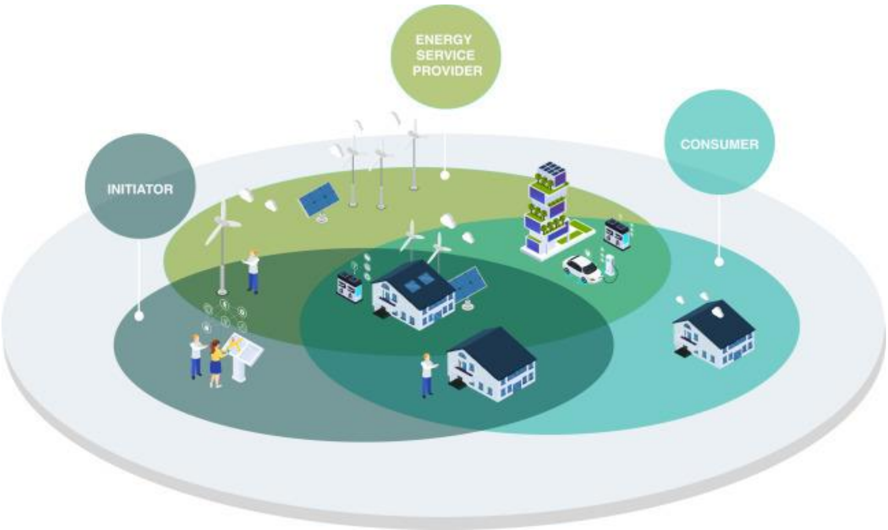


Assessment of the different energy distribution coefficients in a real-case energy community

Gonzalo Olaso Orbañanos

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisor: Dr. Diana Pereira Neves

Examination Committee

Chairperson: Prof. Susana Isabel Carvalho Relvas
Supervisor: Dr. Diana Pereira Neves
Member of the Committee: Prof. Carlos Santos Silva

October 2023

Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

ACKNOWLEDGEMENTS

I want to thank my family for their support since I started this thesis while working at ABEI Energy, the people I am working with to develop a business idea to accelerate the creation of Energy Communities, and my tutor Diana Neves for guiding me on this path.

ABSTRACT

Energy Communities (ECs) were recently incorporated into European regulation with the completion of the "Clean Energy for All Europeans" (CEEP) Package. Following this, Spain transposed these new regulations in RD244/2019 and RD23/2020, providing a legal framework favourable to individual and shared self-consumption. Hence, the need to analyse the best operational way and to maximize their potential and profitability arises.

For this purpose, this work develops a model to assess the impact of different distribution coefficients and peer-to-peer (P2P) model between EC participants, on the energy and economic outputs of an EC performance. The model is tested through a real case study in the urban area of San Sebastian, northern Spain, consisting of 4 households (consumers) and one SportsCenter with PV powerplant (prosumer).

Results show that the EC's self-sufficiency and self-consumption percentages increase by 5% when the production of the EC is adjusted to the demand of its participants and are no longer fixed, this improvement is even higher for the energy savings, increasing by up to 20 % in the best-case scenario. The best results for the EC are obtained for the variable coefficients and the P2P model.

This paper concludes that it is possible to increase the performance and benefits of ECs by actively adjusting the internal energy allocation despite the limitations of the study in terms of the consumers initial investment on the installation. In addition, it is important to highlight the importance of legislative and social support from governments for the further development of ECs.

Key-words: energy community; photovoltaic solar energy; energy transition; self-consumption; distribution coefficients.

RESUMO

As Comunidades de Energia (CE) foram recentemente introduzidas na regulamentação europeia graças à elaboração do pacote "Energia Limpa para Todos os Europeus". Este pacote tinha de ser transposto por todos os estados-membro, de modo a criar um quadro jurídico favorável ao autoconsumo individual e partilhado. Surge assim a necessidade de analisar a melhor forma de desenvolver CEs para maximizar o seu potencial e rentabilidade.

Este trabalho desenvolve um modelo para avaliar o impacto de diferentes coeficientes de distribuição entre os participantes da CE, no seu desempenho energético e económicos. O modelo é testado através de um caso de estudo na área urbana de San Sebastian, no norte de Espanha, constituído por 4 consumidores residenciais e um pavilhão desportivo com uma central fotovoltaica no telhado (prosumidor).

Os resultados mostram que a taxa de autossuficiência e autoconsumo da CE aumentam em 5% quando a distribuição da produção é ajustada à procura dos seus participantes e deixa de ser fixa. Esta melhoria é ainda maior para a poupança de energia, aumentando até 15% no melhor cenário. Os melhores resultados da CE são obtidos para os coeficientes variáveis e o modelo P2P.

Este documento conclui que é possível aumentar o desempenho e os benefícios das CE, ajustando ativamente a atribuição interna de energia, apesar das limitações do estudo por não ter em conta componentes de flexibilidade, como p.e. baterias. Para além disso, é importante realçar a importância do apoio legislativo e social dos governos para um maior desenvolvimento das CEs.

Palavras-chave: comunidade de energia; energia solar fotovoltaica; transição energética; autoconsumo; coeficientes de distribuição.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF GRAPHS

LIST OF EQUATIONS

ACRONYMS

CEC	Citizen Energy Community
DC	Distribution coefficients
EC	Energy Community
EMD	Electricity Market Directive
EU	European Union
GHG	Greenhouse Gases
HV	High voltage
kW	Kilowatt
MW	Medium-voltage
P2P	Peer-to-peer
PV	Photovoltaic
REC	Renewable Energy Community
REDII	Renewable Energy Directive
RES	Renewable Energy Source
SMES	Small and Medium-sized Enterprises

1 INTRODUCTION

1.1 Motivation

In recent years, the quest for sustainable energy solutions has gained unprecedented momentum, driven by the urgent need to combat climate change and reduce our reliance on fossil fuels. As Europe seeks to transition towards a low-carbon future, the emergence of energy communities has become a focal point in the continent's energy landscape. These communities, characterized by their collective ownership and operation of renewable energy resources, offer a promising model for decentralized energy generation, distribution, and consumption. Against this backdrop, this thesis aims to delve into the concept of energy communities in Europe and explore the importance of optimizing distribution coefficients within these communities.

The overarching objective of energy communities is to empower individuals, local businesses, and municipalities to actively participate in the clean energy revolution. By harnessing the potential of renewable energy sources, such as solar and wind power, these communities have the potential to transform the way energy is produced and consumed. However, the effectiveness and sustainability of energy communities rely heavily on the optimization of distribution coefficients. Distribution coefficients, in this context, refer to the allocation and allocation mechanisms of energy within the community, determining the fair and efficient distribution of electricity among its members.

The assessment of distribution coefficients is a critical aspect of energy communities, as it directly impacts the economic viability, social inclusiveness, and environmental impact of the community's energy system. By finding the right balance in distributing energy among participants, energy communities can ensure equitable access to clean energy, promote energy efficiency, foster local economic development, and reduce carbon emissions. Moreover, optimizing distribution coefficients can address potential challenges related to energy intermittency, grid integration, and demand management, thus enhancing the reliability and stability of the community's energy supply.

This thesis will delve into the multifaceted dimensions of energy communities, focusing on the Spanish context. Through this research, we seek to contribute to the growing body of knowledge in the field of sustainable energy systems and provide insights that can inform policymakers, energy planners, and community stakeholders in their efforts to establish and strengthen energy communities in Europe.

1.2 Research question and tasks

This research intends to assess what is the impact of different configurations of distribution coefficients on the energy and economic performance of energy communities.

To accomplish that, the following tasks must be pursued:

- Analyse the current state of energy distribution in energy communities in Europe and Spain and identify the key challenges faced by community members in accessing energy resources.
- Examine the different methods that are currently being used to determine energy distribution coefficients in energy communities and evaluate their effectiveness in promoting fairness and sustainability.
- Analyse using Python tool the economic and environmental benefits of optimized energy distribution coefficients for energy communities.
- Provide guidance and recommendations for energy community stakeholders, policymakers, and researchers on best practices for optimizing energy distribution coefficients in energy communities in Spain.

By addressing these objectives, this thesis aims to fostering the growth of energy communities in a way that makes them as efficient as possible.

1.3 Structure of the thesis

This thesis is organized as follows:

- Chapter 2 is dedicated to a comprehensive literature review, starting with an overview of the state of energy communities (EC) worldwide, with a specific focus on Europe and Spain. This chapter examines the existing literature and research on distribution coefficients within energy communities, highlighting the challenges and considerations associated with their implementation.
- Chapter 3, a case study approach is adopted to gather real-world data and insights. The chapter begins by discussing the sources of data, providing a reliable foundation for the analysis. It then explores various aspects related to energy communities, including their placement, energy prices, breakdowns, and the regulatory frameworks that govern them. Further, the modelled scenarios are introduced.
- Chapter 4 presents the results obtained and analyses different scenarios, providing insights into the impact and effectiveness of different approaches. This chapter sheds light on the

practical implications and benefits of optimizing distribution coefficients within energy communities.

- Finally, Chapter 5 concludes the thesis by summarizing the key findings, discussing limitations encountered during the research, and proposing avenues for future work.

2 Background and literature review

Climate change and the environmental unsustainability of energy systems are global problems and therefore the change of energy model has to be made at a global level. However, this transition has a strong local component and will not face the same problems in developing, emerging or industrialised countries.

2.1 Energy Communities

Energy communities (ECs) have been created to allow citizens, small businesses, cooperatives, and local entities to get involved and participate actively in the fight against climate change.

ECs are born with the purpose of facilitating the participation of new actors in an essential and strategic sector, which has always been in the hands of technical and economic agents of enormous weight. They promote the construction of a new energy model from the local level, designed by and for citizens (Candelise & Ruggieri, 2020). Although ECs can have different definitions (e.g., renewable energy communities, community energy initiatives, citizen energy communities) and regulatory framing, they all convey the same desire to find alternative ways of organising and governing energy systems at local level (Caramizaru et al., n.d.). ECs are thus a powerful instrument to drive the transition towards an energy model that complies with the three pillars of energy governance because they are aligned with the aspects:

1. A decarbonised energy model: Although generation by renewable energy sources is not a restrictive criterion, one of the main objectives of ECs is to promote the "development of renewable energy technologies" (Bauwens, 2017), offer environmental benefits and thus contribute to decarbonising the energy system (IDAE, 2019). This purpose goes beyond renewable generation, by including education, awareness raising and energy efficiency actions to help their members reduce their energy demand.
2. A decentralised energy system: Another characteristic of ECs is their local anchoring (EP, 2010). Indeed, they seek to bring production closer to the consumption of energy services and therefore promote the implementation of energy generation facilities close to where the demand is and self-consumption. Therefore, they align with the concept of decentralisation of energy generation (IDAE, 2019); (Brown et al., 2020).
3. Polycentric energy governance: ECs are characterised by a high degree of citizen participation and as such constitute self-organised local decision-making units that characterise polycentric systems (Bauwens, 2017). Importantly, ECs in themselves are not sufficient to build polycentric governance, which is characterised by the coexistence of

multiple authorities at many scales. In addition to local, bottom-up initiatives, top-down institutions are crucial in the creation and maintenance of any polycentric governance system to ensure a coherent and strategic framework (Bauwens, 2017).

In conclusion, ECs comply with the fundamentals and characteristics of the new energy model outlined and constitute a powerful instrument to drive the energy transition. ECs defend the general postulate that local actions are key in the construction of a new national energy model.

Energy communities are a key element in the reorganisation of energy production and distribution systems. They allow renewable resources to be harnessed where they are located, and they also are an open door for the active participation of citizens in the energy system. The main advantages can be summarised as follows:

- Abandonment of fossil fuels and reduction of the local carbon footprint.
- Increased consumption efficiency, especially in communities aiming to improve distribution and reduce housing and transport costs.
- Collective investment alternatives for the development of renewable energies.
- Implementation of renewables based on respect and community engagement, rather than large-scale projects developed with the public's back to the grid.
- Possible solution to energy poverty. Energy communities can favour lower prices for neighbours with fewer resources.
- Development of the local economy.
- Strengthening of community ties.
- Redistribution of profits, most of which go back to the local community.

Energy communities are, in short, an innovative approach to electricity generation and distribution, as well as a multitude of energy services. Developed at the local level, they place the benefit of the community and its environmental, social, and economic sustainability at the centre.

2.1.1 ECs framing

Although there are experiences prior to this date of what is currently understood as ECs, it is from the 2000s onwards that they began to be considered as new paradigms of people's participation in the energy transition (Candelise & Ruggieri, 2020).

Globally, Europe is the most advanced continent in terms of regulation of the Energy communities, yet countries such as Australia, the United States and Canada also have started developing this type of projects but they are not that advanced on the legislative field (C4CE, n.d.). However, the degree of recognition of the potential contribution of citizens to the energy transition and the level of deployment of EC initiatives still varies considerably across the European continent. Indeed, while community energy initiatives are prevalent in Northern Europe, especially in Denmark, Germany, and the UK, in Southern Europe the movement is still in its roll-out (Candelise & Ruggieri, 2020)). This situation can be explained by the fact that, until recently, ECs lacked clear legal status and recognition at the European level.

Indeed, it was only in 2016, after more than 30 years of strategies to boost the development of renewables in Europe (Sokoøowski, n.d.), that the European Union (EU) first introduced ECs into its legislation, through the Clean Energy for All Europeans (CEP) legislative package also known as the "winter package" (BOE, 2021). In this document, it uses two different denominations that refer to the concept of ECs (IDAE, 2019):

- Citizen Energy Community (CEC), which appears in the legislation for the regulation of the internal market for electricity in the ELE package and has been revised in the Directive on the common regulation of the internal market in electricity ((EU) 2019/944) (IDAE, 2019);
- Renewable Energy Community (REC), which appears in the legislation for the promotion of renewable energy in the ELE package and has been revised in the Renewable Energy Directive. (REDII) (2018/2001/EU) (IDAE, 2019).

In the latest versions of their definition, these two terms have converged to similar statements (IDAE, 2019). However, they still have some differences, which are discussed in *Table 1.*

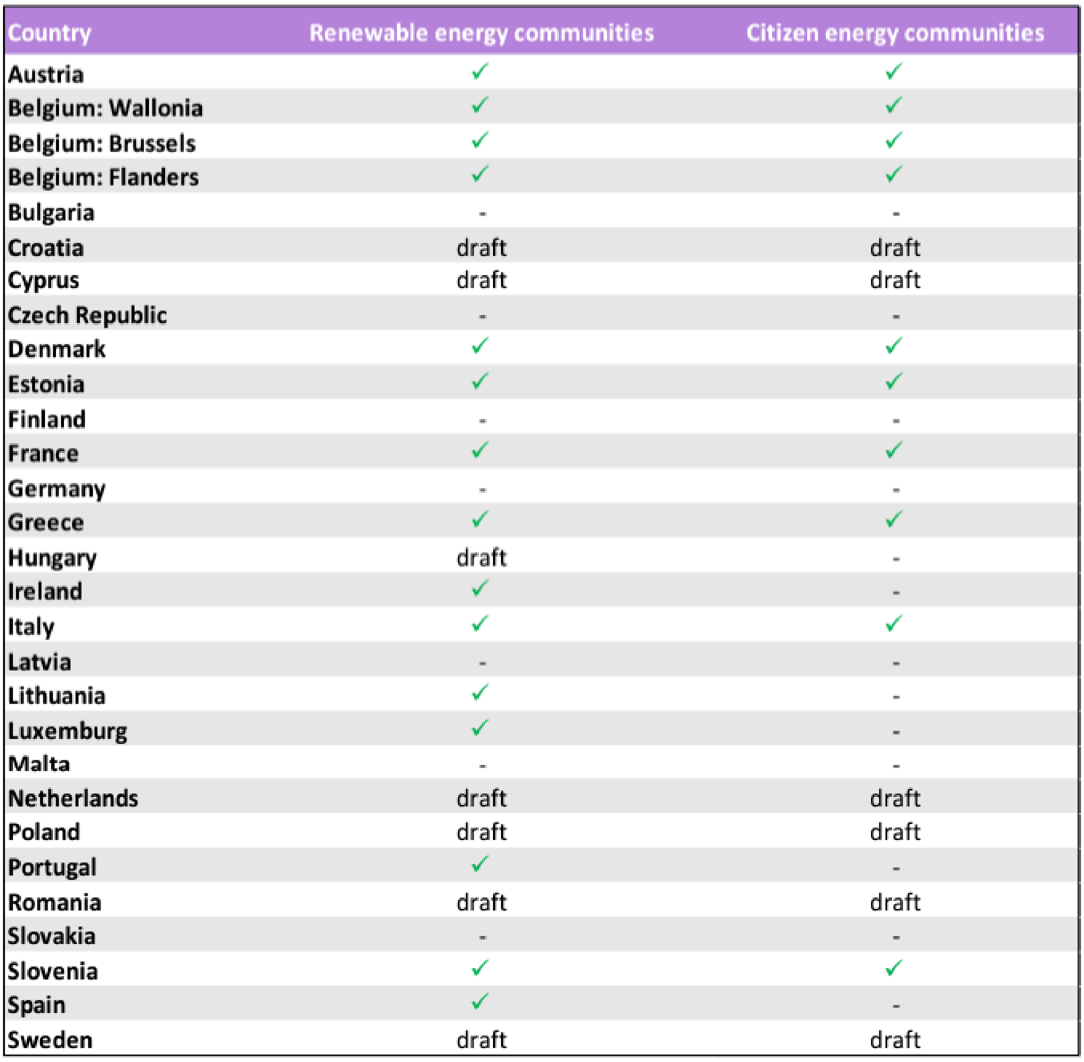
Table 1. Differences between CEC and REC

Differences between CEC and REC		
Indicators	CEC	REC
Energy vector	Electricity	All renewable energy sources
Partners/ Members	All types of actors	Citizens, local authorities, SMEs
Effective control	Based on size of actors (individuals, local authorities, small companies) and their non linkage to the large-scale energy sector	Based on proximity to partners / members
Purpose	Primary purpose to bring environmental, economic, or social benefits to its members or to the locality.	
Activities	Generation, storage, sale, exchange, aggregation or other energy services, distribution	

In the majority of EU nations, regulatory frameworks for RECs, collective self-consumption (CSC), and in a few cases, CECs, have already been prepared in draft or final form. However, there are significant differences in the level of information in the relevant legislative instruments among Member States. To clarify, A REC or a CEC is a broader concept encompassing the collaborative management of energy resources beyond just generation and consumption among multiple users. It involves collective efforts in areas like renewable energy production, storage, distribution, and even the establishment of local energy markets, encouraging active community involvement in decision-making related to energy matters. Conversely, CSC focuses specifically on the shared generation and consumption of energy among a group of users, often through a local renewable energy generation facility like solar panels or wind turbines. Its primary emphasis lies in the communal utilization of locally generated energy, aiming to reduce reliance on conventional grids and promote self-sufficiency among participants.

Be aware that implemented frameworks can have complicated frameworks or only simple definitions. The following table shows the legislative situation of each country in Europe in terms of REC and CEC.

Table 2. Estatus of implementation of REC and CEC in EU countries (Research & Tuerk, 2021)



Country	Renewable energy communities	Citizen energy communities
Austria	✓	✓
Belgium: Wallonia	✓	✓
Belgium: Brussels	✓	✓
Belgium: Flanders	✓	✓
Bulgaria	-	-
Croatia	draft	draft
Cyprus	draft	draft
Czech Republic	-	-
Denmark	✓	✓
Estonia	✓	✓
Finland	-	-
France	✓	✓
Germany	-	-
Greece	✓	✓
Hungary	draft	-
Ireland	✓	-
Italy	✓	✓
Latvia	-	-
Lithuania	✓	-
Luxemburg	✓	-
Malta	-	-
Netherlands	draft	draft
Poland	draft	draft
Portugal	✓	-
Romania	draft	draft
Slovakia	-	-
Slovenia	✓	✓
Spain	✓	-
Sweden	draft	draft

In this scenario, although not all countries are at the same stage of development, the number of energy communities in Europe is growing significantly. The European federation of energy cooperatives ((Https://Www.Rescoop.Eu/) has brought together more than 1,900 energy community projects throughout Europe, with more than 1,250,000 consumers. In Spain, there are several dozen projects, spread throughout the country.

This growth has been achieved in the past through a gradual process of "pollination" between projects and with the support of local institutions. The knowledge that is generated in specific projects is gradually being transferred between actors, which is driving the slow but steady emergence of new local energy community initiatives across Europe. The support of local institutions (city councils, county associations, etc.) is decisive in promoting this type of projects in their initial stages.

In this phase of growth, and since the study of this paper is located in Spain, it is important to contextualize the legislation regarding energy communities. In addition to Spain, it is also important to frame how the neighbouring countries of southern Europe are evolving, such as Portugal, France, Italy and/or Germany. The following is a description of the legislative situation concerning the energy communities in the countries mentioned above:

PORTUGAL

In Portugal, Decree Law 162/2019 (Diário da República, 2019) established a structure for the utilization of renewable energy for self-consumption at both individual and communal level and through renewable energy communities. This law became operational from January 1st, 2020, with a gradual rollout of its included provisions. This enactment partially integrated the REDII directive, although it has not yet encompassed citizen energy communities defined in the EMD. Prior to this, self-consumption was confined to individual usage (Decree-Law No. 153/2014, dated October 20, 2014). The 2019 decree law adopts the primary tenets of the EU REDII, encompassing membership, potential activities, and the necessity to establish a legal entity. The following discourse predominantly centres on the mentioned law 162/2019 and its corresponding regulation 266/2020. Regulation No. 266/2020 further delineates the prerequisites for renewable electricity self-use. However, other forms of renewable energy (notably heat) are currently not included in this structure, and activities beyond self-consumption, as well as the handling of potential excess energy, are yet to be established. Starting January 1st, 2020, individual and collective self-consumption projects and projects related to collective self-consumption within RECs are feasible, provided they incorporate an intelligent metering system and are installed at the same voltage level. Starting January 1st, 2021, other types of self-consumption projects will also be permissible.

The EMD is also responsible for operational management, which includes managing a potential internal network, liaising with system operators, sharing electricity production along with corresponding coefficients, defining commercial relationships for potential surpluses, and connecting to the public grid. The latter necessitates a contract between the management entity and the DSO. In the case of renewable energy communities, the REC itself can fulfil the role of the management entity. Self-consumers possess the right to create and operate internal networks, and in the absence of access to the public network, they can establish and operate direct connections.

Within two years of the enactment of the 2019 decree-law, and subsequently every three years, the DGEG will assess the barriers to and potential of REC. This evaluation will guide the formulation of a framework intended to encourage and expedite REC development. The spatial constraint for renewable energy communities is outdated in the DL 15/2022 (Diário da República, 2022), it says it has to be 2km for low voltage, 4km to MV and 10 to HV.

In the context of electricity sharing, there is no requirement for a supplier license, with a managing entity responsible for coordinating activities and distribution among participants. This entails the establishment of supply contracts and addressing imbalances in the renewable energy community, all while ensuring that all generation installations are registered as self-consumption installations. The DSO plays a crucial role in measuring and attributing electricity generated to different participants, relying on tele counting and bidirectional meters where needed, with costs related to equipment covered by self-consumers. Grid access, distribution, and management encompass using the distribution grid, internal networks, and direct connections when the public grid is unavailable. Grid tariffs are governed by Directive n. º 5/2020 and apply to collective self-consumption and energy communities, with exemptions for RECs and collective self-consumption projects introduced in June 2020. These exemptions reduce a portion of grid charges known as CIEG, associated with energy policy, environmental interests, economic interests, market sustainability, and consumption efficiency promotion, offering cost relief for eligible initiatives registered by 2021 for the initial seven years of operation.

Surplus Energy Trading: Surplus energy from individual or collective self-consumption can be traded, including through aggregation and peer-to-peer transactions:

a) In organized or bilateral markets, with the option of a renewable power purchase contract.
b) Through a market participant, involving a mutually agreed price.
c) Via a market facilitator, subject to an acquisition obligation with market compensation.

If the sale from collective self-consumption or RECs is conducted directly by the managing entity (point a), the entity must establish a network use contract with the transmission system operator (TSO) applicable to producers. The entity is also accountable for integration-related responsibilities and deviations from schedules. When surplus sale does not occur through the listed modalities, the energy is accounted for by the network operator and contributes to network loss reduction (Isabel Azevedo, 2021).

Support Scheme: The energy responsible government official will design a support system considering REC specifics according to RED II. Connecting generation units for self-consumption to the same point as electricity production units covered by guaranteed remuneration schemes is generally prohibited unless the counting system differentiates energy produced by distinct installations.

Electricity Market Access: The primary market activities outlined by the EU framework are incorporated in current Portuguese self-consumption legislation, including RECs. Generation installations for self-consumption schemes must be registered on the national platform.

Energy Services: Similar to REDII, the Portuguese framework refers to aggregation services and "other commercial energy services" by RECs. The storage of energy in electric vehicles with bidirectional charging stations linked to self-consumption units is covered under the definition of "stored energy" in Law 162/2019.

FRANCE

The concept of self-consumption in France is codified within legislation 2017-2277 and decree 2017-676 (L & Mer, 2017)). These legal documents outline provisions for both individual and collective self-consumption, which are incorporated into the renewable energy section of the French Energy Code. As per the definitions, individual self-consumption involves using self-produced electricity without utilizing the public grid for sharing, whereas collective self-consumption (CSC) does necessitate the grid. This distinction forms the basis for varying grid tariffs between these two options. Collective self-consumers have the choice between the standard distribution grid tariff (*Bilan_Electrique_Enedis_Analyse_Annuelle_2019*, n.d.). CSC is permitted when multiple consumers and producers are connected through a legal entity for the production and consumption of electricity. This requirement aligns with the fundamental criteria for energy communities as outlined in the EU framework. To our knowledge, this element is not present in other national frameworks for collective self-consumption. Distribution System Operators (DSOs), primarily Enedis in France, are mandated to provide smart meters to each participant and establish necessary contractual and technical arrangements to facilitate self-consumption in a transparent and fair manner.

Individual self-consumption is restricted to a single person engaged in on-site electricity production and consumption. For CSC, a contract must be established between the DSO and the legal entity, identifying participants, and determining the sharing scheme among consumers involved. Net metering is not permitted for either scheme to prevent excess electricity from being incorrectly classified as self-consumed when compared to the energy consumed within a brief period.

In 2019, the scope of CSC was expanded to include a maximum distance of 2 km between injection and consumption points. This applies to cumulative production facilities with a capacity below 3 MW in continental metropolitan areas and 0.5 MW in non-interconnected regions. A recent amendment introduced an exception, allowing a maximum distance of 20 km between the two farthest participants for isolated projects in sparsely populated areas.

In 2019, France established a fundamental definition for RECs in Article L211-3-2 of the French Energy Code ((De & Écologique, 2021)), largely mirroring the definitions within the REDII framework. This definition is now being further refined and complemented by an explanation of CECs as part of an energy community and self-consumption law currently undergoing public consultation. As a specific adaptation of the optional phrasing in the EU framework, it is stipulated that RECs and CECs are prohibited from owning or operating distribution networks (French Government 2019c).

GERMANY

Germany possesses a well-established history of small-scale collective self-consumption (CSC) initiatives. In 2017, the "Mieterstrommodell" was formally introduced (BMWI, 2017). This model permits operators of installations in multifamily buildings to directly sell locally generated electricity to nearby tenants. However, the lack of a precise definition for "proximity" has led to various case-specific legal rulings ((Verbraucherzentrale, 2019). The operator of the installation assumes the role of an electricity supplier. In cases of multi-apartment structures, the operator receives a self-consumption subsidy from the DSO ranging from 2.1 to 3.7 cents per kWh for solar energy, contingent on installation size, for a 20-year span ((den-belitsky, Bundesnetzagentur 2017). This subsidy is granted if the photovoltaic (PV) installation's capacity doesn't exceed 100 kW and it's located within a residential building. To avail the subsidy, the operator can sell electricity to either: a) tenants of the building or b) apartment owners within the building. The annual capacity supported is limited to 500 MW. The German legislation explicitly dictates that if storage is employed, the self-consumed electricity post-storage, rather than the stored electricity, determines the self-consumption subsidy. Additionally, the operator continues to receive a feed-in tariff/premium for electricity injected into the grid. In contrast to simple self-consumers, collective self-consumers are required to pay the "EEG surcharge," which forms part of the retail electricity price, funding the German renewable energy support scheme (EEG).

In a proposed amendment to the EEG in 2021, the self-consumption support and capacity caps would be raised to range from 3.79 euro cents/kWh (for installations up to 10 kW) to 2.73 euro cents/kWh for installations up to 500 kW in size (Federal Government of Germany 2020).

ITALY

In February 2020, Italy ratified legislation (law N8/2020) (Gazzeta Ufficiale, 2020), that establishes a broad framework for self-consumption and renewable energy communities. Presently, there is a public consultation aimed at fine-tuning the law's implementation details, particularly focusing on tariff structure (ARERA 2020). The consultation document issued by the Italian Authority for Energy, Networks, and Environment (ARERA) proposes the introduction of two distinct participants:

1. Collective self-consumers of renewable energy with a specific emphasis on condominiums: These could be natural persons or commercial entities, engaging in energy generation and exchange that isn't their core business, located within the same building or condominium.

2. Renewable energy communities that encompass natural persons, small and medium enterprises, local or regional authorities (such as municipal administrations), and private companies. This category includes low-income and vulnerable residents. Energy generation and supply should not constitute their primary commercial activities. Generation plants, individually not exceeding 200 kW, are required to be situated in the low or medium voltage network behind the same transformer station. The primary goal of a renewable energy community is, akin to the EU framework, to deliver environmental, economic, or social benefits to its members or the local area, rather than purely financial gains. Such a community can also undertake aggregation activities and function as a balancing service provider.

In Italy, collective self-consumption and renewable energy communities are implemented within the national legislation through a "virtual model" called UVAM (ARERA, 2019). UVAM represents a virtual aggregation of units, including consumption, production, energy storage, and e-mobility, with a minimum modulation capacity of 1 MW and located within the same area. This concept was first introduced in Italy in 2017 and initiated towards the end of 2018 to enable aggregators of consumers, producers, and storage entities to participate in the balancing market.

Italy introduced an incentive program in 2020 based on the UVAM model, targeting self-consumption of renewable energy sources (RES) restricted to the same medium voltage (MV) or low voltage (LV) cabin (renewable energy communities) or at the condominium level (collective self-consumption of RES). In both cases, within the virtual model, these schemes can interconnect and exchange electricity via the public low voltage electricity network. For both collective self-consumption and renewable energy communities, self-consumption is computed on an hourly basis, representing the minimum of aggregate production and consumption.

For electricity shared through the public grid, participants are subject to the standard grid tariff but receive compensation for the electricity exchanged within their community. This compensation covers the consumption-based portion of transmission-related costs and equals 0.822 euros per kWh of self-consumed energy. For collective self-consumers, this tariff is further reduced by the grid losses charge (1.2% for MV and 2.6% for LV), a reduction that does not apply to renewable energy communities. In addition to this grid tariff refund, self-consumers also receive an incentive for their self-consumed electricity. This incentive amounts to 110 euros per MWh for energy communities and 100 euros per

MWh for condominiums, lasting for a period of 20 years, designed to offset the initial renewable plant investment

SPAIN

Having explained the legislation of Spain's neighbouring countries, it is essential to talk about Spanish legislation. To date, Spain lacks comprehensive legislation regarding energy communities. The decree law 23/2020 of June 23, 2020,("BOE-A-2020-6621-Consolidado," 2020) represents the initial introduction of energy communities and aggregators, albeit with a focus on their overall purpose and nature. However, Spain has established an advanced framework for self-consumption, which exceeds the requirements set by Article 21 of REDII regarding collective self-consumption. This approach is elucidated in the subsequent discussion.

On April 5th, 2019, the Spanish government approved Royal Decree 244/19 (BOE, 2019), which regulates the administrative, technical, and economic aspects of self-consumption within Spain. This decree supplements the regulatory structure in response to Royal Decree-Law 15/2018, which eliminated the "sun tax," thereby enhancing user confidence and certainty. The Royal Decree facilitates both individual and collective self-consumption, even among groups of apartment owners or within industrial estates. It streamlines administrative processes, particularly for smaller self-consumers, and introduces a simplified mechanism for compensating surplus energy fed into the public grid. Previously, self-consumption was only permissible if generation facilities were within the same dwelling. Under the present regulations, surplus power can be shared with nearby consumers in other buildings or fed back into the grid. However, collective self-consumption using the public grid is subject to specific physical and geographical restrictions, including the proximity of participating entities, the maximum distance between production and consumption meters, and shared locations within the same cadastral area.

For self-consumption without surpluses, mechanisms must be in place to prevent surplus energy injection into the distribution network. Conversely, self-consumption and surplus supply modes allow excess energy to be injected into the distribution network. Collective self-consumption schemes utilizing the public grid are generally excluded from compensation schemes. Surplus energy that's not self-consumed offsets the energy acquired from the grid at a pre-determined rate. In all forms of self-consumption, consumers and generating facility owners can be distinct individuals or entities. Storage components are permitted across all self-consumption types. Production facilities under 100 kW with surpluses are exempt from registering as electricity suppliers and are solely subject to technical regulations. Special regulations may be established for production facilities under 100 kW to streamline the compensation mechanism between consumer deficits and associated production facility surpluses. For installations exceeding 100 kW, surplus energy is sold on the energy market.

Regarding grid access, production facilities up to 15 kW situated on urbanized land adhering to urban legislation prerequisites are exempt from access and connection permit requirements. Additionally, Spain is revising its tariffs for self-consumption in connection to the use of the public grid and compensation schemes. Given the expanded collective self-consumption scheme, the current Spanish framework can be perceived as a hybrid model blending elements of both collective self-consumption and renewable energy communities. Notably, energy communities entail an organizational structure necessitating a legal entity and encompass activities extending beyond self-consumption.

A driving force for implementing local renewable energy projects in Spain is the existing framework for Energy Consumption Cooperatives ("*Cooperativas de Consumo*"). These cooperatives manage various local energy activities and can execute comprehensive renewable energy projects. The cooperative structure aligns well with energy communities, as it encompasses diverse aspects from distributed energy resources (DER) to citizen and end-user consumption, facilitated by supportive legislation. This cooperative framework offers a foundation for organizing energy communities, shared asset ownership, and collective self-consumption (Frieden et al., 2020).

As can be seen from the legislative breakdown above, there is no clear and centralised EU legislation, each country logically uses different models that best suit their energy market and distribution network.

This diversity of legislation means that there is a great diversity of local energy community models but an EC is not only dependent on legislation, but also on the Energy communities take many forms, depending on other variables such as:

i) The typology of the partners (e.g., citizens, companies, institutions);
ii) The role of the different actors involved, such as partners, local governments, service providers, aggregators, asset managers, distributors;
iii) The configuration of physical renewable generation assets with different technologies and forms of energy (electricity, thermal energy), collective exploitation of bioenergy resources, storage, electric vehicle charging infrastructure, etc.;
iv) The relationship between the physical assets and the distribution grid;
v) The type of activities they carry out, including generation, storage, energy consumption, energy services, building refurbishment, energy efficiency improvement, market surplus optimisation, electric vehicle charging, etc.; or

vi) The management, financing, governance models.

Although there are different models of generating an energy community, a large part of the energy community projects in Spain are still at an early stage of experimentation and development. The energy communities that are being created focus, with some exceptions, on the deployment of renewable energies (wind, photovoltaic, mini hydro, etc.) under different financing schemes and/or shared self-consumption among members. There is a limited level of integration of storage and electric vehicles, although the observed trend indicates that the complexity of distributed energy resource configurations in energy communities will increase in the future. In most cases, there is limited development of digitisation tools, which reduces the possibilities for value generation related to active management and optimisation of energy resources. Also, with a few exceptions, the penetration of new aggregation or active energy consumption management services has so far not taken place, partly due to some gaps in the regulatory framework. It is in this process of energy optimisation and management within energy communities that distribution coefficients come into play.

Three different documents have been presented by the government to promote energy communities as demanded by the European Union. Similar to Europe, Spain still lacks legislation and many advances and legal definitions about the limits and rights of energy communities are to be made in the upcoming years. Nevertheless, we need to base our study on the already existing legislation and directives, which are presented hereafter.

Real Decreto Ley 23/2020

The Real Decreto Ley 23/2020 (BOE-A-2020-6621, 2020)can be understood as the legal basis upon which projects related to renewable energies are built. Thus, its purpose is to incentivize renewable energy projects. It includes the necessary regulations to overcome the barriers blocking the energy transition and boosting the economic reactivation of the country.

Real Decreto 3/2020

This Real Decreto 3/2020 ("BOE-A-2020-6621-Consolidado," 2020)was established to execute programs related to renewable energy, energy self-consumption, and energy storage. In the document, the regulations and mechanisms that establish how financial aid is distributed among projects from different Spanish regions are described.

Plan Nacional Integrado de Energía y Clima 2021-2030 (PNIEC)

This national (MITECO, 2021) has a wide scope within the energy transition in Spain. It describes how carbon emissions are to be reduced and how renewables and energy efficiency are to be developed in the upcoming years. To this end, a roadmap to accomplish all the objectives is included, in which local energy communities are considered. In this sense, some measures closely related to energy communities are also defined, such as measures about the development of self-consumption including renewables, distributed generation, flexibility, storage, and demand management, promotion of the proactive role of the community towards decarbonization, renewables incorporation in the industrial sector, generation of knowledge, divulgation, and sensibilization of the society.

As a conclusion, on the legal framework of the project, within the scope of our energy community it has been considered that the European Citizen Energy Community proposal is more interesting, as it allows us to freely define the activities carried as primary and professional activities without limitations and there is a wider span of energy resources to deal with, even though the initial idea would be to deal with renewable energy production. Moreover, the fact that no geographic limitation applies is more appealing than the REC geographical restriction alternative. Regarding the limited activities, CECs still allow development of the desired activities within the project despite being more restrictive than RECs. Moreover, it also has been noted how although this energy community concept is very promising, the regulatory framework is being developed simultaneously with the deployment of the concept itself. During the interviews conducted to validate our project, different perspectives on this fact have been found on the one hand, the lack of an already settled regulation can be an impediment to the effective implementation of the energy community in terms of ease of being deployed. On the other hand, this absence of a strong legal framework leaves space to the shaping of the new laws to be implemented in the upcoming years, which will need to be made not unilaterally by governments but also in collaboration with industry and other energy stakeholders. This can be seen as an opportunity to boost the concept and obtain an optimal performance of the energy community from an implementation perspective.

2.1.2 P2P Energy communities

P2P is defined as a decentralized structure where all peers cooperate with their available resources to produce, trade, or distribute a good or service. This principle extends beyond the energy system and represents a paradigm shift in the way society trades services and goods. There are prominent examples of this principle already being implemented, such as in public bicycle schemes, peer-to-peer car sharing, and more recently vehicle-to-grid storage (Pigliautile et al., 2022). The P2P business model for electricity trading was first proposed in 2007 and has since seen light in several pilot and demonstration projects, such as the iconic Brooklyn Microgrid project (Mengelkamp et al., 2018). This type of market has the advantage to be fairer and more transparent as a structure that facilitates exchanges under collaborative economy principles and can lead to decreased electricity bills for its participants and increased self-consumption rate for locally produced renewable energy. Different structures can be observed for P2P markets, such as centralized community-based markets and distributed bilateral trading markets. However, direct energy exchanges between prosumers are still heavily curtailed by the regulatory framework in most countries. Fortunately, there is an ongoing movement to adapt these regulations and enable this novel vision of energy markets. One of the tools to simulate this type of energy communities is Grid Singularity, which is an open-source energy technology company.

The Grid Singularity Exchange provides software tools, enabling prosumers and consumers organised in (or considering joining) energy communities, with the support of local companies that facilitate data connectivity to smart metres and energy assets (often local suppliers), to simulate and implement peer-to-peer and community energy trading. While community operation requires real data integration, simulations may also be performed by using historical, forecast, or synthetic data. Importantly, the open source and modular platform optimises the use of local resources and enables individuals with equitable access to energy trading, with large energy suppliers. Energy researchers can deploy more advanced simulation features both in the user interface (e.g. use custom PV tool to integrate solar profiles based on location and weather conditions) and by using the more versatile open-source.

Grid Singularity facilitates an individual or energy asset-centred, bottom-up market design by connecting aggregators and grid operators, through an application interface (Asset API and Grid Operator API, respectively). More specifically, aggregators connect distributed energy assets of a community (including households, businesses, and other energy users), while grid operators account for grid costs and access local flexibility for advanced grid management. Connected energy assets are digitally represented by trading agents pursuing trading strategies currently based on price but with a capability to be based on more advanced user preferences, such as consuming only renewable energy or trading with a preferred partner, achieving diverse degrees of freedom.

Assets are typically grouped inside homes based on the owner and trade in a community market. Multiple communities can be connected inside larger markets depending on the geographical reach of the peer-to-peer system and voltage architecture of the grid.

Figure 1. Scheme of the Grid Singularity Exchange

Grid Singularity's Exchange is a highly innovative and effective grid modernisation solution.

- First, it empowers customer engagement and provides utmost **degrees of freedom** in energy markets enhancing individual and community choices (e.g., type of energy consumed or preferred trading partner), lowering barriers and creating incentives for all participants.
- Second, it creates a **resilient market** by ensuring equal access, transparent pricing, and trading at optimal market levels (i.e., between assets and buildings or facility and grid).
- Third, it **incentivizes and facilitates** the integration of clean distributed energy resources (DERs) onto the grid closer to load centers.
- Fourth, grid operators can use it to **implement flexible grid tariffs** to benefit from the local market flexibility to alleviate congestion.
- Fifth, the Grid Singularity API provides instantaneous granular data to the grid operator–which historically has relied upon changes in detected load and alterations from the forecast–enabling the operator to improve management, flexibility, and grid performance.
- Sixth, peer-to-peer trading is **market-driven**, not based upon predetermined pricing, which optimizes local consumption and thus the use of (cheaper) local renewables, increasing affordability, reducing reliance and overall/peak load on the grid, supporting efficient asset utilization, and reducing system losses.

- Seventh, it **increases community self-sufficiency and energy savings**, providing emergency power backup, and mitigating the need for new transmission infrastructure.
- Finally, the peer-to-peer trading system **incentivizes private investment** in electric system infrastructure by increasing revenue from renewable DERs and providing decision-making tools.

2.1.3 EC Distribution coefficients

The distribution coefficients of the energy produced locally for collective self-consumption determine how much of this shared energy will be delivered to each participant.

This distribution coefficient (βi) will have the values included in the agreement signed by the different participating consumers. In turn, they will have to be notified to the energy distribution company in charge of reading the consumption.

And how is the value of these coefficients calculated? This can be fixed or variable, and be determined based on several elements:

- The power contracted by each of the participants.
- The economic contribution of each consumer for the photovoltaic installation.
- Other elements that have been agreed upon by all the participants in the collective self-consumption.

The coefficients of all participating consumers must add up to 1.

As with legislation, and because the energy system is different in each country, the operation of these distribution coefficients may vary from country to country.

In Portugal different distribution rules ("distribution coefficients") can be defined and communicated to the DSO by the management entity. These coefficients apply to the sum of included generation installations. If no distribution coefficient is communicated, the DSO attributes production in proportion to the measured consumption of each unit in each 15-minute period. The potential types of distribution coefficients (static/dynamic...) are unspecified in the relevant laws, and changes can only be made after a minimum of 12 months from the last change.

2.1.4 EC Distribution coefficients in Spain

In Spain, this distribution is still only possible through fixed or static distribution coefficients. However, as this is limited, the optimal way of distributing energy is based on dynamic distribution coefficients which, nevertheless, are still be implemented. The approval of the dynamic distribution coefficient can be carried out, according to the 5th final provision of RD 244/2019BOE, 2019), by ministerial order. In this Real Decreto several novelties and changes were introduced. The most noteworthy aspects will be presented below:

Firstly, multiple variants of self-consumption are defined, from the point of view of the use of the installation:

- **Individual**: this is a single prosumer. it can adhere to any of the existing modalities (without surpluses, with surplus, surpluses with compensation).
- **Collective:** more than one prosumer registered with nearby generation facilities. All the participants must have the same self-consumption modality and provide an equality agreement signed by all the members to the distributor (through themselves or their marketer). This agreement may be governed by the criteria deemed appropriate by the beneficiary parties. If this is not the case, the distribution coefficients will be assigned according to the contracted power.

In the following lines, the current modalities permitted by RD 15/2018(“BOE-A-2020-6621-Consolidado,” 2020), differentiated by the presence or absence of surpluses, are developed in the regulations.

- **Without surpluses**: an anti-spill mechanism must be installed to prevent the injection of surplus energy into the transmission grid. surplus energy into the transmission and distribution grid.
- **With surplus:** in addition to being installations capable of supplying energy for self-consumption, they can inject the remaining surplus energy into the grid.

In turn, the surplus mode has a further subdivision:

- **Surpluses subject to compensation**: The simplified compensation mechanism is introduced, which, unlike net balancing, which accounts for the watts fed into the grid to recover them later, the watts fed into the grid will be reflected in the form of a discount on the variable term of the final cost at the end of each billing period. The retailer will be responsible for carrying out the compensation through the sale of surplus energy. Subsequently, the corresponding tolls and taxes will be applied, and negative billing periods associated with the energy term cannot be reached. The selling price of surplus energy may be established in two ways:

  - By means of a regulated tariff (for PVPC consumers): the economic remuneration will be that corresponding to the average daily price of the energy acquired at the time of dumping minus the cost of the deviations of the energy extracted at the time of dumping, the prices of which are established daily by OMIE.
  - By means of a tariff agreed with a free marketer: the hourly energy consumed from the consumed from the grid will be valued at the hourly price agreed between the parties, as well as surplus hourly energy.

However, there are a series of conditions to be eligible for this modality, the requirements of which are detailed below:

  - The primary energy source must be of renewable origin.
  - The total installed generation power may not exceed 100 kW in the inverters arranged in terms of rated power.
  - The consumer must have concluded a single contract with a supplier for the associated consumption and ancillary consumption. Each consumer is free to choose his supplier, who will be responsible for net billing according to the sale of surpluses and for supplying energy when the demand is not covered by the installation.
  - The set of consumers and producers must have formalised a self-consumption surplus compensation contract.
  - The production installation may not be granted an additional or specific remuneration system. or specific remuneration scheme.

- **Surpluses not subject to compensation**: those cases that do not meet the aforementioned requirements or those that wish to adhere to it voluntarily will belong to this modality. In this case, the self-consumption unit must become a production unit, so the resulting surpluses will be sold to the electricity market at the pool price or under the specific remuneration regime if granted, and the same rules will apply as to any other electricity production plant. electricity production plant

Along these lines, last March 2021, the Government opened for public consultation the Draft Order modifying Annex I of Real Decreto 244/2019, of 5 April, for the implementation of dynamic distribution coefficients in collective self-consumption (IDAE, 2019). As pointed out by the National Markets and Competition Commission (CNMC) in its report (BOE,2021), the proposed ministerial order introduces the possibility that the distribution coefficients may be different for each hour of the year, unlike the current provision which requires these values to be fixed for all the hours of the same billing period (usually monthly). However, the proposal does not include dynamic distribution in the strict sense, so the CNMC proposes that within one year the necessary regulatory changes be made to allow the necessary adaptations to be made so that ex post dynamic distribution coefficients (based on real readings) are available.

In any case, despite the introduction of variable coefficients, the ministerial order will maintain the possibility of using fixed coefficients for collective self-consumption that prefer it that way. For each consumer and participant in collective self-consumption, this coefficient will take the values that appear in an agreement signed by all consumers participating in collective self-consumption and notified to the distribution company as the person in charge of reading the consumption. The value of these coefficients may be determined based on the power to be billed by each of the participating associated consumers, the economic contribution of each of the consumers for the generation installation, or any other criterion provided that there is an agreement signed by all participants and provided that the sum of these coefficients of all consumers who participate in collective self-consumption is the unit for each hour of the billing period.

Although it is not clearly defined how the legislation will proceed in a short term with these distribution coefficients in the framework, it is key to assume that eventually these coefficients will become dynamic and variable.

In this scenario where there is no clear legislation and the functioning of energy communities is not fully defined, there are many studies around. But the fair distribution of energy resources among community members is a critical aspect of energy communities. Distribution coefficients play a key role in determining how energy is allocated within the community.

Optimizing distribution coefficients is crucial for ensuring efficient energy allocation within energy communities. By optimizing distribution coefficients, energy communities can enhance the utilization of renewable energy resources, improve energy system efficiency, and minimize energy waste. To meet these proposals, researchers have proposed various optimization techniques, such as mathematical programming, stochastic modelling, and evolutionary algorithms, to optimize distribution coefficients and maximize the economic and environmental benefits of energy communities (Villalonga Palou et al., 2023)

Moreover, the advancement of machine learning techniques offers new possibilities for optimizing distribution coefficients within energy communities. Machine learning algorithms can analyse complex energy data, predict energy demand, and supply patterns, and optimize energy allocation based on multiple parameters. (Hernandez-Matheus et al., 2022)

Grid singularity

2.2 Final remarks

While the existing literature provides valuable insights into energy communities and the optimization of distribution coefficients, several research gaps persist. The lack of defined legislation in Spain means that it has not been possible to carry out tests with which to carry out comparative studies between the different distribution coefficients. As such, this work will carry out a comprehensive assessment of the economic environmental benefits of different distribution coefficients within energy communities. The quantitative analysis can provide insights into the cost-effectiveness, and environmental impacts of different optimization strategies, supporting evidence-based decision-making for energy community stakeholders and policymakers.

3 METHODOLOGY

This work developed an EC model to assess the impact of considering different distribution coefficients of locally generated renewable energy within energy communities, analysing energy and economic indicators. The energy community modelling was performed for a real case study in San Sebastian, in Spain. *Figure 2* presents the methodology flowchart.

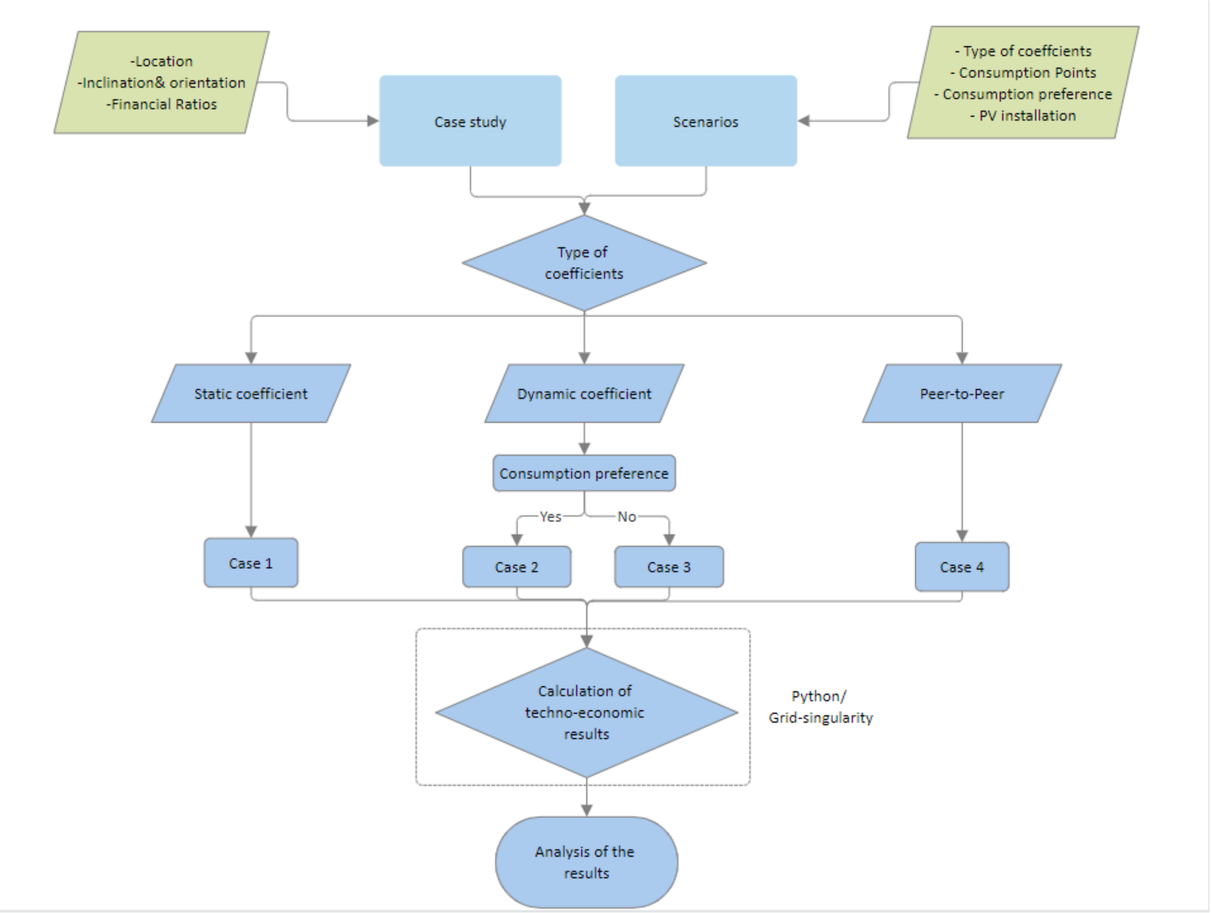


Figure 2. Diagram of the methodology designed to analyse the ECs

The methodology starts by defining the case study and the different scenarios. The case study is defined by the location and size of the EC, i.e. the number of participants and their curve loads, and the capacity factor of the PV installation.

The EC modelling is analysed in terms of cost of energy, the money saved by each household, the self-consumption, and the self-sufficiency rates of the EC. In order to determine whether all demand can be met by the power assigned, it is compared each hour between the power allotted to each user and their demand. Additionally, if a surplus is produced or only a portion of the demand is met by self-consumption, a power deficit results. In either instance, the grid's purchasing or selling power equalizes the created shortfall or surplus. This will ultimately determine how much the EC will pay for electricity, providing us with an indicator we can use to evaluate different scenarios.

In terms of data, the models used demand and PV generation data. For demand data, Synthetic data produced with LoadProfile (Pflugradt et al., 2022) and the users' information. Regarding the PV generation data, hourly capacity factors, determined by orientation, inclination and power losses were calculated with PVsyst software, for various nominal power levels. Due to variable configuration installations, such as the PV capacity inverter relationship, real installations with divergent nominal capacities may differ in their capacity factor. It is important to note that for the study, an analysis of the hourly consumption throughout the year of each house and the SportsCenter has been carried out.

The model analyses the performance over the course of a year and are then reported and compared reported economic (cost of energy and savings) and energy (self-consumption and self-sufficiency rates) metrics. These metrics do not account for potential year-to-year volatility. We thus do not consider any possible financial risks or the volatility of electricity prices.

3.1 Key Performance Indicators

To draw relevant and key conclusions for the value of this work, the following Key performance indicators will be considered to compare the difference between Fixed and Variable coefficients and the P2P model. It is important that to obtain good conclusions, the KPIs take into account both the economic and energy savings of the Energy Community, which is why the following KPIs have been chosen.

- **Self-sufficiency:** Measures the ratio between the total energy consumed and the energy actually used to meet the needs of the community. It can be calculated by dividing Total energy produced by total self-consumed energy:

self-sufficiency (EC) = self-consumed energy/ total energy demanded

Equation 1. Self-Sufficiency calculation.

- **Self-consumption:** Measures the proportion of locally generated energy compared to imported energy. This KPI reflects the community's energy autonomy and its ability to reduce dependence on external energy sources.

$$\text{self-consumption (EC)} = \text{self-consumed energy} / \text{total energy produced}$$

Equation 2. Self Consumption calculation.

- **Energy costs:** Assess the costs associated with the generation, distribution, and consumption of energy in the community. It can be analysed by looking at total costs, average costs per user, or costs in relation to energy consumed.

$$\text{Energy cost} = \text{Energy consumption (kWh)} * \text{Energy price(€/kwh)} - \text{Surplus energy (not shared) (kWh)} * \text{Surplus selling price (€/kWh)}$$

Equation 3. SportsCenter energy cost.

$$\text{Energy cost} = \text{Energy consumption (kWh)} * \text{Energy price(€/kWh)}$$

Equation 4. Consumers (4 houses) energy cost when consuming from the grid.

$$\text{Energy cost} = \text{Energy consumption (kWh)} * \text{Grid tariff (€/kWh)}$$

Equation 5. Consumers (4 houses) energy cost when consuming from the EC.

- **Payback:** The payback in a photovoltaic installation is the period of time it takes to recover the initial investment through savings on electricity bills due to solar energy generation. In simple terms, it's the time it takes to achieve earnings equal to what was spent on installing the solar panels.

$$PB = \text{Initial PV installation investment} / \text{Cashflow (Energy cost savings, Operational costs)}$$

Equation 6. Calculation of the Payback.

There are many business models of energy communities and how to obtain economic benefit from them, but for this case study, it has been estimated that the energy community is public, so all the investment is going to be made by the city council in the rooftop of the municipal sports centre. This implies that the houses that consume the energy from the prosumer will only pay the price of the grid tariff. On the other hand, the prosumer does not receive any money when it shares its energy in the EC, so it is likely that the payback increases when the energy is shared with the other houses, and it acts as a prosumer. All of this is covered by the equations seen in this section.

3.2 Scenarios

Table 3 presents a summary of the EC scenarios modelled. In all scenarios the energy is supplied through the distribution network, but in the first two cases the prosumer has preference in the distribution of energy, and in the third and the fourth cases this fact is ignored.

Table 3.Type of installation and distribution preference used in each scenario.

Case	Prosumer priority on sharing	Distribution coefficient	PV sizes installed
1		Fixed	5, 10, 15 kW
2	x	Variable	
3		Variable	
4		P2P market	

The energy community studied in this paper is composed of 4 consumers and 1 prosumer. The cases studied are described below.

Case 1 the distribution coefficients are fixed and equally distributed, being the same to every household. The coefficients are determined by a contract between the participants of the energy community, the estimated distribution percentages for this first case is 25% to each house.

Case 2, where the distribution coefficients (DC) are going to be variable depending on the consumption of each participant every hour and giving preference to the household with greater demand.

Case 3, where the DC are going to be variable depending on the consumption of each house and adjusting the distribution proportionally to the hourly demand, not prioritizing any house in specific.

Case 4, peer to peer distribution simulated in the Grid Singularity LEM software.

For the first three cases, we use Python model and for case 4 Grid singularity model is used. To also analyse the EC as a function of the size of the PV installation, 3 different PV capacities were modelled. Below we can see a summary table of the studied scenarios:

Table 4. List of design variables and the possible values they can take

Variable	Values
Grid connected	yes
PV Nominal Power	5, 10, 15 kW
Distribution coefficients	Fixed, Variable, Peer-to-Peer
Genereation points	1
Consumption points	5
Grid tariFf periods	P1 & P2

3.3 Case study

3.3.1 Geographical location and climate

The project involves placing a photovoltaic generation facility on the roof of the Manteo municipal sports centre in the city of San Sebastian. As stipulated in RD 18/2022, the users of the EC must be located at less than 2000 metres from the point of electricity generation. This area around the sports centre can be seen in Figure 4. As can be seen, it is close to the Zurriola beach and the area within the ECs reach is a practically not urbanized region to the north-east as it is part of Mount Ulia, but it is densely populated to the south-west with buildings of between 4 and 7 storeys. These are mainly residential buildings with commercial ground floors and there are also some public services such as a school, a church, or a health centre.

Figure 3. Geographical location of the EC

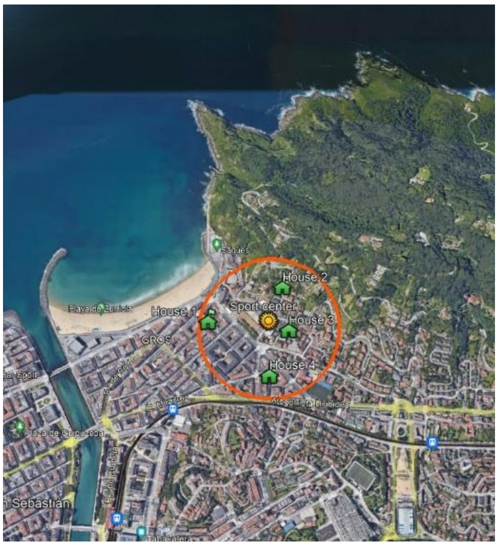


Figure 4. Scope of the energy community

Due to the influence of its proximity to the sea, the municipality of San Sebastián has a temperate oceanic climate, characterised by mild temperatures, high relative humidity, frequent cloudiness, and abundant rainfall distributed regularly throughout the year.

As can be seen in the solar irradiation map of Spain (Figure 5), it is one of the cities with the lowest solar irradiation in the country with an average solar irradiation of 4.62 kWh/m².

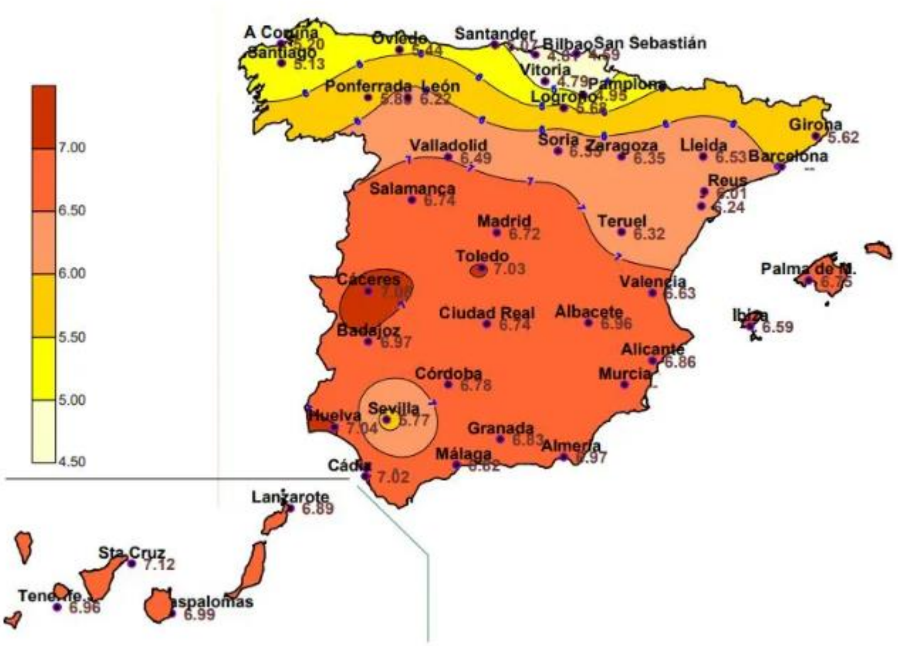


Figure 5. Map of solar irradiation in Spain

3.3.2 PV installation

The system will have a solar photovoltaic installation on top of the sports pavilion (prosumer) with 4 residential household (consumers) connected in the energy community. A schematic of the installation is shown in figure 6.

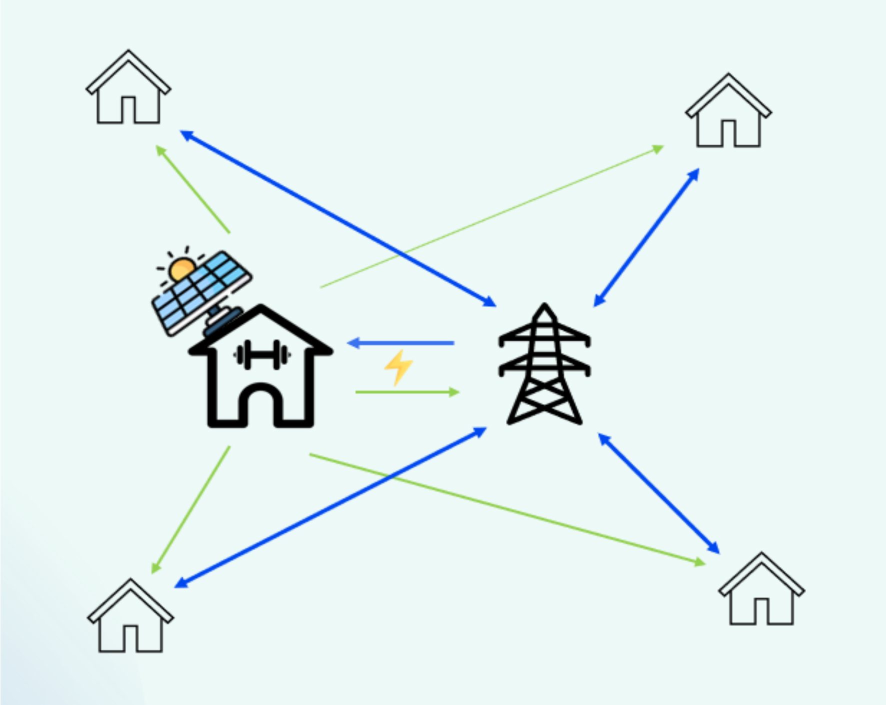


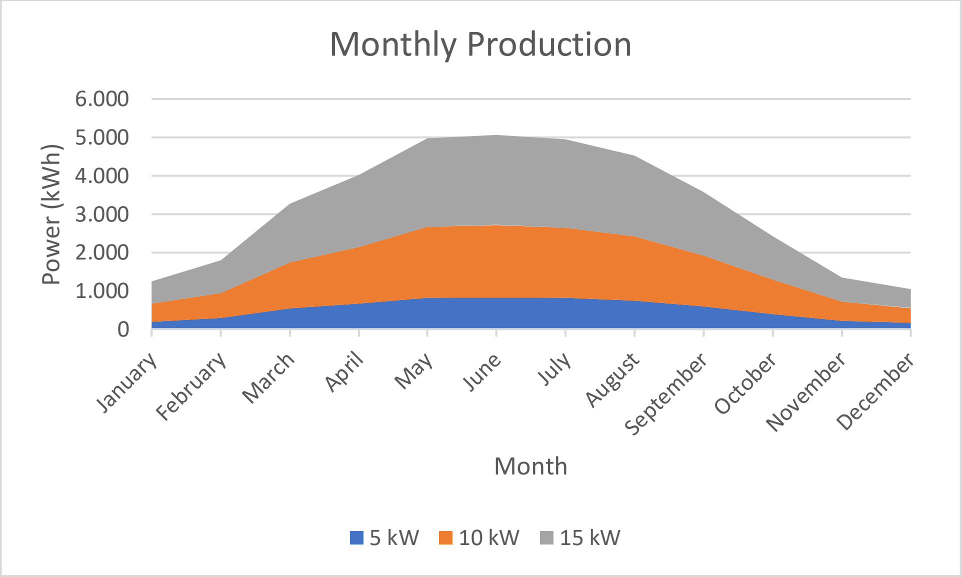
Figure 6. Diagram of the solar installation of the sport-centre in the EC

To determine the parameters and to obtain the approximate production of the PV powerplant, it is important to know the geographic location, the area where the photovoltaic installation will be located and the slope of the roof. To see how the EC behaves as a function of the installed power, the study will be carried out for an installation ranging from 5 kW to 15kW. Table 4 shows the main characteristics of the installation:

Table 5. Main characteristics of the PV installation

Parameter	Value
Location	San Sebastian
Orientation	Southeast (Azimuth: 110º)
Tilt	10 º
PV capacity	5/10/15 kW

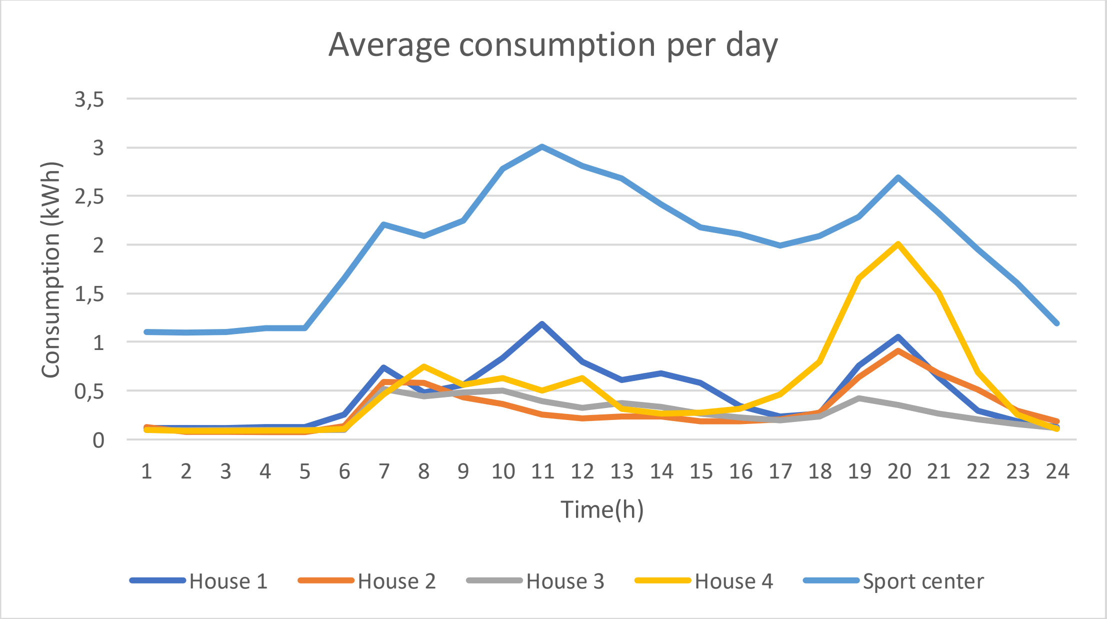
Once all these data have been entered into the PVsyst software and the simulation is run for each PV capacity. The production throughout the year of the 3 installations, is shown in Graph 2.



Graph 1. Monthly production per PV Power

3.3.3 Demand

In order to obtain the demand of each household, the people at each site were contacted and taken their consumption from their distributor's webpage. For house 4, the data provide was not enough so considering their energy consumption data (Table 5) their consumption was simulated on the Load Profile software (Pflugradt et al., 2022). Graph 3 shows the demand of each house over the course of a day as well as the consumption of the sport-centre.



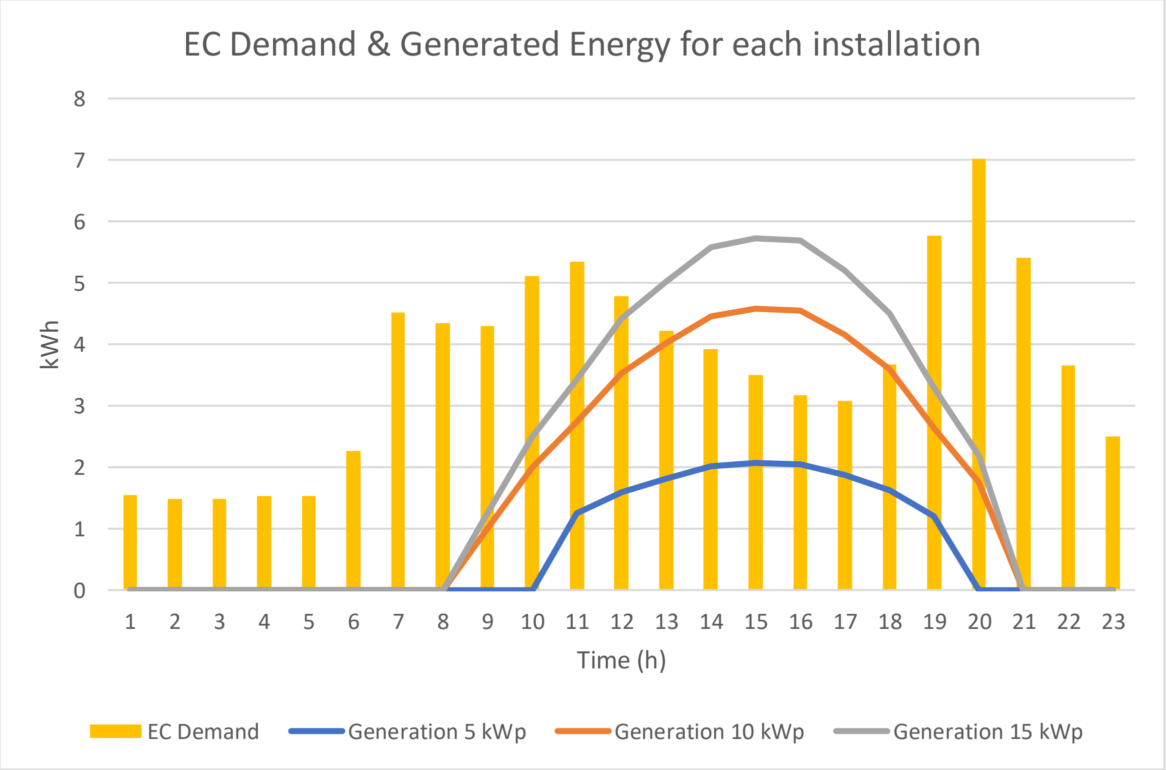
Graph 2. Energy demand per profile

Table 6 shows the contracted and the yearly demand for each of the EC's consumption profiles.

Table 6. Type of consumers, the contracted power and the yearly demand

Type of consumer	**Contracted Power [kW]**	**Yearly demand [kWh]**
Student Flat-sharing	4,9	4122,93
2 Parents, 1 Working, 2 Children	4,6	2766,23
Single man with 2 children, with work	3,7	2337,92
2 adults (1 at work, 1 at home) with 1 child	7	4646,43
Sport-centre	25	17608,69

In Graph 3 it can be seen the energy produced by the different installations at the output of the inverter (nominal power) and the total demand of the EC over one day.



Graph 3. EC Demand & Generated Energy for each installation throughout a day

As mentioned above, the graph represents the energy dynamics of a residential setting over a 24-hour period. Throughout the day, it can be observed that during the early morning and late evening, the demand line shows relatively low levels of energy usage, as most household members are typically asleep. However, as the day progresses and people wake up, the demand gradually increases.

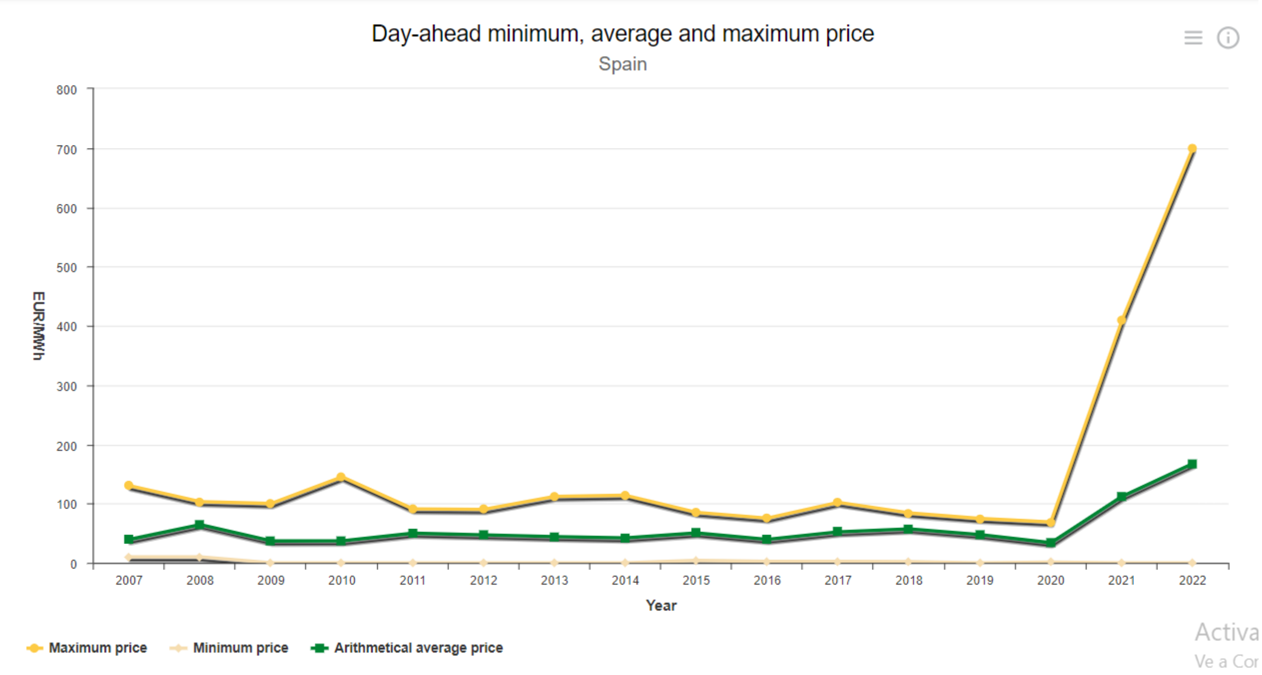
The most notable feature of the graph is the peak in energy demand, which typically occurs during the late afternoon or early evening. This corresponds to the time when residents return home from work or school, switch on various appliances, and engage in evening activities. This period of higher energy demand is often referred to as the "peak consumption period."

On the other hand, the solar generation line shows a clear peak during daylight hours when the sun is shining. This is the time when the solar panels are producing the most energy. If the solar generation peak closely aligns with the demand peak, it can significantly offset the need for electricity from the grid during the expensive peak periods, potentially leading to energy cost savings and reduced reliance on non-renewable energy sources.

The difference in peak demand and production can be easily addressed with batteries in the case of the 10 kW and 15 kW installation as the peak demand is much higher than the demand in those hours. For the 5-kW installation, on the other hand, variable distribution coefficients will be essential to correctly meet the demand. It should be noted that battery installations have not been considered in this study.

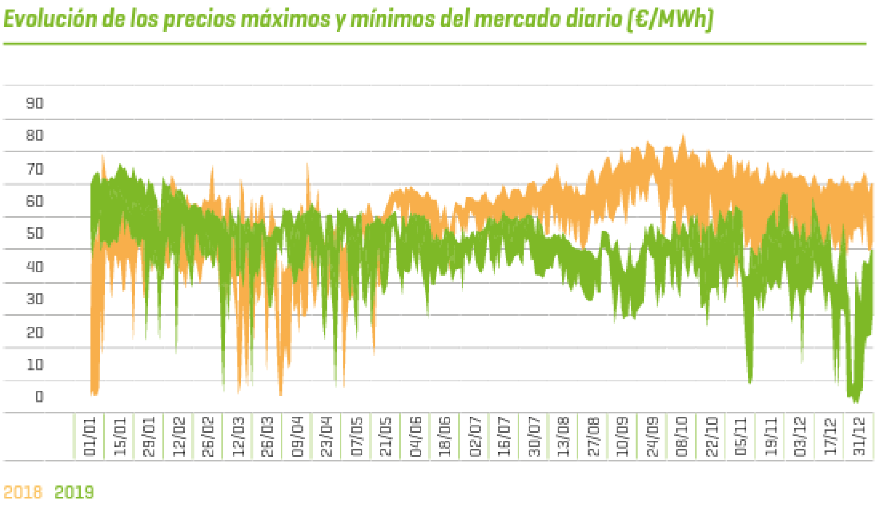
3.3.4 Tariff prices

To have all the inputs that come into play in this model, an essential part is to obtain the price of energy, which is obtained through the (OMIE) portal for Spain and Portugal. OMIE is the designated electricity market operator (NEMO, according to European terminology) for the management of the daily and intraday electricity market in the Iberian Peninsula. These prices can be consulted on OMIE's online platform by date and by hour. For the study, prices for the year 2019 have been taken as this is the most recent full year prior COVID pandemic and the one that will be most similar to future years.



Graph 4. Historical data of the average and maximum electricity prize (OMIE*)*

The Graph 5 shows the evolution of daily market peaks and troughs of the 2018 & 2019. The year chosen to perform the modelling was 2019. That year was chosen because it is the most recent year prior to covid and without fluctuations in the market. As can be seen in the graph since 2020 the markets have soared following the covid crisis and the energy crisis after the start of the Russian war. It is likely that the market in the coming years will not be the same as in 2019 due to the large inclusion of renewable energies and the evolution of the electricity market. But as mentioned it is the most reliable and recent full year we have for this study.



Graph 5. Evolution of the maximum and minimum prices of the daily market (ESIOS-REE)

The table below shows the average prices during the year for the purchase of energy and the sale of surpluses.

Table 7. Average energy prizes (REE)

Average yearly energy prize	**0,116 €/kWh**
Average yearly surplus-energy selling prize	0,0514 €/kWh

For the Tariff prices, this study takes the tariffs imposed on June 2021 in Spain. The tariff regulation that went into effect on June 1st altered the volumetric rates of electricity depending on the hour of the day. The objective was to decrease peak consumption by encouraging consumption during historically low hours. However, the new tariff regulation increases the volumetric prices for peak hours (midday and early at night) and decreases them during valley consumption hours (late at night). That's why prices for both periods (P1 and P2) are taken into account. The hours in which the different periods apply are reflected in Figure 7 where the "Peak" Tariff refers to P1 and the "Valley" Tariff to P2.

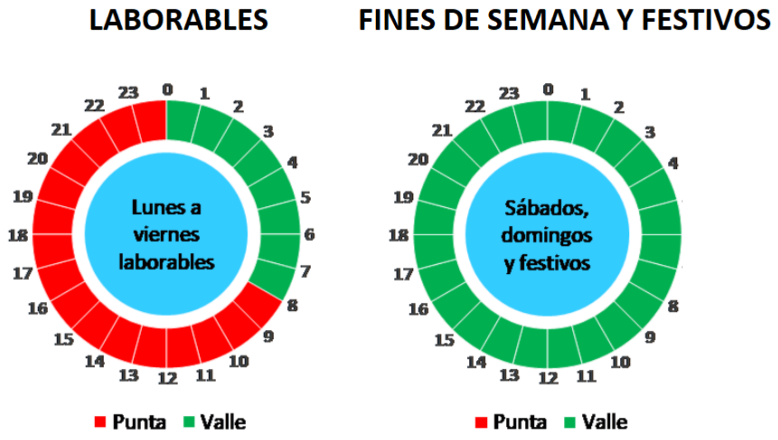


Figure 7. Chart of the hours that correspond to each period.

The prices imposed for each period by Red Electrica de España are shown in Table 8.

Table 8. Grid tariff prizes (REE)

Period	Grid tariff (€/kWh)
P1	0,027
P2	0,02

3.3.5 Techno-economic data

To carry out the economic analysis of our installation, it is important to consider the investment and for our study for several reasons:

1. **Cost-Benefit Analysis**: It allows you to assess the financial feasibility of the project. By comparing the initial investment to the expected returns, you can determine whether the installation is a sound financial decision. This analysis helps you understand if the project will be profitable overall.

2. **Budget Planning:** Accurate cost estimates enable you to plan your budget effectively. You can allocate resources for the installation, including equipment, labor, permits, and other expenses. This ensures that you have the necessary funds available when needed.

3. **Sizing and Design:** Knowing the investment helps in properly sizing and designing the PV system. You can optimize the system's capacity based on your budget and energy needs. This ensures that the installation meets your energy requirements while staying within your financial limits.

4. **Cost Reduction Strategies:** Understanding the investment can lead to cost reduction strategies. You can explore ways to minimize costs through efficient design, equipment selection, and construction practices, potentially increasing the project's overall profitability.

In summary, knowing the investment of a PV installation is essential for making informed decisions, assessing financial viability, and effectively managing the project. It is a critical step in the process of adopting solar energy and transitioning to a more sustainable and cost-effective energy source.

Table 9 show how these parameters behave for the different installations in the study.

Table 9. Techno-economic data of the PV installation

Parameter	Value
PV system lifetime	20 years
PV installation cost	1.033 €/kW
Operating cost	10 €/kW/year
Interest rate	3%

3.4 Implementation

3.4.1 In Python

With the exception of Case 4, the EC modelling was implemented in python. The provided code is an implementation of three Python functions that perform calculations related to energy consumption and production in a set of houses and a sports centre. The three functions, `fixed coefficients` (Case 1), `variable coefficients` (Case 2), and `proportional coefficients` (Case 3), perform similar calculations but with different approaches in terms of how surplus energy is distributed and energy is bought/sold based on various coefficients.

These functions take a Pandas DataFrame `df`, which contains data related to energy consumption and production in houses and a sports centre, and the number of houses `num_houses` as input, returning a dictionary with statistics related to energy consumption and money spent on energy. The statistics include self-consumed energy, self-sufficiency, money spent by each house, money saved by each house, money earned from the sale of energy by each house, money spent by the sports centre, and money saved by the sports centre.

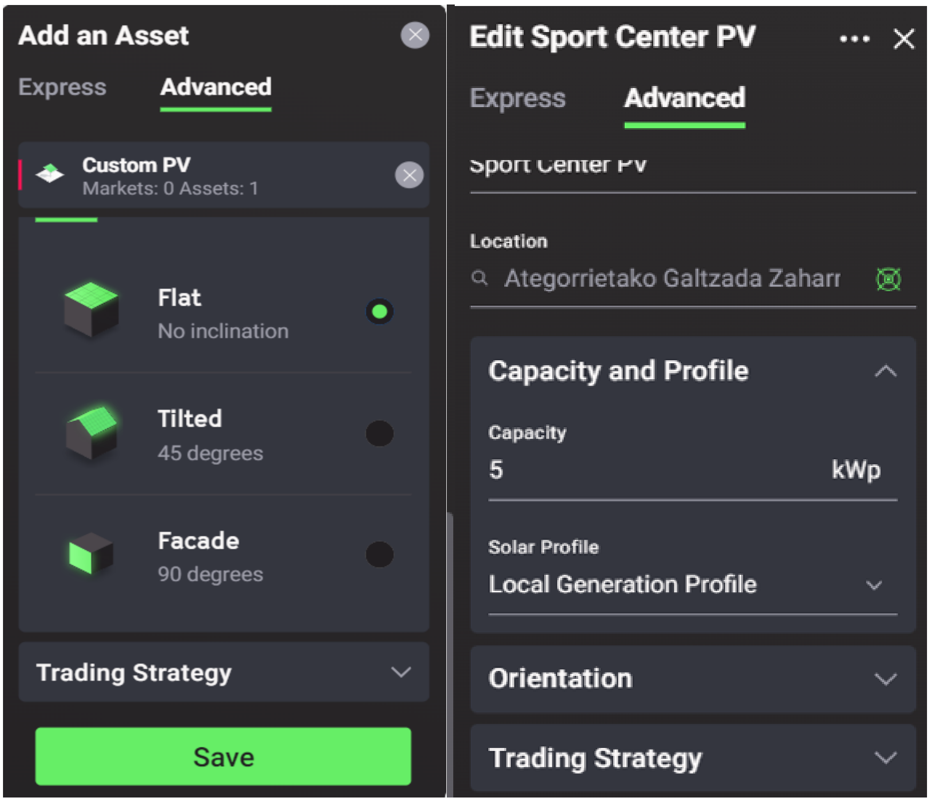
The code in each function performs detailed calculations to determine how surplus energy is distributed among houses and the sports centre, how energy is bought and sold, and costs and associated savings are calculated.

Additionally, the code also includes a `compute_stats_and_print` function that prints various statistics related to self-consumption, self-sufficiency, and other factors based on the data provided in the DataFrame and the statistics calculated by the `fixed_coefficients`, `variable_coefficients`, and `proportional_coefficients` functions. The choice of which of the three functions to use depends on how you want to calculate the distribution of energy and the specific coefficients-based costs and savings. Each function has its own approach and specific calculations to achieve this.

3.4.2 In Grid Singularity

Since the software imposes the inputs to perform the simulation in a certain way, this section explains how these inputs have to be interpreted so that the case is as similar as possible to case 1, 2 and 3 allowing a comparison.

In terms of PV installation and demand, there are no great differences. For the sizing of the PV installation, the system gives you the options shown in the image 16 and you only must enter the data according to your needs. While for demand, there are predefined profiles (Figure 9).



Add an Asset

Custom PV
Markets: 0 Assets: 1

● Flat No inclination
○ Tilted 45 degrees
○ Facade 90 degrees

Edit Sport Center PV

Sport Center PV

Location: Ategorrietako Galtzada Zaharr

Capacity: 5 kWp

Solar Profile: Local Generation Profile

Figure 8. Grid singularity's PV installation characteristics

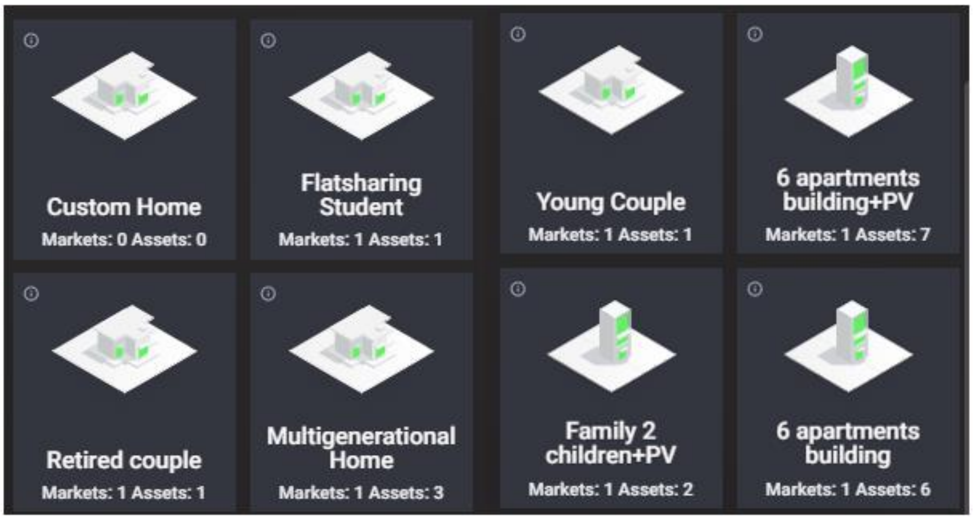


Figure 9. Types of consumption profiles provided by Grid singularity

The profiles chosen for the study are, for house 1 the "*Family 2 children profile*", for house 2 the "*Flatsharing student*" profile, for house 3 the *"Retired Couple" profile* and for house 4 the "*Young Couple*". In the case of simulating the behaviour of the Sport Centre we have chosen the "6 *apartment building"* and added 2 more loads to reach a similar consumption of the Sport Centre. And we have also added the generation at this point where the installed power will be changed for the different scenarios.

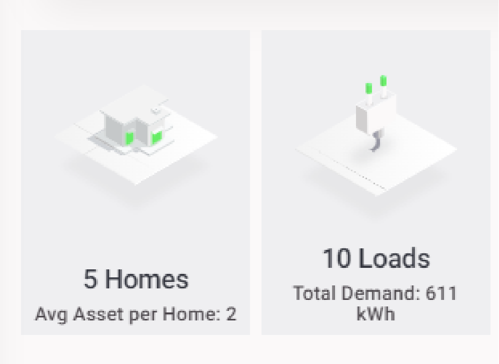


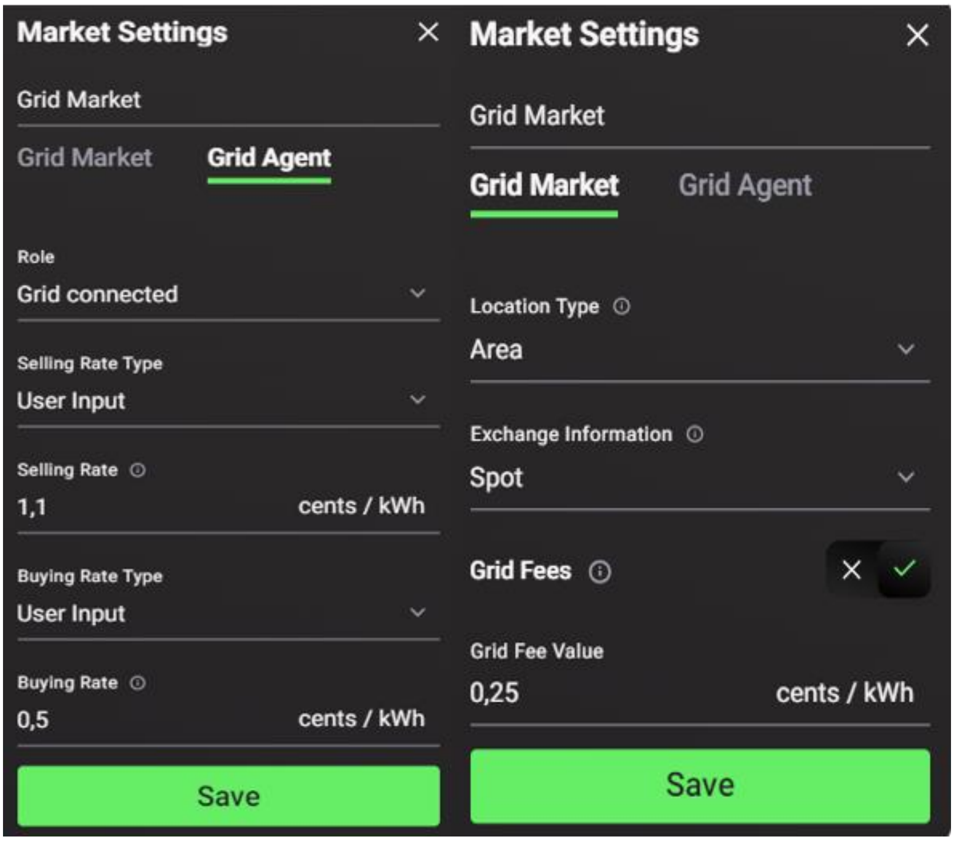
Figure 10. Total demand per week

As we can see in Figure 10 the total demand of the EC is 611 kWh, if we multiply by de weeks of a year it results in 32.383 kWh/year. Which is very similar to the 31.482,2 kWh/year of the Python simulation.

The main difference on the grid singularity modelling is on the market model used to share energy in the energy community. While in case 1-3 distribution coefficients rules were pre-agreed and energy sharing had no associated cost of transaction, here (case 4) the energy is traded between peers (P2P) and will have an associated trading cost. For this purpose, to fill in all the previous values related to the grid singularity EC energy market, it is necessary to make the annual average of the hourly prices used in the original case study since the value to be introduced in the simulation is a single value. To define these values it is important to identify what each term in the model refers to:

- **Selling rate:** this term refers to the price at which the community buys energy deficit from the external grid (utility), this value in our original study case is the same as the Energy price-PVPC which is the one that is taken from the OMIE, as explained above in order to have a single value, the annual average of this value is **0.11 €/kWh.**
- **Buying rate:** This term refers to the price at which the external grid (utility) buys surplus from the community, this value in our original study case is the same as the Surplus Energy price which is the one that is taken from the REE, as explained above in order to have a single value, the annual average of this value is **0.055 €/kWh**.
- **Grid Fee value:** This term refers to the grid fees charged to trade in this market, this value in our original study case is the same as Grid tariff price which is the one that is taken from the retailer, as explained above in order to have a single value, the average between both periods is **0.025 €/kWh**.

Figure 10 show how to enter the values explained in the software.



Role: Grid connected
Selling Rate Type: User Input
Selling Rate: 1,1 cents / kWh
Buying Rate Type: User Input
Buying Rate: 0,5 cents / kWh

Location Type: Area
Exchange Information: Spot
Grid Fees: ✓
Grid Fee Value: 0,25 cents / kWh

Figure 11. Dashboard of the data to be entered in terms of energy and grid tariffs.

The model is run for 7 days, as such it is necessary to extrapolate the results to an entire year.

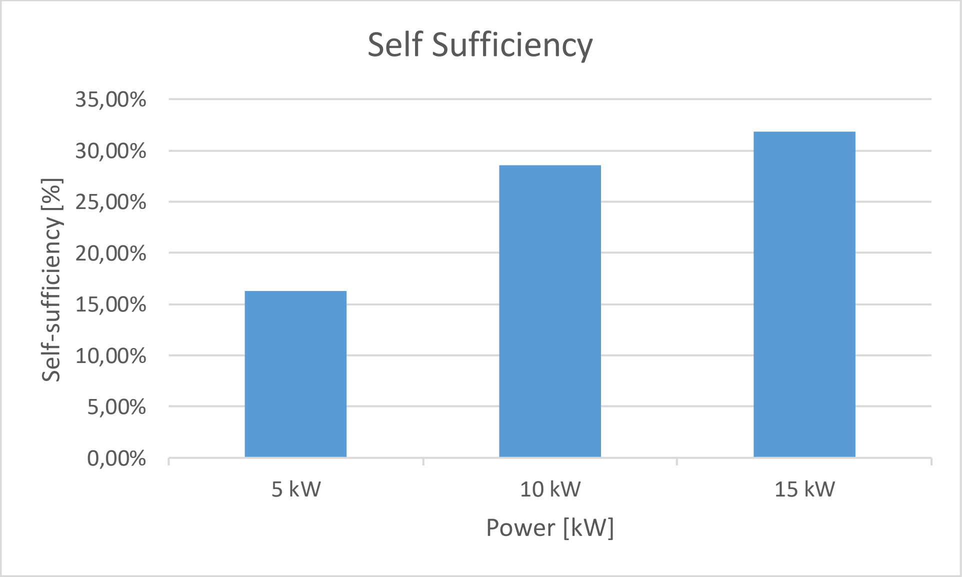
As can be seen, there are several assumptions to simulate the Python case in Grid singularity. The most notable difference between the two software is in the hourly profiles, as the consumptions are similar but in no case comparable, as the consumptions assumed by Grid singularity are different to those of the real case. Another key point to highlight is the tilt, as in the case of Grid singularity it is assumed to be flat and in the case of Python it is 10º. In addition to these differences in the simulations, there is also a differential component as the internal energy distribution in Grid singularity is slightly different from the one imposed in Python because the internal code varies compared to the one done in Python. These slight differences will have a direct impact on the comparison of the cases, and it should be noted that it is not fully comparable due to these conditions.

4 RESULTS

In order to present the results of this case study, we will follow the methodology set by the KPIs explained in order to facilitate the understanding of the figures. First of all, the self-sufficiency of each case will be illustrated, followed by the self-consumption, monetary savings and payback of the EC for each case.

4.1 Case 1

4.1.1 Self-sufficiency

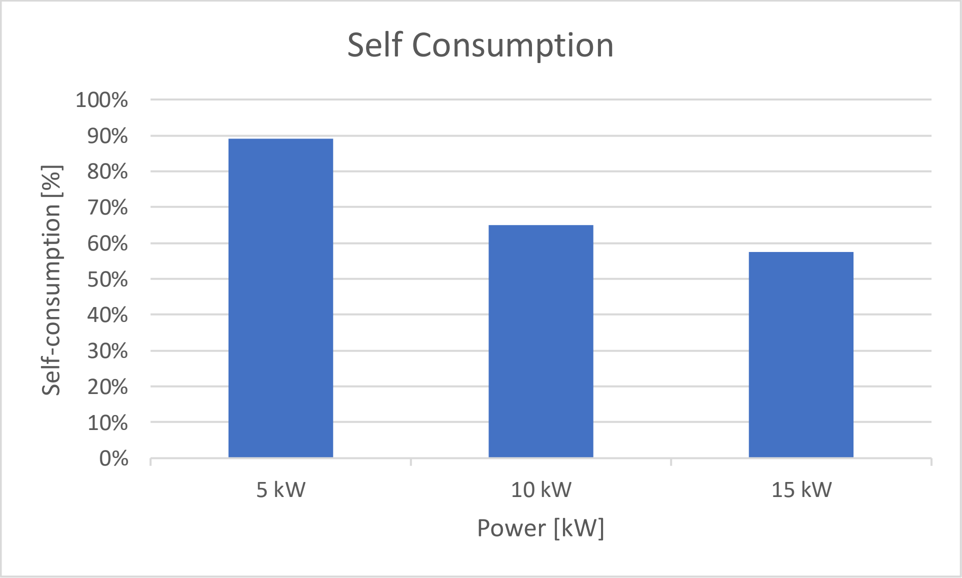


Graph 6. The self-sufficiency of case 1 as a function of the power of the installation PV

As we can see in Graph 6 as the power of the installation increases, the self-sufficiency of our EC also increases. In this particular case, for the 5 kW installation the self-sufficiency is 16,31% but when increasing the installation up to 15 kW its self-sufficiency rises up to 31,83%. This is because a higher capacity allows the community to produce more electricity internally, this results in a reduction of its reliance on external energy sources such as the grid dependence or external energy providers. That increase of PV capacity gives the EC the more energy to generate and manage its own energy without significant dependence on external providers.

4.1.2 Self-consumed energy

This KPI tells us how much of what the EC has generated is consumed by the EC itself. As can be seen in the graph, the more electricity you generate due to the increased capacity of the PV installation, the lower the self-consumption. In this case the self-consumption for the 5-kW solar installation is 89%, for the 10 kW installation is 65% and for the 15 kW installation is 57%. As can be seen, the decrease of the percentage of self-consumption with respect to the increase of energy produced is smoother as the power increases.

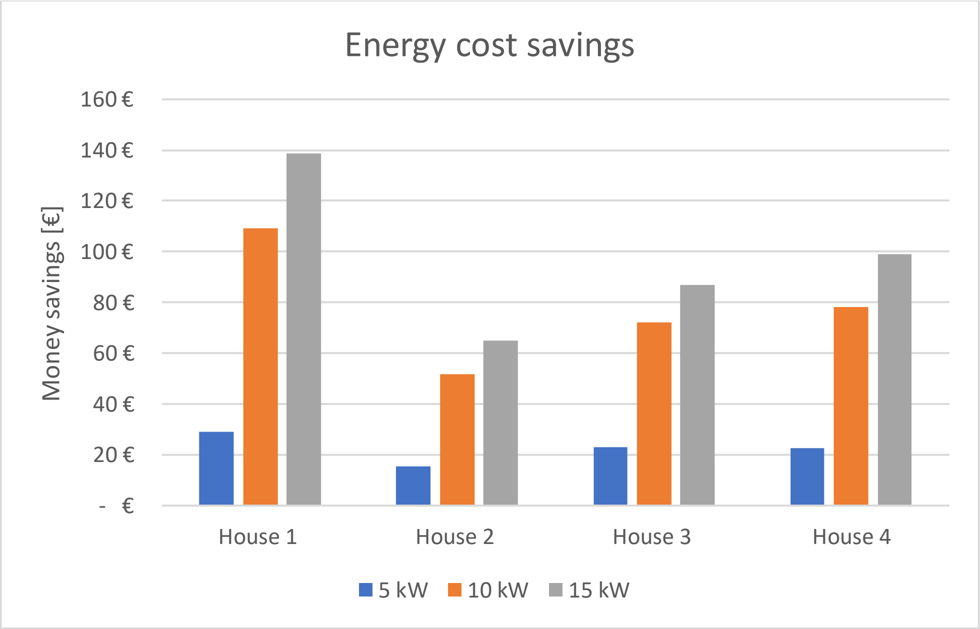


Graph 7. The self-consumption of case 1 as a function of the power of the installation PV

4.1.3 Energy cost savings (yearly)

To analyse the savings, the prosumer savings are separated from the consumer savings, since the savings are much higher for the sport centre due to its higher demand.

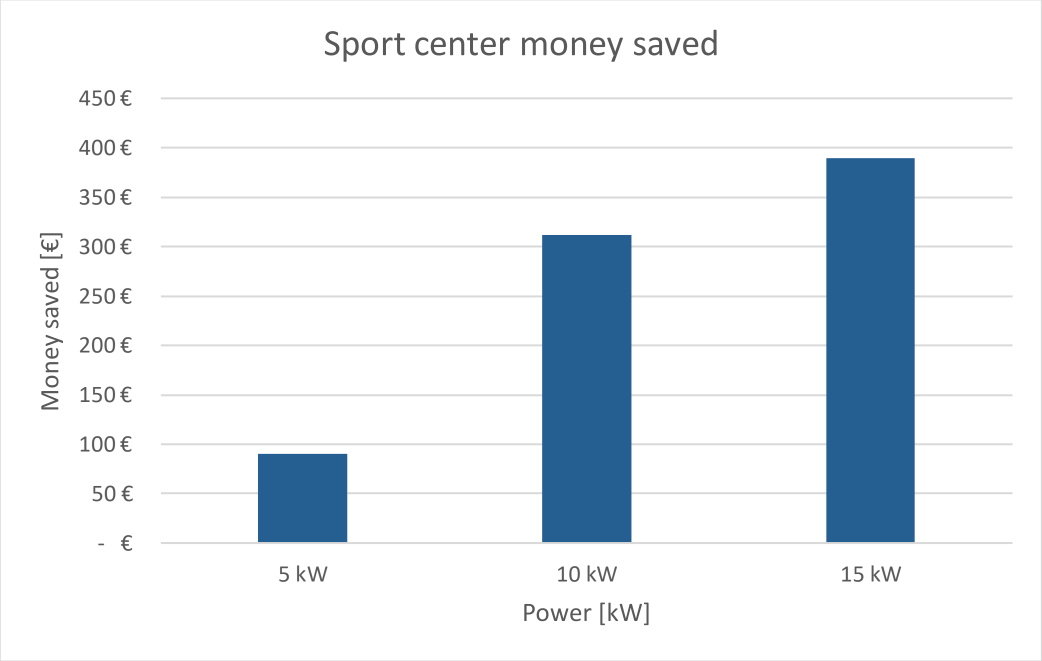
- Consumer



Graph 8.Savings generated in each house depending on PV installation.

One of the most important KPIs in this type of studies is always the monetary one and the amounts saved in each case. For the explanation of this KPI we have separated the energy savings per house and per installation power. As it be seen, in all the houses the savings increase in the same measure as the PV capacity increases. On the other hand, it can be seen how the savings in each house are different, especially in house 1, which has higher consumption and saves more because its consumption is higher. This is because the amount of self-consumed energy is higher than that of the other houses.

- Prosumer



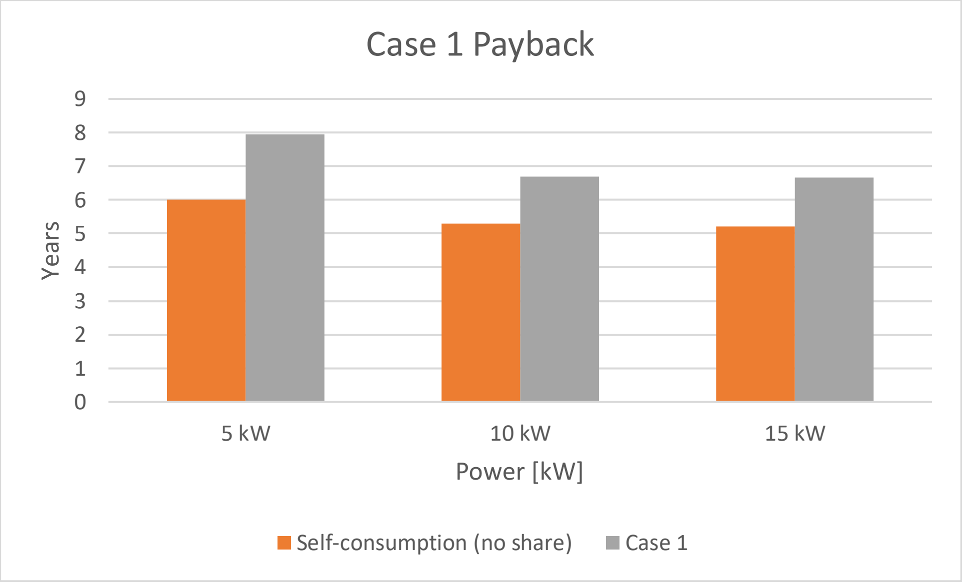
Graph 9. Savings of the sport-centre depending on the PV installation

Apparently, as in the case of consumers, the more renewable energy the installation produces, the greater the savings for the prosumer because in some cases it saves and in others it sells, this savings are reflected in the graph 9.

4.1.4 Payback

For the payback calculation, the installation has been compared in the case of not sharing its energy (self-consumption), vs. collective self-consumption, which is the case of sharing the surplus energy of the sport centre with the 4 houses.

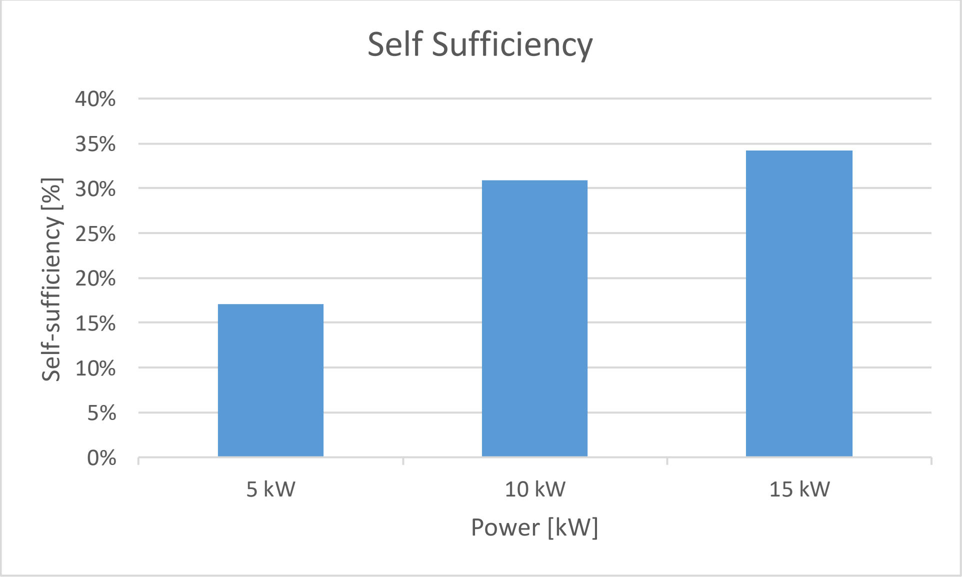
As can be seen in Graph 10, the payback period if you share with neighbouring houses is increased, especially for the 5 kW installation. The payback in this case increases because consumers only pay the grid tariff to consume the prosumer's energy, which does not generate any benefit for the prosumer, who is the one making the investment for this case. The normal thing would be to establish a previously agreed monthly fee in a way that would be a win-win contract. But in this case, the prosumer makes more profit by selling the energy to the grid than by sharing it with neighbours.



Graph 10. Case 1 Payback vs PV installation without sharing the Surplus

4.2 Case 2

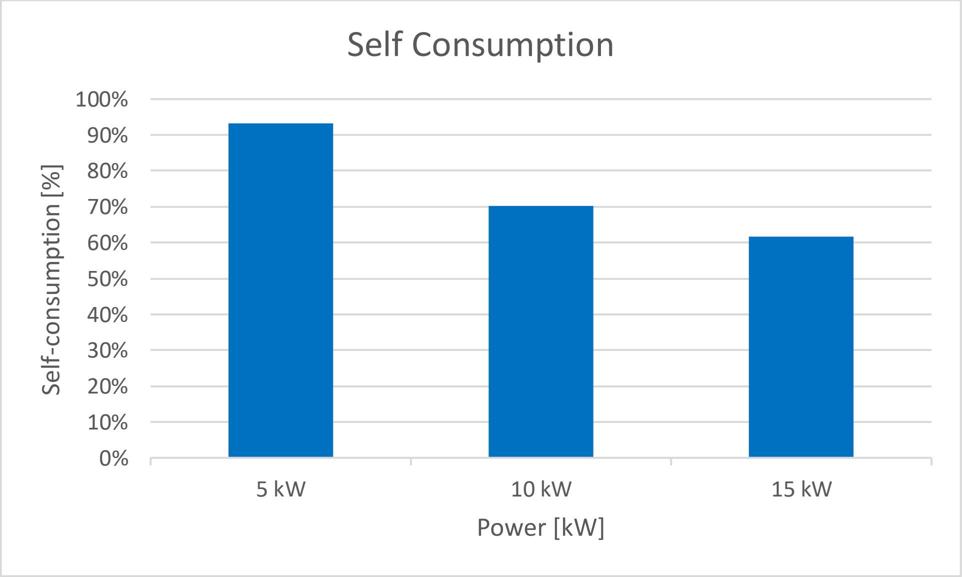
4.2.1 Self-sufficiency



Graph 11.The self-sufficiency of Case 2 as a function of the power of the installation PV

As in case 1, the self-sufficiency increases as the installation increases for the simple reason that in the total energy consumed there is a higher percentage of energy consumed internally by the EC. In this case for the 5 kW system the percentage of self-sufficiency is 17,05%, for the 10 kW system it is 30,87% and for the 15 kW system it is 34,16%.

4.2.2 Self-consumed

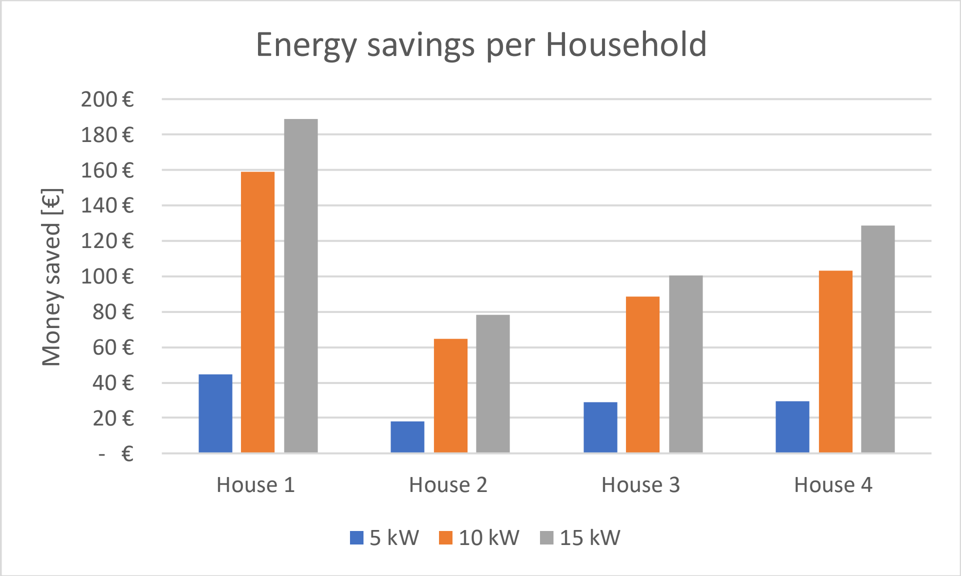


Graph 12. The self-consumption of Case 2 as a function of the power of the installation PV

For self-consumption in this case, as in the previous one, and for the reasons explained above, the percentage decreases as the PV capacity increases. For the 5 kW installation the percentage is 93,13%, for the 10 kW installation it is 70,33% and for the 15 kW installation it is 61,64%.

4.2.3 Energy cost saving

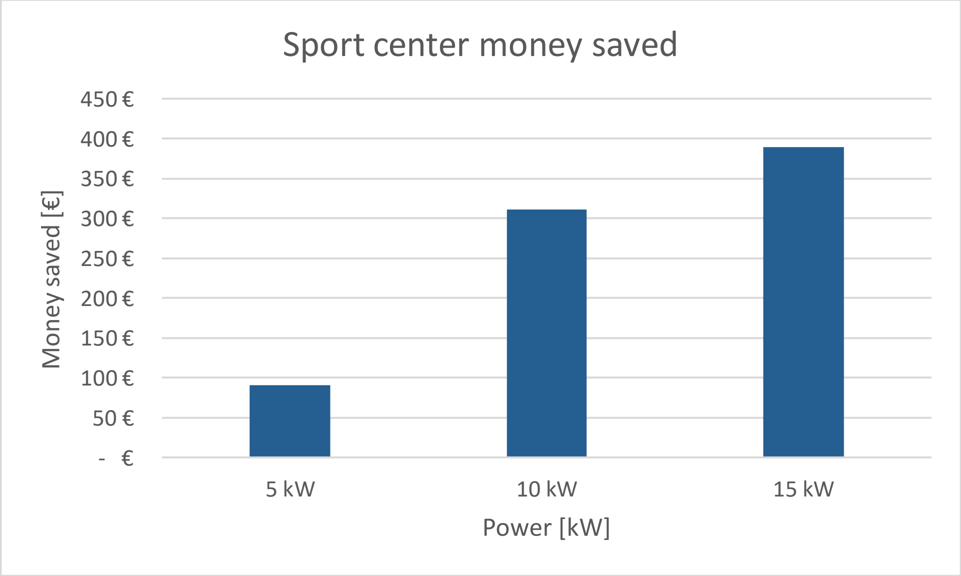
- Consumer



Graph 13. Savings generated in each house depending on PV installation for Case 2

To analyse the savings of each house in this case, we can see that for the same reason as in the previous case, the savings increase when the production is higher. It is worth noting that the savings of the house is significantly higher because the consumption of this house is the highest of the 4, which generates higher savings.

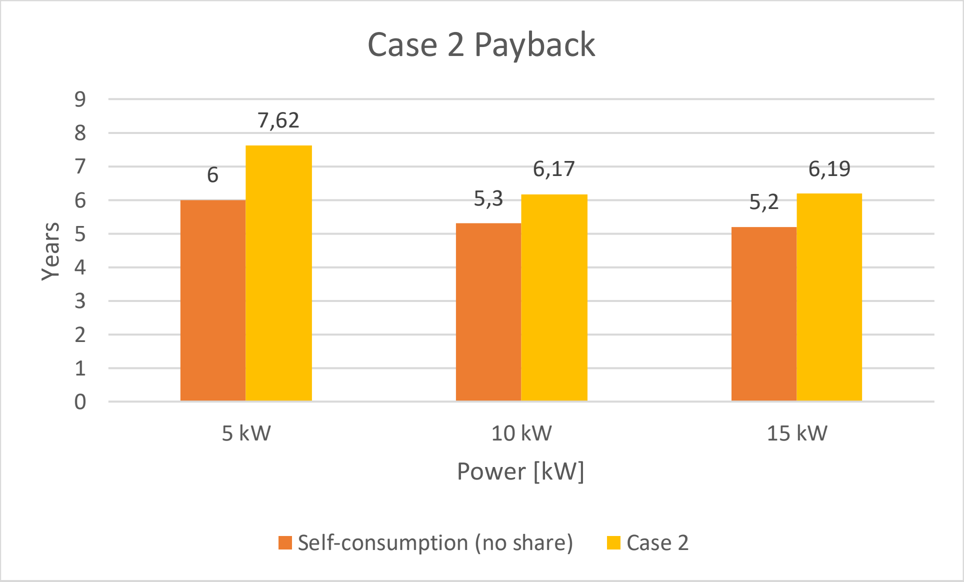
- Prosumer



Graph 14. Savings generated in the sport-centre depending on the PV installation

The same phenomenon as in the previous case, when production increases, the savings of the sport centre are higher. More energy generated means more money saved.

4.2.4 Payback

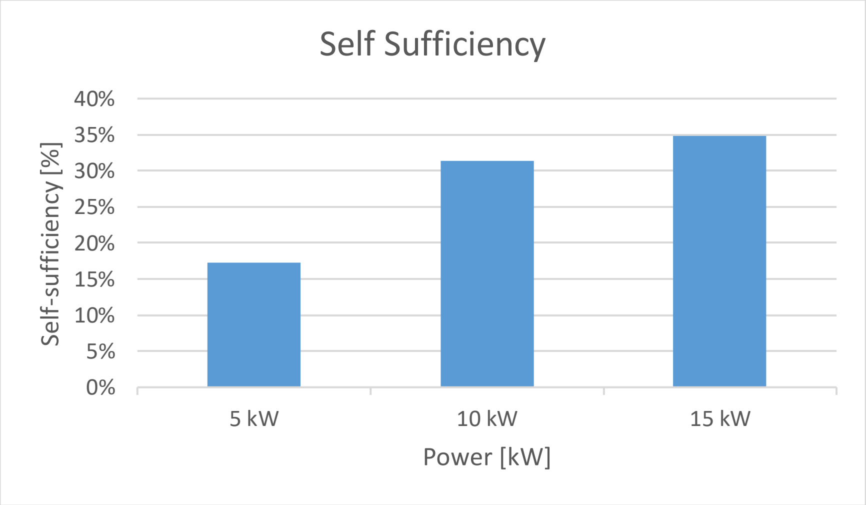


Graph 15. Case 2 Payback vs PV installation without sharing the Surplus

As can be seen in Graph 15, the same phenomenon as for case 1 is fulfilled. The payback increases significantly if the PV installation acts like a prosumer of an EC, especially for the 5 kW installation, The more energy you share without making beneficial contract the higher is the payback. This payback increase is because the investment is assumed to be made by the prosumer.

4.3 Case 3

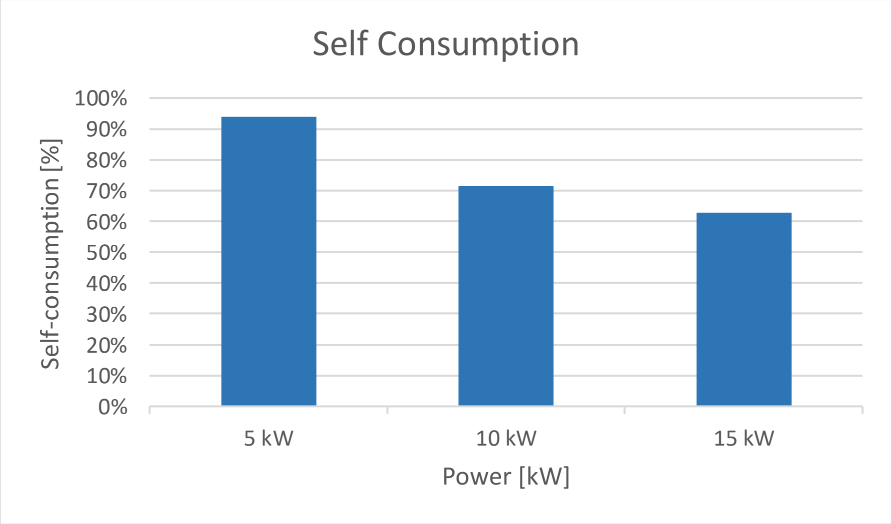
4.3.1 Self-sufficiency



Graph 16.The self-sufficiency of Case 3 as a function of the power of the installation PV

When analysing the self-sufficiency of case 3, it can be seen how for the 5 kW installation the percentage is 17% and when increasing its production to double up to 10 kW its percentage increases proportionally, and the same for the 15 kW installation where the maximum percentage of self-sufficiency is reached. This means that there is still a great margin to increase the local production of the EC to maximise the self-sufficiency although there will be a power in which the self-sufficiency will stabilise as it can never be 100% due to the hours of photovoltaic production.

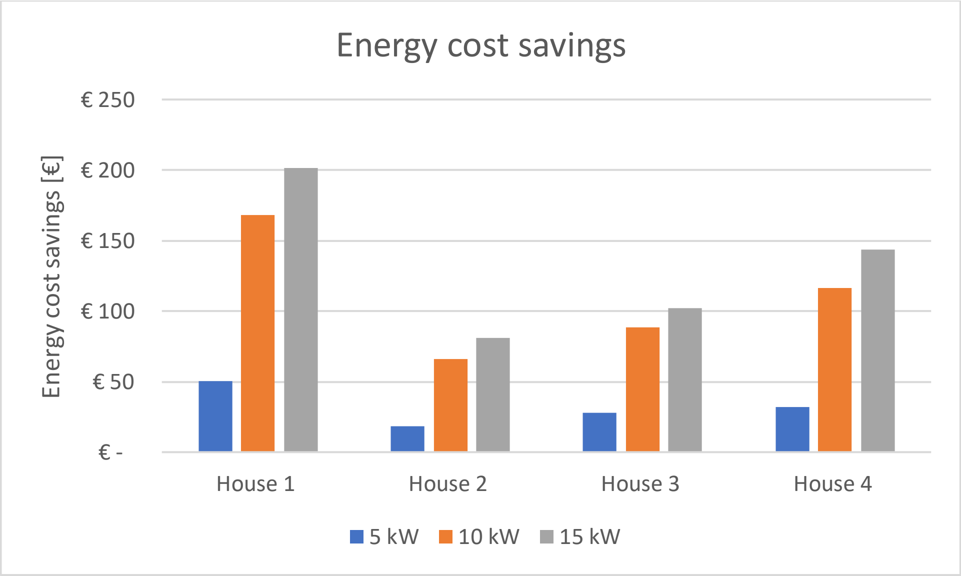
4.3.2 Self-consumption



Graph 17. The self-consumption of Case 3 as a function of the power of the installation PV

Looking at the data for the self-consumption KPI for case 3, it can be seen that for the 5 kW installation this KPI reaches almost 95% and decreases proportionally as the capacity increases. This is due to the fact that not all the energy generated is consumed, since at peak production time the demand is lower in the case of the houses. For factories or offices this behaviour would be different.

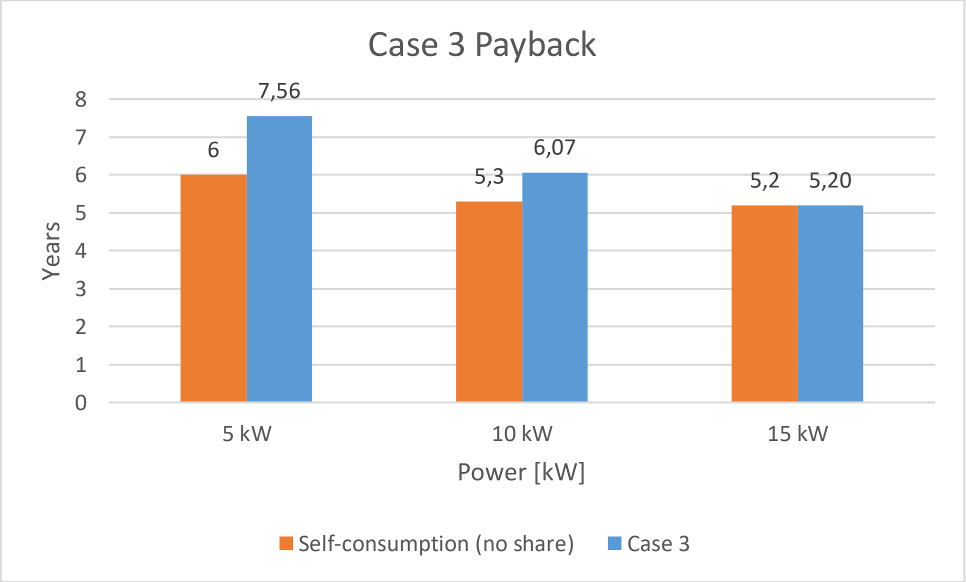
4.3.3 Energy cost savings



Graph 18. Savings generated in each house depending on PV installation for Case 3

The energy savings generated through variable coefficients without preferences triple as soon as the PV Capacity is doubled, this jump is not as noticeable for the difference between the 10 kW and the 15 kW installation. The difference in savings for the first two installations is due to the fact that the 5 kW installation is undersized for the EC in question, so as the appropriate power is adjusted the savings go up.

4.3.4 Payback



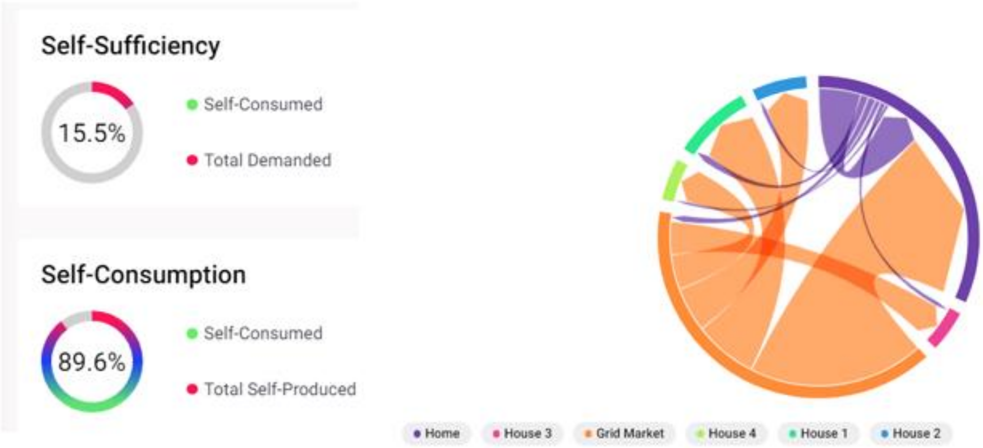
Graph 19. Case 3 Payback vs PV installation this without sharing the Surplus

Same casuistry as the two previous cases, the savings generated to the SportsCenter in the 5 KW PV installation is less than with the other installations but as the cost of the installation is cheaper the difference is more notable in terms of Payback. As the power increases, the gap between the payback of selling the surplus to the network or selling it as a prosumer to neighbours narrows.

4.4 Case 4

The simulation has been carried out in blocks of 7 days to complete a year and thus make a meaningful study in terms of the comparison of cases that is made later. In the following subsections you can see the dashboard results obtained from the simulation of the 3 PV sizes installations.

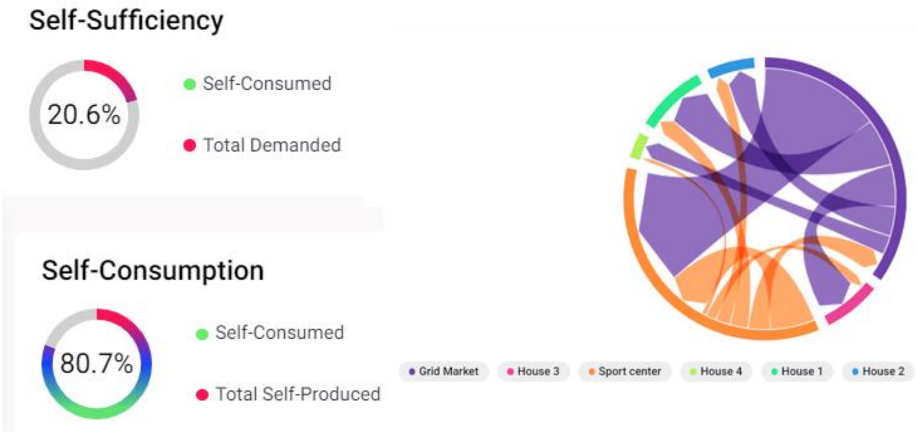
4.4.1 5 kW PV installation



Graph 20. Self-Sufficiency, Self-consumption & energy trades of the Grid singularity simulation (5kW)

Studying the graphs obtained through the Grid Singularity software, it can be seen that for the 5 kW installation, most of the energy consumed is from the grid, which reduces the self-sufficiency to 15,5%. It can also be seen that the sale of energy to the sport centre's grid is small, which means that the self-sufficiency is reduced to 15,5%.

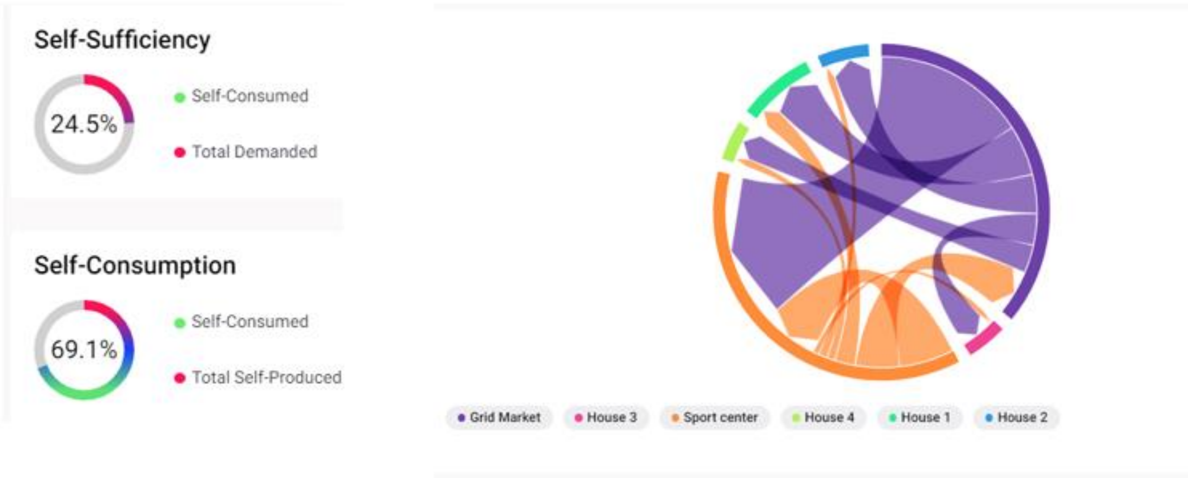
4.4.2 10 kW PV installation



Graph 21. Self-Sufficiency, Self-consumption & energy trades of the Grid singularity simulation (10 kW)

As we can see in Graph 21 in the Trades sub graph, the energy purchased from the sport centre is lower than that exported to the grid because the solar energy generation is higher at times when the houses do not consume energy and this results in a self sufficiency of 20,6%. As for the self consumption, since the excess energy cannot be used internally during peak hours, the percentage ends up being 80%.

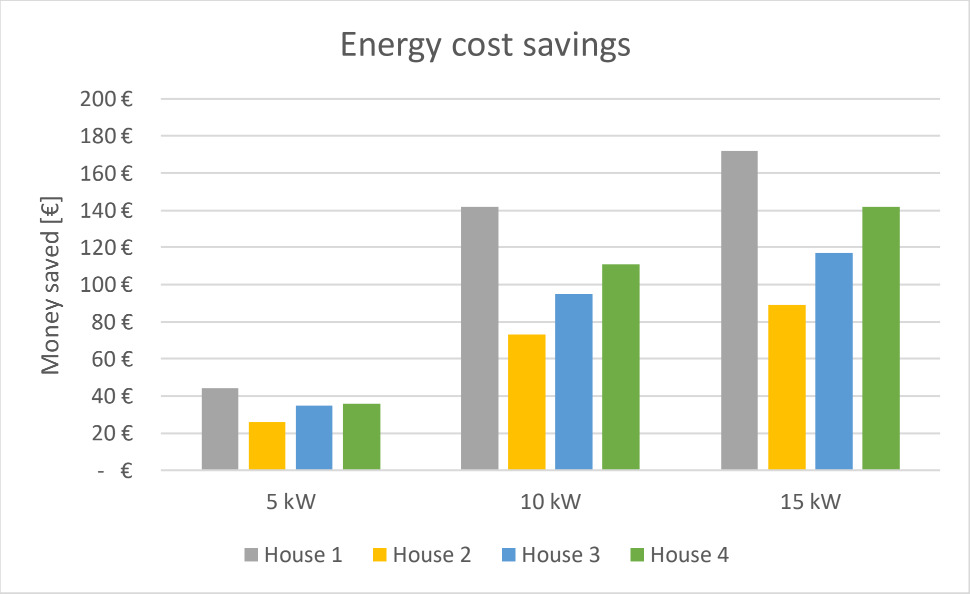
4.4.3 15 kW PV installation



Graph 22. Self-Sufficiency, Self-consumption & energy trades of the Grid singularity simulation (15 kW)

For the highest production plant, the percentages vary with respect to the previous plants. Following the same criteria as the explanation of the 10 kW installation, the problem of not meeting the demand at peak hours and not consuming all the energy produced when the production values are high, generates a reduction in self-consumption very noticeable being in this case 69,1%. This problem could be easily solved by adding batteries to the system.

4.4.4 Energy cost savings

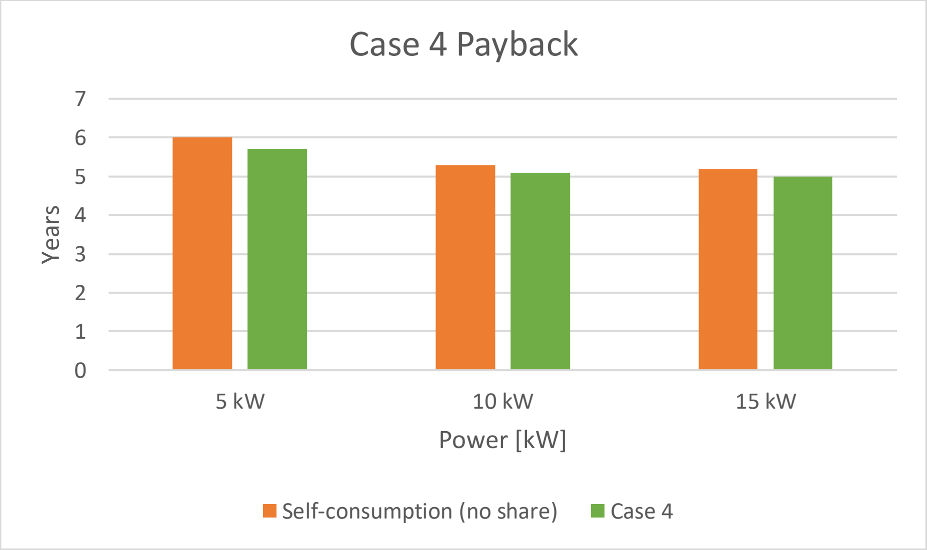


Graph 23. Case 4 energy cost savings

The savings generated through the grid singularity simulation are not very accurate since the simulation has been extrapolated to a whole year's savings, and the variation of electricity prices over the year has not been taken into account. But assuming the average energy prices per month we have obtained the results shown in Graph 23. Actually for the P2P model the savings and energy prices are independent of the electricity market but to make a useful comparison, we have selected data similar to the previous cases.

Even so, it can be seen how the savings for the 5 kW installation is more equitable, although as the capacity of the installation increases, the differences in savings are more noticeable due to the energy demands of each house.

4.4.5 Payback

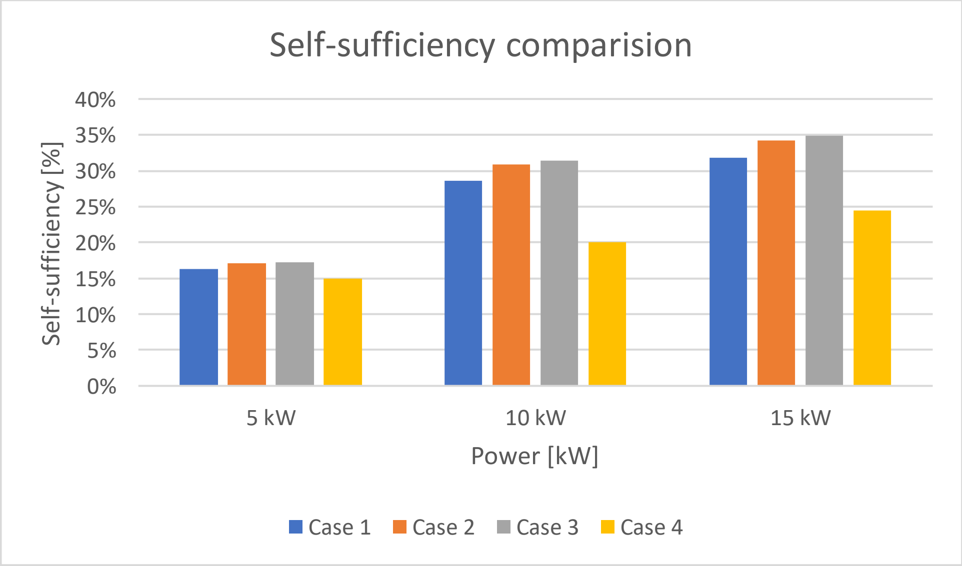


Graph 24. Case 4 Payback

For case 4 it can be seen how the payback is slightly reduced with the calculations performed, this happens because for the P2P case the simulator performs the calculations and targets based on the common benefit of the energy community and not only of the consumers or the consumer or prosumer with the highest demand.

4.5 Case comparison

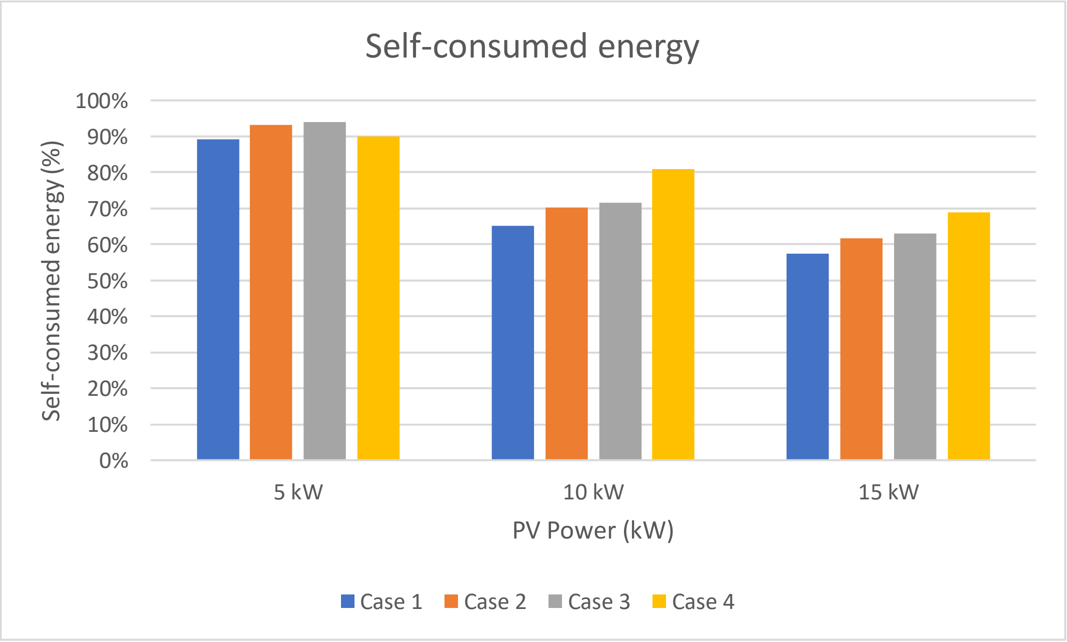
4.5.1 Self-sufficiency



Graph 25. Self-sufficiency comparison between the 4 cases

When comparing the 4 cases in terms of self-sufficiency, it can be seen that for the first three cases the percentage of this KPI is higher than the one of the simulations with Grid singularity. This difference in percentages is due to the fact that the simulations made with Python takes into account the production and demand of the EC over a whole year and per hour. On the other hand, case 4 the self-sufficiency is the lowest, that can happen because for this EC case members have the ability to set their own energy prices, which can vary based on supply and demand dynamics and that affects directly to the distribution and the preferences of each EC. This difference may also be due to the fact that the data are not the same after all, as the grid singularity consumption profiles are simulations that may vary slightly from the house profiles of the first 3 cases. However, for the other cases it can be seen how the percentage of the KPI increases, this is due to the fact that by modifying from a fixed coefficient to a variable coefficient distribution, increases the self-sufficiency by enabling more efficient and tailored energy allocation among the four houses, reducing the need for external energy and optimizing energy distribution to better match changing community needs in real-time. This results in less energy waste, decreased reliance on external energy sources, and a higher proportion of locally generated energy being consumed.

4.5.2 Self-consumption

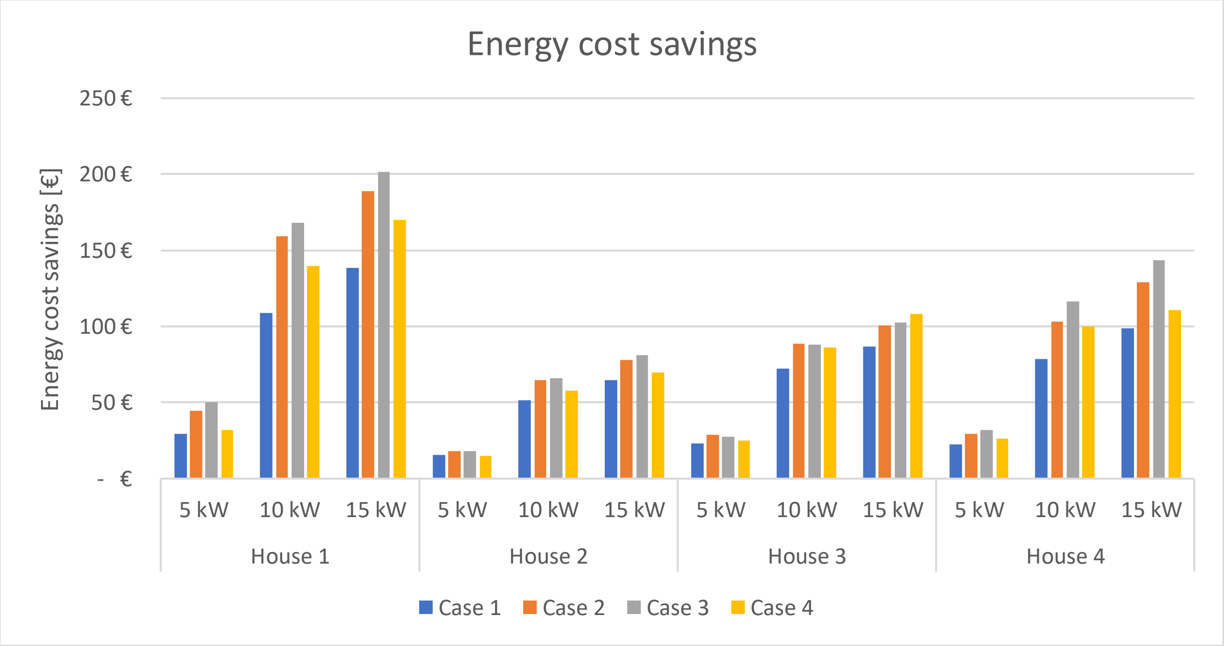


Graph 26. Self-consumed energy between the 4 cases

When approaching the comparison of this KPI, it is important to remember that it measures the capacity of the EC to self-consume what it produces. As we can see in the graph, for case 1 the percentage is lower than the other three cases, this is due to the fact that the energy self-consumed is not the maximum because the distribution coefficients are fixed. This makes sense because as it has been said if you impose that each house consumes an exact amount of the energy produced, there will be a house that at certain times is not needing it and will pour that energy excess to the grid when there is another house that would need that energy at those times, so for case 1 the EC is losing energy produced from the prosumer because the energy distribution is not optimal. For case 2 and case 3 the percentages of self-consumption are very similar also to the percentages of the Grid singularity because although the energy distribution of Case 2 gives preference to the house that consumes the most energy, the energy generated will always be self-consumed to the maximum because the distribution coefficients are variable, this implies that whenever there is production to meet the demand, it will be distributed all without having to evacuate one of the houses excess of energy to the grid, because it first checks if all the houses are satisfied energetically. For case 3, the EC allows a more efficient response to fluctuations in energy generation and consumption, ensuring that the surplus energy is channelled where it's needed most at any given moment, that results in the highest self-consumption of the first 3 cases. In the case of Grid singularity which simulates the operation of the peer-to-peer EC, although the management of the EC can be complicated, it offers a high degree of flexibility, allowing members to adapt to changing energy needs, pricing, and market conditions. This makes self-consumption the maximum for these cases.

It should also be noted that the percentages of all cases decrease as the power of the installation increases, this is due to the fact that throughout the day more energy is produced than can be consumed. For energy communities with higher demand than production, the self-consumption will be higher because everything that is produced will be consumed resulting on a higher percentage of the self-consumption KPI.

4.5.3 Energy cost savings



Graph 27. Energy saving comparison between the first three cases.

When analysing the energy savings of the different cases for the different houses, it is important to focus on Graph 29, the graph also differentiates the savings by the power of the installation. The more energy is produced, the “cheaper” energy each house gets and consequently the more it saves during a year. This phenomenon occurs for each house.

On the other hand, when comparing by type of distribution coefficients, it can be seen that if we keep these coefficients fixed (Case 1), the monetary savings in terms of energy consumption is lower because the energy that is being produced is not being correctly distributed and may receive more energy than necessary, leading to unnecessary external energy purchases.

With a variable coefficient (Cases 2 & 3), the community is more likely to be able to meet its energy needs internally, using locally generated energy. This reduces dependence on external energy purchases, which in turn increases the savings as it can be seen in the graph.

This can be seen directly by comparing the blue columns with the orange or the grey ones. If the distribution coefficients are variable, the monetary savings of the houses increase to almost 20% due to an energy distribution that adjusts to the demand of the houses.

As for the comparison of case 2 and case 3, it can be seen that case 3, apart from being a fairer distribution of energy (because it distributes the energy proportionally to the demand), it generates more savings for all the houses, and it is even more noticeable in the houses where there is more accumulated consumption. This is due to the fact that for case 2 there will be moments in which the houses with lower consumptions will have high punctual consumptions and the houses with higher accumulated consumptions will become secondary to perceive the energy surplus. Case 2 turns out to be detrimental to all households as it does not distribute the energy proportionally every hour.

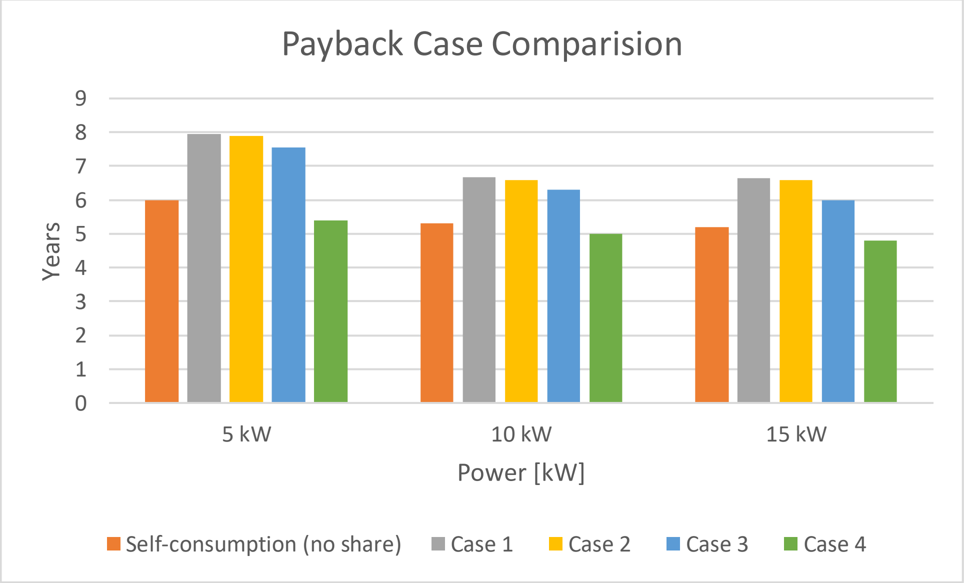
For case 4 the savings are more fluctuating depending on the consumer and each installation, since being a P2P case, each energy community will obtain different results depending on the preferences of each one. For this particular case it can be seen how all consumers save less than with a distribution coefficient EC except for the case of house 3 of the 15 kW installation.

However, it is important to note that in P2P communities, members can set their own energy prices, which can vary according to the dynamics of supply and demand.

4.5.4 Payback

For the comparative analysis of the paybacks of each case, it is worth noting that they have been obtained through the savings generated by the type of distribution of the coefficients and the installation cost obtained in the PVsyst as well as the price of energy mentioned in point 3.3.5.

If we analyse the comparative graph, we can see how the payback is barely reduced with respect to the type of coefficients used, this is because as it has been explained before the payback focuses on the investment made by the SportsCenter. This payback is reduced in the case of the P2P energy community, as several variables come into play that make the prosumer increase his income from the sale of energy to both consumers and the grid.



Graph 28. Comparison between the first 3 cases in terms of Payback

It is noteworthy to mention that to calculate the payback of an energy community, many variables have to be taken into account and can vary greatly depending on how the business model of each one is made. For this case study we try to maximise the savings of the consumers, this means that they only pay the grid tariff for using the distribution network and the prosumer does not benefit from it. The consumers also do not contribute to the initial investment in the PV installation, which generates greater savings but higher costs for the sport centre. These scenarios have been set out to demonstrate what consumers would save with the help of public energy communities subsidised by governments, i.e., with no investment costs. For private ECs, consumers would have to pay an initial investment or an extra monthly fee to the prosumer.

In brief, the specific payback period will vary depending on the economic circumstances of each energy community.

5 CONCLUSIONS

This work started with the objective of technically and economically assessing the best way to share energy between users of a EC. To this end, a specific methodology and model has been developed in order to evaluate which options are most favourable to the economic prospects of the EC, in addition to their degrees of self-consumption and self-sufficiency. This model simulates an EC with an hourly time resolution for a full year so that it is able to evaluate the economic impact of variations in the grid price, the demand curves throughout the year and the management that is carried out of the energy of energy surpluses in the EC.

The model was applied to a case study in the city of San Sebastian using real household and SportsCenter consumption data. In addition, the use of static distribution ratios, as reflected in the current rules, has been compared with variable distribution ratios and a P2P model in order to assess the impact of making ECs more flexibles. The results obtained show that the EC's self-sufficiency and self-consumption percentages are increase by 5% when the production of the EC is adjusted to the demand of its participants and are no longer fixed, either by making the fixed coefficients variable or by using the P2P model. This improvement is even higher for the energy savings, increasing by up to 20 % in the best-case scenario. The best results for the EC are obtained for the variable coefficients and the P2P model. It is important to note that, as explained in the assumptions made for the Grid-singularity P2P, the comparison with the other cases is not entirely reliable due to software restrictions and assumptions.

Although it is important to note that the payback for these cases is not reduced by the same percentage as the savings, this is due to the assumption that the investment in the solar installation corresponds to the prosumer, but this assumption can be modified for another study and make all participants contribute an initial investment, which would generate a lower payback. Another option could be to increase the prosumer's revenue by charging a monthly/annual fee from the consumers, such as P2P which considers the energy exchange between neighbours paying amounts of money directly to each other. That is why the payback of the P2P model (Case 4) is the shortest of all.

This work focuses specifically on energy production and demand, one of the limitations of this work is not having included in the EC a battery system that would make the EC a more efficient smart grid and generate more savings. One of the points for future work should be to include batteries in the system. In addition, another proposal would be to make contracts and financial agreements between the participants of the energy communities which would decrease the payback and make the EC more enriching for all the members who belong to it.

Energy community projects have a lot of potential to advance towards a more sustainable and fairer energy transition as shown by the literature. However, this potential needs to be understood by the society to make the right efforts and investments. Therefore, one of the first recommendations to be made to the ECs would be to implement models such as the Variable coefficients or P2P model so that users can be given economic security and profit at the moment of joining this kind of projects.

For those reasons the use of variable coefficients is recommended to achieve a better match between production and demand. However, the current regulatory framework does not yet allow the use of variable coefficients and the actual framework only contemplates updating the fixed ones once a year. Therefore, a recommendation for the ECs is to lobby public entities to achieve a favourable and stable regulatory framework that provides certainty, clarity, and predictability to the development of ECs. To have an impact in this area, collaboration between the different energy communities will be important in order to achieve synergies that favour all those who embark on these projects and encourage the entry of new ECs. Collaboration between people will be essential to achieve a human-scale and fair energy transition.

REFERENCES

ARERA. (2019). *ULTERIORI DISPOSIZIONI IN MERITO ALLA SUDDIVISIONE DELLA RETE RILEVANTE IN ZONE, IN ESITO AL PROCESSO DI REVISIONE SVOLTO AI SENSI DEL REGOLAMENTO (UE) 2015/1222 (CACM) L'AUTORITÀ DI REGOLAZIONE PER ENERGIA RETI E AMBIENTE*.

Bauwens, T. (2017). Polycentric governance approaches for a low-carbon transition: The roles of community-based energy initiatives in enhancing the resilience of future energy systems. In *Green Energy and Technology* (Vol. 0, Issue 9783319337524, pp. 119–145). Springer Verlag. https://doi.org/10.1007/978-3-319-33753-1_6

Bilan_Electrique_Enedis_Analyse_Annuelle_2019. (n.d.).

BMWI. (2017). *Renewable Energy Sources Act (EEG 2017)*.

BOE. (2019). *DIRECTIVA (UE) 2018/ 2001 DEL PARLAMENTO EUROPEO Y DEL CONSEJO - de 11 de diciembre de 2018 - relativa al fomento del uso de energía procedente de fuentes renovables*.

BOE-A-2020-6621-consolidado. (2020). *BOE* .

Brown, D., Hall, S., & Davis, M. E. (2020). What is prosumerism for? Exploring the normative dimensions of decentralised energy transitions. *Energy Research and Social Science*, *66*. https://doi.org/10.1016/j.erss.2020.101475

C4CE. (n.d.). National-Community-Energy-Strategy. *C4CE*.

Candelise, C., & Ruggieri, G. (2020). Estatus and evolution of the community energy sector in Italy. *Energies*, *13*(8). https://doi.org/10.3390/en13081888

Caramizaru, Aura., Uihlein, Andreas., & European Commission. Joint Research Centre. (n.d.). *Energy communities : an overview of energy and social innovation.*

De, M., & Écologique, L. T. (2021). *Décrets, arrêtés, circulaires TEXTES GÉNÉRAUX*.

del Río, B. (2017). La gobernanza global de la energía. *Anuario Español de Derecho Internacional*, *32*, 439–473. https://doi.org/10.15581/010.32.439-473

den-belitsky. (n.d.). *Annual Report 2017 Networks for the future*.

Diário da República. (2019). *Diário da República, 1.ª série PRESIDÊNCIA DO CONSELHO DE MINISTROS.*

Diário da República. (2022). *Diário da República, 1.ª série PRESIDÊNCIA DO CONSELHO DE MINISTROS.*

Frieden, D., Tuerk, A., & Neumann, C. (2020). *Collective self-consumption and energy communities: Trends and challenges in the transposition of the EU framework*. https://doi.org/10.13140/RG.2.2.25685.04321

Gazzeta Ufficiale. (2020). *662-Filiale di Roma Roma-Sabato, 29 febbraio 2020 Supplemento ordinario alla “Gazzetta Ufficiale” n. 51 del 29 febbraio 2020-Serie generale Spediz. abb. post.-art. 1, comma 1 Legge*.

Hernandez-Matheus, A., Löschenbrand, M., Berg, K., Fuchs, I., Aragüés-Peñalba, M., Bullich-Massagué, E., & Sumper, A. (2022). A systematic review of machine learning techniques related to local energy communities. In *Renewable and Sustainable Energy Reviews* (Vol. 170). Elsevier Ltd. https://doi.org/10.1016/j.rser.2022.112651

https://www.rescoop.eu/. (n.d.). 2023.

IDAE. (2019). *guia_para-desarrollo-instrumentos-fomento_comunidades_energeticas_locales_20032019*.

IEA (2020), If the energy sector is to tackle climate change, it must also think about water, IEA, Paris https://www.iea.org/commentaries/if-the-energy-sector-is-to-tackle-climate-change-it-must-also-think-about-water. (n.d.).

Isabel Azevedo. (2021). *Renewable Energy Communities: Will they have room to grow in Portugal?*

L, M. DE, & Mer, D. LA. (2017). *Décrets, arrêtés, circulaires TEXTES GÉNÉRAUX Décret n o 2017-676 du 28 avril 2017 relatif à l’autoconsommation d’électricité et modifiant les articles D. 314-15 et D. 314-23 à D. 314-25 du code de l’énergie*. http://www.

Lin, B., & Raza, M. Y. (2020). Analysis of energy security indicators and CO2 emissions. A case from a developing economy. *Energy*, *200*, 117575. https://doi.org/10.1016/J.ENERGY.2020.117575

Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L., & Weinhardt, C. (2018). Designing microgrid energy markets: A case study: The Brooklyn Microgrid. *Applied Energy*, *210*, 870–880. https://doi.org/10.1016/j.apenergy.2017.06.054

MITECO. (2021). *PLAN NACIONAL INTEGRADO DE ENERGÍA Y CLIMA*.

Nouicer, A., Kehoe, A.-M., Nysten, J., Fouquet, D., Hancher, L., & Meeus, L. (2020). *THE EU CLEAN ENERGY PACKAGE*. https://doi.org/10.2870/58299

Núm. (2019). *BOE*. http://www.boe.es

OMIE. (n.d.). *Integrated Report OMI 2022*.

Pflugradt, N., Stenzel, P., Kotzur, L., & Stolten, D. (2022). LoadProfileGenerator: An Agent-Based Behavior Simulation for Generating Residential Load Profiles. *Journal of Open Source Software*, *7*(71), 3574. https://doi.org/10.21105/joss.03574

Pigliautile, I., Breukers, S., Boekelo, M., Carnero, P., Causone, F., Arko, S., Ferroni, S., Pioppi, B., Pisello, A. L., Solar, A., Swens, J., Tarpani, E., & D’Oca, S. (2022). Peer-to-peer energy communities: regulatory barriers in the EU context. *Open Research Europe*, *2*, 147. https://doi.org/10.12688/openreseurope.15282.1

Research, J., & Tuerk, A. (2022). *Deliverable information Deliverable Number: Deliverable Title Yearly policy briefs on regulation Work Package Number Work Package Title Lead Organisation Main authors Nature Dissemination Level PU-Public Deliverable Date Draft Number Final Version history*. JR.

Resumen. (2015). *Análisis Documento de Análisis EL CAMBIO CLIMÁTICO: UNA RESPONSABILIDAD COMÚN PERO DIFERENCIADA Visitar la WEB Recibir BOLETÍN ELECTRÓNICO*. http://www.euractiv.com/sections/eu-priorities-2020/cop-21-negotiations-kick-geneva-311948

Sanderink, L. (2020). Shattered frames in global energy governance: Exploring fragmented interpretations among renewable energy institutions. *Energy Research and Social Science*, *61*. https://doi.org/10.1016/j.erss.2019.101355

Sokoøowski, M. M. (n.d.). *European Law on the Energy Communities European Law on the Energy Communities: a Long Way to a Direct Legal Framework*. https://ec.europa.eu/energy/en/news/

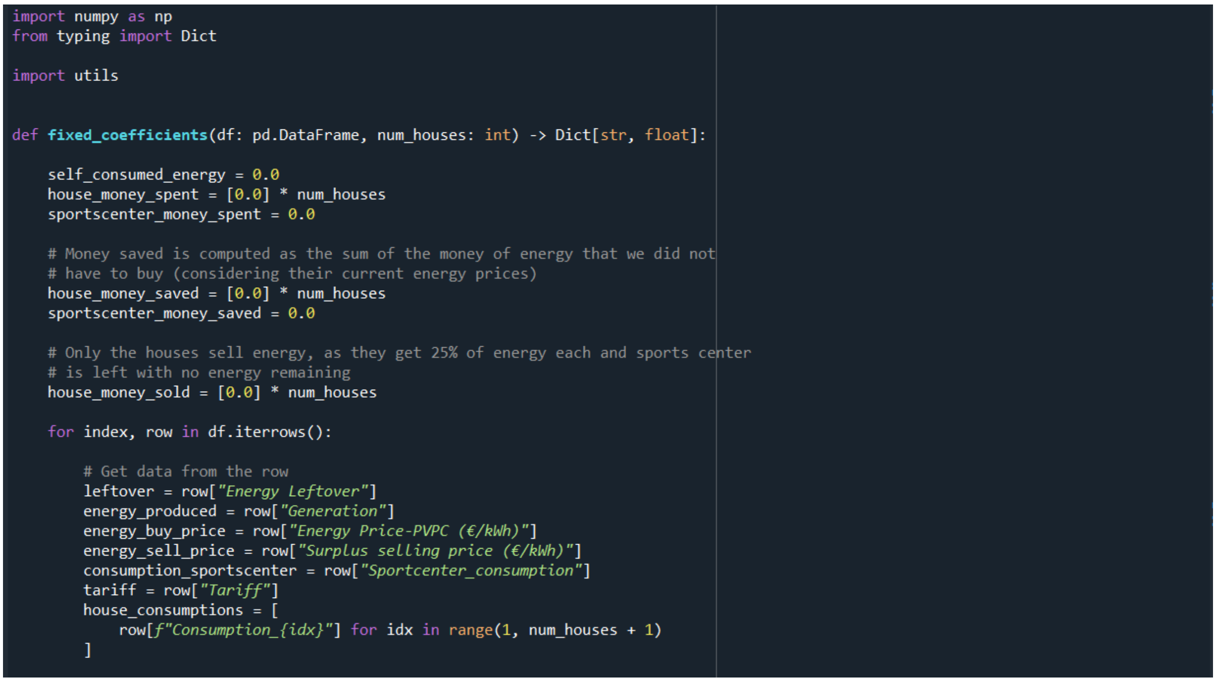
Verbraucherzentrale. (2019). *Gesetzentwurf der Bundesregierung Entwurf eines Gesetzes zur Änderung des Erneuerbare-Energien-Gesetzes und weiterer energierechtlicher Vorschriften 1)*.

Villalonga Palou, J. T., Serrano González, J., Riquelme Santos, J. M., Álvarez Alonso, C., & Roldán Fernández, J. M. (2023). Sharing approaches in collective self-consumption systems: A techno-economic analysis of the Spanish regulatory framework. *Energy Strategy Reviews*, *45*. https://doi.org/10.1016/j.esr.2023.101055

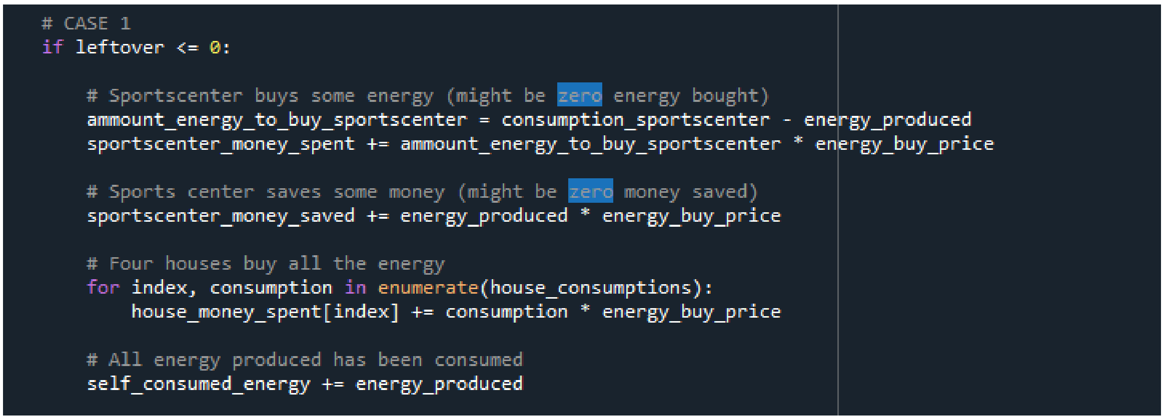
Wolf, F., Surroop, D., Singh, A., & Leal, W. (2016). Energy access and security strategies in Small Island Developing States. *Energy Policy*, *98*, 663–673. https://doi.org/10.1016/J.ENPOL.2016.04.020

APPENDICES

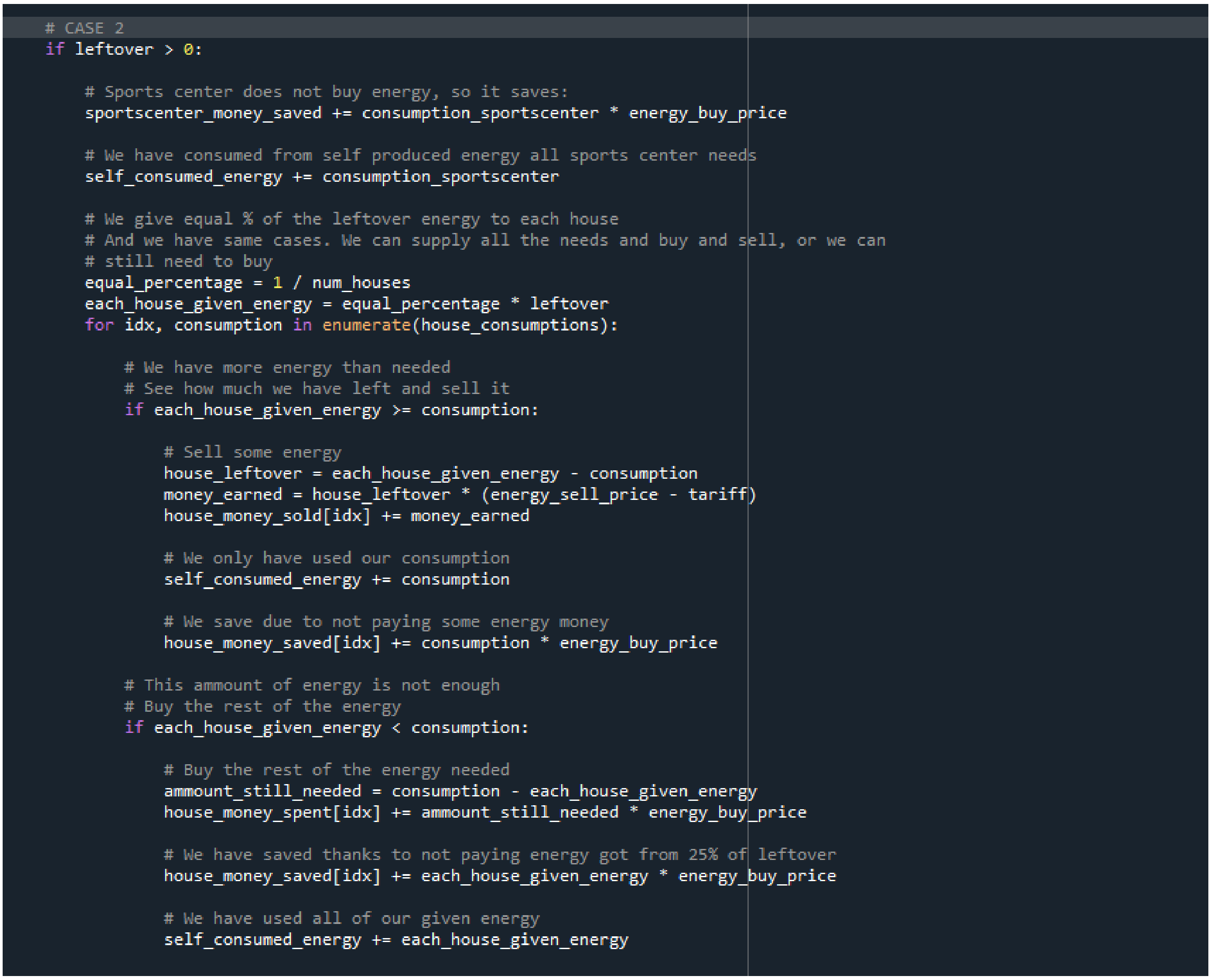
Python code



```python
import numpy as np
from typing import Dict

import utils


def fixed_coefficients(df: pd.DataFrame, num_houses: int) -> Dict[str, float]:

    self_consumed_energy = 0.0
    house_money_spent = [0.0] * num_houses
    sportscenter_money_spent = 0.0

    # Money saved is computed as the sum of the money of energy that we did not
    # have to buy (considering their current energy prices)
    house_money_saved = [0.0] * num_houses
    sportscenter_money_saved = 0.0

    # Only the houses sell energy, as they get 25% of energy each and sports center
    # is left with no energy remaining
    house_money_sold = [0.0] * num_houses

    for index, row in df.iterrows():

        # Get data from the row
        leftover = row["Energy Leftover"]
        energy_produced = row["Generation"]
        energy_buy_price = row["Energy Price-PVPC (€/kWh)"]
        energy_sell_price = row["Surplus selling price (€/kWh)"]
        consumption_sportscenter = row["Sportcenter_consumption"]
        tariff = row["Tariff"]
        house_consumptions = [
            row[f"Consumption_{idx}"] for idx in range(1, num_houses + 1)
        ]
```



```python
    # CASE 1
    if leftover <= 0:

        # Sportscenter buys some energy (might be zero energy bought)
        ammount_energy_to_buy_sportscenter = consumption_sportscenter - energy_produced
        sportscenter_money_spent += ammount_energy_to_buy_sportscenter * energy_buy_price

        # Sports center saves some money (might be zero money saved)
        sportscenter_money_saved += energy_produced * energy_buy_price

        # Four houses buy all the energy
        for index, consumption in enumerate(house_consumptions):
            house_money_spent[index] += consumption * energy_buy_price

        # All energy produced has been consumed
        self_consumed_energy += energy_produced
```

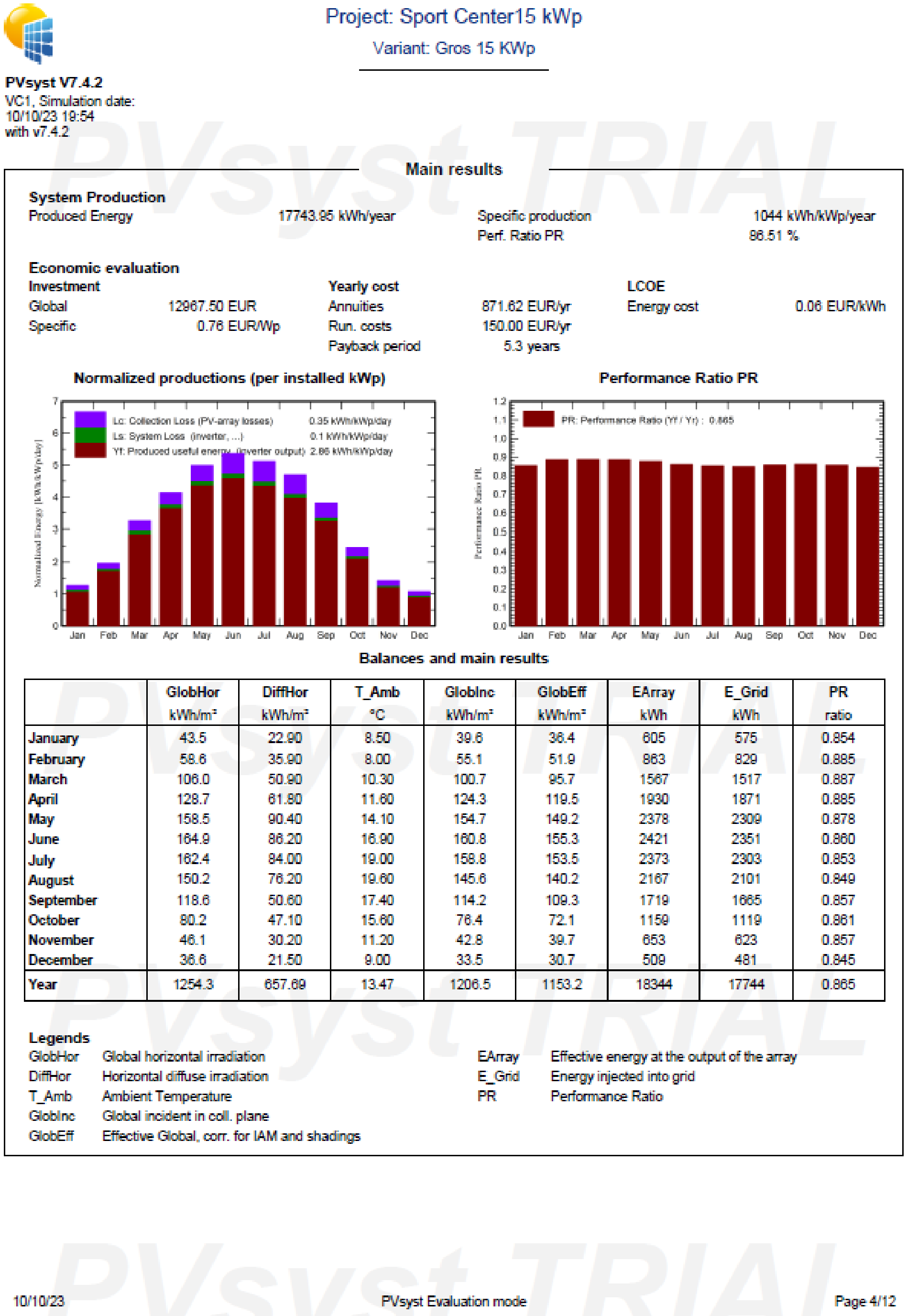


```
# CASE 2
if leftover > 0:

    # Sports center does not buy energy, so it saves:
    sportscenter_money_saved += consumption_sportscenter * energy_buy_price

    # We have consumed from self produced energy all sports center needs
    self_consumed_energy += consumption_sportscenter

    # We give equal % of the leftover energy to each house
    # And we have same cases. We can supply all the needs and buy and sell, or we can
    # still need to buy
    equal_percentage = 1 / num_houses
    each_house_given_energy = equal_percentage * leftover
    for idx, consumption in enumerate(house_consumptions):

        # We have more energy than needed
        # See how much we have left and sell it
        if each_house_given_energy >= consumption:

            # Sell some energy
            house_leftover = each_house_given_energy - consumption
            money_earned = house_leftover * (energy_sell_price - tariff)
            house_money_sold[idx] += money_earned

            # We only have used our consumption
            self_consumed_energy += consumption

            # We save due to not paying some energy money
            house_money_saved[idx] += consumption * energy_buy_price

        # This ammount of energy is not enough
        # Buy the rest of the energy
        if each_house_given_energy < consumption:

            # Buy the rest of the energy needed
            ammount_still_needed = consumption - each_house_given_energy
            house_money_spent[idx] += ammount_still_needed * energy_buy_price

            # We have saved thanks to not paying energy got from 25% of leftover
            house_money_saved[idx] += each_house_given_energy * energy_buy_price

            # We have used all of our given energy
            self_consumed_energy += each_house_given_energy
```

```
# CASE 2
if leftover > 0:

    # Sports center does not buy energy, so it saves:
    sportscenter_money_saved += consumption_sportscenter * energy_buy_price

    # We have consumed all sports center needs with self production:
    self_consumed_energy += consumption_sportscenter

    # We give the leftover energy to each house. To optimal assign resources
    # we assign all the energy to the most demandant house, then to the second...
    #
    # And we still have same cases. We can supply all the needs and buy
    # and sell, or we can still need to buy

    # Start by sorting houses by their needs and iterating that way
    sorted_indixes = utils.sorted_indixes(house_consumptions)

    for idx in sorted_indixes:

        consumption = house_consumptions[idx]

        # We have more energy than needed, so we can consume all from them
        if leftover >= consumption:

            # We only have used our consumption
            self_consumed_energy += consumption

            # We save due to not paying some energy money
            house_money_saved[idx] += consumption * energy_buy_price

            # We have now less leftover energy
            leftover -= consumption

        # This ammount of energy is not enough
        # Buy the rest of the energy
        if leftover < consumption:

            # Buy the rest of the energy needed
            ammount_still_needed = consumption - leftover
            house_money_spent[idx] += ammount_still_needed * energy_buy_price

            # We have saved by not paying of remaining leftover
            house_money_saved[idx] += leftover * energy_buy_price

            # We have used all of the remaining leftover
            self_consumed_energy += leftover

            # We have consumed all the leftover
            leftover = 0

    # After the four houses, we still have energy remaining. So sell it And
    # split among the all the houses equally
    if leftover > 0:
        money_earned = leftover * (energy_sell_price - tariff)
        equal_percentage = 1 / num_houses
        for idx, _ in enumerate(house_money_sold):
            house_money_sold[idx] += money_earned * equal_percentage
```

```
    # CASE 2
    if leftover > 0:

        # Sports center does not buy energy, so it saves:
        sportscenter_money_saved += consumption_sportscenter * energy_buy_price

        # We have consumed all sports center needs with self production:
        self_consumed_energy += consumption_sportscenter

        # We have a leftover, so we assign the leftover proportional to the
        # consumption. Compute the ammount of energy we are going to give
        # to each house
        proportional_leftovers = utils.compute_proportional_leftovers(
            leftover = leftover,
            percentages = percentages
        )

        # Safety check, we are no longer using this leftover
        del leftover

        # Now iterate using that proportional leftovers
        # We do not care about the iteration order
        for idx, current_leftover in enumerate(proportional_leftovers):

            consumption = house_consumptions[idx]

            # We have more energy than needed, so we can consume all from the generation
            # and sell some
            if current_leftover >= consumption:

                # We only have used our consumption
                self_consumed_energy += consumption

                # We save due to not paying some energy money
                house_money_saved[idx] += consumption * energy_buy_price

                # We sell the leftover
                current_leftover = current_leftover - consumption
                house_money_sold[idx] += current_leftover * energy_sell_price

            # This ammount of energy is not enough
            # Buy the rest of the energy
            if current_leftover < consumption:

                # Buy the rest of the energy needed
                ammount_still_needed = consumption - current_leftover
                house_money_spent[idx] += ammount_still_needed * energy_buy_price

                # We have saved by not paying of remaining leftover
                house_money_saved[idx] += current_leftover * energy_buy_price

                # We have used all of the remaining leftover
                self_consumed_energy += current_leftover

        # In this algorithm, we do not have to check at the end if we
        # still have some leftovers. Leftover selling is done per each
        # house, considering the percentages
```

PVsyst simulation



PVsyst V7.4.2
VC1, Simulation date:
10/10/23 19:54
with v7.4.2

Project: Sport Center15 kWp

Variant: Gros 15 KWp

Main results

System Production

Produced Energy	17743.95 kWh/year	Specific production	1044 kWh/kWp/year
		Perf. Ratio PR	86.51 %

Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	12967.50 EUR	Annuities	871.62 EUR/yr	Energy cost	0.06 EUR/kWh
Specific	0.76 EUR/Wp	Run. costs	150.00 EUR/yr		
		Payback period	5.3 years		

Normalized productions (per installed kWp)

Performance Ratio PR

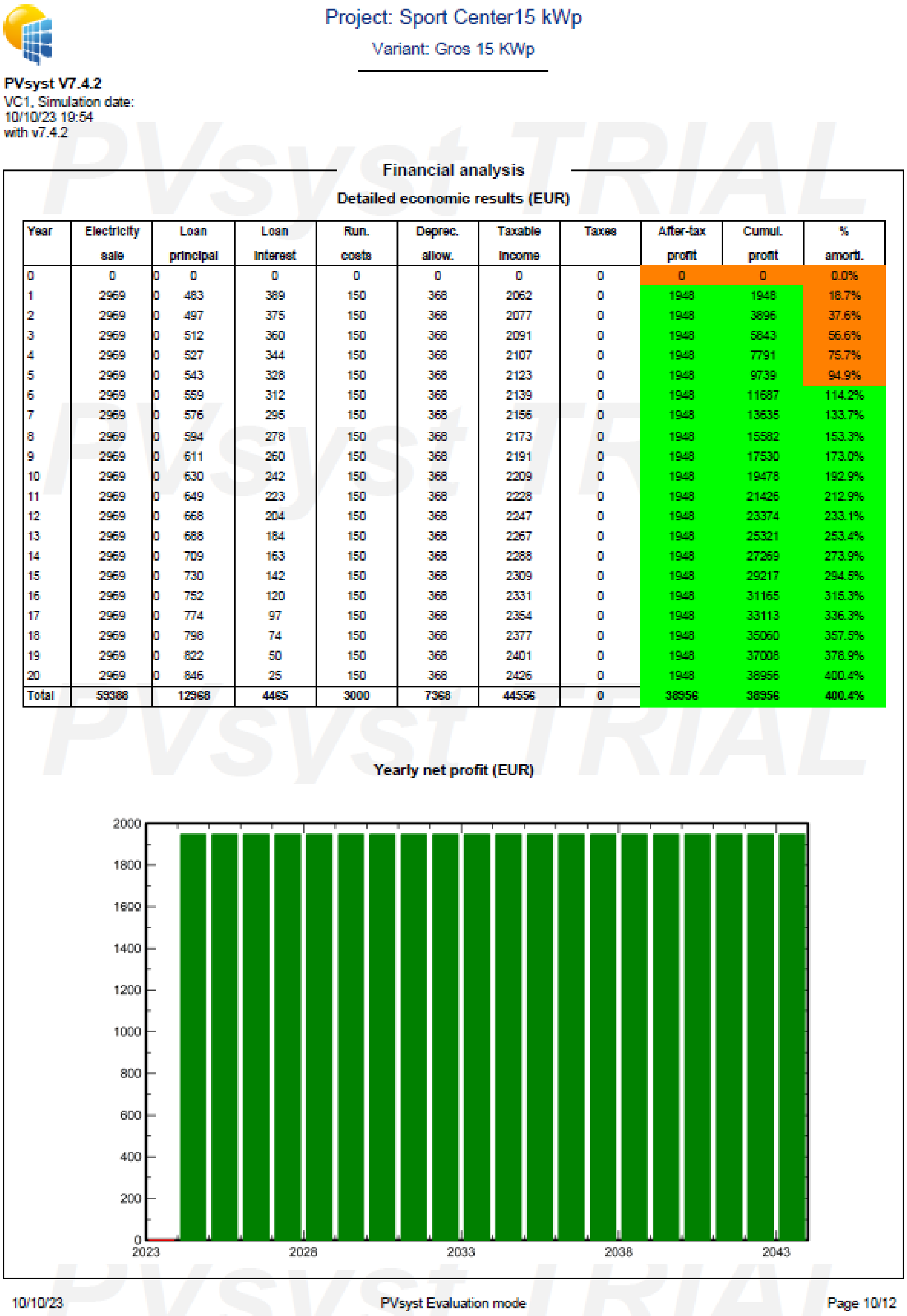
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	43.5	22.90	8.50	39.6	36.4	605	575	0.854
February	58.6	35.90	8.00	55.1	51.9	863	829	0.885
March	106.0	50.90	10.30	100.7	95.7	1567	1517	0.887
April	128.7	61.80	11.60	124.3	119.5	1930	1871	0.885
May	158.5	90.40	14.10	154.7	149.2	2378	2309	0.878
June	164.9	86.20	16.90	160.8	155.3	2421	2351	0.860
July	162.4	84.00	19.00	158.8	153.5	2373	2303	0.853
August	150.2	76.20	19.60	145.6	140.2	2167	2101	0.849
September	118.6	50.60	17.40	114.2	109.3	1719	1665	0.857
October	80.2	47.10	15.60	76.4	72.1	1159	1119	0.861
November	46.1	30.20	11.20	42.8	39.7	653	623	0.857
December	36.6	21.50	9.00	33.5	30.7	509	481	0.845
Year	1254.3	657.69	13.47	1206.5	1153.2	18344	17744	0.865

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

10/10/23 PVsyst Evaluation mode Page 4/12



PVsyst V7.4.2
VC1, Simulation date:
10/10/23 19:54
with v7.4.2

Project: Sport Center15 kWp

Variant: Gros 15 KWp

Financial analysis

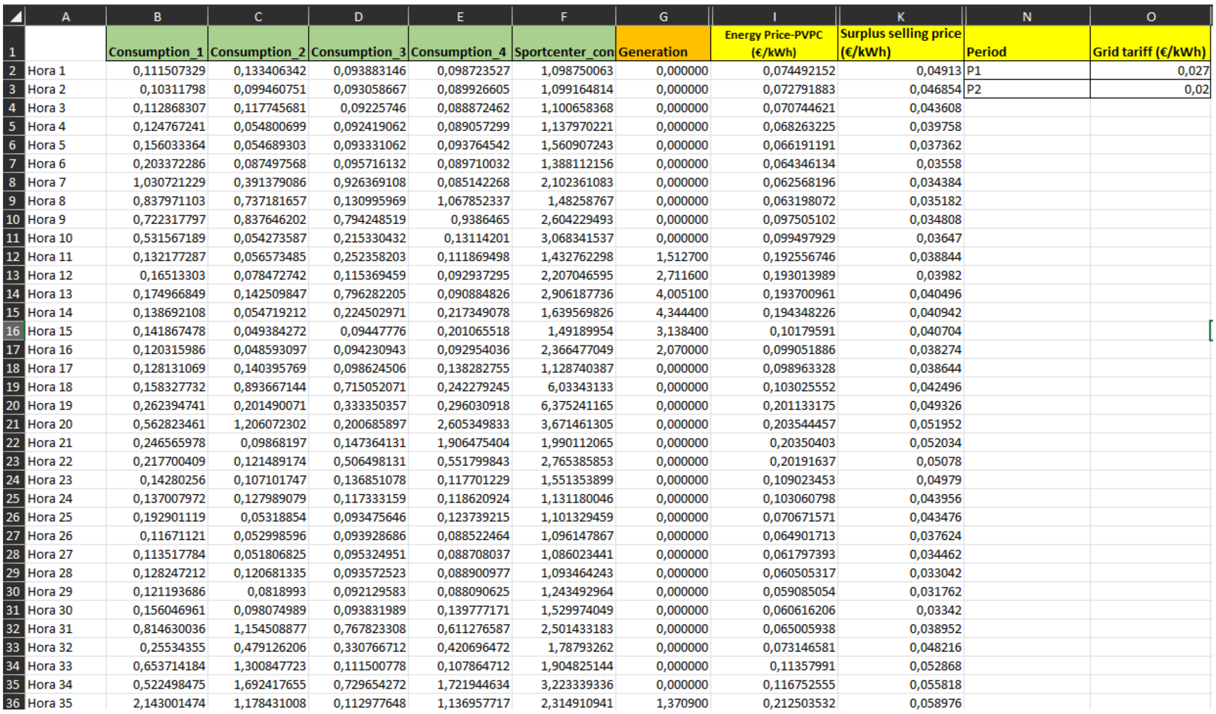
Detailed economic results (EUR)

Year	Electricity sale	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
0	0	0 0	0	0	0	0	0	0	0	0.0%
1	2969	0 483	389	150	368	2062	0	1948	1948	18.7%
2	2969	0 497	375	150	368	2077	0	1948	3896	37.6%
3	2969	0 512	360	150	368	2091	0	1948	5843	56.6%
4	2969	0 527	344	150	368	2107	0	1948	7791	75.7%
5	2969	0 543	328	150	368	2123	0	1948	9739	94.9%
6	2969	0 559	312	150	368	2139	0	1948	11687	114.2%
7	2969	0 576	295	150	368	2156	0	1948	13635	133.7%
8	2969	0 594	278	150	368	2173	0	1948	15582	153.3%
9	2969	0 611	260	150	368	2191	0	1948	17530	173.0%
10	2969	0 630	242	150	368	2209	0	1948	19478	192.9%
11	2969	0 649	223	150	368	2228	0	1948	21426	212.9%
12	2969	0 668	204	150	368	2247	0	1948	23374	233.1%
13	2969	0 688	184	150	368	2267	0	1948	25321	253.4%
14	2969	0 709	163	150	368	2288	0	1948	27269	273.9%
15	2969	0 730	142	150	368	2309	0	1948	29217	294.5%
16	2969	0 752	120	150	368	2331	0	1948	31165	315.3%
17	2969	0 774	97	150	368	2354	0	1948	33113	336.3%
18	2969	0 798	74	150	368	2377	0	1948	35060	357.5%
19	2969	0 822	50	150	368	2401	0	1948	37008	378.9%
20	2969	0 846	25	150	368	2426	0	1948	38956	400.4%
Total	**59388**	**12968**	**4465**	**3000**	**7368**	**44556**	**0**	**38956**	**38956**	**400.4%**

Yearly net profit (EUR)

10/10/23 PVsyst Evaluation mode Page 10/12

Excel



	A	B	C	D	E	F	G	I	K	N	O
1		Consumption_1	Consumption_2	Consumption_3	Consumption_4	Sportcenter_con	Generation	Energy Price-PVPC (€/kWh)	Surplus selling price (€/kWh)	Period	Grid tariff (€/kWh)
2	Hora 1	0,111507329	0,133406342	0,093883146	0,098723527	1,098750063	0,000000	0,074492152	0,04913	P1	0,027
3	Hora 2	0,10311798	0,099460751	0,093058667	0,089926605	1,099164814	0,000000	0,072791883	0,046854	P2	0,02
4	Hora 3	0,112868307	0,117745681	0,09225746	0,088872462	1,100658368	0,000000	0,070744621	0,043608		
5	Hora 4	0,124767241	0,054800699	0,092419062	0,089057299	1,137970221	0,000000	0,068263225	0,039758		
6	Hora 5	0,156033364	0,054689303	0,093331062	0,093764542	1,560907243	0,000000	0,066191191	0,037362		
7	Hora 6	0,203372286	0,087497568	0,095716132	0,089710032	1,388112156	0,000000	0,064346134	0,03558		
8	Hora 7	1,030721229	0,391379086	0,926369108	0,085142268	2,102361083	0,000000	0,062568196	0,034384		
9	Hora 8	0,837971103	0,737181657	0,130995969	1,067852337	1,48258767	0,000000	0,063198072	0,035182		
10	Hora 9	0,722317797	0,837646202	0,794248519	0,9386465	2,604229493	0,000000	0,097505102	0,034808		
11	Hora 10	0,531567189	0,054273587	0,215330432	0,13114201	3,068341537	0,000000	0,099497929	0,03647		
12	Hora 11	0,132177287	0,056573485	0,252358203	0,111869498	1,432762298	1,512700	0,192556746	0,038844		
13	Hora 12	0,16513303	0,078472742	0,115369459	0,092937295	2,207046595	2,711600	0,193013989	0,03982		
14	Hora 13	0,174966849	0,142509847	0,796282205	0,090884826	2,906187736	4,005100	0,193700961	0,040496		
15	Hora 14	0,138692108	0,054719212	0,224502971	0,217349078	1,639569826	4,344400	0,194348226	0,040942		
16	Hora 15	0,141867478	0,049384272	0,09447776	0,201065518	1,49189954	3,138400	0,10179591	0,040704		
17	Hora 16	0,120315986	0,048593097	0,094230943	0,092954036	2,366477049	2,070000	0,099051886	0,038274		
18	Hora 17	0,128131069	0,140395769	0,098624506	0,138282755	1,128740387	0,000000	0,098963328	0,038644		
19	Hora 18	0,158327732	0,893667144	0,715052071	0,242279245	6,03343133	0,000000	0,103025552	0,042496		
20	Hora 19	0,262394741	0,201490071	0,333350357	0,296030918	6,375241165	0,000000	0,201133175	0,049326		
21	Hora 20	0,562823461	1,206072302	0,200685897	2,605349833	3,671461305	0,000000	0,203544457	0,051952		
22	Hora 21	0,246565978	0,09868197	0,147364131	1,906475404	1,990112065	0,000000	0,20350403	0,052034		
23	Hora 22	0,217700409	0,121489174	0,506498131	0,551799843	2,765385853	0,000000	0,20191637	0,05078		
24	Hora 23	0,14280256	0,107101747	0,136851078	0,117701229	1,551353899	0,000000	0,109023453	0,04979		
25	Hora 24	0,137007972	0,127989079	0,117333159	0,118620924	1,131180046	0,000000	0,103060798	0,043956		
26	Hora 25	0,192901119	0,05318854	0,093475646	0,123739215	1,101329459	0,000000	0,070671571	0,043476		
27	Hora 26	0,11671121	0,052998596	0,093928686	0,088522464	1,096147867	0,000000	0,064901713	0,037624		
28	Hora 27	0,113517784	0,051806825	0,095324951	0,088708037	1,086023441	0,000000	0,061797393	0,034462		
29	Hora 28	0,128247212	0,120681335	0,093572523	0,088900977	1,093464243	0,000000	0,060505317	0,033042		
30	Hora 29	0,121193686	0,0818993	0,092129583	0,088090625	1,243492964	0,000000	0,059085054	0,031762		
31	Hora 30	0,156046961	0,098074989	0,093831989	0,139777171	1,529974049	0,000000	0,060616206	0,03342		
32	Hora 31	0,814630036	1,154508877	0,767823308	0,611276587	2,501433183	0,000000	0,065005938	0,038952		
33	Hora 32	0,25534355	0,479126206	0,330766712	0,420696472	1,78793262	0,000000	0,073146581	0,048216		
34	Hora 33	0,653714184	1,300847723	0,111500778	0,107864712	1,904825144	0,000000	0,11357991	0,052868		
35	Hora 34	0,522498475	1,692417655	0,729654272	1,721944634	3,223339336	0,000000	0,116752555	0,055818		
36	Hora 35	2,143001474	1,178431008	0,112977648	1,136957717	2,314910941	1,370900	0,212503532	0,058976		