules, the location and area of the project [13]. This is a measure to accelerate and ease the deployment renewable energy. Later in the process, the proof of communication emitted by the city must be submitted into DGEG´s portal.

Additionally, the installation of PV panels in delimited areas, like big commercial areas, campsites, car parking or in buildings, as long as the implantation do not exceed the building's coverage area and its height by 1 meter, represent an irrelevant urban work so it is not subject to any previous control by the local administration regarding urban operations. This is also applied to wind turbine generators if they do not exceed the building's coverage area by 4 meters and the radius of the equipment is smaller than 1,5 meters [14]. In this case, it is also only needed to inform the city hall before the installation.

For an UPAC exempted from DGEG's control, it is not necessary to inform the city hall.

2.3 Stakeholders

Every stakeholder has interest in the success of deployment of RECs, some to allow the consumer to have access to clean energy and others to benefit from the community.

It is identified three stakeholders, as a whole:

- The European Union
- Portuguese Government
- Consumers

The parties have their own and common interests, the EU wants to conquer its energetic sovereignty and comply with the Green Deal, Portugal in turn, wants to accomplish with its own targets but also the obligations with EU. Finally, consumers want to enjoy the benefits that RECs are able to provide.

2.3.1 European union

Over the last years, the EU has been developing policies in order to increase the share of renewables in the energy mix of all member countries, understanding that the bigger the number of actors participating and committed to change, the faster will be the transition to the climate neutral electric system. For that, the protection of the citizens and allow them to own part of the system was needed and have been achieved with three directives:

- Clean Energy for all Europeans package, in 2016 [6], adopted in 2019
- Revised Renewable Energy Directive, in 2018
- Revised Internal Market in Electricity Directive, in 2019

All of them with significant relevance, in 2016 giving the right to become a prosumer, in 2018 defining the legal form of Renewable Energy Communities and promising access to support schemes without discrimination, finally in 2019 defining the status of Citizen Energy Communities in the electricity market.

There are several reasons why the EU is so bound to lead the way to energy transition, for example, the commitment to the Paris Agreement on climate change, the plan to become climate neutral by 2050 and the Fit for 55 package. These ambitious targets result in amendments to the existing and in new directives, to keep or increase the rhythm, but also to set even higher final goals.

In order to accomplish the commitment, it is imperative to change the way the electric sector works, giant power plants based on fossil fuels delivering electricity to consumers several kilometers away, so EU is setting the framework to achieve a new form, a more decentralized and carbon free energy system. This new system will only be possible to happen, or at least easier and faster, if the citizens are involved and preferably contributing actively. Renewable Energy Communities are identified as an enabler and enhancer for the active participation in this transition.

More recently, in May 2022, all forms of prosumption were recognized as an important asset to reduce the dependence on fossil fuels and fight climate changes as proposed in the REPowerEU plan [15]. While this doesn´t result into countries measures, there is the request for all citizen, but mostly for those who are willing to contribute, to reduce their energy consumption, switch to renewable energy providers and choose a more sustainable lifestyle, as a short-term measure. Renewable Energy Communities provide short- and long-term actions, as people are encouraged to and informed how to reduce their consumptions and in the long run it is supplied by renewable sources.

In conclusion, the involvement of the citizens is crucial, since the greater the number of prosumers, the faster EU goals will be accomplished, and as concerning to investment power, it will be significantly higher, thus faster and easier development of projects. The proposition carried by the REDII supports that RECs are a way of giving back power to people but also a very important complementary model, part of the electric system.

There are more reasons why the EU needs to be interested in the success of RECs, for example, the recent electricity price soar makes it necessary to take protective measures for the citizens. When participating in an energy community, the price is stable even in cases of market excitement, allowing consumers to be independent and not affected in terms of electricity supply.

2.3.2 Portuguese Government

At Portuguese government level, the reasons why they need to contribute with simple and effective legislation are many, as RECs will, for example, help to achieve a solution to some of the existing problems referring to electricity and help to accomplish the goals set to climate, environment and energy, as in "Plano Nacional de Energia e Clima 2030" (PNEC 2030), "Roteiro para a Neutralidade Carbónica 2050" (RNC 2050) and other programs promoted and still the common targets for EU.

Under the right conditions of deployment, RECs fight energy poverty and since the government has not yet come up with a long-term program, as it is being developed, this could be a huge help to solve this problem, both in the short and long term.

The PNEC plan hopes to achieve, among others, a reduction of CO2 emissions in around 50%, increase the energetic efficiency by 35% (reducing primary energy consumption) and 80% of the electricity consumed from renewable sources, and it is under review process to set more ambitious targets. The numbers for 2022 state that around 45% of the electricity was generated by renewable sources, that means that a lot more of green energy capacity has to be installed [5].

2.3.3 Citizens and local authorities

There are a lot of different reasons that lead a group of people to start a REC and for any consumer become a member, the desire to become energy independent, the possibility to become an active member on the energy system, helping in the transition to a carbon-free society, guarantee continuous supply in crisis or when the quality of the service is bad, but above all, the most important is the economic aspect, that means, the potential reduction of the energy bills of the consumers.

Local authorities are a key asset to help develop the deployment of RECs, contributing with investments, legal advice or being a member, thus enhancing the trust on the project. In exchange, RECs enable municipalities to achieve the goals set for climate, environment and energy, at a local level, respecting for example the Covenant of Mayors, for those committed to it. In line with the reasons enumerated for the citizens, municipalities also benefit from lower electricity bills and energetic independence.

2.4 Barriers

To succeed with a faster implementation of RECs, it is necessary to overcome lots of different barriers:

- Overwhelming and slow registration, permitting and licensing processes
- Administrative hurdles associated with the design and operation
- Financing
- Developing a good business model
- Social acceptance and trust
- Lack of interest in collective forms of ownership
- Lack of awareness of REC
- Lack of time

These are some of the barriers found around the development of a REC, especially when the community relies only on its voluntary members, often not specialized on the subject. These members are required to understand a wide range of expertise, potentially slowing down the project when not mastered.

Some of these problems are being gradually overtaken, as new legislation and guides are being made, to simplify and reduce the time and effort needed.

For now, the biggest priority is to reduce the time of the registration, permitting and licensing processes, as there are lots of pioneers who are interested in accomplish the purpose of the REC itself and start to produce electricity. As read in [16], by January 20th, 2023, there were only 4 RECs or Collective Self-Consumption (it is not differentiated on the article) and 372 projects submitted to the first step of the licensing process, 59 of those who had the approval and may begin installation the PV power plant. The European Union has already realized this issue and is preparing a recommendation to hasten the permitting especially in low environmental risk areas, under the REPowerEU Plan, aiming to make it possible to obtain a permit for solar rooftop installation in maximum in 3 months. In September 2023, the number of operating RECs is around 300 and 600 are under the licensing process [17].

Although the number of requests is significant, considering the period of existence of the regulatory framework, and still growing, this number has the potential to be significantly higher when a good financing scheme is set up. The first investment program made by the Government, specific for RECs and collective self-consumption ended on 17th February 2023 and the total amount was 30 million Euros, with public institutions, private companies and households as beneficiaries, each intended with 10 million total. This amount of money, divided nationwide, does not result in many projects. For example, with the maximum reimbursement allowed, the minimum number of RECs would be 20 of each category, i.e., 60 communities [18]. For an effective and continuous support another way of financing needs to be developed, as this kind of program does not recover directly the money invested, meaning that future attendants need to wait for the next budget slack or, for now, the Recovery and Resilience Plan (PRR) to be executed.

Low-income households are often discouraged from participating in RECs, either by the upfront costs of the project or membership fees may be too high.

There are RECs almost fully functioning, as they are restricted from their full potential, as the regulation for dynamic coefficients for energy sharing, market services and local markets are not approved yet. This problem does not slow down the creation of the community, but its operation is limited.

2.5 Proximity concept

A decentralized electricity production system imposes the setting of rules to better organize and simplify the process of deployment, protecting the interests of the citizens but also of the system operators. One of these rules is the proximity concept, which determines the maximum distance between a consumer and the power plant, when the electricity is transmitted through the public grid, applied both to collective and individual self-consumption and for Renewable Energy Communities.

The proximity concept is based on a combination of the connection voltage level of the UPAC with the consumer facility and the distance from each other, as follows, with the help of Figure 2.1, Figure 2.2 and Figure 2.3.

When the connection is through Low Voltage (BT) (V ≤ 1kV), the UPAC and the consumer(s):

- Must be up to 2 km in geographic distance:

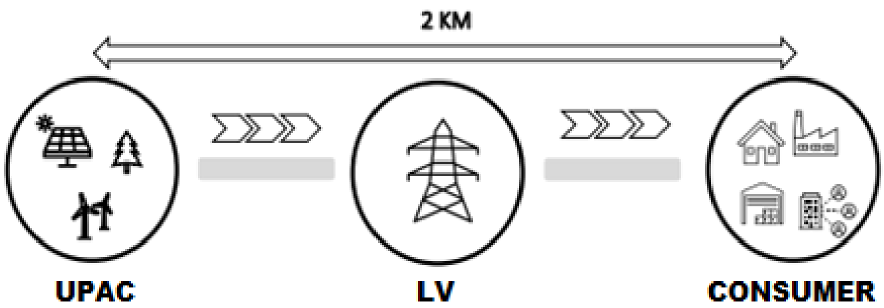


Figure 2.1 – Distance of UPAC and consumer w/o PT (BT), adapted from [12].

Note: the distance considered is geographic, i.e., the distance from one point to another, and not the distance through the grid.

- Are connected on the same power transformer:

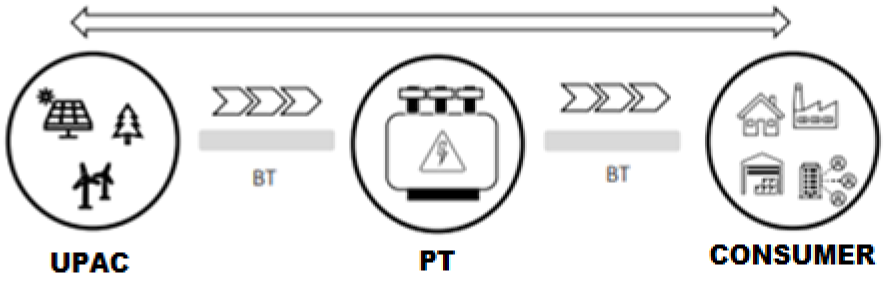


Figure 2.2 – Distance of UPAC and consumer with PT (BT), adapted from [12].

When the connection is trough Medium, High or Very high voltage, the UPAC and the consumer(s) are connected to the same substation:

- Medium voltage (MT) (1kV < V ≤ 45kV) the distance is up to 4 km
- High voltage (AT) (45kV < V ≤ 110kV) the distance is up to 10 km
- Very high voltage (MAT) (V > 110kV) the distance is up to 20 km

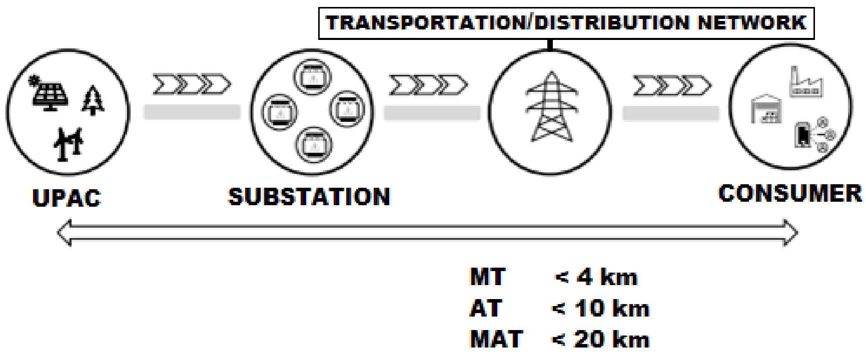


Figure 2.3 – Distance of UPAC and consumer over substation (>BT), adapted from [12].

In addition to that, in very specific cases, such as optimization criteria, within the provision of essential public services or the development of territorial strategies at the municipal or regional level, there is the possibility to ask DGEG an assessment of the proximity criteria.

In the cases where the RESP isn't necessary, in other words, the power plant(s) and the consumer(s) are connected via direct line (private electrical line connecting an isolated production point to consumers) or via internal grid (private electrical grid, installed within a confined area, which is composed by the cables and other electrical installations needed to transmit the energy from an UPAC or storage facility to one or more consumer), the proximity rule doesn't apply.

2.6 Manager entity of collective self-consumption (EGAC)

The EGAC is the entity responsible for all the operational management of collective self-consumption, namely:

- Manage the internal grid, when existing
- Articulation with DGEG's electronic platform
- Connection with RESP (Grid Usage Contract)
- Articulation with operators, namely in terms of production sharing and respective coefficients
- Commercial relationship to be adopted for surpluses
- Other functions assigned by self-consumers

When in a collective self-consumption, the appointment of this entity is made by the prosumers, before starting the activity, bearing in mind that the license for the production of energy issued in the prior control by DGEG, is emitted in its name.

In the case of the RECs, the responsibilities of the EGAC can be exercised by the community itself but also by another appointed entity.

The EGAC may take the form of a natural or legal person and may or may not be a self-consumer.

2.7 Energy sharing

Whether selling or ceding the energy produced by the UPAC at its service, to the community members, the term energy sharing is applied, together with the sharing models.

Whenever the RESP is used, the EGAC must inform, previously and in case of any change in the sharing models to the system operator, through the self-consumer DGEG´s portal. Whenever the network operator isn't aware of the sharing coefficients, it proceeds with a proportional division, based on the consumption of each member, as regulated by Energy Services Regulatory Authority (ERSE).

Sharing modes can be based on:

- Fixed coefficients, which may differentiate working days from holidays or weekends, and which may or may not consider the seasons of the year
- Consumption proportional coefficients

It is still under development two other models:

- Hierarchical sharing
- Dynamic sharing

Although these models are still under development, while it isn't still decided their structure, if any EGAC has interest, it is possible to join the DSO pilot project, to one of these models [19]. This is a temporary measure aiming to provide the DSO relevant data to further develop these models.

The supply of reactive energy complies with the rules of the Grid Regulation.

2.8 Challenges caused by renewable sources

As the capacity of Renewable Energy Sources (RES) installed increase, one step further on decarbonization is taken, but since these are known for their inherently variable production, new challenges are emerging, such as, to change the way the electric system works, which is now based on the demand of electricity, to a model that is supply driven, so that way it is taken advantage of the availability of electricity on the moment. Since that is not always possible or practicable, a series of actions need to be addressed to answer the problem.

In order to have a system based on supply and to maintain the stability of the power grid, active and stationary measures will have to be done, for example:

- Demand-side flexibility or management – adjust the energy demanded to match the supply.

This is an active measure, as it needs to be done by the system operator every time it is required. On this topic, RECs can have an important contribution by offering the service of flexibility.

Stationary measures are the ones that are made once, in other words, the kind of infrastructures that will be necessary, and some are listed below:

- Short-term energy storage – to compensate for daily (or a few days) fluctuations in consumption, short term storage is needed, for example, batteries, high energy capacitors, flywheels, heat storage or others. With that, the short-term matching can be easily done, including the night demand.

- Long-term (and seasonal) energy storage – this type of storage is necessary to cover long periods of low generation, for example, during stormy winters, where there is not much irradiation from the sun and wind turbines do not operate or to harness the power when there is a long period of over production, storing it for later. Nowadays, the most discussed option for this role is green hydrogen, where renewable sources of electricity are used for production.

With the decentralization of production, reinforcement of the power grid and improved interconnections will have to occur.

- Digitalization of the electric system – to handle all different sources, locations and power, and match the demand with the supply, a smart grid is necessary, only that way it is possible to manage the whole system and to assess which, where and what is the best option (cut the power for flexibility providers, which battery to connect, etc.), avoiding for example, to disturb other clients by cutting their power and optimizing the system to reduce energy loss caused by long distances.

Another problem that will have to be assessed is the way the grid financing is made, since the contributions to the system will decrease, as more consumers won't use the public grid and will be exempt from grid fees. Without a structural recast, there would be only two options:

- Maintain the fee and reduce the investment
- Raise the fees for the remaining consumers

These options are impossible, inviable, or unfair, as the investment must continue, and the remaining consumers must not be injured, especially low-income households. For now, the number of autonomous self-consumers is still irrelevant to cause damage, but within few years the number of prosumers is expected to grow at a rate of 70 to 80 thousand per year, said that, a solution needs to be thought as soon as possible, but it is most likely that there will be no grid fees exemptions [20].

In large-scale systems, the connection with the grid is done in a designed studied point, considering its capability of receiving the power, but with a decentralized system, the dispersion of the production causes that the distribution network needs to be reinforced instead.

When a household produces its own electricity, there is the possibility that they may become more unconcerned with efficiency or use more energy, creating a rebound effect, which in a certain way is a step back.

Prosumption models may be seen as an enemy of large-scale company owned power plants, but for the electric system, both types of projects, in fact, are complementary, each of them with their benefits and disadvantages.

2.8.1 Local market

One more step is given on the decarbonization process and social development with the contribution of the full potential RECs can provide, together with the digitalization of the grid, by performing local market activities, such as flexibility or peer-to-peer energy transactions. This still under explored activity can make the current electrical system unrecognizable, decentralizing production and developing the local economy. This activity is also possible to be performed with non-renewable energy sources, however, due to project characteristics, only limited locations are possible. In the other hand, especially photovoltaic power plants, the number of possible locations to install is nearly unlimited

Peer-to-peer energy sharing

This activity has the potential to increase the amount of energy sold at more interesting prices for the seller and at the same time for the buyer, since this model is able to involve a greater number of consumers.

There are different ways to carry out this operation, as shown in Figure 2.4, with a, b, c and d, representing one potential model.

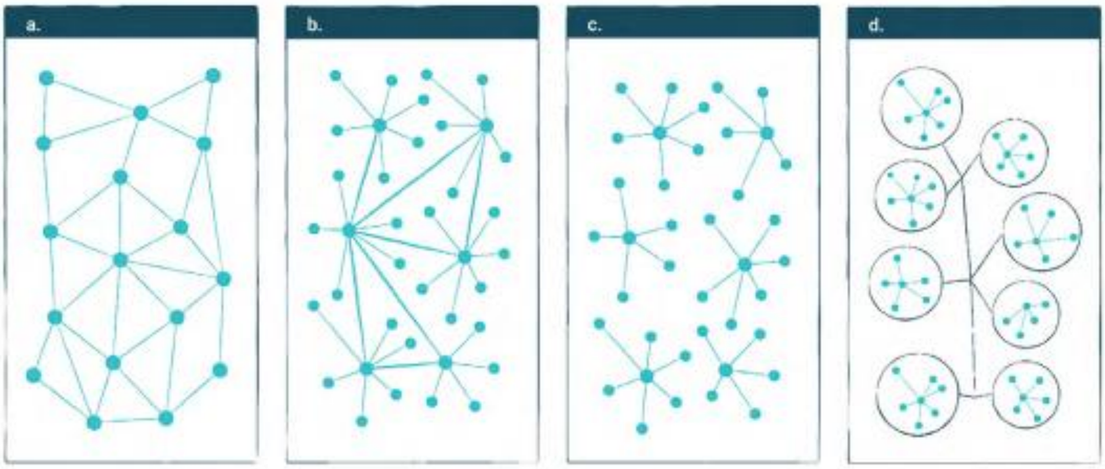


Figure 2.4 – Structures of peer-to-peer markets [21].

On model a, every prosumer links directly to each other and buys or sells the electric service.

On model b, prosumers supply a micro grid, which is connected to another micro grid, thus, its prosumers. The energy is traded inside one grid and between grids.

On model c, prosumers supply a micro grid that isn't connected to any other grid or to RESP, and the electricity is exchanged between the prosumers inside the grid.

Finally, the model d, prosumers, represented by the dots, transact energy between them inside the community (circle), which is connected to another community. The role of the community is to manage a Virtual Power Plant (VPP) and connect to others.

Due to the complexity that the models a, b and c would bring, for example, to the amount of Grid Usage Contracts (one per prosumer), the model d, is potentially more suitable to a real case of local market for electricity, where only one contract in the name of the community, is needed.

Although the deployment of RECs is still at the very beginning, the regulation contemplates the interaction between the community and a producer, a consumer or other communities, to purchase or sell clean energy.

Flexibility

From the point of view of the management of the grid, specifically on the balancing of the consumption and the supply, as the number of intermittent sources being installed increases, there is a greater interest in also increasing the number of ancillary services suppliers, namely flexibility, to face lack of power and this is where Renewable Energy Communities can help, by joining and managing a more relevant number of consumers.

When the grid is imbalanced, it is fundamental to take measures to restore the balance. For example, when it is needed to reduce consumption, it is easier for the EGAC to cut the unimportant consumption than for the manager of the SEN to redispatch the power or to avoid the need to shed loads. It is also more environmentally beneficial to use the extra power supplied from the communities' UPAC. Additionally to the available power from the UPAC, in the cases that the community also relies on storage, this energy could also be used.

With the penetration of electrical vehicles on the streets, the electricity consumption will increase and future investments on the grid will increase exponentially, if the charging isn't distributed throughout the day. A REC could provide its members and the global manager of the SEN with the service of flexibility of charging, choosing the best hours to charge the batteries, i.e., when the SEN manager would want more consumption and at the same time would be cheaper for the member. In addition to this measure, when the laws are in place, the transfer of energy from a vehicle to the grid can also be in charge of the community and not only the vehicle owner.

2.9 Chapter conclusion

The way it is designed to operate, allowing that the investment for the UPAC is made by third parties, RECs may represent a good tool to spread renewable energy sources across the whole society, with special care for the most vulnerable ones.

The three backbone impacts mentioned, are said that in some cases they may not be accomplished, however, it leaves no doubt that regarding the environmental aspect, if deployed responsibly, it will always be more beneficial, in face to traditional power plants. Most of the time, a REC represents a smaller environmental disturbance than commercial photovoltaic power plants, due to the location they are usually installed, roofs versus on the ground.

There are several challenges to face in the future electrical system, but there are already good tools and guidelines to successfully solve this problems.

As the creation of a REC must go through the licensing process and the operation must comply with conditions such as the proximity concept or the sharing coefficients, there is the need for some expertise in the subject, so it is very difficult to have the common citizen to go through the process of creating a REC, even when clear information is transmitted.

3 TARIFFS

A customer connected to the grid has to pay the fees for the service provided, however, it is differentiated when there is only consumption from the grid and when the grid is used only to transport the energy produced. When only consuming, the designation, consumer, applies and when there is production, self-consumer is the term.

3.1 Tariff applied to consumers

General consumers are subject to pay the electricity consumed plus the service it takes to distribute electricity. The final price depends on where the consumer contract is held.

3.1.1 Liberalized market

The grid access tariff consists of the addition of several installments, being the monetary amount of each, defined annually by ERSE (quarterly monitored) and referring to the different activities of the sector, namely:

- Global management of the system
- Electricity transportation
- Electricity distribution
- Merchant Change Logistics Operation (OLMC)

The sum of these four components forms the Grid usage tariff.

The following figure, Figure 3.1, will present the price structure of the electricity supply for the liberalized market. It contemplates, in addition to the grid tariffs, the parcel of energy and fees and taxes, totaling the amount to be paid by the consumer.

It is also described, the beneficiary entity of the value of each installment paid by the customer.

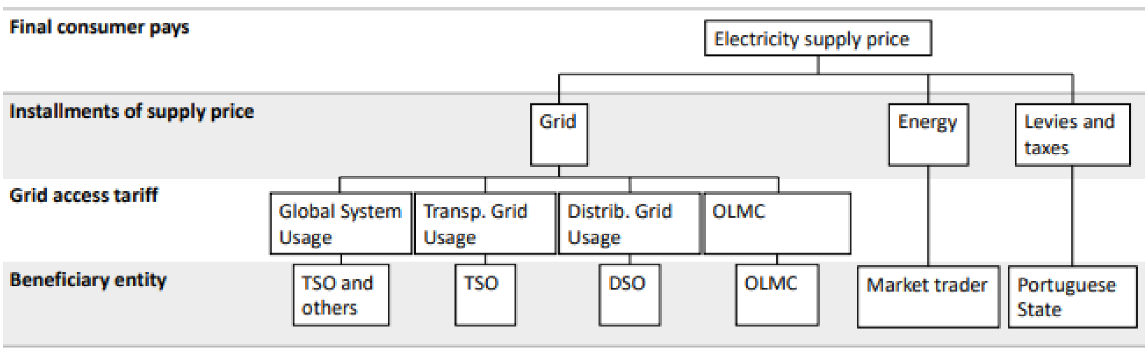


Figure 3.1 – Power supply price structure - Liberalized market, adapted from [22, p. 5].

The energy price is agreed with the market trader.

3.1.2 Regulated market

In the regulated market, in addition to the portions that together, make up the Grid Access Tariff, the following tariffs are added:

- Electricity tariff
- Tariff for the commercialization of electricity

With the addition of these two components with the others shown for liberalized market, it is formed the Final Customer Selling Tariff, as will be shown in Figure 3.2

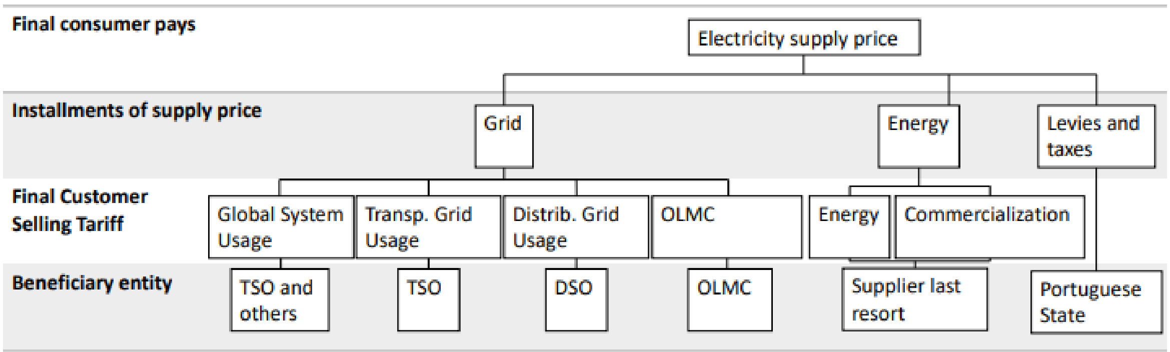


Figure 3.2 – Power supply price structure regulated market, adapted from [22, p. 6].

The absence of these two components on the liberalized market is due to the values be negotiated between the client and the supplier. Normally, all regulated activities have their price fixed by ERSE on the year before, to rule on the subsequent year, with quarterly monitoring, being updated if ERSE intends it is necessary, as happened in April 2023.

Despite the liberalization of the electricity sector being underway and with it, the extinction of the regulated market, it is still important to explore this form of commercial relationship, as consumers in this market will represent, in 2023, according to ERSE's estimate, 5,7% of total consumption [22, p. 4]. This represents a higher value than in the last four years, being in the last two under 5%. This growth is due to a Portuguese government decision to allow customers to return to this market, in order to protect them from the sharp rise in electricity prices experienced in 2022.

However, as provided for by Ordinance No. 83/2020, of April 1, the extinction of the regulated market must take place by December 31, 2025, for Normal Low Voltage (BTN- Power purchased ≤ 41,4 kVA) final customers and December 31, 2022, for Special Low Voltage (BTE- Power purchased > 41,4 kVA) final consumers [23].

3.2 Tariff applied to self-consumers

3.2.1 Structure of the Grid Access Tariff

As described in the Tariff Regulation, the general structure of the Grid Access Tariff to be applied to self-consumption through the RESP is divided in two, one for self-consumption in BTN and another for the remaining power levels in BTE, MT, AT and MAT [24]. This tariff is applied on the referential of the prosumer installation. In a REC, it is necessary to have attention to members individually.

For prosumers with power contracted in BTE, MT, AT and MAT, the tariff prices will be:

- Peak hour power prices, in Euros per kW per day
- Active energy prices, defined in Euros per kWh.

For facilities with BTN contract:

- Active energy prices, defined in Euros per kWh.

The referred prices for the different voltage levels are detailed in the Tariff Regulation, with different tariff periods, which include the different seasons of the year, hourly cycles, weekly cycles and others [24, p. 34].

The application of the Grid Access Tariff, with regard to the metering cycle, voltage level and tariff periods, are the same as if the consumption were provided by a market supplier.

It is important to point out that the Grid Access Tariffs for self-consumption apply to the fraction of consumption that comes from the UPAC. For the remaining consumption, if existent, carried out under a contract with a market agent, it is applied the usual Grid Access fees (all upstream voltage levels are accounted).

It should be noted that none of the tariff structures for self-consumption include the price of reactive energy, the reason for that is that if consumption does exist, it will be under the contract with a supplier and, in turn, does not concern the Grid Access Tariffs applied to self-consumption.

3.2.2 Grid Access Tariff

On all types of self-consumption activities, whenever the RESP is used to take the electricity to prosumers, there are different charges to which they are obligated to, similarly to the so-called, normal consumers, but considering that in some cases not all levels of voltage are used and that there are benefits on this type of production to the electrical system, such as the reduction of energy loss on the transmission.

The charges to be paid are the different components of the grid access tariff, applied the deductions provided by Decree-Law No. 15/2022, of January 14 and which establishes the payment of:

- The Grid Access Tariff, regarding to the voltage level of connection between the UPAC and the consumer, with partial or total deduction of Grid Usage Tariff of the levels upstream the connection
- Costs of General Economic Interest (CIEG)

The partial or total deduction on the grid access tariff may or may not be applied, depending on whether or not there is an inversion of the energy flow in the RESP, i.e., the UPAC is injecting energy upstream its connection voltage level.

Considering the current neglectable dimension that self-consumption projects have to cause an inversion of the flow in the RESP, ERSE considers that for the year 2023, the deduction is total. For the following years, the deduction will depend on the analysis carried out by ERSE, of the study carried out by E-Redes, characterizing situations of inversion of the flow between voltage levels [22, pp. 38-44].

The partial or total deduction of the CIEG is dependent on the Government order. If the responsible member doesn't emit the order, it is up to ERSE to define the eventual amount to be deducted.

In 2020, the Government issued the Order No. 6453/2020, of June 19, which determined the conditions for exemption from CIEG in self-consumption, applied to projects implemented until December 31, 2021, to rule during seven years, as follows:

- 50% exemption to Individual Self-consumption
- 100% exemption to Collective Self-consumption and to RECs

Later, in October 2021, through Order No. 10376/2021, the Government amends the order that was in force and extends for one year, to December 31 of 2022, the period of licensing or registration, that would benefit from the exemptions.

In 2023, CIEG presents a negative value in all voltage levels, so, in order to be fair for all, this cost takes the value zero [25, p. 130]. Its value is negative due to basically three reasons [25, p. 334]:

- Cost differential with negative Special Regime Production (PRE)
- Negative Power Purchase Agreement (CAE) cost differential
- Revenues from ISP (Tax on Petroleum Products)

For the next years it isn't certain about the maintenance of the negative values, as for example, the European Commission recommended governments to end support measures for energy prices, this would end the Extraordinary Contribution to the Energy Sector (CESE) and transfers from the Environmental Fund to SEN right away and also the cost differential may assume positive values in the future [26].

In Table 3.1 it is presented grid access tariff due to payment for the usage of the public grid, accounting all possible voltage levels.

Table 3.1 – Grid access tariffs.

GRID ACCESS TARIFF TO SELF-CONSUMPTION THROUGH RESP – 0% CIEG EXEMPTION							
Voltage level and tariff option (Consumer)	**Number of daily time cycles**	**Voltage level (Production)**	**Peak hour power**	**Active Energy EUR/kWh**			
			EUR/(kW.day)	**Peak hours**	**Middle hours**	**Normal off-peak hours**	**Super off-peak hours**
MAT	**4**	MAT	0,0597	-0,0153	-0,0154	-0,0154	-0,0155
AT	**4**	AT	0,0172	-0,0153	-0,0154	-0,0157	-0,0158
		MAT	0,1329	-0,0144	-0,0146	-0,0149	-0,0151
MT	**4**	MT	0,0855	-0,0136	-0,0140	-0,0149	-0,0151
		AT	0,1069	-0,0127	-0,0132	-0,0143	-0,0146
		MAT	0,2283	-0,0118	-0,0123	-0,0135	-0,0139
BTE	**4**	BT	0,2047	-0,0184	-0,0192	-0,0205	-0,0220
		MT	0,3274	-0,0156	-0,0168	-0,0189	-0,0208
		AT	0,3511	-0,0146	-0,0159	-0,0183	-0,0203
		MAT	0,4854	-0,0136	-0,0149	-0,0174	-0,0195
BTN>	**3**	BT	null	-0,0077	-0,0085	-0,0253	
		MT		0,0404	-0,0061	-0,0239	
		AT		0,0502	-0,0052	-0,0233	
		MAT		0,1008	-0,0042	-0,0224	
BTN< triple	**3**	BT	null	-0,0267	-0,0275	-0,0378	
		MT		0,0214	-0,0251	-0,0364	
		AT		0,0312	-0,0242	-0,0358	
		MAT		0,0818	-0,0232	-0,0349	
BTN double	**2**	BT	null	-0,0275		-0,0378	
		MT		-0,0151		-0,0364	
		AT		-0,0123		-0,0358	
		MAT		-0,0005		-0,0349	
BTN single	**1**	BT	null	-0,0310			
		MT		-0,0223			
		AT		-0,0202			
		MAT		-0,0121			

Source: Adapted from [27, p. 19].

When there is energy transmitted through RESP, and the project isn't exempted from CIEG costs, the values on Table 3.1 that were subject to an update by ERSE, will apply from July to December 2023.

At this date, it is already possible to confirm that for the year 2024, the grid access tariffs value will increase due to the stabilization of the price of the electricity on the market, reducing the over gains to return to consumers.

3.3 Chapter conclusion

The final price consumers pay for the electricity used is highly dependent on the market, while on the regulated market the energy price is constant over the regulated period, on the liberalized market the price can fluctuate according to the market. An active tracking of the market can bring considerable money savings, however this requires attention and time to compare the prices.

With the current legislation, the factor that will influence the most the amount self-consumers need to pay for the use of RESP, is the CIEG cost, which is of course dependent on the energy transmitted. For now, the electrical system is in part financing self-consumers to use the grid. But when the CIEG assumes a positive value or even less negative, the scenario changes, and self-consumers will pay the same amount of grid access tariffs that other consumers pay but having always in account the voltage levels.

Since the CIEG cost assumes the value zero, the deductions granted of 50% and 100% cause that the grid access tariff is the same for both cases, i.e., no deduction is made.

Despite the values are still not publicly known, with the increase of the grid access tariffs, the energy bills for all users of the RESP will be higher as no further exemption is expected.

4 PRACTICAL CASE ASSESSMENT

4.1 Average cost of power plants

Together with the analysis of the economic impacts of RECs and prosumer models on the electric system and on consumers, it is also important to understand, based on costs, what is the best option to follow.

The values presented on Table 4.1 are referred to estimated costs of new power plants in Europe in 2021. With emphasis on the three renewable options that REC can deploy and natural gas for comparison, both solar and wind sources have become more competitive than the usual fossil fuel, explaining in part, the urge to deploy especially, photovoltaic panels in large scale.

Table 4.1 – Cost of different sources.

Source	Cost [€/MWh]
Natural gas	77,9 – 130,6
Large-scale PV	31,2 – 57
Small-scale PV	58,1 – 80,4
Wind Onshore	39,4 – 82,9

Source: Adapted from [28].

The cost of generation by RES has been decreasing along the past years, with major relevance to photovoltaics which has become the most competitive technology on the market [29]. It is interesting to compare the cost of it with the so common Combined Cycle Gas Turbine (CCGT) and see that the price of a renewable system could be half of the non-renewable one. In fact, in Portugal, as the private interest in investing in solar farms is very high, the minimum price for the energy, has become a world record, with a value of 11,4 €/MWh [30].

These values have in account the power density of each technology regarding area needed. Note that PV plants with the lowest power density are still very competitive.

So, to assess the investment needed to lead us to a carbon-neutral electric system, it is fundamental to have in mind that depending on the share of each RES, the cost of the system will vary. The deployment of REC will in the long term be financially more expensive, as they are usually Small-scale PV, potentially costing twice (or five times more, comparing to the record) as much as the large-scale utility owned power plant.

In any case, the cost for prosumers and members of RECs will be always lower, considering the future savings in electricity, thus returning the investment in a few years.

4.2 Geographic characteristics

Instituto Superior de Engenharia de Coimbra (ISEC) is located in Coimbra, Portugal, at Rua Pedro Nunes.

From Global Solar atlas' website, the darker the coloring on Figure 4.1, the greater the potential energy output from solar farms [31].

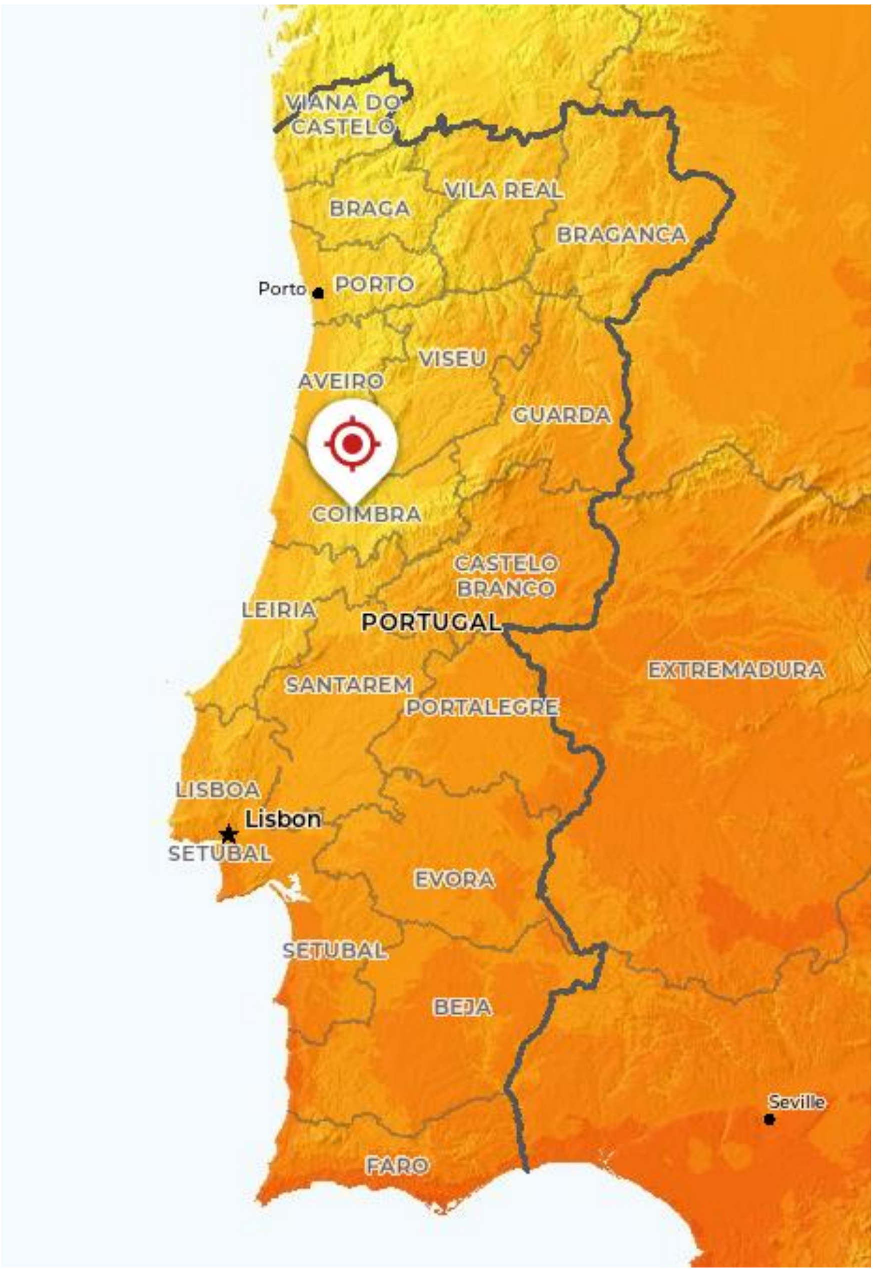


Figure 4.1 – ISEC´s location, from [31].

As visible on Figure 4.1, the center and south regions of Portugal are more suitable for this type of projects, especially with commercial applications. For the purpose of self-consumption, the entire country has the ability to provide prosumers a significant value of sunny hours, resulting in around 4 kWh/kWp per day, of electricity production by photovoltaic panels.

4.3 Electrical characteristics

With six teaching area departments [Civil (DEC), Informatic (DEIS), Electrotechnics (DEE), Mechanical (DEM), Chemistry and biology (DEQ) and Physics and mathematics (DFM/GERAIS)] and operational services, it is divided into several buildings.

The electricity is transported to ISEC through a 15kV underground cable from Alto de São João´s Substation which exclusively supply the two transformer stations of the Institute, PT1 and PT2. This main cable emerges inside the cabin of PT1 (see Figure 4.3), feeding its transformers and also providing the 15kV line to PT2 (see Figure 4.2).

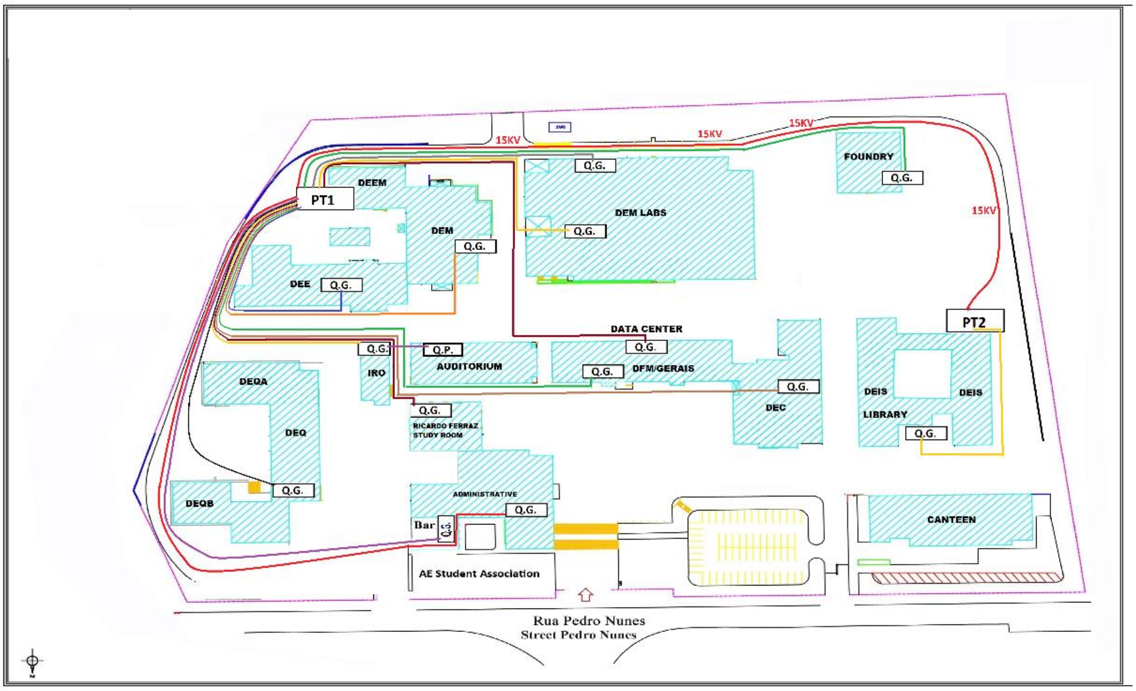


Figure 4.2 – Main wiring.

Through field searching, it was possible to come up with the approximate cabling route from the station to each department’s main electric board (Q.G.), resulting in Figure 4.2.

Figure 4.3 – 15kV cable in surface.

Figure 4.3 shows the underground cable emerging (left) and following to PT2 (right). Both lines are protected by disconnectors.

4.3.1 Power station 1 (PT1)

PT1 consists of two power transformers A and B, with 315kVA each. On the upper part of the Figure 4.4 is visible part of the connection to the transformer. Their connections are secured at medium voltage, by disconnectors. On the low-voltage side, the protection is located on the main electrical board (Figure 4.7).

Figure 4.4 – Transformers A and B.

PT1 power transformer station contains the main power transformers, which feed most of the buildings, namely, DEE, DEM, DEM Labs, DEQ, DFM, DEC, Administrative, BAR, Foundry, Auditorium and Data Center, at 400V three-phase.

Transformer A and B

Both transformers present the same electrical characteristics. The transformer's voltage levels are 15000/400V 3-phase and may support a 5% deviation on medium voltage, as its nameplates show in Figure 4.5 and Figure 4.6.

Figure 4.5 – Nameplate transformer A.

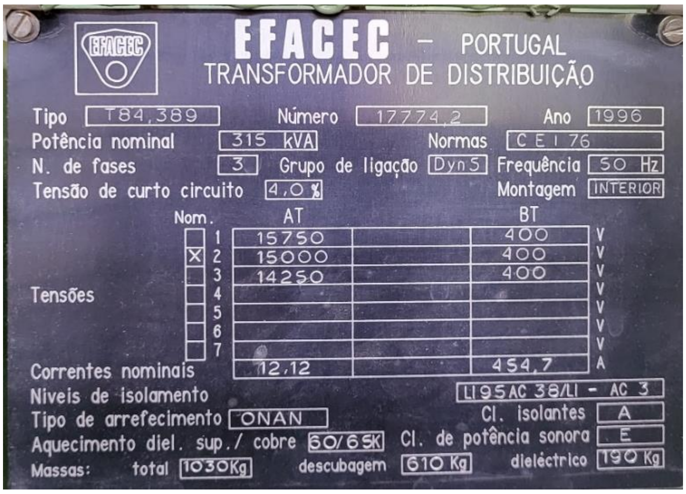


Figure 4.6 – Nameplate transformer B.

Note: The designation transformer A and B is a designation from this project.

Regarding currents, on the medium voltage side, the nominal current is 12,12A and on low-voltage side, the nominal value is 454,7A. These are oil cooled transformers with natural convection.

Both A and B are connected to the transformer's station main electrical board (Figure 4.7), which proceeds to the distribution and protection of the lines, with switch disconnectors. From this board, all underground cables follow to its respective department´s Q.G., as represented in Figure 4.2. On the bottom right in Figure 4.7, the two switches are the low voltage power cut, i.e., one switch for each transformer. Here is also connected the power factor compensation system.

Figure 4.7 – PT1 electrical board.

The remaining switch disconnectors on this board are the ones to each department and protections to other circuits like exterior lighting, voltage and current meters.

Figure 4.8 shows some of the switch disconnectors on the main electrical board and the devices to proceed to the electricity consumption measuring (white clamp meter, measuring all phases currents).

Figure 4.8 – Switch disconnectors and clamps.

4.3.2 Power station 2 (PT2)

PT2 consists of one transformer with 160kVA of power.

The connection is secured at medium voltage, by disconnectors. On PT1 it is also possible to cut the power of this line. In Figure 4.9 it is possible to see the 15kV cable arriving from PT1 and a disconnector to secure part of the line.

Figure 4.9 – 15kV cable emerging on PT2

In Figure 4.10, on upper left corner is visible part of the 15kV line and on the bottom left is the disconnector to this line. On the low-voltage side, the protection is located on the main electrical board.

Figure 4.10 – Transformer PT2.

The PT2 supplies the DEIS department which includes informatics and the library, representing a much smaller consumption than PT1, reason why it has only one transformer, resulting in ¼ of the power of PT1.

Transformer PT2

The transformer voltage levels are 15000/400V 3-phase and may support a 5% deviation on medium voltage, as its nameplates show in Figure 4.11.

Regarding currents, on the medium voltage side, the nominal current is 6,158A and on low-voltage side, the nominal value is 230,9A.

This is also an oil cooled transformer with natural convection.

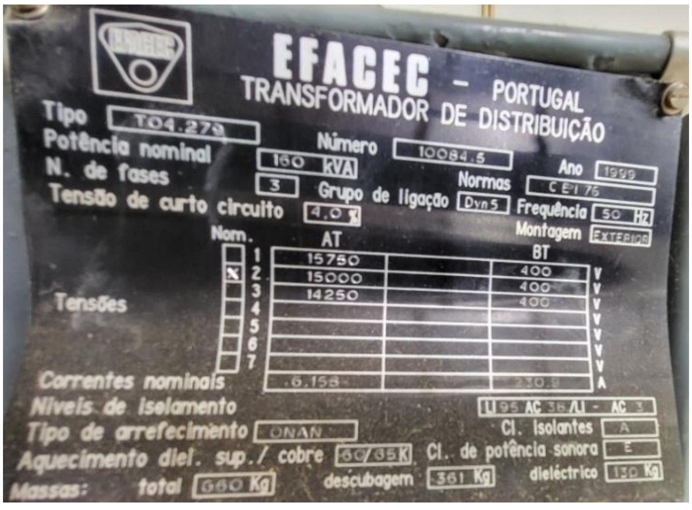


Figure 4.11 – Nameplate Transformer PT2.

PT2 is connected to its main electrical board, Figure 4.12 which contains the disconnector to low voltage protection. It also holds the switch disconnector to the single line that follows to the DEIS Q.G., the power factor compensation device, energy consumption meter and the vehicle charging station.

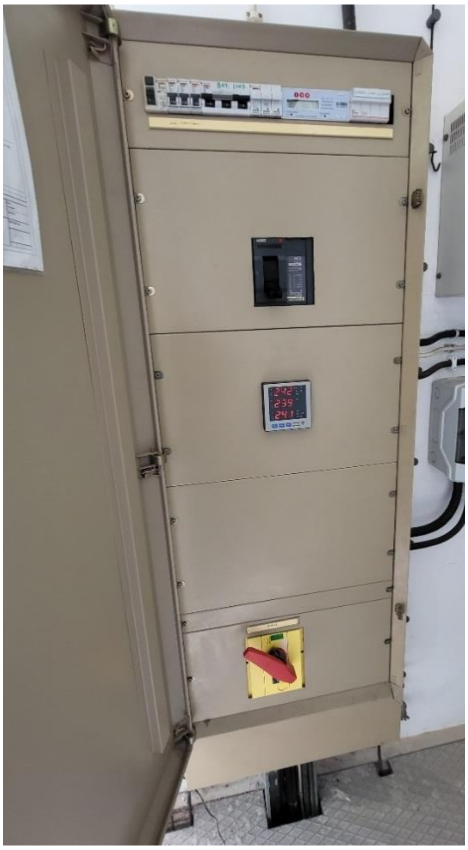


Figure 4.12 – PT2 electrical board.

On the upper part of Figure 4.12, the line of protections are the ones to P.F. compensation, energy meter and lighting inside the station. Below this line is visible the switch disconnector of DEIS. Then a voltage meter to each phase. On the bottom comes the disconnector to low voltage.

4.3.3 Power factor compensation

Due to the existence of several reactive loads, it is mandatory to equip some device to correct the power factor, otherwise this energy would be requested from the grid and would be reflected on the electricity bill. The reactive energy consumption is punished by a high price, encouraging consumers to install their own power factor compensation devices, capacitor and inductor banks, depending on each case.

In the case of ISEC, most of the loads are inductive ones, resulting in the need for a capacitive bank.

Actually, in this case, there are two capacitive banks, one in transformer power station, PT1 and other in PT2, as shown in Figure 4.13 and Figure 4.14 in, respectively.

Figure 4.13 – Condenser bank PT1.

Figure 4.14 – Condenser bank PT2.

Looking very closely to Figure 4.13, it is possible to see that the power factor at the moment the photo was taken was 1,00, but it wasn't possible to check the nameplate with the bank characteristics.

The available power on PT2 is 6,2kVAr.

4.3.4 Designing the cables and protections

One side of this project consists in simulating the existing power lines and protections through the software SIMARIS design 11, to better visualize the connections and loads of each electrical board, with high focus on each department main Q.G., since it supports the connection to the transformer or eventually to other electricity source, e.g., photovoltaic panels or wind turbine. In order to achieve that, it was carried out several on field excursions to register where and which components are used.

Through all of the searches, came up Figure 4.2, where the approximated location for each cable and main electrical boards are shown. It is important to point out that despite the proximity to some departments' Q.G., it wasn't chosen the shortest path, but kept a high level of consistency on the route.

There are 13 circuits connected to the PT1 main board that will lead to departments and the range of lengths varies between 100 and 280 meters. These distances are very important in the designing of the photovoltaic project due to voltage drop levels. The maximum admissible values, compared to the nominal voltage, differ with the voltage of electricity supply, as shown on Table 4.2:

Table 4.2 – Voltage drops maximum values.

Power supply	Lighting	Others
Low voltage	3%	5%
Medim voltage	6%	8%
Preferably, for MT, when possible do not exceed the values from LV.		

Source: Adapted from [32, p. 70]

For the case of ISEC, the maximum accepted value is 8% of drop on the nominal voltage, measured on the consumption device, i.e., at the end of the line.

The complexity and size of the design on the software is enormous, specially to display on this document, but an overview of the result is shown in Figure 4.15.

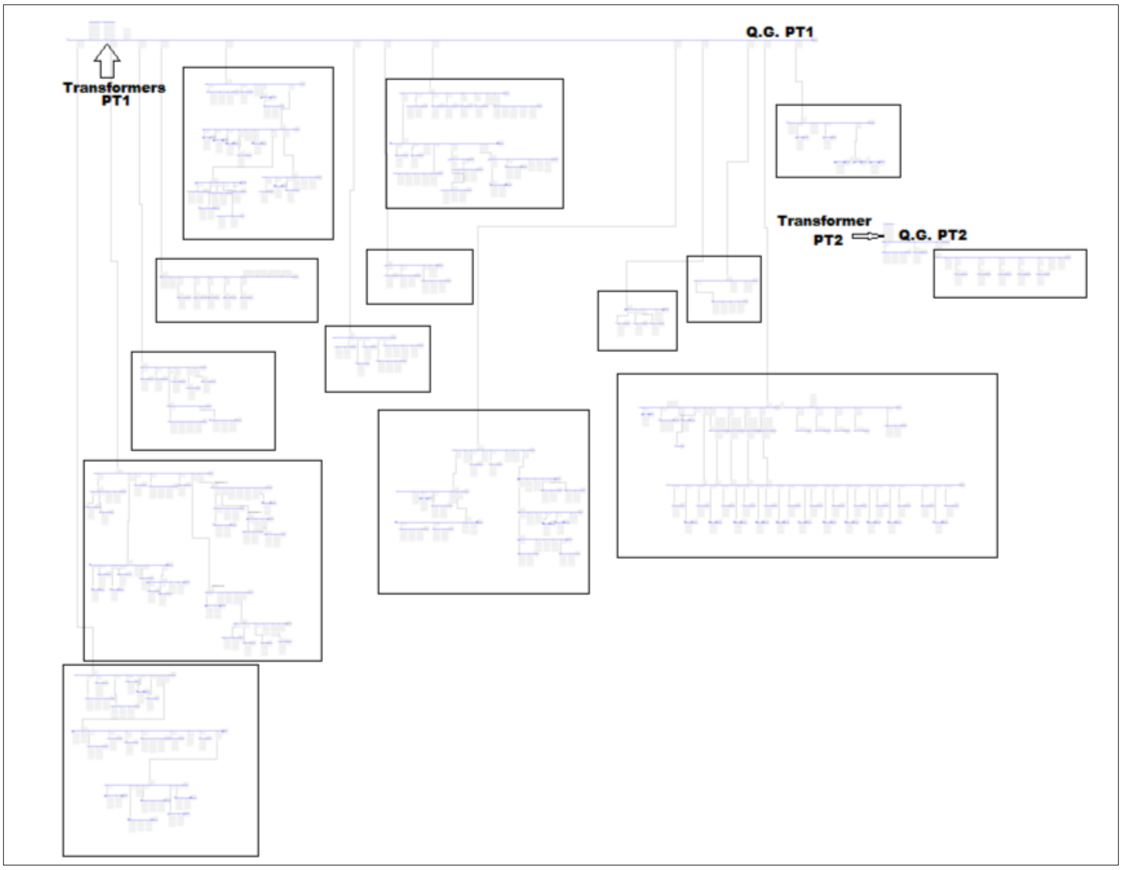


Figure 4.15 – Circuit overview on SIMARIS.

It isn't possible to properly show the results in a detailed way, to make it easier to understand the rectangles were added, each one representing one department's single-wiring circuit. A detailed diagram is added to the annex section, Annex B.

Since the cabling is buried or inside the walls, the results on the software could not be compared to what is in reality. Due to the age of the installation, resulting in several upgrades on the grid, lack of the original electrical diagrams and further upgrades, the design could not be 100% similar as some protection devices in the simulation don't correspond to reality (around 10 devices), in terms of currents, they aren't available in the software's library. For example in Figure 4.16, the installed switch has 40A, when the software only allows a 63A device.

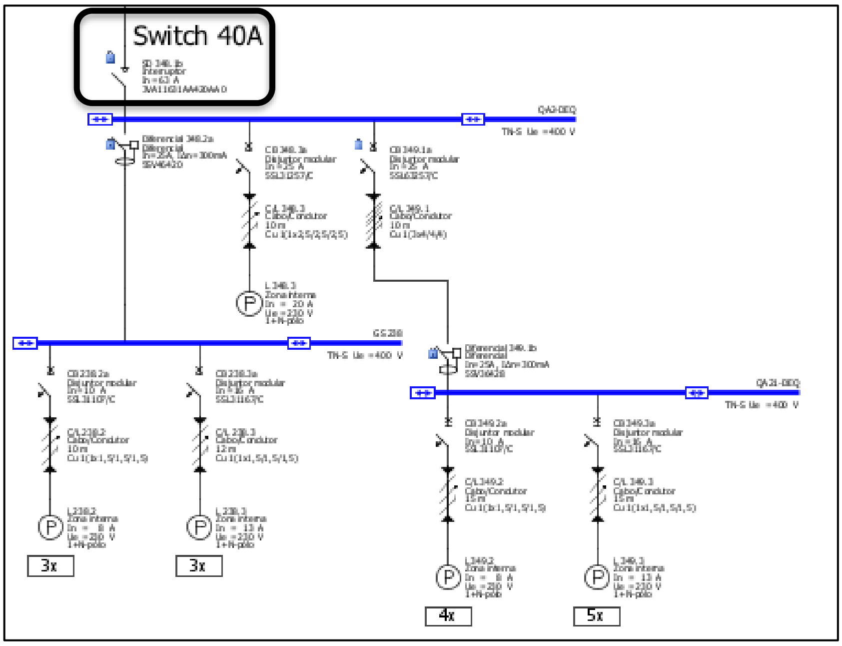


Figure 4.16 – QA2-DEQ circuit diagram.

4.4 Consumption

When designing a photovoltaic system, an analysis on the electricity consumption plays the most important role in the project. This will highlight the power needs of the consumer, hence determine how powerful power plants must be.

Ideally, the consumer facility is equipped with analyzers for a long period to get the real profile of the consumer throughout the day, weeks, and months. It happens that most of the time this isn't a possible task, either due to the amount of resulting data or due to the hurry to install the power plant.

The solution to get an approximate value of power usually comes on the monthly bill. There, it is possible to get the electricity consumption for the previous month and then it is possible to reach the power. It is also important to have access to at least a whole year of consumption in order to trace a consumption profile for the months, therefore seasons.

The applied law for this area states that when designing a self-consumption system, it is mandatory that the electricity generated by the power plant is as close as possible to the consumer needs, to reduce the surplus, improving the relation power need and project cost, since most of the times the surplus injected on the grid isn't paid or has a very low price. The same rule applies when designing a REC, but existing the commercial side, it is possible to sell the excess electricity on the market, so the importance given to oversizing the power plant is lower.

For the specific project of ISEC´s REC, in first place it is necessary to work the existing data, meaning that the monthly consumption back to 2011 was analyzed. This brings not only advantages to the design but also tracks how the consumption over the years is evolving. These numbers come from the department´s electricity meter. In Figure 4.17 are some of them.

Figure 4.17 – Electricity meters.

Each department has its own meter and most of them are located in the power station, but there are some on the main electrical board of its department. The reading is done manually for each and stored in an excel sheet. Their working principle is continuously registering the energy flowing through them, meaning that to get a monthly value it is necessary to subtract the number between two months. The values of the data center aren't registered so an estimation had to be done and the result was around 35000kWh. To every month's consumption, 35000kWh was added. On the tables, Table 4.3 and Table 4.4, it is presented the monthly consumption values that resulted from the analysis and preparation of the gathered data provided for this project.

Table 4.3 – Electricity consumption 2023-2018.

	2023	**2022**	**2021**	**2020**	**2019**	**2018**
	kWh	**kWh**	**kWh**	**kWh**	**kWh**	**kWh**
JAN	89557	77302	71192	85021	80855	91689
FEB	72958	76839	52950	69630	88395	81098
MAR	72920	75981	54484	60504	78934	86273
APR	60399	67155	54848	51658	87583	70194
MAY	67511	64538	57592	49287	77297	70194
JUN	75884	64748	64310	50266	69527	70194
JUL	-	78015	55792	52679	69527	70194
AUG	-	53012	53208	52679	69527	70194
SEP	-	53012	84946	58622	69527	70194
OCT	-	66464	54896	58622	69527	70194
NOV	-	82009	54896	58622	69527	70194
DEC	-	75670	68503	63644	79037	70194

Table 4.4 – Electricity consumption 2017-2011.

	2017	2016	2015	2014	2013	2012	2011
	kWh	kWh	kWh	kWh	kWh	kWh	kWh
JAN	93905	60267	98804	113895	-	108556	111999
FEB	89156	60267	92833	109112	-	123212	120046
MAR	95927	78965	69711	143462	-	96902	93368
APR	68866	79350	77730	53735	-	84224	89482
MAY	71146	114774	69764	53735	-	84321	80585
JUN	86971	127945	88753	65947	-	88868	95135
JUL	61042	63928	70003	67141	-	76877	80015
AUG	63967	63529	57056	47162	-	57133	56747
SEP	62612	81953	80062	70889	-	67947	68379
OCT	82825	112404	74578	88914	104116	81965	87247
NOV	77238	93905	106794	99794	64830	123341	94447
DEC	142085	93905	104112	69320	-	92589	100313

First, as it is eye catching, the values in red are estimates for the corresponding month, when it is possible to do that. This happens because the months in question don´t have a reading of the consumption, affecting the monthly profile of consumption, but not the yearly profile. The way to not affect the yearly consumption is to have the first and last reading of the year to get the total value, and most of the cases these readings exist.

For 2013 it is impossible to come up with the missing numbers as the nature of data is different, one comes from readings and other comes from monthly bills.

Regarding 2023, as the data is available only until June, at this date, it is also impossible to reach the remaining values.

That being said, with the values from Table 4.3 and Table 4.4, it would be inaccurate to draw the consumption profile to each month for every year, but it is still possible to present the majority of the annual values precisely, as shown on Table 4.5.

Table 4.5 – Yearly consumption.

Year	Consumption [kWh]
2011	1077763
2012	1085935
2013	-
2014	981106
2015	990140
2016	1031193
2017	995740
2018	890808
2019	909262
2020	711235
2021	727255
2022	801341

As the Table 4.5 highlights, when working the existent data, it is possible to get the mentioned solid values, despite some are missing. This can be used to visualize the annual consumption levels.

To better visualize the evolution of ISEC´s electricity usage, these values are used to graph Figure 4.18 to further analysis.

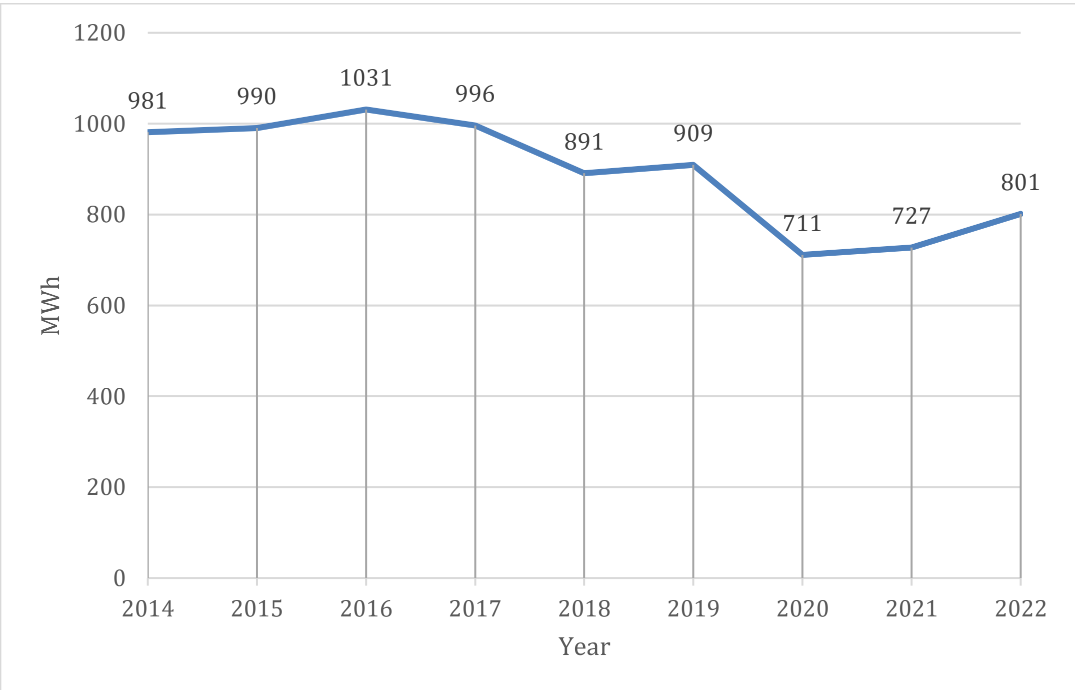


Figure 4.18 – Consumption evolution

As it is expected, due to being embraced by efficiency programs, electricity consumption has decreased over the last years, with active measures being taken, e.g., installing more efficient HVAC or changing the lighting technology.

When comparing the value from 2014 to the one in 2022, the reduction is around 18,3% which is very significant, given the period of time. In other words, the consumption fell 179MWh.

The beginning of this decade was defined by the pandemic lockdowns, impacting the 2020 and 2021 values, which are notably outlier from the other values in roughly about 90,1MWh and 74MWh respectively, when comparing to 2022.

In 2022, with the return of presential lectures, the consumption has risen to normal levels. Not knowing the consumption reduction measures taken during 2020 and 2021 and without 2023 value, it isn't possible to say whether the value will stabilize around 800MWh or 900MWh, also because the consumption is also affected by climate, creating a lot of volatility.

4.5 Site assessment

The site assessment in terms of orientation is the characteristic that will dictate the future a project like this, as it influences several factors such as the cost, linked to the amount of infrastructure and electricity production.

In order to minimize the cost and amount of material to install PV panels, which will sit on top of the departments, through Google Maps, the identification of every south faced roof, plus the ones without inclination was made, since these are the most suitable orientation to install, despite only south is preferred.

With the identification complete, with the help of an online tool, EDP bairro solar, which calculates the number of panels that it is possible to deploy in an area drawn by the user, using satellite images, resulted Figure 4.19 [8].

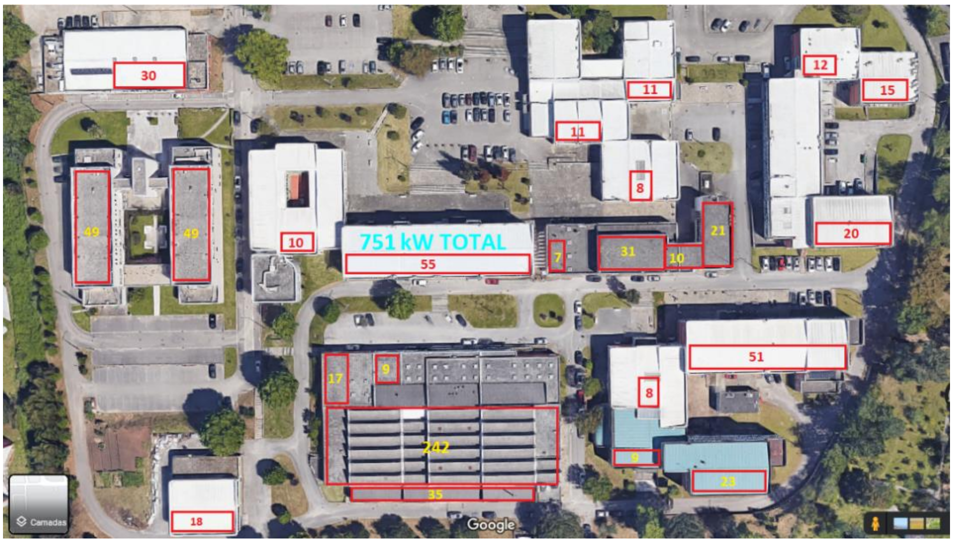


Figure 4.19 – Maximum power possible.

To reach the total power of 751kW, each rectangle had to be drawn individually on this tool and after that add up the resulting numbers. This simulation, also due to its quickness, was important to provide not only a comparison basis to discussion before moving to the software PVsyst, but also for later when using it, especially regarding the roofs to be used.

The resulting power, 751kW, isn't necessarily the power needed for ISEC, but it is the full potential of the best roofs to deploy PV panels, and in fact this number will be different when using PVsyst, as later will be presented, since the software has its own measuring tool.

4.6 Power choices

Two sceneries were studied, one using the maximum potential for photovoltaic panels and a second, a smaller system based on a value from a monthly bill from 2011 with peak value of 440kW. Both values from the proposed sceneries are criticizable, as was already discussed, the values of electricity consumption have decreased, so using old data pushes the system away from reality, but the inexistence of more recent data forced this choice.

Using the PVsyst measuring tool, the design resulted in powers slightly different on both cases, one in 764kWp and the other 439kWp of installed PV panels.

Figure 4.20 and Figure 4.21 to the implementation on PVsyst of the information acquired on the EDP bairro solar.

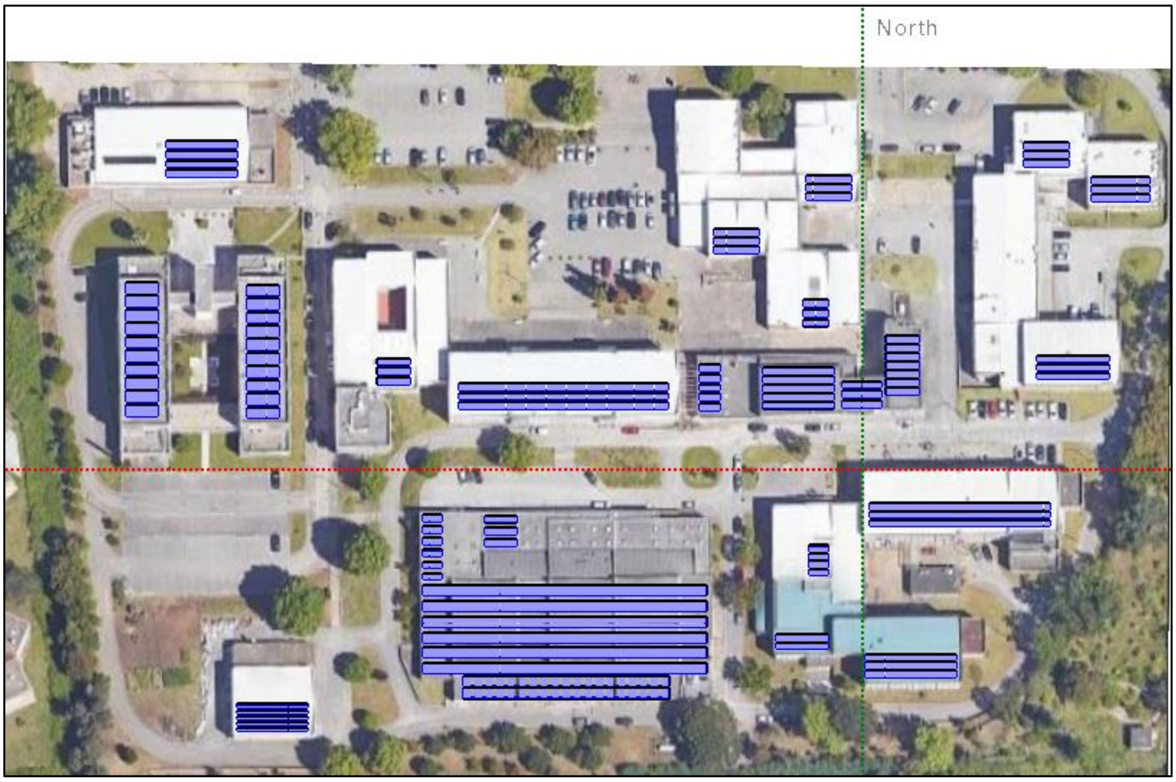


Figure 4.20 – System 764kWp.

In Figure 4.20 is drawn the system with 764kWp, meaning that all roofs facing south are covered with photovoltaic panels and the range of power vary from 8,4kWp to 240kWp nominal power per array, at Standard Test Conditions (STC).

Closer to the actual needed power is Figure 4.21, with the 439kWp system.

Figure 4.21 – System 439kWp.

The range of array power goes from 8,4kWp to 56,1kWp nominal power, at STC. To reach this power, choices about which array to remove from the bigger system, resulted in Figure 4.21, but in reality, now with more available roof space, the system could be more spread. Nevertheless, for project purposes, the choice has been made.

4.7 Load profiles

The PVsyst software allows the input of different profiles of consumption that goes from hourly to monthly profiles, considering seasons and working days. The possibility of insert detailed hourly values or just a fixed constant value throughout the day makes a difference when designing.

In this project, to give a better understanding of the importance of detailed data and how it will affect the final results, two profiles of consumption were drawn, both on a daily basis. One, considering working and weekend days and the other also daily, but considering that all days have the same consumption. Although lacking the daily values, by studying the average profile that the consumption assumes during the day, an assumption of these values was made, adapted to the values of ISEC.

The mentioned values of ISEC, in the first place, are based on monthly consumption and here another choice was made: to take the highest value of each month in the last three years, including 2023, this way it is expected for one year, the worst case. This combination of values resulted in Table 4.6 and it is suitable for all simulations.

Table 4.6 – Expected monthly consumption.

Month	Consumption [kWh]
January	89557
February	76839
March	75981
April	67155
May	67511
June	75884
July	78015
August	53208
September	84946
October	66464
November	82009
December	75670
Total	**893239**

As expected, during the winter months, the consumption is higher, as days are usually darker and colder, however in summer, despite having much brighter days, these are becoming abnormally hot, causing also the need of some form of air treatment, thus, also a high consumption.

When presenting results, the software works on a yearly basis, meaning for example, the energy produced in one year, carbon savings per year or yearly user's needs for electricity. This means that when inserting the values on the software, the value that matters is 893MWh/year, which is the sum of the values of Table 4.6.

Explaining the profiles in detail comes:

- Considering that all days have the same consumption, monthly modulation, the user has to give two types of input, the monthly values and a daily profile.
- Differentiating week to weekend days, weekly modulation, the user can only define one profile for week and other for weekend.

Both choices have critical implications, in monthly modulation, the daily profile will be the same for every day of the year and in weekly modulation, the user has to match himself the consumption for the year, 893MWh, but the monthly values will be different from the ones in Table 4.6.

Also, using the monthly modulation makes the peak power of a day go down, as there are more days to be accounted for the average.

4.7.1 Weekly modulation 439kWp

In Figure 4.22 it is shown the window for selection of the type of load, and in this case, among all possible loads, weekly modulation is selected, with five days of work, being possible to change this number.

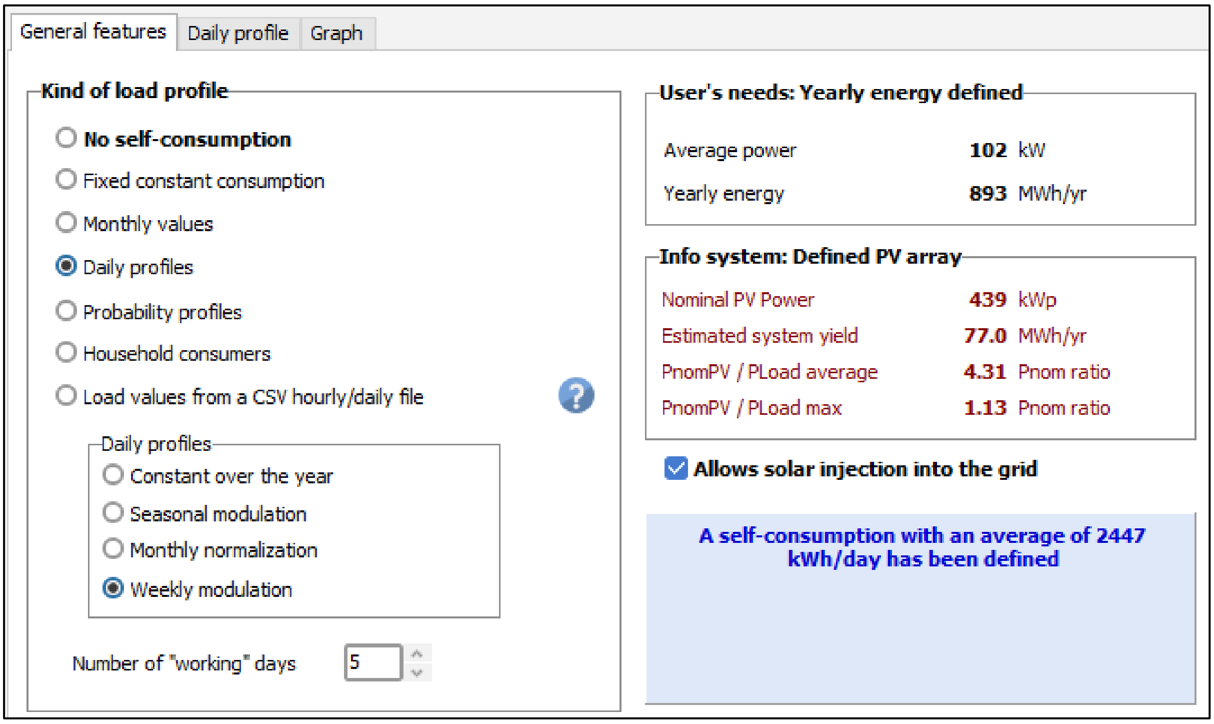


Figure 4.22 – Weekly modulation yearly value.

Here, after the profiles are defined, two parameters are eye catching, PnomPV/PLoad average and PnomPV/PLoadmax, with values, 4,31 and 1,13. The first state that, the power of the designed system, 439kWp, comparing to the average the power needed, 102kW, is over 4 times higher, meaning that in average only ¼ of the system peak power would be used. The other parameter, which compares the nominal power of the system with the peak power defined on the profile, states that it is only 1,13 times higher, meaning that even the peak load would be covered by the photovoltaic system. In reality the system isn't able to produce its nominal power due to efficiency and losses, as later in the simulation will be shown, thus can't supply all the required peak power.

In Figure 4.23 and Figure 4.24 are the values assumed for the profile of consumption for week and weekends, which in each category will be the same throughout the year and served as basis to calculate the values mentioned above.

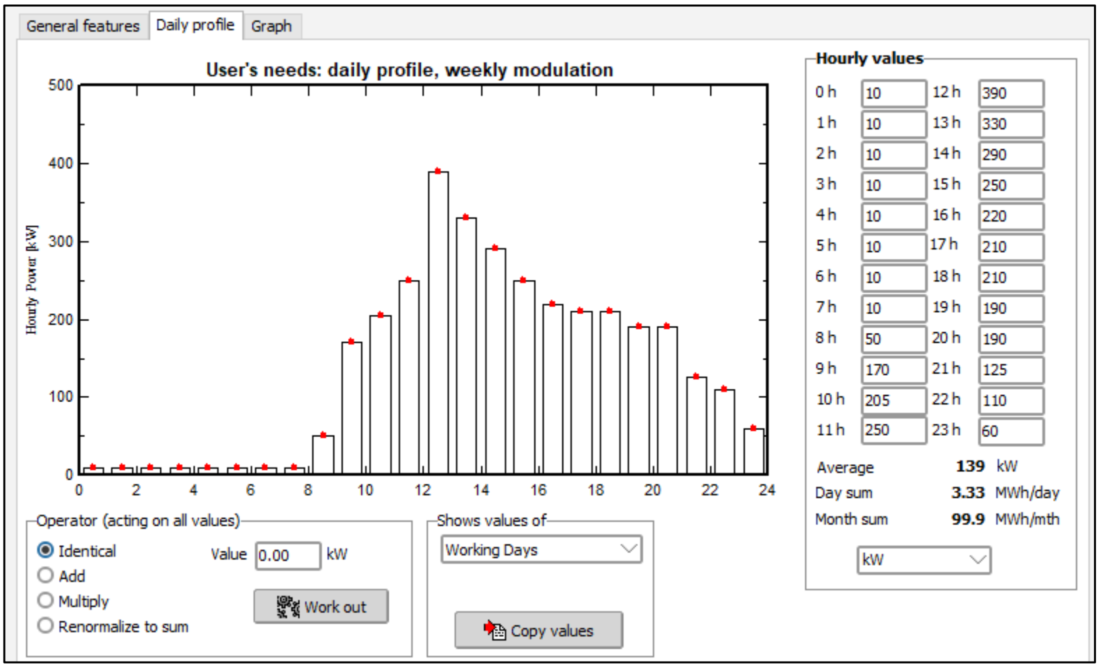


Figure 4.23 – Weekly profile.

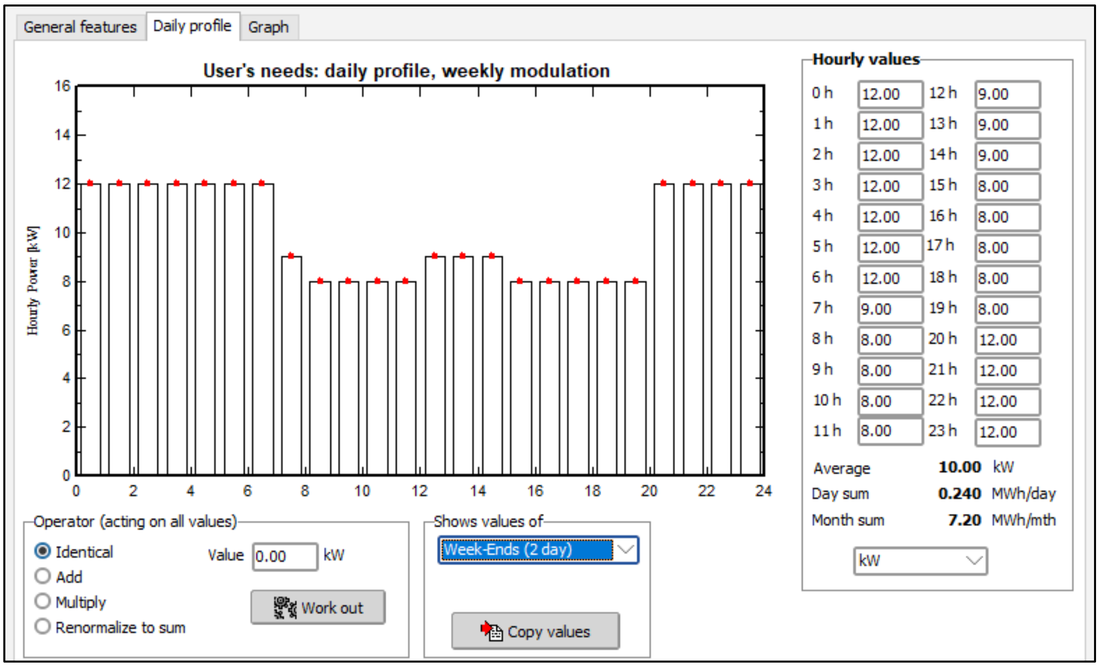


Figure 4.24 – Weekend profile.

In Figure 4.23 the consumption has a high variability, tending to follow the amount of activity in ISEC, starting at 8:30 and ending 23:30, with peak value in the morning and almost continuously decreasing during the afternoon. The peak power is 390kW around noon. This is the value that comparing to the nominal power of the system mentioned above results in a ratio of 1,13.

Since during the weekend there isn't activity in ISEC and mainly loads that are continuously on, the consumption has an almost flat profile, but trying to reproduce what is the lighting consumption during the dark periods.

4.7.2 Monthly modulation 439kWp

In Figure 4.25, monthly modulation is selected among the options.

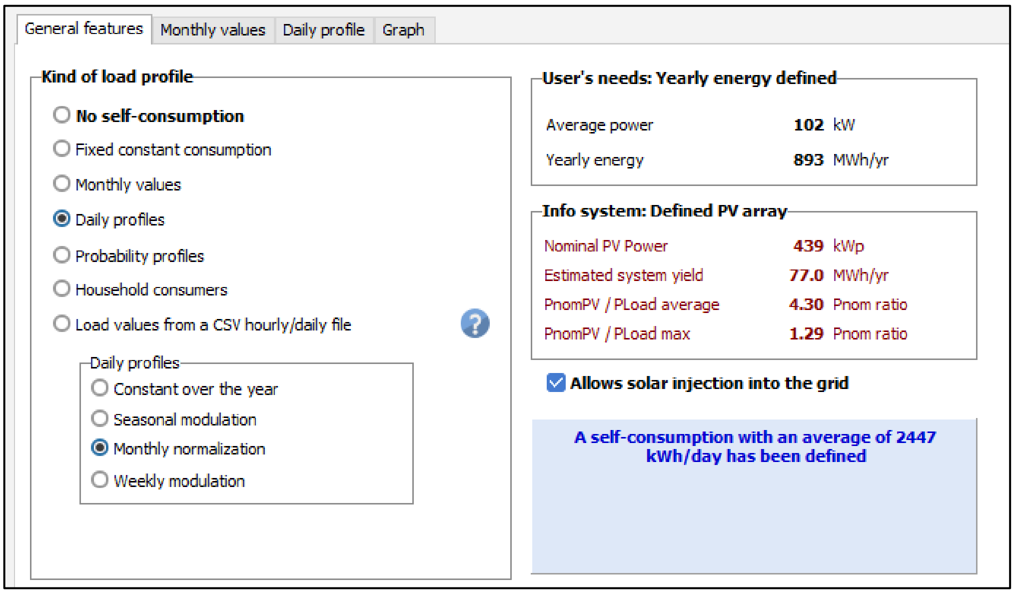


Figure 4.25 – Monthly modulation yearly value.

Similarly to the weekly modulation, the average power needed is 102kW. Being the same system, the nominal power and the energy produced are the same, 439kW and 893MWh/year, respectively, so the two ratio indicators are affected only by the load. In this case, as the peak load is lower, the PnomPV/PLoadmax is higher, 1,29. This means that the nominal power can, as well, cover the load demand. Contrarily to weekly modulation, in this case, by lowering the peak load, the system will sometimes be able to supply the power asked, as there is a high fluctuation in monthly values of consumption, 12 different numbers, one per month, as in Figure 4.26.

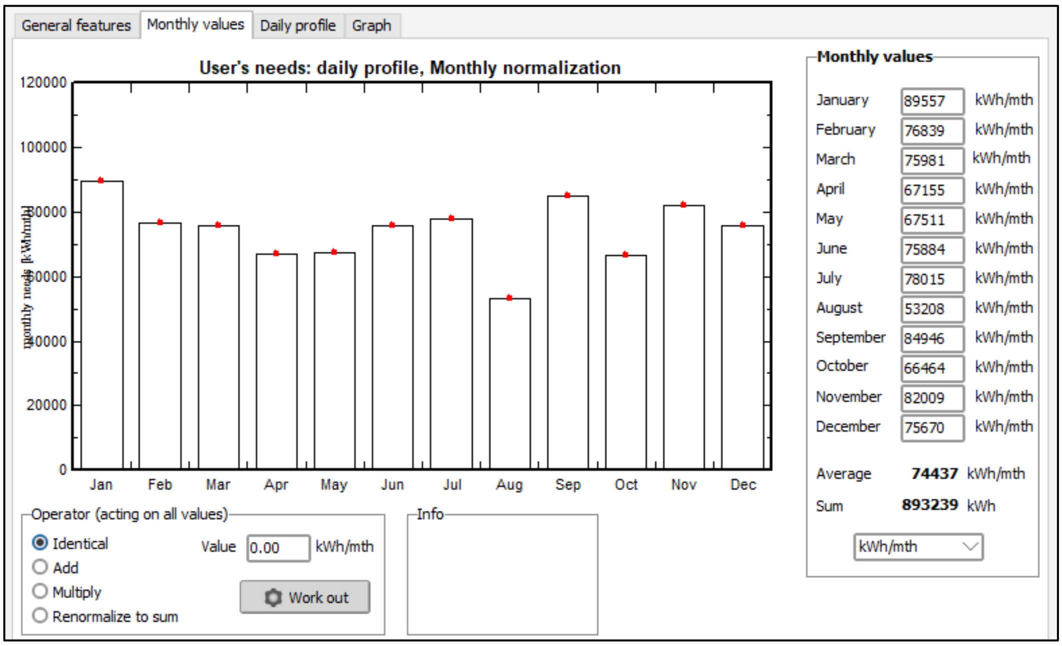


Figure 4.26 – Yearly profile.

From Figure 4.27 to Figure 4.33 the detailed daily profile of consumption is presented.

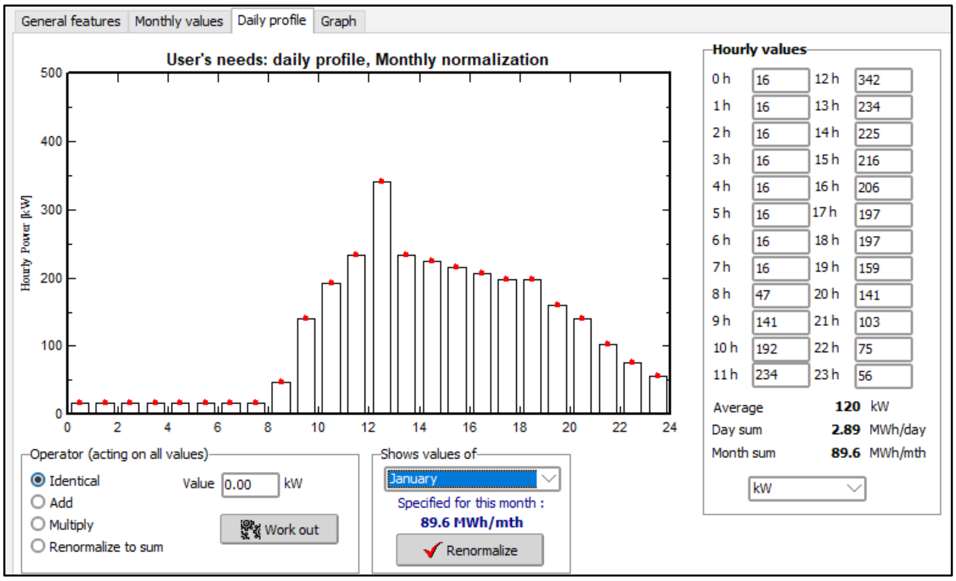
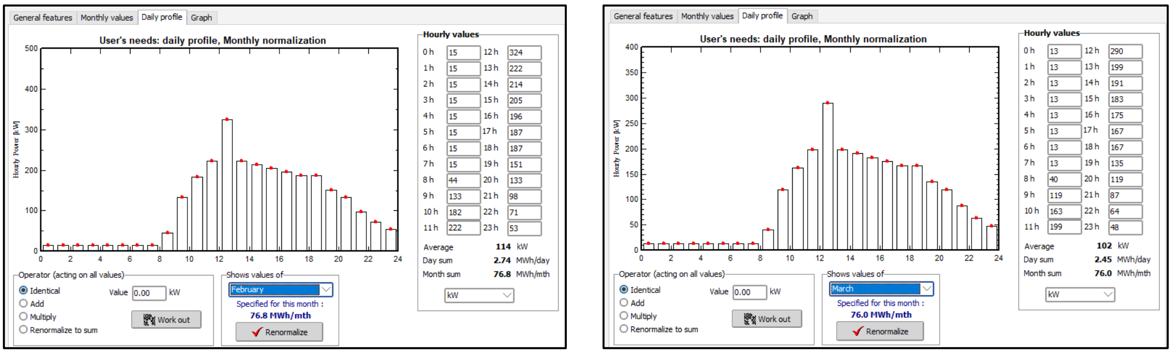


Figure 4.27 – January's profile.



a) b)

Figure 4.28 – Profiles: a) February's b) March's.

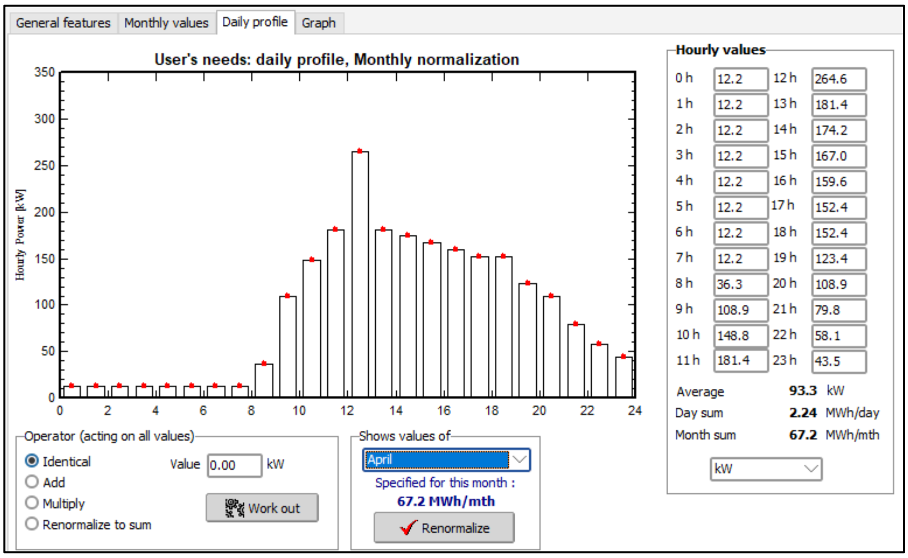
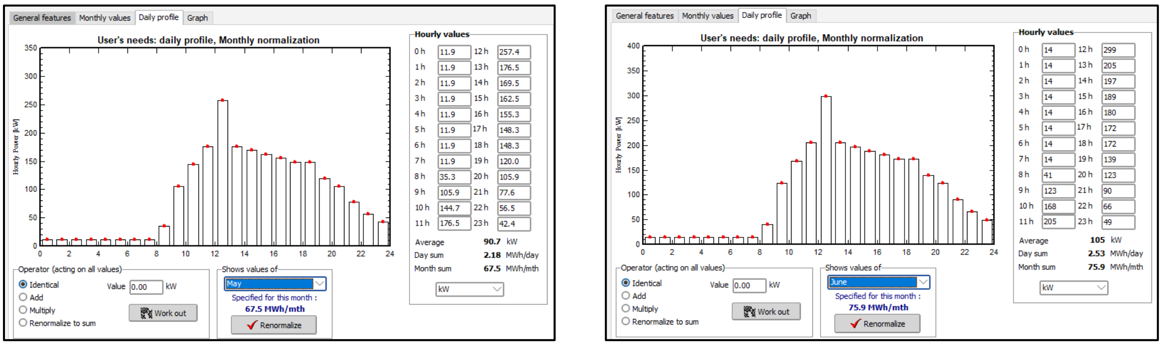
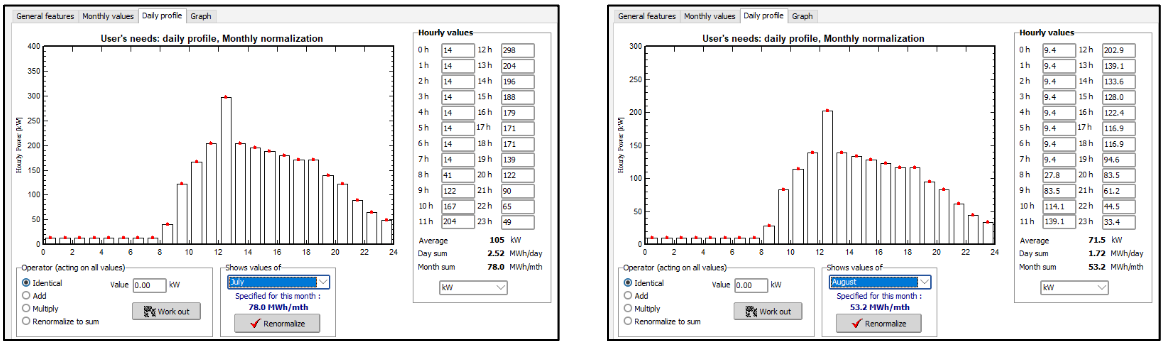


Figure 4.29 – April's profile.



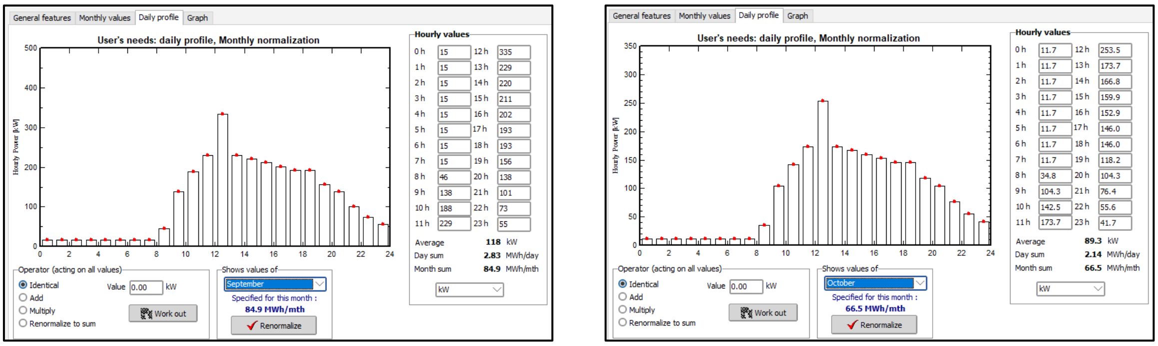
a) b)

Figure 4.30 – Profiles: a) May's b) June's.



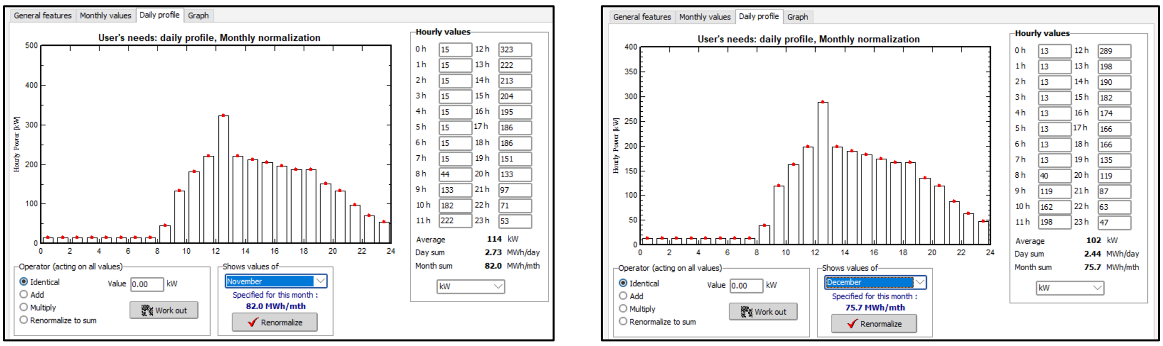
a) b)

Figure 4.31 – Profiles: a) July's b) August 's.



a) b)

Figure 4.32 – Profiles: a) September's b) October's.



a) b)

Figure 4.33 – Profiles: a) November's b) December's.

4.7.3 Weekly modulation 764kWp

The load modulation for the simulation, in Figure 4.34, for the 764kW power plant, assume the same values as the less powerful system. This way it was kept a comparison basis.

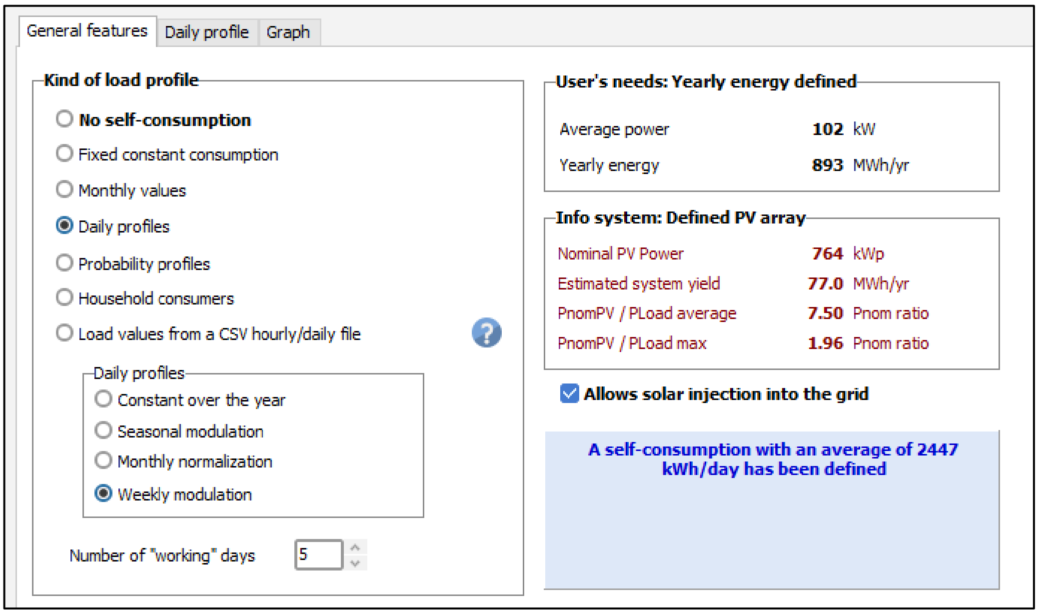


Figure 4.34 – Weekly modulation yearly value.

In this case, the values of PnomPV/PLoad average and PnomPV/PLoadmax, 7,5 and 1,96, respectively, show that the system is way oversized.

4.7.4 Monthly modulation 764kWp

The data for the load in Figure 4.35 was kept the same as the one in the 449kW system.

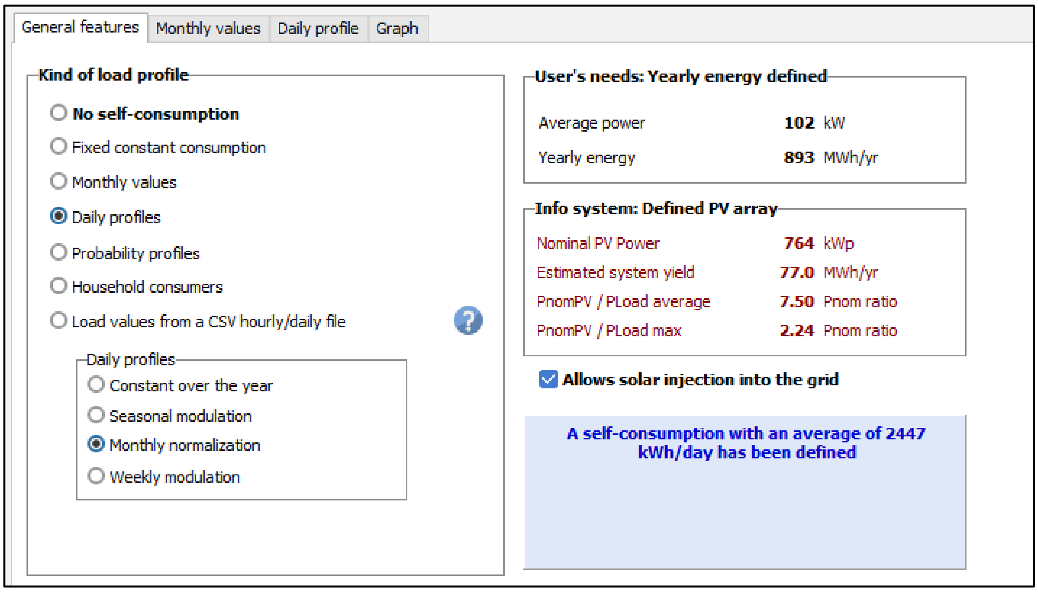


Figure 4.35 – Monthly modulation yearly value.

These ratio values in Figure 4.35 are independent and need to be analyzed carefully.

It is a fact that for peak values the system is 2,24 times oversized, and when it comes to average power, 102kW, the system has 7,5 times more power than the needed. This means that the average and the peak power demand are very distinctive. In terms of independence, the average load demand can be lowered without influencing the maximum value.

The value of the nominal power compared to the average load, PnomPV/PLoad average, acknowledges that the average load is very low, due to its high variability of values throughout the day, lowering from the peak value of 342kW to 102kW.

4.8 Chapter conclusion

Wind turbines may present a faster return of the investment and less land required but the solar photovoltaic power source has become very competitive in terms of price per energy unit, surpassing the first option in most cases.

Although power transformer PT2 has only ¼ of the power PT1 has, proportionally this represents a significant value for only one department, including the library.

To be sure the consumption is lowering over the last years and where it will establish, it is necessary to have at least the 2023 value, since the last three years are affected by lockdowns and home schooling.

In practice, the number of panels to be installed may be different from the simulated, as it is based on the software's tool and in reality, may be required more or less space to each or between panels.

Despite huge importance to the load modulation was given, in reality it will be proven that there is some difference but not to the point of heavily affect the results during the project, in the other hand, during operation of the REC, it makes difference to know the power needs in detail.

5 RESULTS

5.1 Electricity production

Based on the existent meteorological data in the software, from 1996 to 2015, and the details of the power plant, it is made a prediction of the energy produced by the system.

To get a picture of what would be the daily energy flow on ISEC, the figures below show the daily electricity demand and the production, thus, the energy coming from and being injected into the grid.

It was selected the same six remarkable days of the year for all the four simulations, representing different amounts of sunny hours along the year's seasons, to see the impact on the electricity production.

Of course the results computed by the software, despite having a considerable number of years in its data basis for the climate, in reality, might be different, and will be, since last years, especially winters are much sunnier. External factors such as maintenance and cleanliness of the system can also make a huge impact on electricity production.

5.1.1 Weekly vs monthly modulation – 439kW

The best way to visualize the effects of the load design on the predictions of the electricity consumption is to compare the same system for both loads. From Figure 5.1 to Figure 5.9 this exercise is carried out.

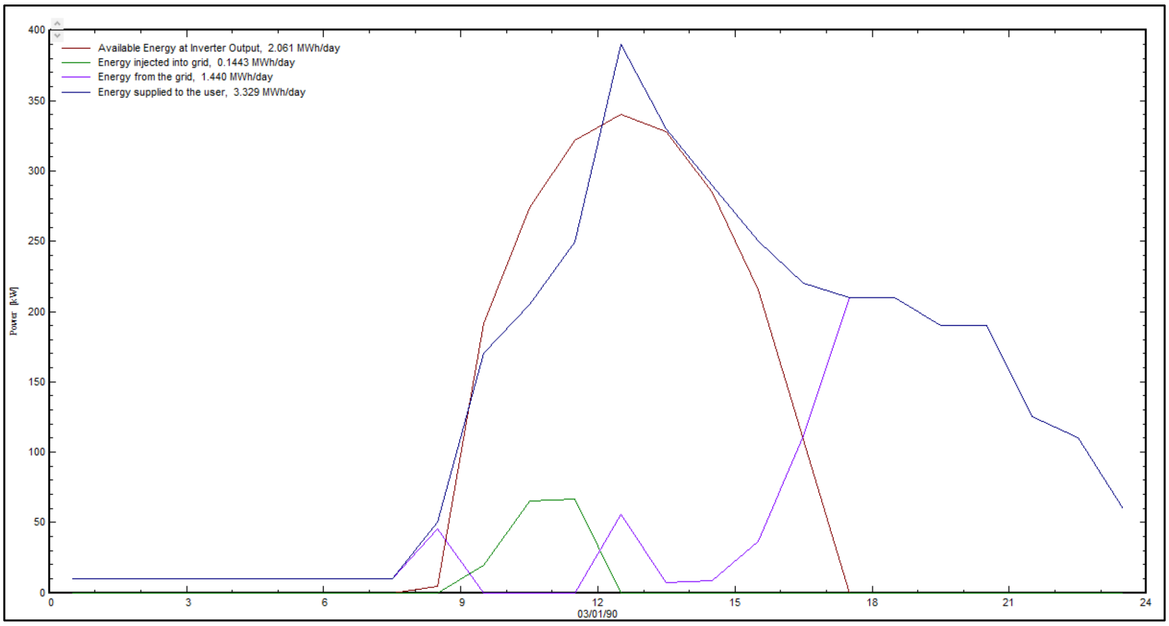


Figure 5.1 – Daily source - 3/Jan.

Note: regarding the year, 90, is a default value of the software for a generic year.

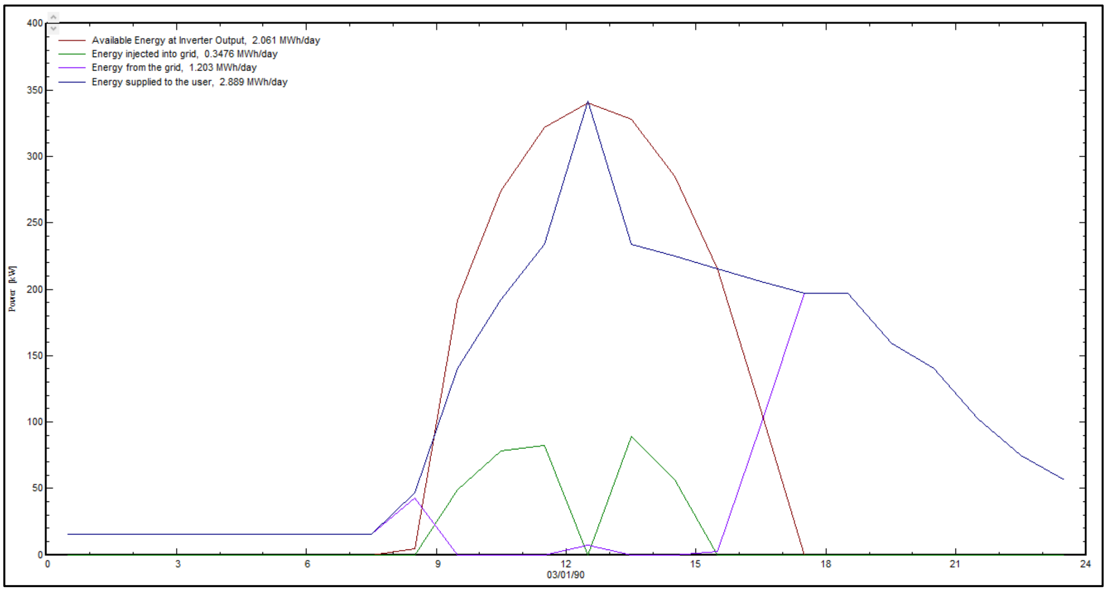


Figure 5.2 – Daily source - 3/Jan- Monthly.

Figure 5.1 and Figure 5.2 are referred to January 3rd.

Both present the same available energy output at inverter, 2,061MWh/day, but while in weekly modulation users' needs is 3,329 MWh/day, in monthly modulation the value is 2,889 MWh/day. Here it is visible that depending on the type of load chosen, the system will or not be able to cover the demanded energy, as mentioned.

Although in small values, at the scale of the figures, from weekly to monthly modulation, the injected electricity into the grid more than doubled in this last one.

On Figure 5.3 and Figure 5.4, the daily production is low, representing a cloudy day. All the produced energy will be consumed locally, and the main difference is the amount of electricity fed by the RESP.

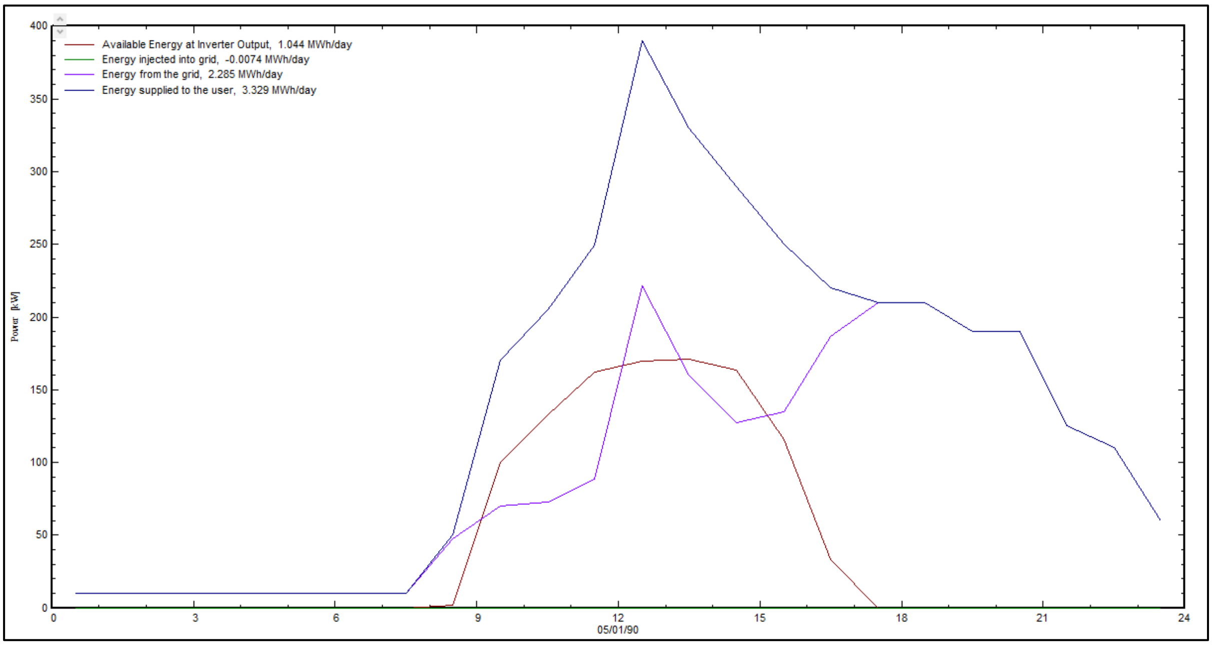


Figure 5.3 – Daily source - 5/Jan.

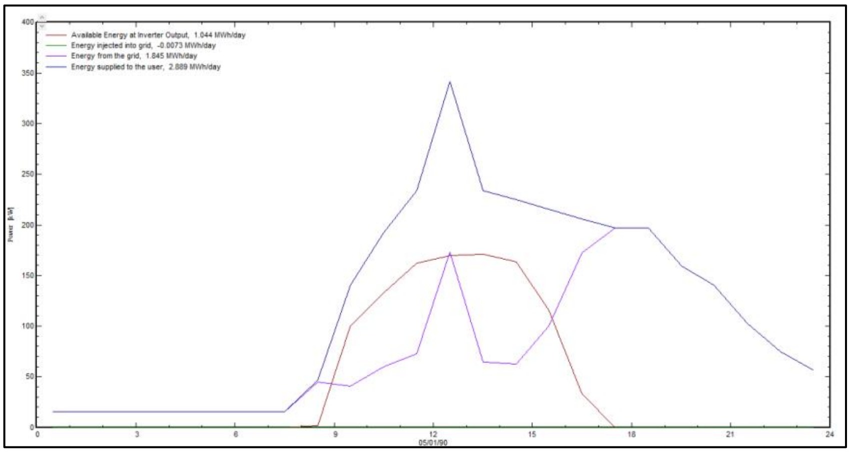


Figure 5.4 – Daily source - 5/Jan – Monthly.

The biggest difference between the two modulation types is seen on Figure 5.5 and Figure 5.6, the accounting of the weekends.

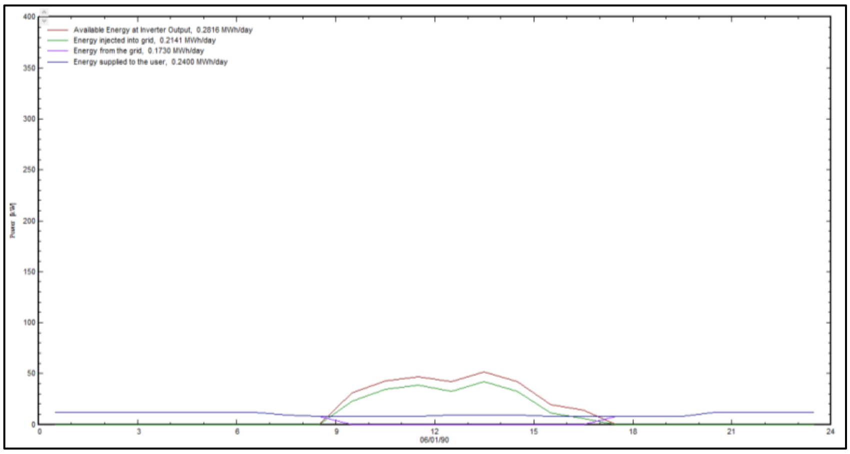


Figure 5.5 – Daily source - 6/Jan.

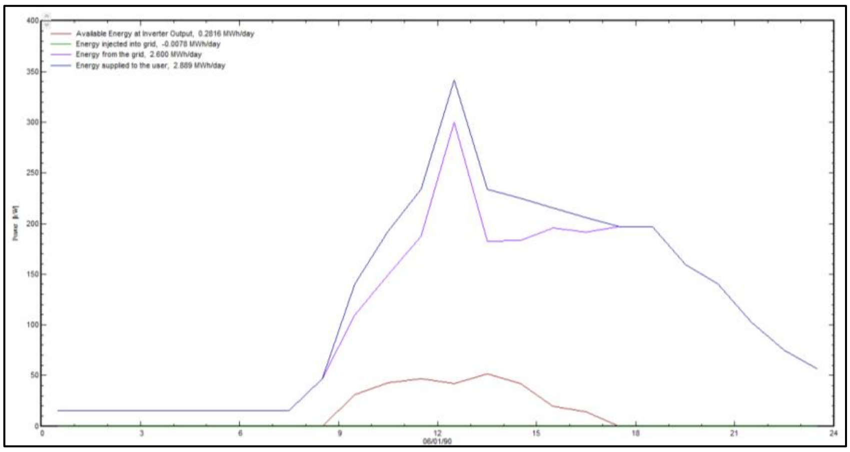
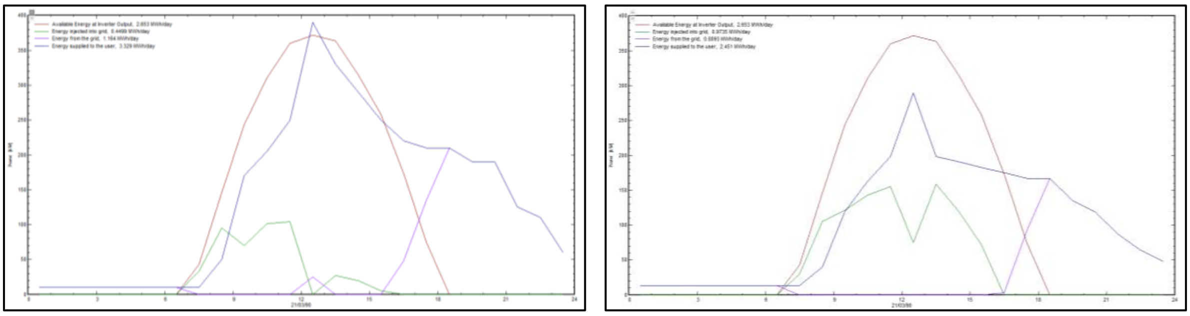


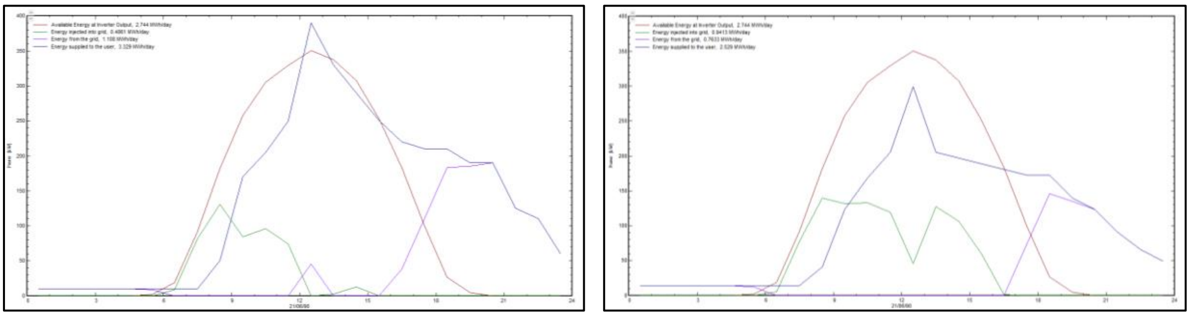
Figure 5.6 – Daily source - 6/Jan- Monthly.

On Figure 5.5 besides it is a weekend, and the energy consumption is lower, the energy production is also lower. Nevertheless, almost all the production is injected into the grid, in the other hand, on Figure 5.6 none is injected.



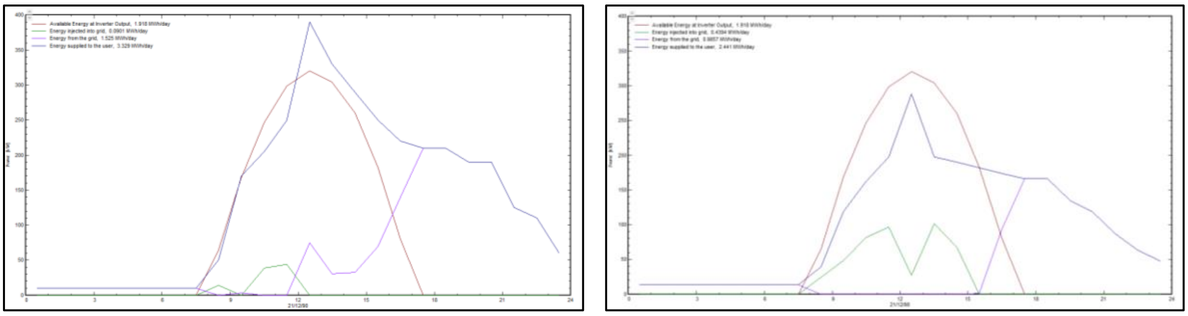
a) b)

Figure 5.7 – Daily source: a) 21/Mar weekly b) 21/Mar monthly.



a) b)

Figure 5.8 – Daily source: a) 21/Jun weekly b) 21/Jun monthly.



a) b)

Figure 5.9 – Daily source: a) 21/Dec weekly b) 21/Dec monthly.

Analyzing the figures above it is now obvious that with this system, there will be energy to be injected on the RESP throughout the year, although most of it will be consumed locally, adding details, 268 and 218 MWh/year, respectively, weekly and monthly modulated.

With production numbers of 2,653MWh/day for Figure 5.7 and a grid injection of 0,4499MWh/day on a) but an injection of 0,9735MWh/day for b). For Figure 5.8, the production is 2,744MWh/day and the injection are 0,4861MWh/day and 0,9413MWh/day, respectively a) and b). In Figure 5.9 the production has a value of 1,918MWh/day and the injection, assuming a low value of 90,1kWh/day on Figure 5.9 a) but an already decent value of 439,4kWh/day for Figure 5.9 b).

Since the surplus will occur on a daily basis, highlights the importance of having a destination to this energy, inside a REC.

Also, despite the system having a nominal power of 439kWp, the maximum power output predicted by the software is around 370kW.

5.1.2 Weekly vs monthly modulation – 764kWp

Having the same load modulation as the 439kWp system, the 764kWp system will maintain the users' needs but will enhance the amount of energy produced, thus, the amount injected into the grid. From Figure 5.10 to Figure 5.17, the comparison between the two modulations is performed.

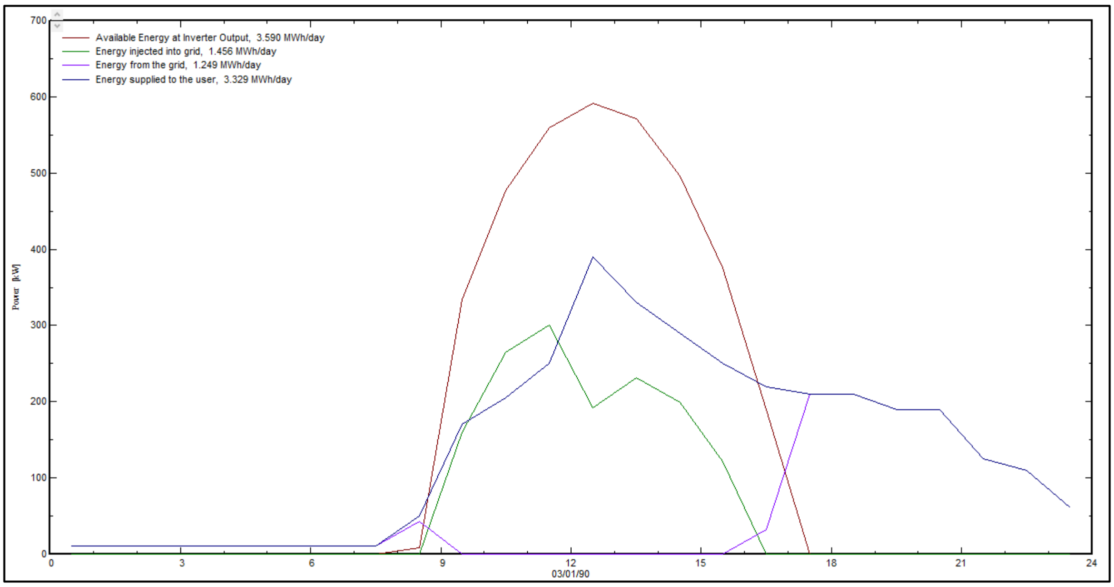


Figure 5.10 – Daily source - 3/Jan

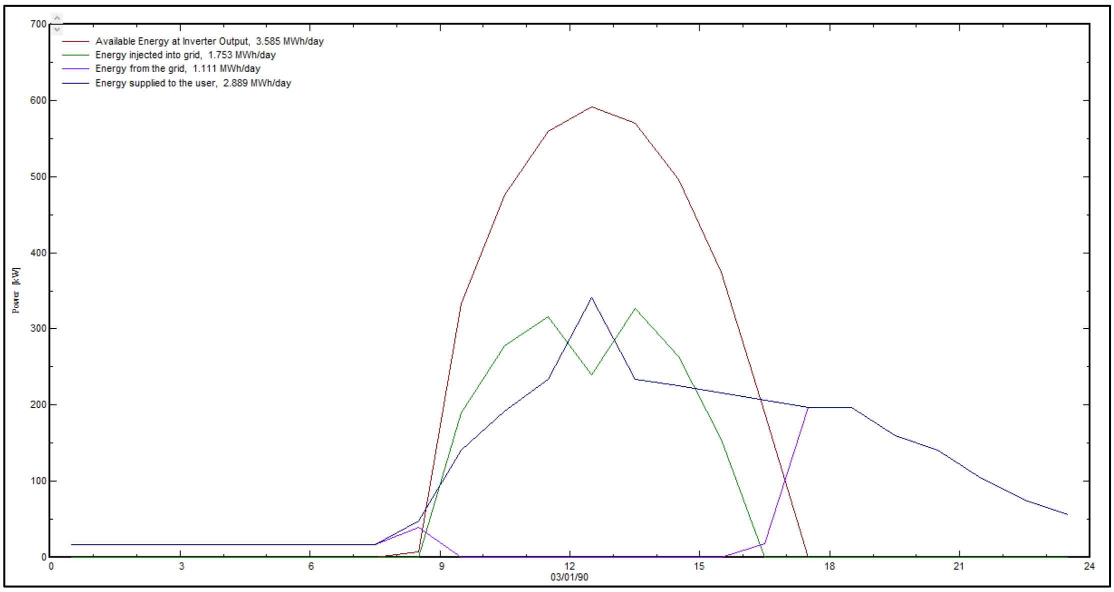


Figure 5.11 – Daily source - 3/Jan monthly

From Figure 5.10 to Figure 5.11 there is an 8% increase in injection, meaning around 300 kWh more. But also a small decrease in the value of energy supplied from the grid.

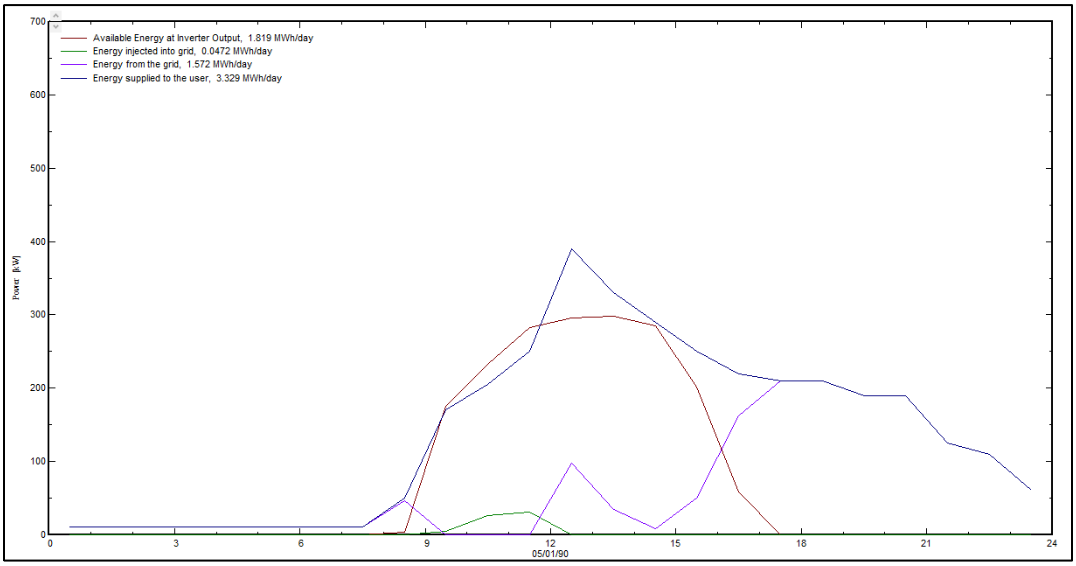


Figure 5.12 – Daily source - 5/Jan

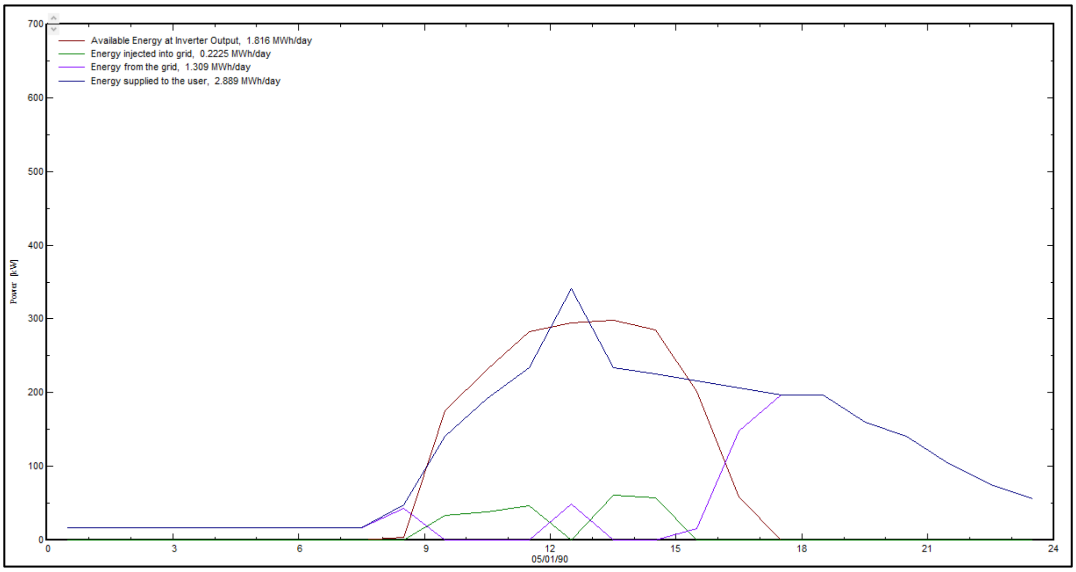
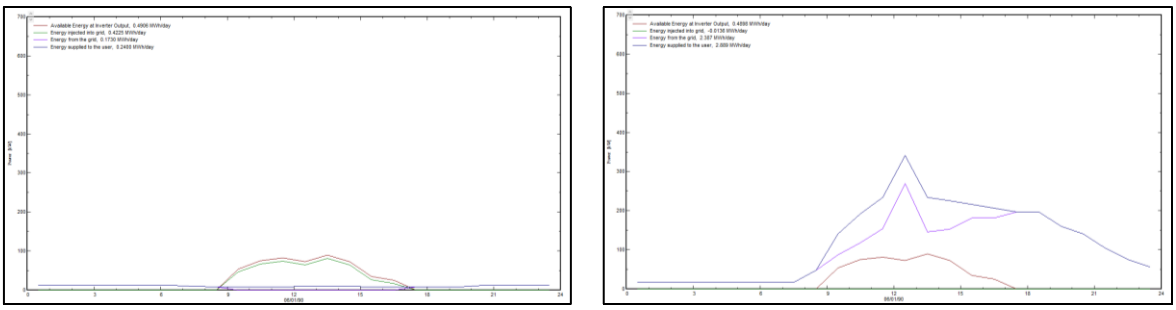


Figure 5.13 – Daily source - 5/Jan monthly

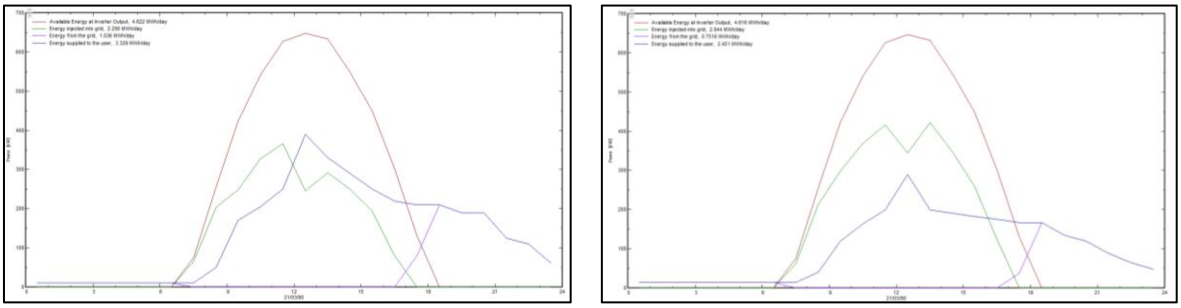
In a low production day, influenced by the profile of the load, in one case the injection into the grid is almost null (Figure 5.12) and in other case almost 10 % is injected (Figure 5.13).



a) b)

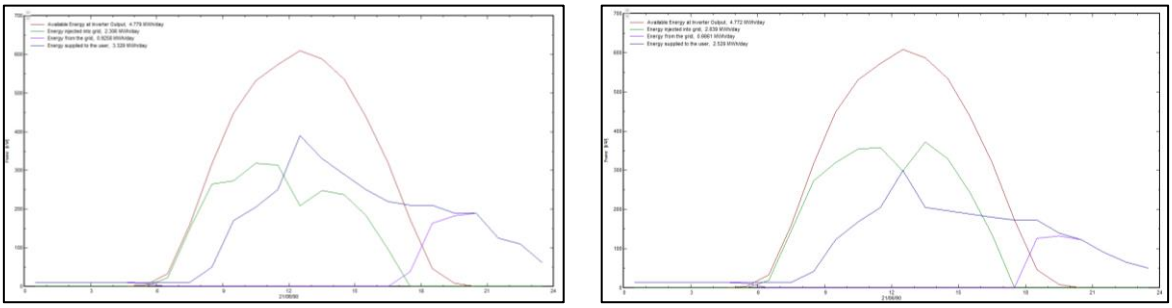
Figure 5.14 – Daily source: a) 6/Jan weekly b) 6/Jan monthly.

As already mentioned, during the weekend, in monthly modulation the load is oversized and, in that case the production on Figure 5.14 b), which is low, is said to be locally consumed. Different from a) which almost all electricity is a surplus.



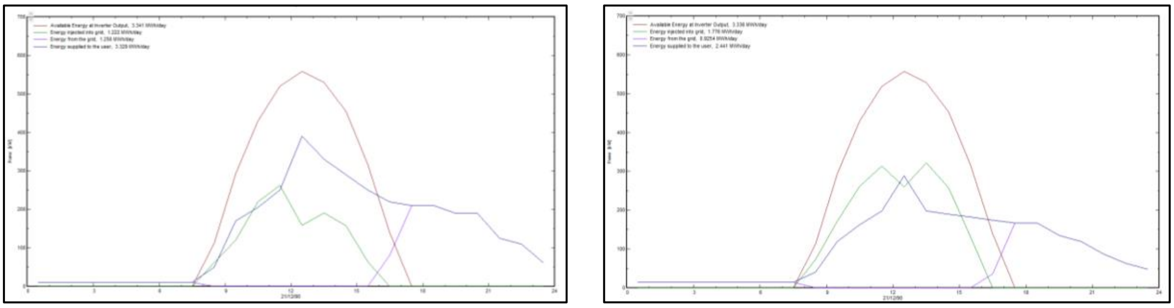
a) b)

Figure 5.15 – Daily source: a) 21/Mar weekly b) 21/Mar monthly.



a) b)

Figure 5.16 – Daily source: a) 21/Jun weekly b) 21/Jun monthly.



a) b)

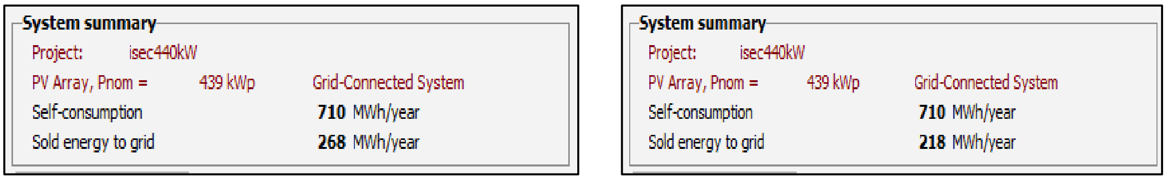
Figure 5.17 – Daily source: a) 21/Dec weekly b) 21/Dec monthly.

In a highly productive day, the energy injected on the grid can reach, 48% in Figure 5.16a) or 60% of the output, as in Figure 5.16b).

5.1.3 Electricity production conclusion

The load modulation used in the software will dictate the energy surplus injected on the grid and in the end the economic evaluation will count with different values.

For example, in Figure 5.18 the difference between the two options is 50MWh/year in electricity injected into the RESP, meaning 20% more. This happens because although the peak power value of consumption is lower on a monthly basis, increasing the amount injected, using Saturdays and Sundays as a working day will make a difference.

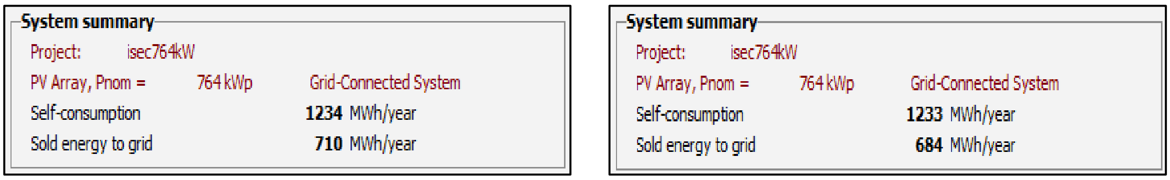


a) b)

Figure 5.18 – Annual energy produced and surplus - 439kWp system: a) Weekly b) Monthly.

710MWh/year is the amount of energy produced by the system and not necessarily the energy consumed locally.

When assessing the 764kWp system, the consequences of the load design are the same as the 439kWp system, only the values are higher. For this power plant, the annual electricity production is 1234MWh, as in Figure 5.19.



a) b)

Figure 5.19 – Annual energy produced and surplus - 764kWp system: a) Weekly b) Monthly

There is only a small difference of 26MWh, the conclusion is that the system is so oversized that even accounting weekends will not make much impact, in this conditions.

When comparing the two systems, regarding energy gains for self-consumption, choosing the bigger, instead of the smaller power plant, using values of Figure 5.1 and Figure 5.10 the extra value that would be achieved of around 13% less energy supplied by RESP, contrasting with a power increase of around 75%, causes the system to only make sense when in a REC, in order to sell the surplus. The extra energy is only due to higher power in the morning and in the afternoon when the sun is setting.

5.2 Economic evaluation

Many factors need to be accounted to perform an economic evaluation of the desired system, the installation cost, the prices of electricity, grid access tariffs or taxes, only this way the viability of the project is assessed.

Having two different systems proposed in this document, at the end of this chapter, the most interesting one in economic matters is revealed.

5.2.1 Installation costs

The project will never start before several tenders are compared and the project owner decides which one is the best option to move forward.

It is presented one approximated price for each system, giving an approximate value for each part of the project, PV modules, inverters, supports, installation and cabling, and in the end, reaching the average cost for a new power plant, as already mentioned (Table 4.1) and can be compared with the Levelized Cost of Electricity (LCOE) in Figure 5.20.

Financial summary

Installation costs	**1.29**	EUR/Wp
Total yearly cost	**0.02**	EUR/Wp/year
LCOE	**0.0567**	EUR/kWh
Payback period	**5.9**	years

Figure 5.20 – Levelized cost of electricity for the 439kWp system

The cost of each part is submitted individually in the software, as shown in Figure 5.21.

Installation costs

Description	Quantity	Unit price	Total	
PV modules			0.37	EUR/Wp
Inverters			0.30	EUR/Wp
Other components			0.32	EUR/Wp
Studies and analysis			0.00	EUR/Wp
Installation			0.30	EUR/Wp
Insurance			0.00	EUR/Wp
		Total installation cost	**1.29**	**EUR/Wp**
		Depreciable asset	0.67	EUR/Wp

Figure 5.21 – Installation cost of the 439kWp system

In this case, the value of each part was inserted by the unit and converted in function to Wp. For the 764kWp system, the individual values of each unit are the same as the ones in the 439kWp system, thus the same €/Wp, only changing the number of items. In the other hand, the LCOE is slightly different, Figure 5.22.

Financial summary

Installation costs	**1.29**	EUR/Wp
Total yearly cost	**0.02**	EUR/Wp/year
LCOE	**0.0550**	EUR/kWh
Payback period	**6.5**	years

Figure 5.22 – Levelized cost of electricity for the 764kWp system

For the component's values, the scale effect wasn't considered, i.e., all items have the same price, and no discounts were added.

5.2.2 Electricity tariff

For both systems, the price of electricity is considered the same. But there is a difference in price for consumed and sold electricity. As part of a possible business model for a REC, the price of electricity to be sold is set to be 20% lower than the demanded from the grid.

The national electricity tariff structure has four components for active electricity prices, two peak and two off-peak values, Table 5.1,

Table 5.1 – Regulated price for energy tariff.

Tariff applied by last resort supplier (CUR)		Prices
Fixed term tariff		**€/day**
		0,2827
Power		**€/(kW.day)**
	Peak hour	0,2283
	Purchased	0,0155
Active energy		**€/kWh**
Season I and IV	**Peak hour**	0,1732
	Middle hours	0,1614
	Normal off-peak hours	0,1348
	Super off-peak hours	0,1182
Season II and III	**Peak hour**	0,1585
	Middle hours	0,1531
	Normal off-peak hours	0,1309
	Super off-peak hours	0,1257
Reactive energy		**€/kVArh**
Inductive		0,0015
Capacitive		0,0011

Source: Adapted from [27, p. 36].

but in this case, for the simulation, because there are only two possibilities, the highest value in each category was considered and the values are on Figure 5.23.

The values of Table 5.1 are the price for the electricity on the regulated market that applies from July until December 2023.

Feed-in tariff

	Summer	Winter	
Peak tariff	0.1268	0.1386	EUR/kWh
Off-peak tariff	0.1047	0.1078	EUR/kWh

a)

Consumption tariff

	Summer	Winter	
Consumption tariff (peak)	0.1585	0.1732	EUR/kWh
Consumption tariff (off-peak)	0.1309	0.1348	EUR/kWh
Annual tariff variation	1.00		%/year

b)

Figure 5.23 – Electricity tariffs for simulation: a) Selling price; b) Consuming price.

On a), the proposed tariff when selling electricity to the members of the community. In b), the current tariff in the regulated market for a medium voltage customer.

5.2.3 Financial analysis

The price difference between buying and selling makes it to be more profitable to consume than to selling the electricity, for example, for the 439kWp system, when selling 218 rather than 268MWh/year, the payback time is slightly lower.

Figure 5.24, Figure 5.25, Figure 5.26 and Figure 5.27 show the energy sold to the grid and the payback time to all four simulations.

System summary			Financial summary		
Project:	isec440kW		Installation costs	1.29	EUR/Wp
PV Array, Pnom =	439 kWp	Grid-Connected System	Total yearly cost	0.02	EUR/Wp/year
Self-consumption		710 MWh/year	LCOE	0.0567	EUR/kWh
Sold energy to grid		268 MWh/year	Payback period	5.9	years

Figure 5.24 – Payback 439kWp system - weekly modulation.

System summary			Financial summary		
Project:	isec440kW		Installation costs	1.29	EUR/Wp
PV Array, Pnom =	439 kWp	Grid-Connected System	Total yearly cost	0.02	EUR/Wp/year
Self-consumption		710 MWh/year	LCOE	0.0567	EUR/kWh
Sold energy to grid		218 MWh/year	Payback period	5.7	years

Figure 5.25 – Payback 439kWp system - monthly modulation.

System summary			Financial summary		
Project:	isec764kW		Installation costs	1.29	EUR/Wp
PV Array, Pnom =	764 kWp	Grid-Connected System	Total yearly cost	0.02	EUR/Wp/year
Self-consumption		1234 MWh/year	LCOE	0.0550	EUR/kWh
Sold energy to grid		710 MWh/year	Payback period	6.5	years

Figure 5.26– Payback 764kWp system - weekly modulation.

System summary			Financial summary		
Project:	isec764kW		Installation costs	1.29	EUR/Wp
PV Array, Pnom =	764 kWp	Grid-Connected System	Total yearly cost	0.02	EUR/Wp/year
Self-consumption		1233 MWh/year	LCOE	0.0550	EUR/kWh
Sold energy to grid		684 MWh/year	Payback period	6.4	years

Figure 5.27– Payback 764kWp system - monthly modulation.

Also recapping the amount injected energy for each simulation for a better feeling of values, comparing Figure 5.24 with Figure 5.25, selling 50MWh more per year, makes a difference on the payback time in around 2,5 months. When the difference is only 26MWh/year, as in Figure 5.26 versus Figure 5.27, the difference is just over 1 month.

Due to the similarities, from now on, only the results with a weekly load modulation will be presented, as the achieved goal was to show the differences, regarding self-consumption and the surplus.

Assuming a smooth operation during the life cycle of the system, i.e., there is no additional maintenance than the predicted or any other undesired costs, Table 5.2 presents the expected economic.

Table 5.2 – Economic results - 439kWp system – weekly.

Year	After-tax profit [€]	Self-cons. saving [€]	Cumul. profit [€]
0	0	0	-566548
1	21249	72517	-472782
2	21249	73242	-376290
3	21249	73975	-283067
4	21249	74714	-187103
5	21249	75462	-90393
6	21249	76216	7073
7	21249	76978	105300
8	21249	77748	204297
9	21249	78526	304072
10	21249	79311	404632
11	21249	80104	505985
12	21249	80905	608139
13	21249	81714	711102
14	21249	82531	814883
15	21249	83356	919488
16	21249	84190	1024927
17	21249	85032	1131208
18	21249	85882	1238340
19	21249	86741	1346330
20	21249	87608	1455188
Total	**424983**	**1596753**	**1455188**

These outstanding results are the ones from the weekly modulation with the 439kWp system. The tax applied to the profits is 23%. The profit (yearly value) over the 20 years is the same as it wasn't considered the evolution of the price of the electricity sold, unlike the 1% yearly rise considered for the tariff when consuming from the RESP.

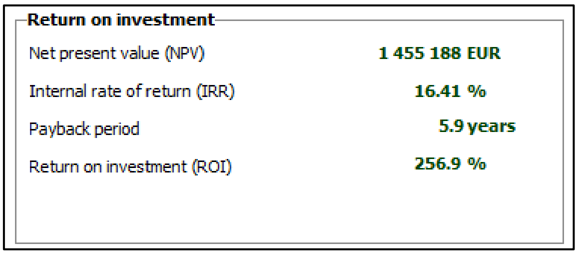
Regarding the 764kWp system, as the expected injection into the grid is as much as the total production from the smaller system, the cumulative profit in absolute values will be higher, as in Table 5.3.

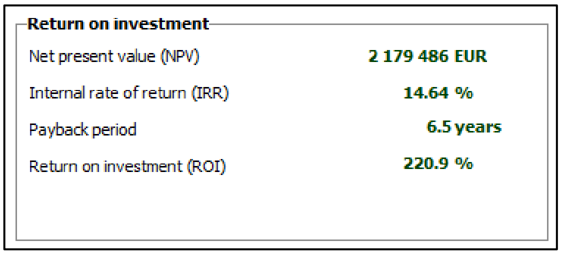
Table 5.3 – Economic results - 764kWp system - weekly

Year	After-tax profit [€]	Self-cons. saving [€]	Cumul. profit [€]
0	0	0	-986708
1	63143	86441	-837125
2	63143	87305	-686677
3	63143	88178	-535356
4	63143	89060	-383153
5	63143	89951	-230060
6	63143	90850	-76067
7	63143	91759	78835
8	63143	92676	234654
9	63143	93603	391399
10	63143	94539	549081
11	63143	95484	707708
12	63143	96439	867290
13	63143	97404	1027836
14	63143	98378	1189357
15	63143	99362	1351861
16	63143	100355	1515359
17	63143	101359	1679860
18	63143	102372	1845375
19	63143	103396	2011914
20	63143	104430	2179486
Total	**1262853**	**1903341**	**2179486**

Once again, the profit from energy selling is constant over the years, while there is a 1% rise in tariff when buying. Also as already explored, with the 764kWp power plant, the self-consumption is higher, leading the self-consumption savings presented here to be higher than with a less powerful system.

In relative terms, the 439kWp is more profitable, i.e., the Return of the Investment (ROI) is higher. In Figure 5.28, both ROI can be compared.





a) b)

Figure 5.28 – Return of investment: a) 439kWp system b) 764kWp system

The fact that the system b) injects more electricity, despite having a higher self-consumption, injecting more electricity at a lower tariff doesn't make up for the gain in self-consuming. Nevertheless, with the previsions given here, the investments more than doubled. If, by any chance, the update in the prices of the electricity from the grid is higher than 1% per year, there is still a big margin to make the system unprofitable.

Currently, with the negative CIEG costs, the tariff for transmission through the RESP is very generous, but if or when the CIEG has a positive value, the grid access tariff will impact significantly on the revenues of the community.

In the end there are also other costs, apart from electricity production and selling, that have to be considered and will significantly change these economic results. Costs as insurance, metering devices or a manager to the design and licensing process.

5.3 Environmental savings

The CO2 emission saved by a photovoltaic system during its life cycle is proof that renewable energies are the energy of the future.

The average annual footprint of one Portuguese person is 4,84 ton/CO2, lower than European Union's 6,8 tons but higher than global 4,79 ton carbon emission [33].

Considering a life span of 20 years for ISEC's Renewable Energy Community, the estimate is based on the software's data, regarding the carbon footprint for the manufacturing and installation of the system and the average amount of CO2 emissions per energy unit for the electricity produced by the Grid.

To achieve the amount saved by the system it is necessary to calculate the value saved with the green electricity production and subtract the amount caused by the manufacturing and installation of the system.

For the 439kWp system the result is in Figure 5.29 and for the 764kWp power plant, the outcome is in Figure 5.30.

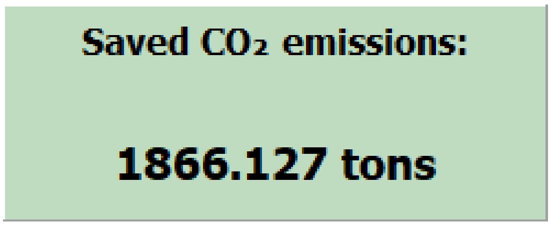


Figure 5.29 – Carbon savings 439kWp system.

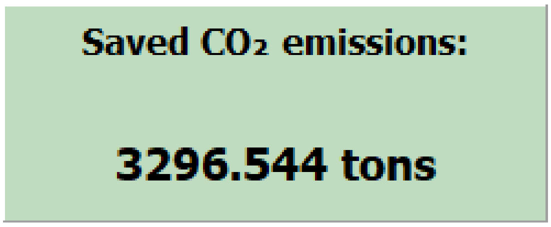


Figure 5.30– Carbon savings 764kWp system.

Although the result is positive for both systems, when comparing to the annual emission per capita in Portugal, the offset achieved can only make up for 19 and 34 citizens, respectively, a year. This seems a low gain, however ISEC´s carbon emission will decrease significantly, and reach a point where it contributes positively to the environment.

5.4 Chapter conclusion

The profile modulation didn't severely affect these results that would serve for the project phase, nevertheless it is important to know the consumption in detail to be able to understand what can be shared among members of the community.

Selling electricity to members of the community at a lower price is less profitable than if this energy had been self-consumed, but since this isn't possible, selling at a lower tariff is better than injecting it on the grid and account as grid loss. Additionally, even with profit not being the main goal of the community, the financial outcome can be significant.

In terms of carbon footprint, as the national supply of electricity isn't still completely renewable, every renewable energy project is better than being supported by the grid. When the targets for become carbon neutral for electricity are achieved, the benefits for a renewable energy project will be mainly financial.

6 CONCLUSIONS

6.1 Document conclusions

Analyzing the key aspects about REC approached on this document, it is possible to conclude that the statement "the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits" is not guaranteed. While economic and environmental benefits are true, in terms of positive social impacts, its occurrence can be influenced by various factors, such as community engagement, resources availability (both financial and technical), the local support and leadership or the local context and may or may not be true. The existence and an equitable distribution of the social benefits within a REC, will depend above all on the objectives traced for the community when designing the project, not focusing only on the economic or environmental benefits.

The licensing process by DGEG may be long and cumbersome as it depends on the power and type of activity (Self-Consumption or industrial activity) and in some cases may be required the pronunciation of the DSO, the TSO or even the SEN manager. These pronunciations take time and in the worst case if every entity takes the regulated limit time to give their deliberation, the process will for sure be long.

Stakeholders are putting lot of effort developing new laws and directives to increase the penetration of Renewable Energy Sources on the electrical system, but as concerning REC, in Portugal, there is still the need to put more effort on the permitting process and financial assistance. With a proper financial scheme it would be possible to involve a larger number of citizens, with special attention to the most vulnerable consumers.

On the challenges RES will bring to the electrical system, it is evidenced why the deployment of intermittent sources is a bigger challenge than it seems. It will require a much higher level of planning than with the current system to manage all different sources and keep the balance of the RESP. To adopt the supply driven model for the electrical system, it will also be required additional investment on storage, in order to be prepared for any unexpected problem and for low levels of electricity production, specifically during adverse weather conditions.

In the other hand, this distributed energy production increases the efficiency of the grid, by avoiding energy loss on the transport for long distances or by avoiding congestion. This type of production is one action existent on the demand side management, which potentially has the ability to reduce the need for investment on the RESP.

The proposed practical case presents outstanding results on two of the three pillars intended for a REC, but the third (social), are hard to be evaluated directly, i.e., what social benefits the community will bring during the period it will operate. On the other hand, several social benefits are granted, such as sustainable development, a positive image of the institution or community engagement. Energy justice, the representation of vulnerable society groups, could only happen under certain conditions, as the target for future community members must be connected in medium voltage. At this voltage level, only social institutions are existent, it is the case for example, of the student's residence near ISEC, thus within the range of 4 kilometers on the proximity concept.

Respecting the 4km distance between the production and consumption, can be found a firefighter headquarters, schools, theater, shopping or shops and they can become a member as long as they are supplied in medium voltage by the same substation as ISEC (Alto de São João).

For the design process of an UPAC, there are many considerations to be done, consumption, power needs, orientation or space.

Regarding the practical case suggested, the ones that point out the most are the consumption and the power of the UPAC. The consumption has to be attached to a profile in order to better understand what the needs in terms of power are and as was demonstrated, it is very important that the best approximation to reality is made, to get a more reliable result.

For the simulation to the suggested case, on the available data, an error margin has to be added, as some estimate had to be done to the consumption, which will also influence the two load modulations/consumption profiles on the software, the weekly modulation and the monthly modulation. Although neither of these modulations are a perfect fit to reality, the real purpose of having two modulations, is to understand how it would affect the final results, and some results are presented:

- Lower the peak power
- Less surplus

This happens when using the monthly modulation, but to ISEC´s community or any other, the UPAC design does not have to be "millimetric", basically because the electricity can be easily shared among community members. It was also interesting to conclude that, due to the discounted price for energy selling, the less electricity sold, the better would the financial outcome be, all this for the same system. This was shown by the payback period of the modulation.

In terms of environmental outcome, the result only depends on the power of the system, inherently to the electricity production, and the bigger the system the greater the carbon savings will be.

Considerations to be added to the simulations:

- Grid access tariff cost
- Injection point
- Other costs

The grid access tariffs can influence the financial results of a community in a way that it really needs to be under supervision, due to the CIEG costs. Using data from Figure 5.8a) to calculate, currently the value to payment would be around 3,64€ but if the active energy component to pay wasn't negative due to CIEG cost, the tariff could be around 10,26€.

The injection points considered in this project were the main electrical board, PT1 and PT2 (distributing most of the power to PT1), this means that from each UPAC a cable would have to be directed to the transformer stations. In reality, a more suitable option would be to connect the UPACs to departments' main electrical boards, ensuring that the cable sections are correctly dimensioned.

The payment of other expenses not considered in the financial results, has to be expected, such as the constitution of the legal person for the community operation, insurance or the metering equipment. Furthermore, by counting on several distributed production points, for each of them, as the power is over 4kW, metering equipment has to be installed.

On the environmental savings section, the comparison between the carbon saved by the system and the carbon footprint of an average Portuguese person has the purpose to give an comparison, but to be more correct, this last value contemplates all the activities performed by and to support the person needs, in all greenhouse gas emitting sectors. If the comparison was made equally, only in terms of electricity production, the number of consumers would be much higher.

To conclude, overall, both on the side of the consumer and of the policy makers, a big effort and will to adopt sustainable energy sources on the energy mix is being held, with evident results. This would already be significant, but the climate related targets are ambitious, the effort must be even bigger.

6.2 Future work

The current conditions to develop a REC were assessed on this document, but since there are constant changes on the rules trying to regulate and to make it easier for the interested parts, as occurred for example in the middle of this year, it is recommended to keep track of the laws that encompass RECs for this project to be updated when necessary.

To better understand the viability of ISEC's REC, it is necessary to raise members, i.e., if the possible clients mentioned above are interested in such a project.

This REC was based on photovoltaic panels, yet the assessment of a system based also on wind turbines should be done as well.

Based on this project, a scientific paper will be submitted to 59th International Universities Power Engineering Conference – UPEC2024. The article abstract is in annexes, Annex A.

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ANNEXES

Annex A - Article abstract

RENEWABLE ENERGY COMMUNITIES – THE CONTRIBUTION FROM THE DEMAND SIDE

M. Melo. F. J. (1), C. I. Faustino Agreira (2), Rui Pestana (3)

IPC/ Instituto Superior de Engenharia de Coimbra – Departamento de Engenharia Eletrotécnica, Coimbra, Portugal
(1) ISEC, Coimbra Polytechnic ISEC, Coimbra, Portugal, SUScita - Research Group on Sustainability, Cities and Urban Intelligence, INESC Coimbra, Coimbra Portugal
(2) REN - Rede Eléctrica Nacional, S.A., Sacavém, Portugal, System Operator Department

EXTENDED ABSTRACT

The successful penetration of Renewable Energy Sources (RES) in the energy mix of Portugal is dependent on the reorganization of the electrical system, i.e., don’t focus only on the supply side, but also on the demand side. This paradigm change, opens the opportunity for Renewable Energy Communities (RECs) to show their potential to help on the energy transition, acting locally, but with sectorial impact. Allowing RECs to operate as a market agent can bring also benefits for the manager of the electrical system, which now can count on a significant power to perform local market activities such as flexibility.

The implementation of a REC, however, must comply with the current legislation, which is Decree-law 15/2022, of January 14, that resulted from the partial implementation of the EU´s directive 2018/2001. It is also under all the regulations issued by the Portuguese Energy Services Regulatory Authority (ERSE), that determines for example the coefficients for sharing electricity, the metering, and the commercial relations.

Conducting a simulation by software to understand the potential electrical yield, a photovoltaic power plant on the roof of a school would bring to the constitution of a REC, has given significant results in terms of energy self-sufficiency, carbon emission reduction and in financial results, although this last one, under the hypothesis made for the system price and operation costs.

Index terms: Renewable Energy Communities, Energy Transition, Renewable Energies regulation, REDII

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Annex B – Simaris circuit diagram