PV Assessment and Analysis for Deploying a Municipality-wide Energy Community

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Utvärdering och analys av solceller för att införa en kommunövergripande energigemenskap

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Sammanfattning

Gemenskaper för förnybar energi (REC) är ett instrument som ger konsumenterna inflytande och hjälper dem att bli prosumenter i energiomställningen för att minska koldioxidhalten i energinätet. Europeiska kommissionen införde konceptet genom direktivet om förnybar energi (RED2) 2019. Många energisamhällen lobbade under utarbetandet av ändringen för att få det infört. Därmed beaktades deras erfarenheter och svårigheter för att underlätta genomförandet.

Rivas-Vaciamadrid (RIVAS) är en kommun i Spanien som vill omvandla sig själv till en REC. Ett av de första stegen för att uppnå detta mål har varit att bedöma dess potential för solceller. I januari 2022 inledde RIVAS projektet, och Research to Market Solutions (R2M) vann anbudsförfarandet genom att erbjuda ett grundligt förslag för att utföra bedömningen av solcellerna och definiera en strategi för att införa REC.

Avhandlingen är inriktad på att utvärdera potentialen hos RIVAS REC genom att skapa ett byggnadsbestånd med hjälp av geografiska informationssystem. Analysen skapar byggnadsarketyper för att individuellt skapa profiler för energiefterfrågan och få fram den årliga energiefterfrågan. Arketyperna används också för att utvärdera den tillgängliga solcellsytan i varje byggnad. Genom att använda en simuleringsmotor från företaget IES simuleras energisamhället.

Resultaten visar att RIVAS REC har en elförbrukning på 271,32 GWh/år. Kostnaden för denna el är 75,9 miljoner euro. Dess potentiella solcellskapacitet är 292,81 GWh/år. Den producerade solcellselen täcker 41 % av efterfrågan. 38 % av den producerade solcellselen är självförbrukad. Kommunen består av fyra sektorer: bostäder, handel, industri och högteknologi. Bostadssektorn förbrukar 51 % av den totala elektriciteten. REC gynnar sig själv genom en 42-procentig minskning av sin elavgift.

Den föreslagna affärsmodellen går ut på att använda kommunens byggnader och installera solceller på deras tak. Dessa byggnader kommer att fungera som knutpunkter för att skapa 17 energisamhällen. Den producerade elen är självförbrukad, vilket minskar deras elräkning med 42 %. Överskottsel säljs till medlemmarna och ger en vinst som kan återinvesteras för att stödja ytterligare installation av solceller. REC kan uppnå fullständig installation av solceller på 10-17 år beroende på kostnaderna för att driva den.

KTH Industrial Engineering and Management	Master of Science Thesis TRITA-ITM-EX 2023:15 **PV Assessment and Analysis for Deploying a Municipality–wide Energy Community** Rodrigo Peñaloza Andrade	
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Abstract

Renewable energy communities (REC) are an instrument that empowers consumers and helps them become prosumers in the energy transition to decarbonize the energy grid. The European Commission introduced the concept through the Renewable Energy Directive (RED2) in 2019. Many energy communities lobbied during the elaboration of the amendment to have it introduced. In so doing, their experience and hardships were considered to facilitate their implementation.

Rivas-Vaciamadrid (RIVAS) is a municipality in Spain that aims to convert itself to a REC. One of the first steps to accomplish this goal has been assessing its PV potential. In January 2022, RIVAS launched the project, and Research to Market Solutions (R2M) won the tendering process by offering a thorough proposal to perform the PV assessment and define a strategy to deploy the REC.

The thesis work is focused on evaluating the potential of RIVAS REC by creating the buildings' stock through the use of geographical information systems. The analysis creates building archetypes to individually create the energy demand profiles and obtain the annual energy demand. The archetypes are also used to evaluate the PV area available in each building. Through the use of a simulation engine from the company IES, the simulation of the energy community is performed.

The results show that RIVAS REC has an electricity consumption of 271.32 GWh/year. The cost of this electricity is 75.9 m€. Its PV potential capacity is of 292.81GWh/year. The annual PV produced generates a 41% self-sufficiency and 38% self-consumption. The municipality is composed of 4 sectors, residential, commercial, tertiary and industrial. The residential sector consumes 51% of the total electricity. The REC benefits itself by a 42% reduction in its annual electric tariff.

The business model proposed consists of using the municipality buildings and deploying PVs on their roofs. These buildings will serve as hubs to create 17 energy communities. The electricity produced is self-consumed, reducing their electricity bill by 42%. The surplus electricity is sold to the members obtaining a profit that can be reinvested to support the additional PV deployment. The REC can achieve complete PV deployment from 10 to 17 years according to its operating expenses.

Foreword

As I started the journey into my Master's studies, it was filled with many doubts, challenges, and opportunities. It was a bold step to take while the world was in the middle of a pandemic. It certainly modified what I had in mind about how the road was going to be. Yet, as I remember the road taken, it brings me joy and gratefulness for taking it. The people I've met, the places I've been, and the knowledge and experience I have acquired will lead to a bright future.

Thanks to my programme coordinators, Maria, Cesar, and Peter. Their support in Spain and Sweden was always present, and with their help, I was able to tackle every challenge presented.

I take this opportunity to acknowledge my colleagues and now friends for all their support. Pau, which was an anchor for us in Spain. Felipe and Andres welcomed us to Barcelona and made us feel like we were back home. Of course, everybody there made it feel special. I was able to learn a lot from everyone there. Natasha, Marta, Patryk, Sid, Stathis, Vitto, Emet, and Sankar. My journey to KTH in Stockholm forged stronger friendships with the KTH crew, as we shared many classes and experiences. I also got to work with the rest of my innoenergy friends, Paula, Yue, Jasper, Rahul, and Yamil. Their support while analyzing the Renewable Energy Directive implementation in EU countries was inspiring.

The SELECT programme successfully networked everyone in the industry. We met Laura from R2M, which I have to thank for her support during the iPoy and, later on, for putting me in contact to do my Master's Thesis in R2M. When I learned about the concept of energy communities, I thought it was a new policy to allow more households and businesses to install solar PV or wind turbines. As I have increased my knowledge of this topic, I am convinced about its potential and the impact it will have. It will indeed have a place in the energy transition and will be replicated in many more countries.

I am particularly grateful to Raymond Sterling and Alessandro Piccinini from R2M and my supervisor Hatef Madani from KTH for providing me the opportunity to work on the topic of energy communities and complete my understanding on how they can make a big impact in the energy transition. Their expertise and support were instrumental in helping me deepen my understanding of this important and rapidly developing field.

I would also like to recognize the incredible support from my brothers, David and Octavio, for their support to reach my goals and my nephew David for bringing me closer to them. Thanks a million.

I am grateful for the unwavering support and love from my girlfriend Edith. Her presence has been a constant source of comfort and motivation throughout this journey. It has been amazing to have her by my side on this adventure. We are just getting started.

Lastly, I would like to express my deepest gratitude to my mother, Carmen, to whom I dedicate this thesis. Her unconditional love and support has been the driving force behind my achievements. I am forever grateful to her for her guidance and support, and I am honored to be able to dedicate this thesis to her.

Rodrigo Peñaloza Andrade
Stockholm, February, 2023.

Nomenclature

Here are the Abbreviations and Notations that are used throughout the Master thesis.

Abbreviations

BEC	Building Energy Cluster
BEM	Building Energy Modelling
CEP	Clean Energy Package
DSO	Distribution System Operator
EC	Energy Cluster
GIS	Geographical Information System
ICL	Intelligent Community Lifecycle
IDAE	Instituto para la Diversificación y Ahorro de la energía. (Institute for the diversification and energy savings)
KPI	Key performance indicators
OSM	Open Street Map
REC	Renewable Energy Community
RED	Renewable Energy Directive
RES	Renewable Energy System
RIVAS	Municipality Rivas-Vaciamadrid
UBEM	Urban Building Energy Model
UEM	Urban Energy Model

Notations

GWh	Gigawatt per hour
€	Euro
Ha	Hectare
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt per hour
m^2	Square meter

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1. Introduction

The implementation of energy communities has been an effort that started before the proper legislation was taken into place. These communities had many different problems while facing the big utility companies. One of these problems, for example, was what to do with the excess electricity. If the utility company, in this case, the Distribution System Operators (DSO), were to handle it, the consumer would have to pay for it. A second challenge falls in sharing and exchanging their surplus electricity between consumers, which normally is handled by the DSO without the consumers being aware of it [1]. In summary, there was not a level playing field for them to develop.

An energy community can only thrive if there is an economic and legal framework in which it can thrive. Although people tend to support renewables, there is the movement of not in my backyard (NIMBY), in which communities tend to reject electric generation projects in general. People see them as other people exploiting their available resources for their own profit. One such example is wind turbines. They have been rejected throughout the world by local communities. They feel the benefits are being sent away without visible return for the community. However, promoters of energy communities, such as Dirk Vansintjan, president of the European Federation of Citizen Energy Cooperatives (REScoop), state that they have found that ownership matters. People will rally behind wind turbines when they are theirs and can make a profit from them [2].

The Clean Energy Package (CEP) for all Europeans first laid the foundations for governments to speed up the energy transition. One of its main objectives is that the "Consumers should be at the heart of the energy transition". The Clean Energy Package holds a set of policies aiming to ease it. The Energy Performance of Buildings Directive (EU 2018/844) sets measures to reduce buildings' energy consumption, which currently holds 40% of the energy consumption. The Directive on Energy Efficiency (EU 2018/2002) looks to increase efficiency from current levels by 32.5% by 2030. The policy of interest in the CEP is the Renewable Energy Directive (RED). It aims to have 32% of renewable energy sources in the energy matrix by 2030. The RED also introduced the concept of Renewable Energy Communities (REC) [3].

A Renewable Energy Community, as it is defined in the RED, is a legal entity based on open and voluntary participation. Anybody can participate; it can be a person, small-medium enterprises (SME), local authorities, or municipalities. Its main objective is to benefit environmental, economic, or social communities rather than financial profits. The benefits can be for members, shareholders, or local areas [4].

According to the RED, governments must provide information and training on this behalf. From providing information about the support mechanisms available, benefits of participating in a REC, equipment cost, and even certification schemes for installers. An important obligation is that governments have to develop information to increase awareness and elaborate training programs.

It must be remembered that the European Commission sets up the RED. Each country's responsibility is to transpose it into its own objectives and laws. In Spain, there have been decrees that state measurements to support the implementation of energy communities. One of them is the royal decree 23/2020 which incorporates new business models that the energy sector demands, such as energy storage and independent aggregators, and regulates RECs that encourage the participation of citizens in the energy transition. The economic support available could benefit from 50% up to 80% of the upfront cost of implementing it [5]. The Institute of Diversification and Energy Savings (IDAE – Instituto para la Diversificación y Ahorro de la Energía) is in charge of these programs in Spain.

The municipality Rivas-Vaciamadrid is planning forward to transform itself into a municipality-wide energy community. In this regard, they have launched a tendering process to define its potential and strategy to implement it.

The municipality Rivas-Vaciamadrid is located 15 km southeast of Madrid. It has a population of over 90 thousand. Its size is 67.38 km^2; however, only 14 km^2 is urbanized [6]. According to the cadaster office, it is divided into 45 zones mixed with residential and commercial buildings and 5 industrial zones.

1.1. Objectives and Research Questions

This master's thesis aims to assess the PV potential of the municipality RIVAS-Vaciamadrid and find key performance indicators that will assist in the decision-making process to deploy the renewable energy community.

Due to the new nature of an energy community and lack of legislation, policymakers, utility companies, and consumers do not clearly see how an energy community operates and the cash flows it can produce. In this regard, four main questions are addressed.

1. For a defined size of an energy community, how much energy can it produce?
2. According to the energy and cash flows, how will they be managed to harness the surplus energy and the economic benefits it can produce?
3. Can KPIs be used to further assess other communities according to the region's demographics and the historic electricity demand?
4. Considering that the investment to implement the energy community is substantial, what kind of strategy be implemented to develop it sustainably and reduce the initial investments?

1.2. Limitations

Urban energy modeling simulates the demand and generation of energy for a building, a neighborhood, or city. In this process, there will exist a tradeoff between the level of detail the model uses and the accuracy of the results. The simulation had to consider assumptions to speed up the process and deliver adequate results quickly. While the project is limited in time, it is also limited in the availability of information.

- The information available determines the assessment of the electricity demand and solar PV potential. The starting point of the analysis is the 3D model obtained through Open Street Maps (OSM). This platform showed numerous gaps in the information available for the municipality, and the classification of the buildings was clustered to speed up the process.
- During the clustering of buildings, there were limitations in the accuracy of the measurements of each building. The buildings have been subject to renovations to include additional rooms over garages or in the backyard. These extensions were not considered, and it was assumed that the only usable area was the buildings' roofs. It is possible that in an actual installation, the system could be modeled to increase the efficiency in the capacity and its energy production using additional areas not considered in the analysis. Measures were taken to observe the results obtained while changing the available PV area ratio; thus, a conservative ratio was used only considering three roof types.
- Regarding the electricity demand profile, an aggregated profile was used. The literature review shows that this approach does not reflect the actual behavior of the occupants of buildings. New approaches suggest implementing probabilistic analysis to the profiles to determine the final electricity demand. To compensate the electricity demand, calibrations of the model were done regarding the individual analysis of tariffs 2.0TD and 3.0TD based on historical consumption on an aggregated level. The available information to determine the historical total electricity demand cannot be segregated to identify single users but rather the electricity demand according to the zip codes.
- Another critical factor is how the electricity demand is expected to change throughout the years. The adoption of electric vehicles threatens the electricity grid by increasing demand. Additionally, the policies aimed to increase the efficiency of electricity usage could help diminish the impact of EVs on the grid. There are strategies from utility companies aiming to incentivize EV charging during off-peak periods. The increase in the electricity demand was not considered during the analysis.

The tariff calculation is subjected to factors that have been simplified.

- The penalizations for exceeding the power contracted for the grid are not calculated. This term was neglected in the calculations since it was considered that during the design phase, a proper electrician must calculate the required power demand. In most cases, electricians take the safe route and overestimate the requirement to prevent penalties. However, energy audits and certifications of the energy consumption of a building are required by Spanish law to determine the energy consumption by square meters. It is assumed that the energy audits are performed with the correct methodology, which will also include feedback to the consumer on how to power up their machines and prevent penalties.
- Another simplified factor is that the tariff calculation is defined by one fixed price for the different consumption periods throughout the year. This assumption was based on the prices recorded from the DSOs on their websites, showing the current monthly price of electricity for the applicable periods and tariffs. These values changed throughout the master's thesis period reflecting world events. Since current prices do not reflect the common trend seen in historical prices, the increase and fluctuation throughout the year were not considered.
- A second reason for maintaining a single price throughout the year was the availability of information on the feed-in tariff for consumer solar PV production. Only the energy community SOM Energy was identified with published prices for generation and consumption. The analysis presented in section 6.1.5 shows the relationship between both prices. It was identified as a feed-in tariff ratio in which, for each kWh taken from the grid, the consumer has to provide 2.5 kWh during the valley period and 2.1 kWh during peak periods.

2. Frame of Reference

The forecast of an energy community, the size of RIVAS, requires the analysis of the energy interchange between the demand and production sides throughout the whole municipality. The energy community is modeled from the demand side with residential, commercial, services, and industrial buildings. All of these members have the potential to produce a share of their electricity demand with the use of PV panels. The PV installations will be producing electricity according to the hourly and seasonal changes. There is a need to integrate a vast number of members with different consumption profiles according to their hourly use. From an electricity production point of view, the question arises about the final use of the PV electricity produced. Depending on the time of the year, more or less electricity will be produced which can be dispatched to the network for selling in the energy market. The first usage of the PV electricity produced is as self-consumption. The second usage lies in feeding it to the grid and sharing it between members of the REC. The third usage can be used to sell the surplus PV electricity in electricity markets. Finally, a fourth usage includes the possibility of storing the surplus electricity produced during PV peak hours and then being used within the energy community to satisfy the demand.

The electricity tariffs play a significant role in the simulation of the REC. The consumers and stakeholders involved in the project's development must know the savings this project will bring everyone involved. The savings and initial profits will maintain and further expand the energy community to reach a municipality energy community. The calculated results aim to show the savings for the individual consumers joining the REC and RIVAS on the potential income that is available to develop and manage the REC in the long run.

2.1. Urban Energy Modeling

The energy simulation can be performed according to the principles of urban energy models (UEM). This process requires the creation of energy clusters (EC) or building energy clusters (BEC). UEM started with the simulation of the energy consumption of buildings. This analysis has been done individually without interaction with next-door buildings. As the requirements to predict and plan the future energy consumption of cities, the analysis has grown to include how different buildings work together and aggregate their consumption, eventually increasing the area scope of the analysis resulting in UEM [7].

2.1.1. Urban Energy Modeling Categories

To understand how a UEM can be performed, it is classified according to the hierarchy of input information, from a top-down and bottom-up approach [8].

A top-down approach looks into energy use at an aggregated level. It then links it to associated drivers identified in socio-econometric variables and climate. This approach depends highly on historical data and the system's technical descriptions. The limitations this approach faces are that it relies heavily on historical data and the availability of the building stock to be studied.

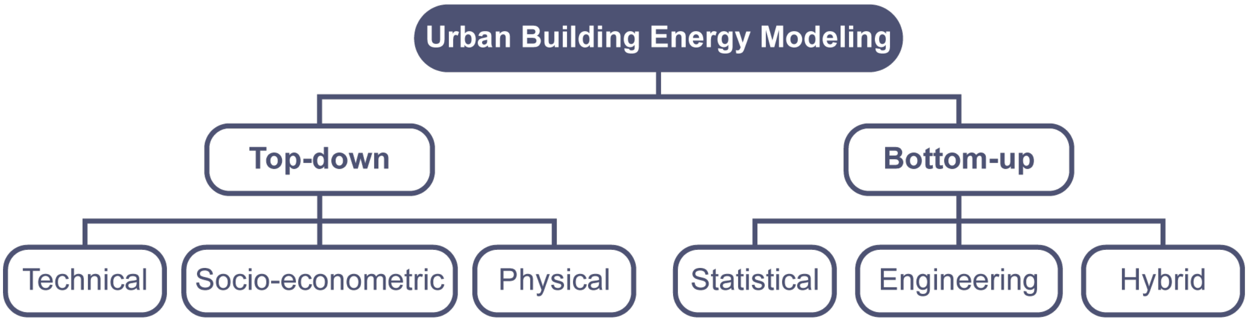


Figure 1. Urban building energy modeling categories.

A bottom-up approach counteracts the limitations of the previous approach. It analyzes the individual energy use of each building resulting in an aggregation of the energy demand of the buildings considered. Since the analysis starts with the building information, this can be inputted in different manners to create the UEM. The result is also known as an urban building energy model (UBEM), divided into three categories in which the information can be used to create the model: statistical, engineering, and hybrid models.

An example of a statistical approach lies in the association of the statistical individual energy end-use with the buildings' characteristics, such as type of windows, insulation, and size, to name a few. The engineering model requires the calculation of the energy demand of each building based on the technical and technological characteristics of each building. Finally, the hybrid model simulates each building according to its physical characteristics. However, the information that is missing is computed based on historical data. One example can be the buildings' occupants' schedules. The limitations of the first two methods are compensated with the use of the hybrid model.

Since there is no clear building stock related to the energy demand for RIVAS, a bottom-up approach with a hybrid model will serve as the selected method to perform the UEM.

2.2. Urban Building Energy Modeling Process

The modeling process is comprised of three main steps. It starts with creating the model through the geometric identification of the buildings. This step includes defining the building's shape, roof, dimensions, location, etc. To complete the model, each building has to be classified according to its archetype. This will represent the most significant features of the building stock. This can include the materials of the building, occupancy schedules, energy demand, etc. These elements are introduced to the UBEM software to simulate either the electricity or thermal energy consumption.

The second step is to create the model simulation. The simulation will be defined according to the weather information available. For UBEMs, which evaluate the thermal variations of buildings, will incorporate radiation models to determine the energy balance due to the solar radiation that reaches each building's surface.

The third and final step is the visualization of the results. The results can be shown in an external or complementary program, such as a worksheet or map visualization tool.

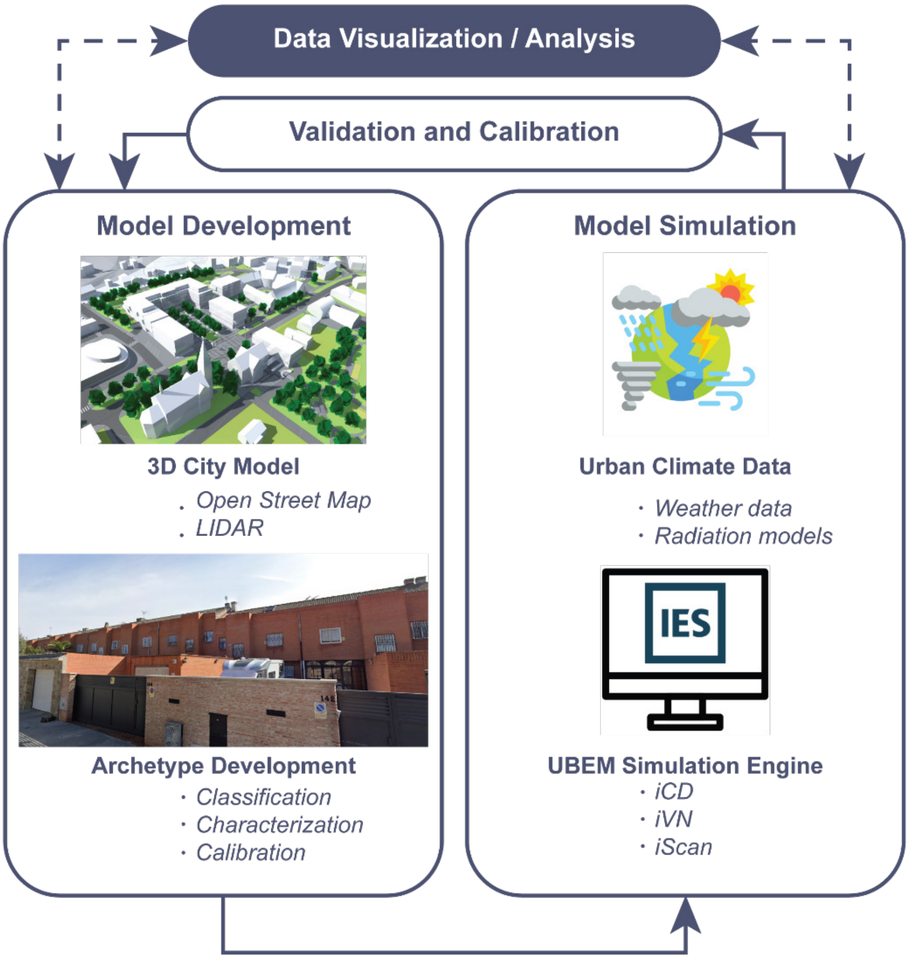


Figure 2. Urban building modeling process.

2.2.1. Creation of the 3D model

The UBEM accuracy is highly dependent on the level of detail of the buildings, their location, and the precision of the 3D model generated. The Open Geospatial Consortium (OGC) proposed a classification for the level of detail available in the 3D models [9].

- **Level of Detail 1**
  The buildings are represented as boxes constructed based on information from the cadaster office or by satellite images that allow the boxes to be extruded from the footprint view (Figure 3).

Figure 3. LOD1 for the Karlsruhe Institute of Technology [4].

- **Level of Detail 2**
  The building is detailed to a more exact representation of its shape. The roof, chimneys, and walls are modeled to show a more detailed representation. This kind of detail can be useful for performing solar analysis with reasonable accuracy since it can determine the PV array's orientation, spacing, and distribution. Additionally, it can be used to perform shadow analysis of the building or adjacent buildings. In Figure 4, the church is represented by its geometric shape. However, the buildings are only represented as a texture for the 3D, and no additional obstacles can be identified.

Figure 4. Textured LOD2 model of a church [4].

- **Level of Detail 3**
  This level of detail shows a more precise representation of the building, in which roof extensions, terraces, and windows are modeled. This level of detail in the building provides very precise planning of a PV installation, in which obstacles, shadows, and extra areas can be identified to install PV panels. Additionally, due to the representation of the glazing ratios, this LOD is more beneficial for thermal modeling.

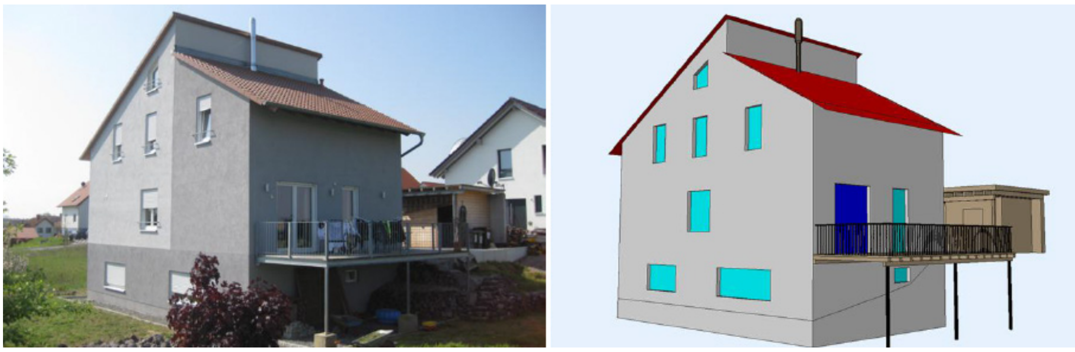


Figure 5. LOD3 for a house with terrace and cottage detailing [4].

One of the most significant challenges identified is how to simplify the analysis of the buildings in the municipality. The literature review showed that there had been different attempts to streamline this process. Schiefelbein et al [10] successfully integrated different python scripts to automate the creation of UEBM. The methodology starts by extracting the data available from Geographical Information Systems (GIS). Furthermore, the data is linked with the city topological information and enriched based on the analysis requirements and user profiles. The results show that it is highly dependent on the initially available information.

Mainzer et al [11] offers a methodology to apply different image processing algorithms to detect the roof's edges based on satellite images. The results show that the algorithms must be dynamically adjusted according to their ability to detect edges. Additionally, satellite images are not enough to determine the tilt of each roof. Thus, further integration with LIDAR data has to be employed to determine it correctly. The methodology applies simplification in this regard by defining an average of 37°.

Figure 6. LIDAR Resolution Available in Spain [6].

For the generation of the 3D model, LIDAR techniques have been used when there is no 3D model available. The LIDAR solution offers a cloud of points with a particular resolution in this case. Spain has publicly available LIDAR data. For the case of the community of Rivas-Vaciamadrid, it has a spatial resolution of 1 point per m^2 [12]. Figure 6 shows the available data for Spain, in which the required resolution is limited.

Figure 8. Zoco Rivas commercial building [9].

Using this technique, the analysis compares the information that can be obtained. In Figure 8, the footprint area for a commercial building is measured through Google Maps. The result is a footprint area of 2.041 m^2. Comparing the result with LIDAR data in Figure 7 obtained from IDEM [13], the result is similar with a footprint area of 2.054 m^2. However, the LIDAR data does not provide the required resolution to identify the obstacles that can be identified in Figure 8. The approach selected was to create the building stock by using the OSM approach and analyze the building's dimensions and cluster them according to their archetype while examining the municipality. The UBEM engine (iCD) doesn't have the required processing platform to analyze LIDAR data and automatize the process.

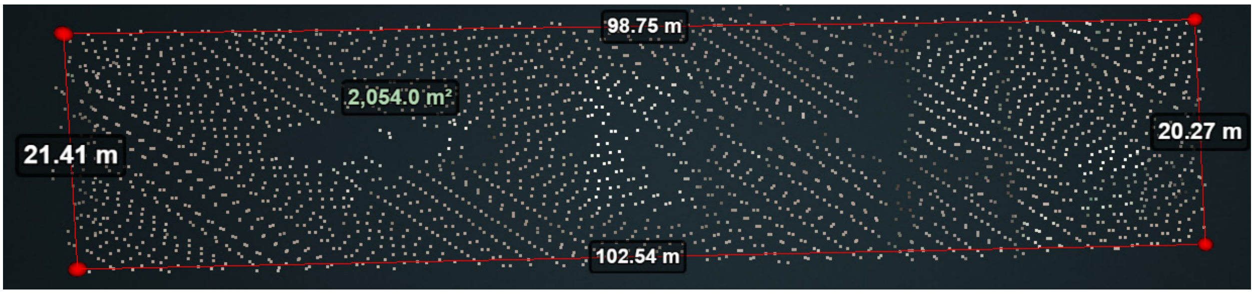


Figure 7. Zoco Rivas LIDAR data [7].

2.2.2. Building's archetype definition

The building stock can be clustered according to similar characteristics to other buildings. This process could be defined as iterative and is defined by the classification and characterization of the archetypes with the final calibration of the input data. The essential characteristics to identify are the building's occupancy, energy demand, and typology, such as a residential or commercial building. There are three different approaches to performing the archetype classification: deterministic, probabilistic and clustered.

In a deterministic approach, the typology of the building and its parameters are used to define the energy demand profile. The age, shape, and floor area can allow good approximations. However, this approach can lead to simplifications that could misrepresent the real dynamics of the buildings analyzed for higher spatiotemporal resolutions.

A probabilistic approach can help improve the accuracy of a deterministic approach. It is necessary to define important parameters that could influence the real energy use intensity. However, this process is limited to the availability of measured energy use data.

The utility companies already use a clustered approach. This method classifies the consumers based on their electricity use profile. This approach is especially interesting to define the tariffs and perform demand side management.

Characterizing archetypes rely on studying specific real cases according to the identified class. The convenience is to use building codes and standards approved by the municipalities. The project TABULA [14] is a detailed study for 20 European countries which identifies energy consumption profiles according to different building archetypes from different years. For Spain, buildings are characterized according to three climate regions, Mediterranean, Continental, and Atlantic. Buildings are also grouped into four main categories: single-family, terraced, multifamily, and apartment blocks. This tool is focused on thermal analysis and defining the thermal envelope and the heating systems installed. For Spain, additional resources are available to obtain the electricity demand intensity for the typology of buildings.

The main driver for energy usage is the building's occupation, which is defined by the occupant's behavior. Additionally, the glazing ratio, air change frequency, and the thermal properties of the buildings are other parameters that can assist in define the building's energy usage in the probabilistic approach. Unfortunately, this approach has not yet been implemented in available UBEM software tools, but it is expected that they will be introduced in the future.

Finally, the archetypes defined need to be calibrated. This process is done once the results have been obtained from the main UBEM. This could be from discrepancies from the calculated values faced with actual measurements.

2.2.3. Model Simulation

The buildings' properties and energy demand characterizations are imported into the UBEM simulation engine, which can be a commercially available engine or custom-made. It was decided to use an already commercially available software for UBEM simulations. Even though this selection will bring validation to the simulations performed, the results will still be validated to develop the analysis and planning of the thesis.

Zygmunt and Gawin [7] analyze different software already available to perform energy simulations at a district level. In this paper, four different software are analyzed to show the differences in the results by simulating the same district. The research paper concluded on the similarities of the results presented when simulating all the energy interchange in the district, from heating demand, electrical systems, and renewable energy systems (RES).

In this sense, the software Intelligent Community Lifecycle (ICL) has been used as the simulation engine. It has been developed by IES, which started as the Ph.D. work of its founder on computer simulation of renewable energy devices. The company identified that most of the tools available for building analysis were in the academic circle. The buildings lacked the proper design to make them more efficient and reduce their CO2 emissions [15]. One of the tools available is a BEM capable of predicting building energy consumption, CO2 emissions, peak energy demands, energy costs, and renewable production [16].

Figure 9. ICL tools and collaboration cloud.

The software ICL's goal is to become a digital twin which will respond and behave like its real-world counterpart. The methodology has many features that enable the simulation to reach its goal. The simulation is performed through a physics engine. It integrates climate information into the calculations. It has integrated zero-carbon standards to perform the designs. It can perform calculations from communities and allow the integration of RES. The results can be analyzed according to the setup of virtual sensors. According to the results obtained, ICL can perform optimizations. The information can be easily presented with the help of its own dashboards [17].

The ICL software (Figure 9) is integrated with four tools to achieve its goals. It manages itself in a collaboration cloud that holds the databases to perform the calculation. Each tool takes advantage of the data and results from each section to perform the complete analysis.

- VE is an integrated analysis tool for the design and optimization of buildings.
- iCD allows the creation of a city master plan to simulate the interaction between buildings.
- iSCAN allows the optimization of building performance at an individual or cluster level.
- iVN is used to analyze energy networks to optimize and manage its resources.

The main tools used throughout the thesis are iCD, iSCAN, and iVN. iCD was used to calculate the buildings' and zones' electricity demand, footprint and total areas, and solar PV production. iVN was used to model and integrate the different networks into a whole REC. It evaluated the PV production and the incorporation of the batteries according to the most convenient place to install them according to the excess PV production. iSCAN was used as the bridge between iCD and IVN for the information exchange.

The urban climate data is handled in the tool iCD. It has a database to weather data that allows the calculation of the energy demand based on historical weather data. The data is generated from historical measurements from 20 to 30 years and is defined as typical meteorological years.

The ability to perform a detailed 3D model with a complete and detailed building stock with its archetypes had to be balanced.

2.3. Spanish Electricity Tariff Scheme

The electricity bill in Spain is composed of the following concepts [18]:

- Cost of energy: it is the actual cost to produce electricity.
- Distribution profit: is the margin the DSO receives for the services offered.
- Access tariff: includes the transportation costs on the electric grid (tolls) and government incentives for renewables implementation.
- Measuring equipment: it refers to the rent cost of the electric meter.
- Taxes: includes a 5% tax for the cost of energy and access tariff, and 21% VAT applied at the end of the electricity bill.

On June 1st, 2021 the Spanish electric market adopted a new tariff scheme that applies to all electricity consumers of the electric grid [19]. The changes include the breakdown of the access tariff into tolls and charges. Additionally, all consumers have a tariff based on hourly discrimination regarding energy and power. This results in a different price according to the schedules known as valley, flat, and peak. The prices are lowest in the valley period and highest during the peak one.

All tariffs have two components to settle the electricity bill. The energy term and the power term set and measured hourly. The meter registers the consumption and maximum power demand per hour. The energy term is calculated by multiplying the amount of electricity consumed in each period, by the tariff set. The power term is set by the user for each period at the beginning of the contract with the DSO. The meter will monitor the power demand is not exceeded. If the user exceeds the rated power contracted, it will be subject to a penalty fee. The cost of the power term is calculated by multiplying the hired power by the annual price and then it is divided monthly to charge it in the electricity bill.

The government regulates the tariffs, and the price is subject to change according to the DSO that provides the service. The Spanish DSOs used as reference are Endesa, Repsol, Total Energies, Naturgy, and SOM Energy. It is essential to distinguish that SOM Energy is already an energy community in Spain. Since it allows the possibility to produce energy and feed it to the REC, it has set prices for consumption and production.

2.3.1. Tariff 2.0TD

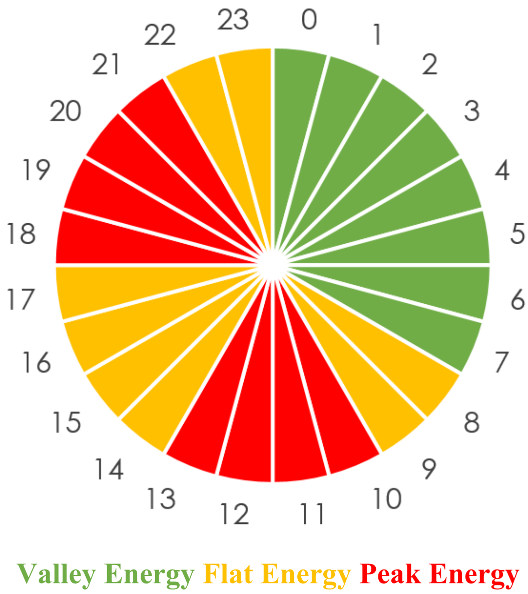


Figure 10. Tariff 2.0TD weekday hourly distribution.

This tariff is set for consumers with a contracted power below 15 kW [20]. This tariff does not differentiate between residential and commercial consumers. It is set by the amount of power contracted to the utility company. In the analysis, tariff 2.0TD is applied to residential consumers.

It is divided into three hourly discrimination periods for the energy term during weekdays, as seen in Figure 10. Weekends and holidays correspond to the valley tariff.

The power term is divided into two periods. The valley power is set for 0:00 to 8:00, and the peak power is set for 8:00 to 24:00. On weekends and holidays, the valley power is charged.

Different companies are offering the service, and the consumer is free to choose the electricity supplier that offers the best price. In Table 1, the main electricity suppliers are shown, as well as their prices offered for June 2022.

Table 1. Reference prices for tariff 2.0TD for June 2022.

Tariff 2.0 TD Energy Prices (€/kWh)					
Supplier	**Endesa**	**Repsol**	**Total Energies**	**Naturgy**	**Som Energy**
Valley Energy	0.1832	0.1796	0.2170	0.1909	0.2410
Flat Energy	0.2226	0.1986	0.2412	0.2418	0.2930
Peak Energy	0.2806	0.2485	0.3073	0.2990	0.3570
Tariff 2.0 TD Power Prices (€/kW)					
Valley Power	0.0219	0.0109	0.0092	0.0142	0.0081
Peak Power	0.0927	0.0973	0.0810	0.0827	0.0767

2.3.2. Tariff 3.0TD and Tariff 6.XTD

Tariff 3.0TD is applied for consumers using a low voltage connection above 15 kW and less than 100 kW [21]. Tariff 6.XTD is destined for consumers that are connected to a high voltage supply above 1 kV [22]. It usually is for big buildings and industries. According to the tension, the building is connected, and the price of the electricity will be set (Table 2). In the analysis, tariff 3.0TD has been applied to commercial and tertiary buildings, and tariff 6.XTD has been applied to industrial buildings.

Table 2. Tariff 6.XTD available according to the tension required.

Tariff	Voltage (kV)
6.1TD	1 – 3
6.2TD	30 – 72.5
6.3TD	72.5 – 145
6.4TD	Above 145

Both tariffs have similar hourly discrimination periods for the energy and power terms. It has 6 periods throughout the year that are applied according to the season. In Figure 11, the weekday periods are shown. In essence, both tariffs have valley, flat, and peak periods but the price change according to the season, hence the six periods available. While for January and February, the valley price is represented as period 2, for March, period 2 corresponds to the peak tariff. On weekends and holidays, the tariff applied is period 6.

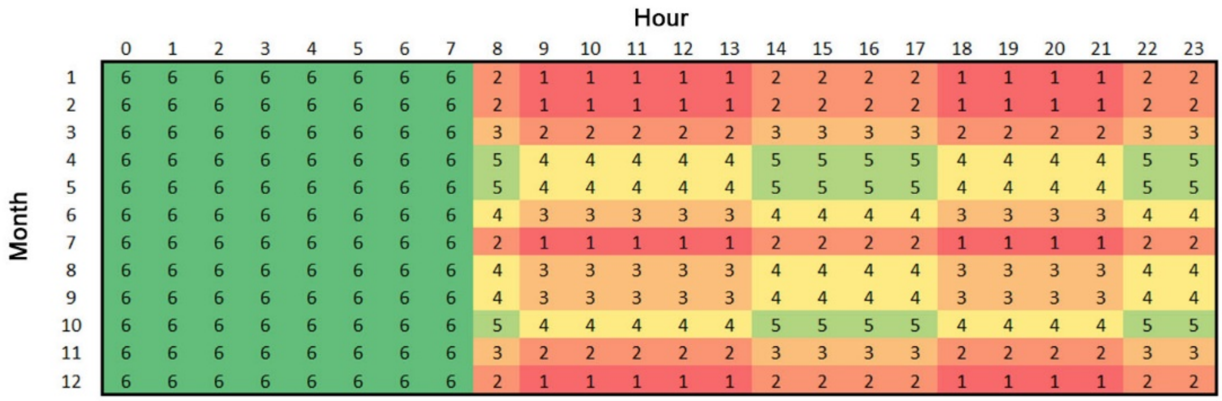


Figure 11. Tariff 3.0TD and tariff 6.X TD Weekday hourly distribution [12].

Table 3. Tariff 6.1TD power and energy prices for June 2022 [21].

Tariff 3TD Power Term (€/kW day)					
	Gesternova	**Iberdrola**	**Endesa**	**ODF**	**Som Energy**
P1	0.0437	0.0446	0.0407	0.0396	0.0396
P2	0.0346	0.0329	0.0316	0.0305	0.0305
P3	0.0181	0.0155	0.0151	0.0140	0.0140
P4	0.0157	0.0129	0.0127	0.0116	0.0116
P5	0.0111	0.0127	0.0081	0.0070	0.0070
P6	0.0090	0.0108	0.0060	0.0049	0.0049
Tariff 3TD Energy Term (€/kWh)					
P1	0.2846	0.2480	0.3586	0.2771	0.3550
P2	0.2605	0.2409	0.3586	0.2554	0.3240
P3	0.2426	0.2267	0.3586	0.2354	0.2960
P4	0.2300	0.2203	0.3586	0.2322	0.2690
P5	0.2027	0.2147	0.3586	0.2092	0.2460
P6	0.2059	0.2073	0.3586	0.2048	0.2390

Table 4. Tariff 6.1TD power and energy prices for June 2022 [22].

Tariff 6.1TD Power Term (€/kW day)				
	Iberdrola	**Naturgy**	**ODF**	**SomEnergy**
P1	0.0837	0.0837	0.0837	0.0614
P2	0.0709	0.0709	0.0709	0.0558
P3	0.0408	0.0408	0.0408	0.0314
P4	0.0331	0.0331	0.0331	0.0248
P5	0.0108	0.0108	0.0108	0.0055
P6	0.0058	0.0058	0.0058	0.0032
Tariff 6.1TD Energy Term (€/kWh)				
P1	0.1395	0.1802	0.1700	0.3140
P2	0.1278	0.1606	0.1536	0.2890
P3	0.1110	0.1368	0.1319	0.2710
P4	0.1014	0.1188	0.1164	0.2440
P5	0.0927	0.0985	0.0994	0.2260
P6	0.0871	0.0991	0.1010	0.2190

Table 3 and Table 4 show the prices for the energy and power terms for each tariff. Since RIVAS does not have big industries, it was assigned the tariff 6.1TD to analyze it.

2.3.3. Solar PV Generation Prices

SOM energy is an energy community that has prices for demand and generation. The generation price was taken into account to calculate the amount of money each building will receive for the solar PV generated according to the installed solar PVs on site. No prices were identified for the other companies to be used in the analysis and finding the best company where the consumers could contract the electricity service. Table 5 shows the prices for the generation of each tariff. The price SOM Energy assigns is lower than the consumed electricity. This value can also be taken into account as a feed-in ratio. There is no power term assigned for PV generation.

Table 5. SOM Energy PV generation prices for June 2022 (€ /kWh)

	Tariff 2.0TD	**Tariff 3.0TD**	**Tariff 6.1TD**
P1 (Peak)	0.170	0.142	0.101
P2 (Flat)	0.120	0.130	0.093
P3 (Valley)	0.096	0.107	0.079
P4	-	0.095	0.072
P5	-	0.083	0.062
P6	-	0.091	0.069

3. Implementation

As presented in chapter 2, Frame of Reference, the creation of the UBEM for the RIVAS energy community starts with the creation of the city 3D model. RIVAS' buildings are analyzed to define their archetype. The information gathered with the help of GIS tools is introduced in the simulation engine ICL from IES to calculate the total energy demand and possible potential PV generation. The development throughout the creation of the UBEM is presented in this chapter.

3.1. Municipality Division

The municipality Rivas-Vaciamadrid (RIVAS) has been analyzed using the census sections from the cadaster's office [23]. The division shown in Figure 12 shows 45 sections that include residential, commercial, and tertiary buildings. The tertiary buildings are service buildings such as government offices, police stations, and school buildings. RIVAS also has 5 industrial sections shown in the southwest corner. These sections are not limited to industrial buildings but also hold the three types of buildings. These sections will be used to analyze the whole municipality in a structured order and to create individual energy communities in the development plan.

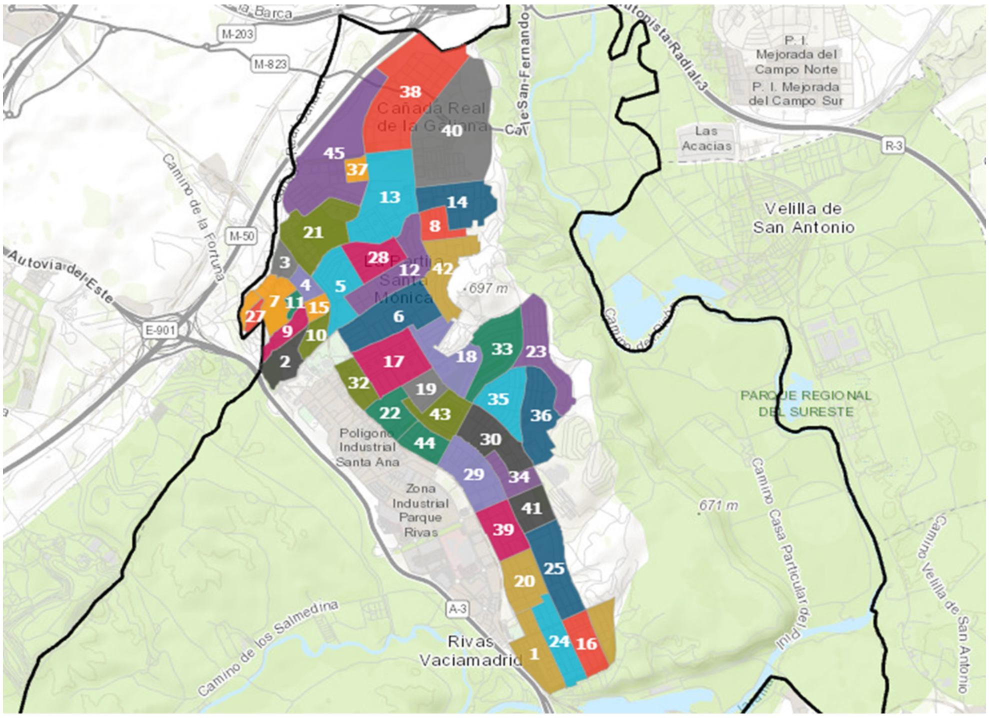


Figure 12. Rivas Vaciamadrid census sections [15].

3.2. Creation of the 3D city model

The software iCD works as an interface in the SketchUp program. iCD is also linked to the OSM database to obtain the buildings' footprints. The information required to assess the PV potential is the building's shape, size, type of roof, and orientation. To determine the energy demand for the building, the total area of the building is used.

3.2.1. OSM Database Analysis

The information imported by OSM for RIVAS was used as an initial approach to obtain the building stock for the energy community. The analysis showed that the information is not complete and has a LOD0. This detailed level means it only provides general information about the footprint. Figure 13 shows the buildings for census sections 12 and 28. As it can be seen, there are gaps in information about the buildings and their similarities.

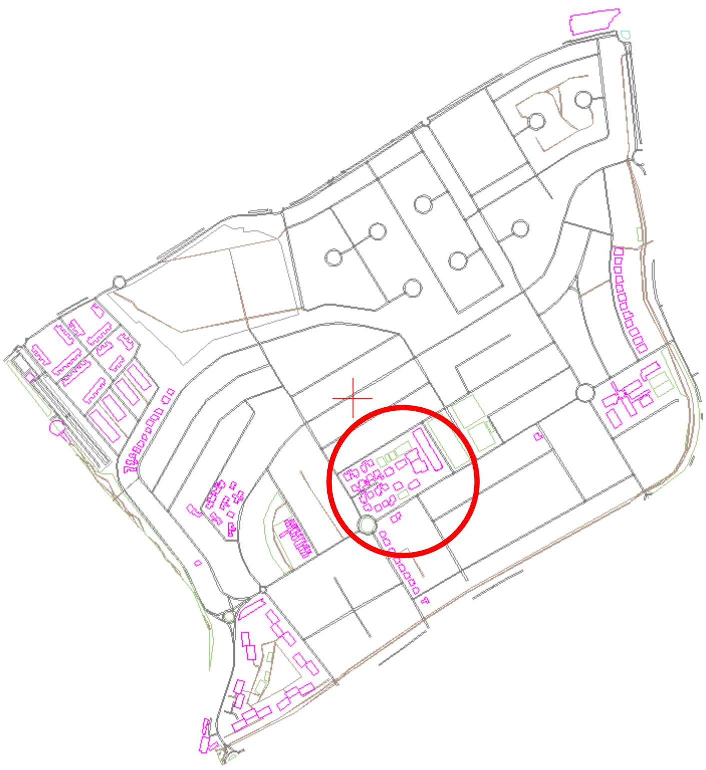


Figure 13. Census sections 12 and 28.

Further analysis of the buildings available showed that the information provided by OSM required further processing to obtain the building's properties required to create the archetype. As shown in Figure 14 and Figure 15, the commercial building Zocco, at the far right of Figure 14, is well-defined in its size. However, the obstacles in the roof that will reduce the PV area available are not indicated. On the left side of Figure 14, different residential buildings need to be accounted for. Additionally, Figure 15 shows additional areas of the buildings that are not necessary on the roof but garages in which it will not be feasible to install PVs.

Figure 15. Close up for buildings in section 12.

Figure 14. Aerial view of census section 28 [16].

In general, the database available from OSM is incomplete and will require extensive hours of processing to make it usable.

3.3. Archetype Development

Figure 16. Clustering of similar buildings [5].

The analysis of the buildings in RIVAS showed high replicability of them. As shown in Figure 16, the municipality's construction used similar residential buildings to develop entire neighborhoods. A clustered approach was employed in which similar buildings were analyzed to obtain the total building stock and then apply the electricity profiles according to their electricity demand.

3.3.1. Archetype Classification

The archetype analysis was divided into sections, and each building was measured according to the habitable space, disregarding modifications to the houses such as extensions or extra roofs that were identified.

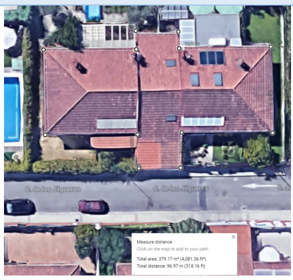
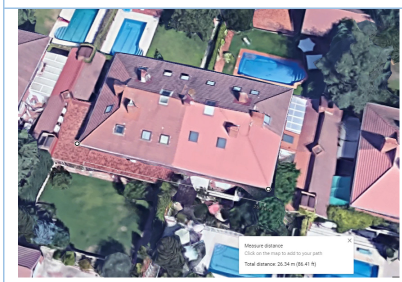
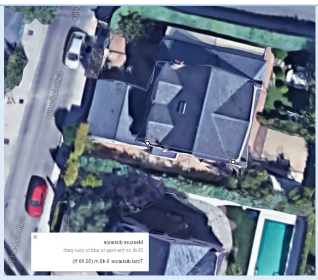
There were a minimal number of houses that had already integrated solar PV. This was not taken into account to determine the existing PV installed.

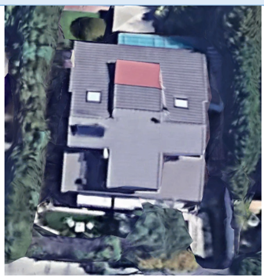
3.3.2. Archetype Characterization

The archetype characterization identified the different buildings in the RIVAS census sections. A name was assigned for each building composed of the number of sections, its type, a letter identifying the orientation of the building, such as south or east, the consecutive number according to its type, and the number of buildings similar to it. For example, one type of building is

"28_residential1_44S", which means it belongs to section 28; it is a residential type of building; it is the first building on the list; there are 44 similar types of buildings, and they face south. The information of each building, such as name, footprint area, number of buildings, predominant orientation, and type of roof, is added to tables for each section. Table 6 shows an example of the buildings characterized for RIVAS census section 28.

Table 6. Characterization of census section 28.

Building	Name	Footprint Area	Orientation	Type of Roof
	28_Commercial1_1	2,003.29	South	Flat
	28_Residential 1_2E	189.36	East	Gable
	28_Residential1_44S		South	
	28_Residential2_28E	55.35	East	Gable
	28_Residential2_39S		South	
	28_Residential3_32S	212.10	South	Gable
	28_Residential4_30S	82.91	South	Hipped

Building	Name	Footprint Area	Orientation	Type of Roof
	28_Residential5_35S	109.78	South	Gable
	28_Residential5_4E		East	
	28_Residential6_15S	140.71	South	Flat
	28_Residential7_1S	226.60	South	Hipped
	28_Residential8_2E	182.98	East	Gable
	28_Residential8_3S		South	Gable
	28_Residential9_13E	120.94	East	Gable

Building	Name	Footprint Area	Orientation	Type of Roof
	28_Tertiary1_1S	441.02	South	Flat
	28_Tertiary2_1S	518.37	South	Gable
	28_Tertiary3_2S	442.85	South	Gable
	28_Tertiary4_2S	393.66	South	Gable

3.3.3. Creation of buildings in SketchUp-ICD

The information from the tables created in section 3.3.2 Archetype Characterization was introduced in the program SketchUp. The buildings are represented in the number of floors and type of roof (Figure 17). The program iCD creates the database with the information required to calculate the electricity demand. The previous tables are updated with the total footprint area and the number of floors.

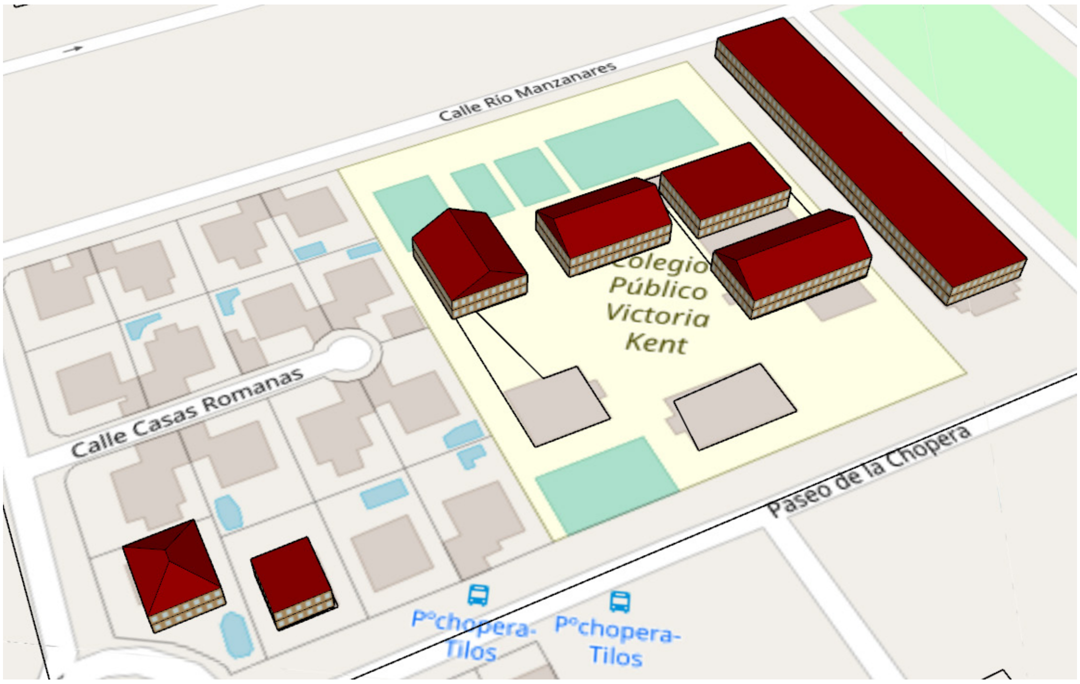


Figure 17. SketchUp - iCD 3D Buildings for tertiary and commercial buildings in section 28.

3.3.4. Electricity Demand for Buildings

The annual electricity demand of each building was defined according to two procedures. The first procedure takes into account the annual intensity of electricity consumption according to the total building area in m^2. The second procedure consists in simulating the electricity demand in iCD.

This requires a longer processing time and assumptions of unknown parameters for each building, such as heat transfer values, type of building, ventilation systems, etc.

The first procedure has the benefit that it is fast, it requires a smaller number of parameters, and the electricity consumption profiles are known from the literature. This procedure is applied to residential, commercial, and tertiary buildings. The electricity consumption for industrial buildings was not available in the literature researched.

Procedure 1. Standard Electricity Consumption

This procedure aims to find the total electricity consumption by area (residential, commercial, and tertiary.) and by section. It begins with the measurement of the area of the buildings to obtain the total construction area. The individual area is multiplied by the total number of similar buildings. The total areas are added according to the zone to obtain the total area of the section. This is represented in Equation 1.

$$Total\ Building\ area = \sum Building\ area\ \times floors\ \times similar\ buildings$$

Equation 1. Total building area

The total area for each building was multiplied by the annual intensity of electricity consumption according to Table 7. The total electricity consumption is shown in Table 8.

Table 7. Annual intensity of electricity.

Electricity consumption (kWh/ m^2 per year)		
Residential [24]	**Commercial** [25] [26]	**Tertiary** [27] [28]
27.61	158.90	102.56

The annual electricity consumption of each building was introduced into an electricity consumption profiler to obtain the hourly consumption according to the type of building. This profiler has an input of the annual electricity consumption and distributes it hourly for one year.

Table 8. Calculation of total annual electricity consumption for section 28.

Building Name	Total Building Area (m2)	Number of Buildings	Total Buildings Area (m^2)	Total Building Annual Electricity Consumption (kWh / year)
28_Commercial1_1	4,007	1	4,006.57	636,641
28_Residential1_2E	189	2	378.72	10,458
28_Residential1_44S	189	44	8,331.88	230,074

Building Name	Total Building Area (m2)	Number of Buildings	Total Buildings Area (m^2)	Total Building Annual Electricity Consumption (kWh / year)
28_Residential10_15S	348	15	5,220.04	144,145
28_Residential2_28E	111	28	3,099.86	85,599
28_Residential2_39S	111	39	4,317.66	119,227
28_Residential3_32S	424	32	13,574.40	374,840
28_Residential4_30S	166	30	4,974.50	137,365
28_Residential5_35S	220	35	7,684.64	212,202
28_Residential5_4E	220	4	878.24	24,252
28_Residential6_15	281	15	4,221.39	116,568
28_Residential7_1S	453	1	453.21	12,515
28_Residential8_2E	366	2	731.94	20,212
28_Residential8_3S	366	3	1,097.91	30,317
28_Residential9_13E	242	13	3,144.31	86,826
28_Tertiary1_1S	1,037	1	1,036.75	106,332
28_Tertiary2_1	882	1	882.04	90,465
28_Tertiary3_2S	886	2	1,771.39	181,680
28_Tertiary4_2S	787	2	1,574.65	161,501
Total for Section 28		270	67,380	2,781,217

Table 8. Calculation of total annual electricity consumption for section 28.

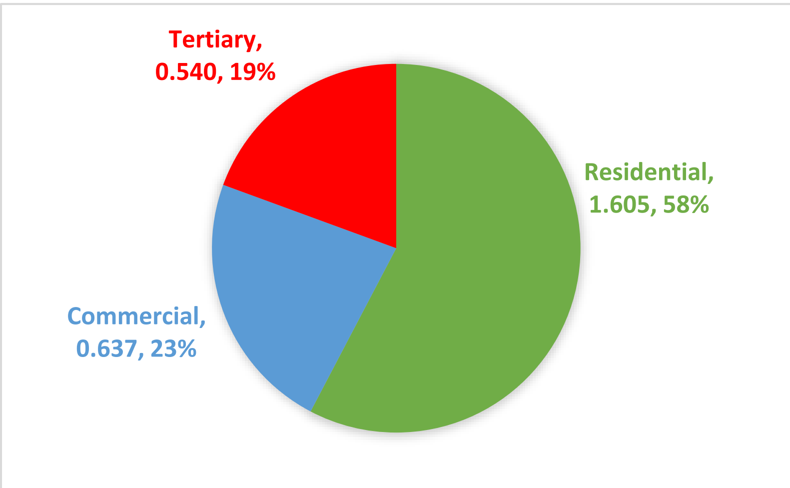


Figure 18. Section 28, Annual Electricity Consumption (GWh/year).

Procedure 2. Simulation of Industrial Electricity Consumption

The electricity profile for the industrial buildings was performed using the software IESVE. In this program, the building is selected as an industrial warehouse with the year 2000 as the construction year and the industry category it belongs to. The categories selected were:

- Car retail,
- Food processing
- Logistics warehouse,
- Manufacturing facilities
- Metal industry
- Wood industry

The simulation engine generated the results for the whole year. The simulation results were 34% less than the ones using procedure 1 with outdated literature. Additionally, the results were compared with the webpage DATADIS [29], which presents the accumulated energy and electricity contracts according to the tariff.

3.3.5. Electricity Profiles for Tariffs 2.0TD and 3.0TD.

The electricity profiles used to calculate the hourly consumption for each section are shown in Figure 19. The graph shows the sum of the hourly consumption for the whole year. It presents the annual hourly electricity demand. Figure 20 shows the electricity demand annual hourly average and the ranges for the seasonal changes for each tariff. The tariff 2.0TD profile was used for residential buildings. The tariff 3.0TD profile is used for commercial and tertiary buildings, and the tariff 6.1TD profile is used for industrial buildings.

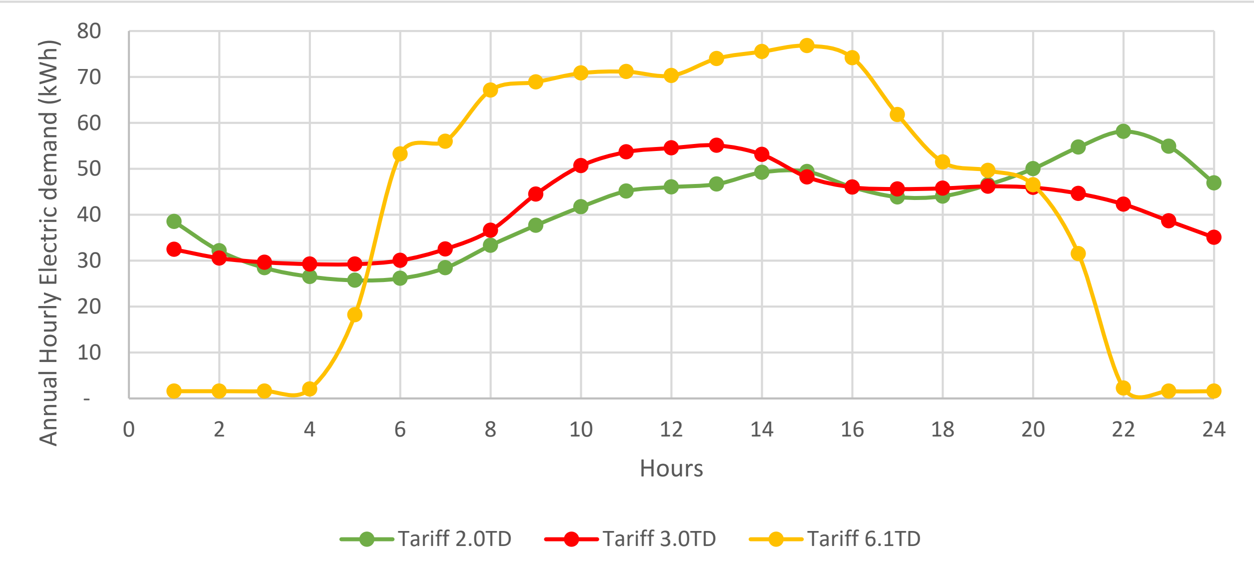
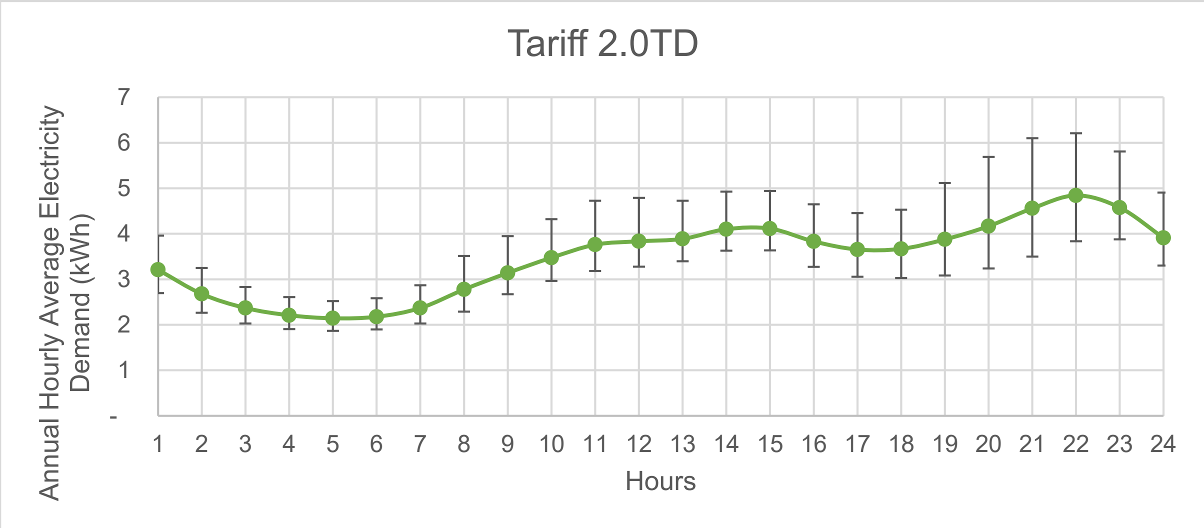
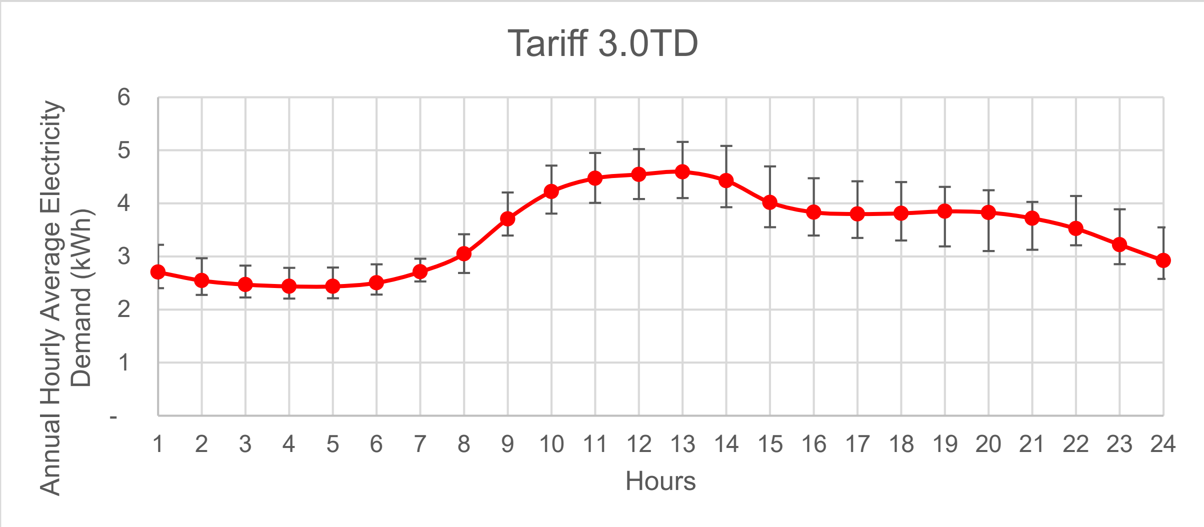


Figure 19. 1 MWh/year normalized electricity profiles.





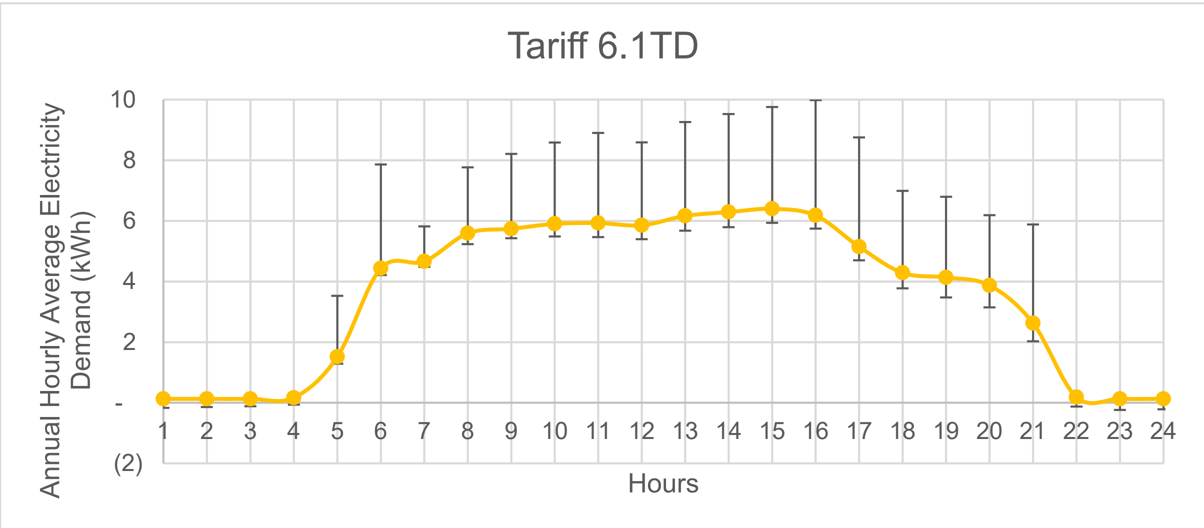


Figure 20. Annual hourly average electricity demand.

3.3.6. Characterization of available roof space

The roof characterization of the building was focused entirely on installing the PV panels array. Several factors influence the space available. These factors are listed below.

- The availability of a 3D model of the area assessed.
- Shadows forecast for vegetation or adjacent buildings.
- Spacing between linear PV arrays for self-casting shadows.
- Structures within the rooftop that limit the deployment of PV installations.
- Type of roof for the installation, a flat roof, a hyped roof, and a gable roof.
- Orientation of the buildings.

Characterizing the building's roof considers two types of installation of PV panels. The first approach considered the installation of the panels oriented to the south. This approach benefited from installing the PV modules with the best configuration to maximize electricity production. The drawback is that the area utilization is not optimized, and many more PVs could be installed. In RIVAS, there are buildings oriented in this manner. Figure 21 shows two examples. The first is a residential building that adapted the PV panels in many rows and sections of the building. This building could incorporate more PV panels if they are aligned along the axis of the building to maximize the capacity installed. The PV panels are installed in the building's southern corner for the second building. Additional panels could be installed in the western corner of the building and take advantage of that area. Considering the PVs installed, the area used for PVs for these buildings was 20% and 14%, respectively.

Figure 21. PV panels oriented to the south [22].

The second approach is to install the PV panels maximizing the capacity installed using the main axis of the buildings. Some buildings in RIVAS were identified that use this approach. Figure 22 shows in the first picture a tertiary building. In it, most of the area was used to install PV panels.

Figure 22. PV panels oriented in the main axis of the building.

However, some areas were left without PVs installed. There might be considerations taken to optimize the arrays of the PV installation considering the grid inverter in use. It was impossible to obtain this installation's technical specifications to analyze the design implemented. In the second picture, a residential house is shown with a hipped roof. The PV panels in this house are oriented southeast, following the shape of the roof. This procedure optimizes the installation costs, reducing additional tilting hardware to align the PV panels in the southern direction. The analysis of this installation led to an area usage of 21% and 16%, respectively.

An industrial case can be seen in Figure 23. Although it is in an inclined roof, this type of building was considered a flat roof due to its availability. Without going into a detailed shadow analysis of the structure, the buildings were favored due to their orientation to the south. The image shows

Figure 23. PV Deployment industrial sector with flat roofs.

that the PVs installed in the warehouses use the total roof area. An 80% usage for this kind of building was estimated while considering a maintenance walkway and spacing between modules.

Finally, the analysis was made in a 3D model to determine the total area available in an ideal case. This resulted in an available area of 46% of its footprint. The results use a 48% area available for flat roofs and 31% for hip and gable roofs. An optimum scenario was defined by increasing the PV area available to 70% for flat roofs and 46% for hip and gable roofs.

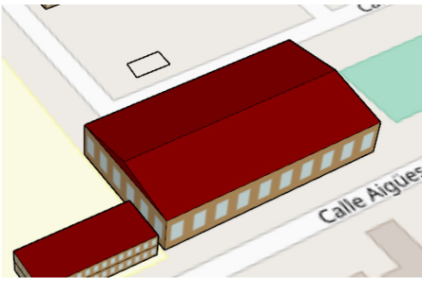


Figure 24. Ideal hipped roof type.

3.4. Electricity Simulation

The information generated from iCD was exported into CSV files. These files were exported to iSCAN to transfer them to iVN for its analysis. iSCAN is an online tool that synchronizes information between different software. iVN was used to create the individual networks referring to each section and finally integrate all the sections.

3.4.1. Creation of networks in IVN

iVN works by creating an abstract mode of the grid. It can incorporate different kinds of assets to simulate their interaction. In this case, the input information has been divided according to their sector. The electricity production was divided into PV installations in the east and south directions. Even though there are buildings oriented west, simplifying the classification process led to grouping them in the eastern direction. This could yield a higher production of electricity in the

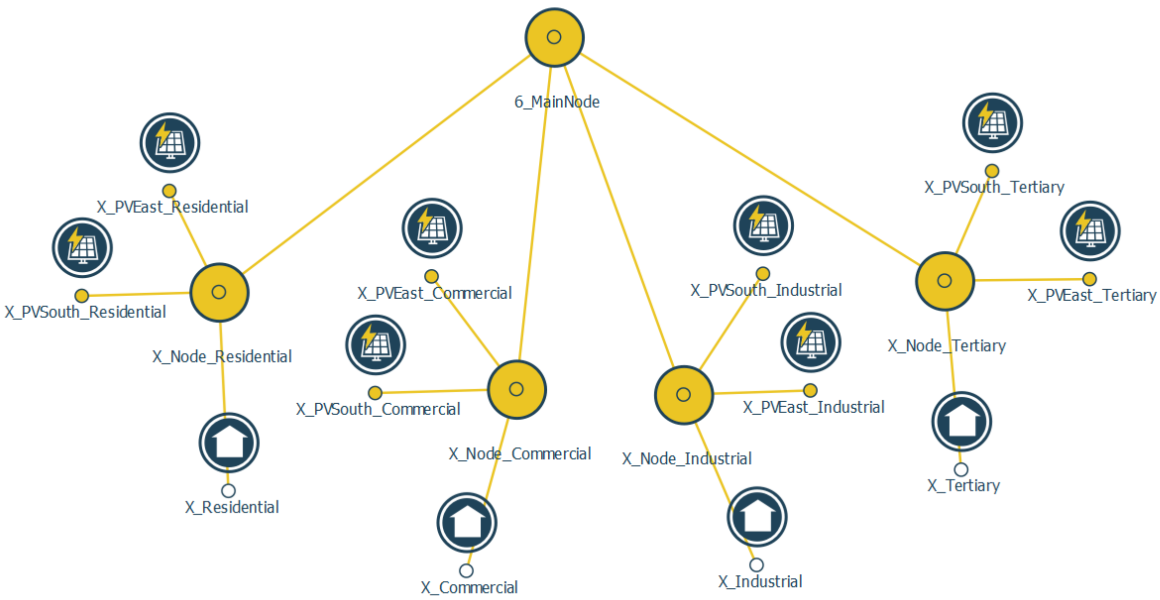


Figure 25. iVN simulation grid.

morning. However, by selecting an eastern orientation, a conservative scenario was selected as it is examined in section 5.5. The structure shown in Figure 25 shows the primary grid created. In it, each parameter of the building was defined.

For the electricity demand, the hourly information was linked through iSCAN. The PV installation was defined as a 200 watt solar panel with an azimuth of 0°, or 270°—a degradation factor of 1, with an inclination of 35°. The nominal cell temperature is 42°C, and it has a nominal efficiency of 20%. Since most buildings do not interfere and cast shadows between each other, the shading factor is defined as 1.

As many sections have different grids, the process was defined for each section. Figure 26 shows the resulting grid for section 12. This section only has residential and tertiary buildings. Additionally, the tertiary buildings in it have a flat roof and were considered to face south. iVN calculates the solar production based on its weather data specifying the location for RIVAS.

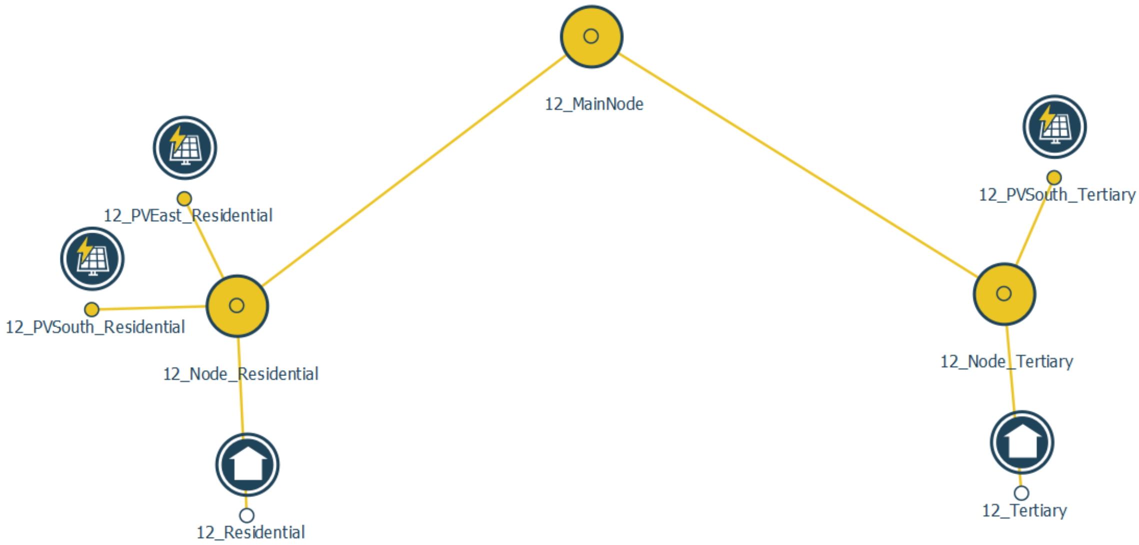


Figure 26. iVN grid example for section 12.

4. Results

This chapter presents the results of the calculations of the electricity consumption by sector and by sections as well as the electricity costs associated with implementing the energy community.

4.1. Electricity Demand Results

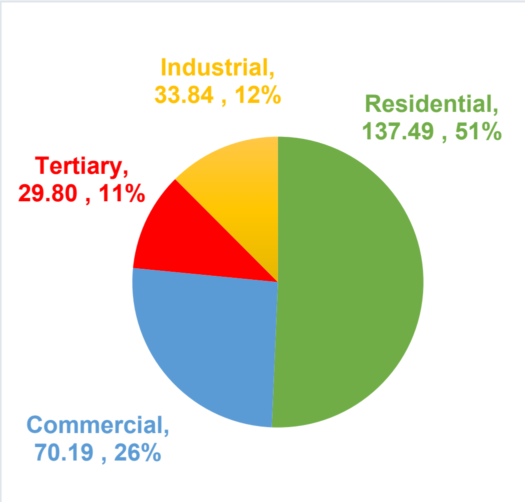


Figure 28. Electricity Demand Distribution per Sector (GWh/year).

RIVAS estimated electricity demand is **271.32 GWh per year**. Figure 27 shows that the sector with the highest consumption is residential. The residential sector contributes 51% of the total electricity demand. The commercial sector represents the second largest consumption with 26%.

Figure 28 shows the electricity demand per section. Overall, sections 1 through 45 have an approximate average electricity demand of **4.05 GWh per year,** with a slight variance. The section known as Industrial 2 (IND2) has the highest consumption overall. It is composed of commercial buildings in reality. The electricity demand of section IND2 represents **14.95%** of the total electricity demand, equivalent to **40.57 GWh per year**.

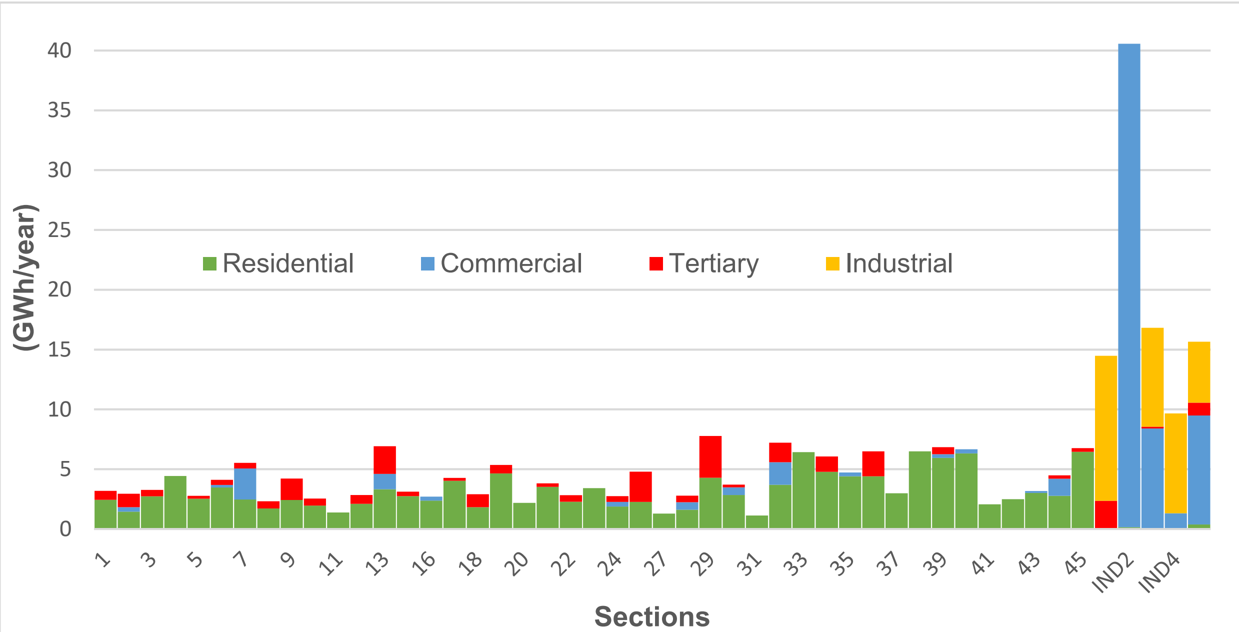


Figure 27. Annual electricity demand per section.

4.2. Annual PV Production

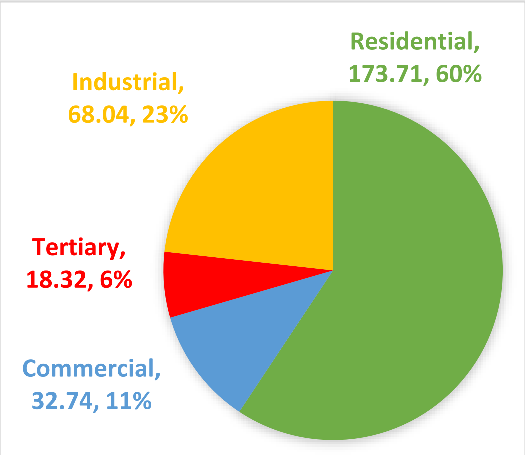


Figure 29. Annual PV production by sector (GWh/year).

RIVAS has the potential to install solar PV in the majority of buildings. It has the maximum potential to have a solar PV production of **292.81 GWh per year**. Figure 29 shows that the residential sector contributes the most solar PV production, with **173.71 GWh per year**, equivalent to **59% of the total PV production**. The industrial sector has the second largest potential, with **23%**. Figure 30 shows the PV production per section. Sections 1 through 45 have an average electricity production of 4.50 GWh per year. Industrial section 3 (IND3) has the highest PV potential. It represents 11.3% of the total PV production. It can produce **33.13 GWh per year**.

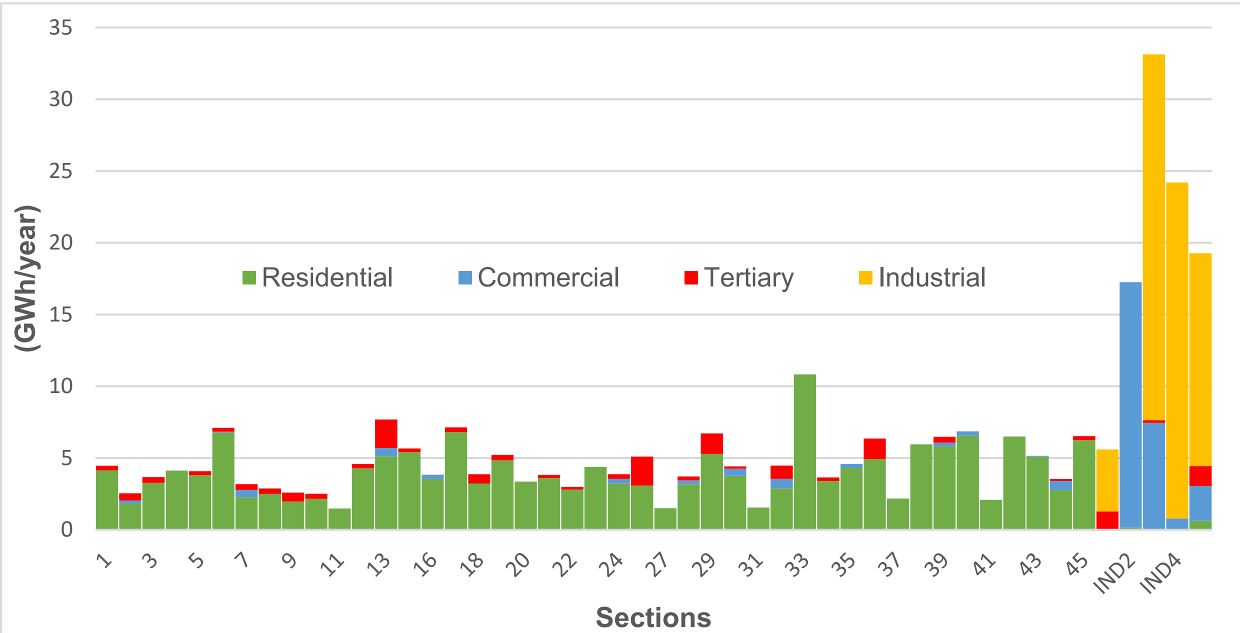


Figure 30. Annual PV production per section.

4.3. Electricity Demand and Annual PV Production Validation

The validation of the UBEM results is based on the validity of the input data. The electricity profiles for tariff 2.0TD, 3.0TD and 6.1TD were taken from IDAE [24] and the Madrid Energy Foundation [25] [28]. The validity of the PV production calculated is based on the solar model integrated in the IES software. This chapter aims to validate the results based in external resources to obtain the electricity demand, the electricity demand profiles and the PV production.

4.3.1. Electricity Demand Validation

The Electric Companies Association (ASEME) is a Spanish organization of DSOs. Its members are E-Distribucion from Endesa, E-Redes from EDP, I-DE from Iberdrola, and UFD from Naturgy. ASEME developed the platform datadis to facilitate the access to users to their electricity consumption. Datadis also serves as a general consulting service to the electricity demand for Spain [30].

Datadis has limitations. It has a data range from August 2019 to May 2022. It doesn't display all records due to personal data protection law which limit the consumption and the users displayed. It aggregates data per zip code for queries. The individual user electricity profile is not displayed. Access to information for users of tariff 3.0TD and 6.1TD is not displayed. The aggregated residential information per zip code was used. The UBEM model created doesn't consider a zip code division, so it was analyzed in an aggregated level.

The municipality Rivas-Vaciamadrid has three zipcodes, 28521, 28522, and 28523. The queries delivered the number of clients and electricity consumption for the residential sector. The annual electricity consumption for the year 2020 is **104.64 GWh** and for the year 2021 is **118.32 GWh**. The annual electricity consumption calculated through the UBEM is **137.49 GWh** which is 31% and 16% more of the real data respectively. The increase in the electricity demand from the year 2020 and 2021 is due to the increase in the number of clients. Figure 31shows a continuous increase of the registered users with a spike in the month of April 2020. RIVAS is a municipality that is still under construction. During the analysis of OSM images, the historical views showed an increased number of buildings. The expansion of the municipality is not taken into account in the analysis, only to explain the higher consumption of electricity through the years.

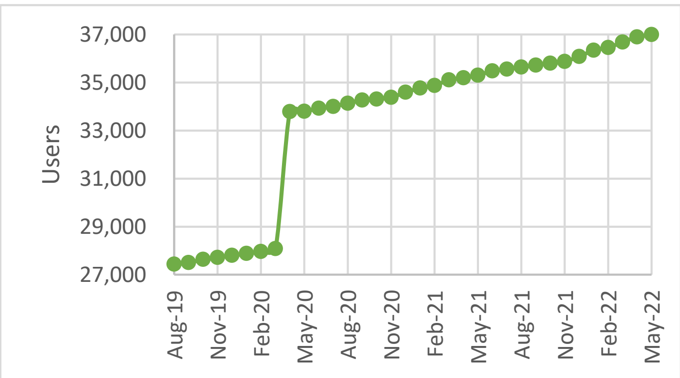


Figure 31. Registered users in datadis [29].

Another important aspect is the validity of the electric demand profiles, which correlate with the tariff and self-consumption results. Figure 32 shows the average real time data provided from datadis along with its maximum and minimum values from the available data. It is compared with the electricity demand profile from IDAE [24] which is used in the UBEM. Although the data is not exactly the same, it shows a similar trend line with maximums during the winter and summer months. The difference in the values is associated to the data from IDAE, which is the result of a more extensive study with more historical data taken into account.

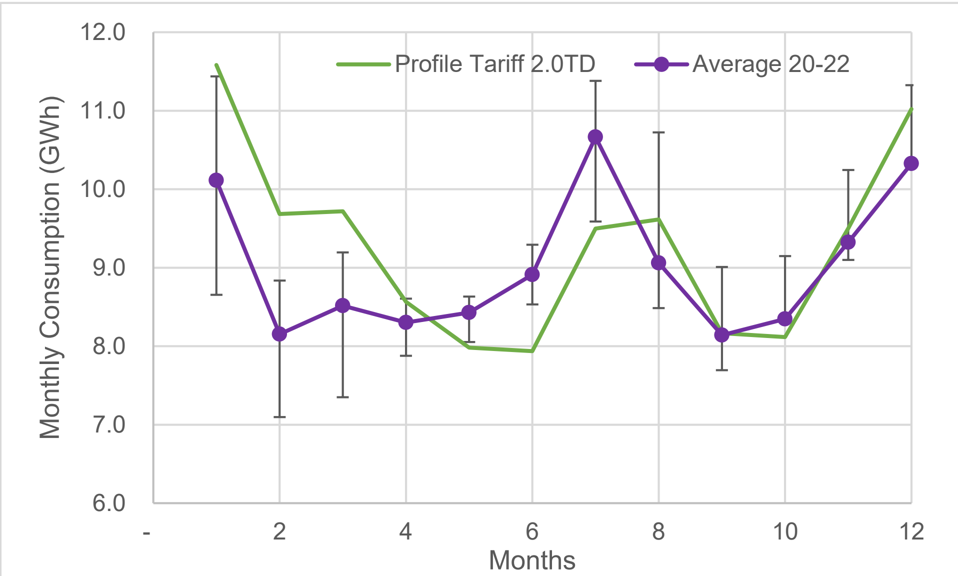


Figure 32. Datadis average electricity consumption profile.

The electricity demand results obtained in section 4.1 are validated through these verifications. Although the tariff 3.0TD and 6.1TD are not analyzed, the source of the information can be assumed to be valid through the source it was generated which is similar to the one used for tariff 2.0TD. It can be assumed beneficial for the RIVAS analysis a higher electricity consumption since it will require more PV to satisfy its demand or the cost of electricity will be higher.

4.3.2. PV Production Validation

The European Commission has developed the tool Photovoltaic Geographical Information System (PVG Tool) to assist in the evaluation of the PV potential for any location around the world [31]. It is based on irradiation data, such as PVGIS-SARAH2 for Spain. The tool allows to input the solar PV installation specifications to assess the energy produced. The settings used are a 35° inclination and 0°, -90° azimuth to represent the systems that are installed to the east and south, similar as in the UBEM.

The validation performed consists of three scenarios. The first scenario considers a comparison between the UBEM results and the PVG Tool. The second scenario considers an optimum scenario with 100% PV installed oriented south. The third scenario is a simulation with historical data to analyze the PV production throughout the years.

For the first scenario, it was calculated a total PV area for RIVAS of 989,382 m^2 according to the building stock generated. 83% of the available PV area is oriented south and 17% is oriented east. The result of the UBEM has a PV installed capacity of **196.19 MWp** which was used as input in the PVG tool. Table 9 shows the results provided through the PVG Tool. The annual PV production is **305.83 GWh/year** vs. **292.81 GWh/year**, which is 4% more than the one calculated.

Table 9. PV Validation

	South	East	Total
UBEM Results (GWh/year)	-	-	292.81
PV Capacity Installed (MWp)	162.72	33.46	196.19
PV Produced (GWh/year)	263.13	43.86	305.83
PV Produced (GWh/year)	317.10		317.10
	Min	**Max**	**Average**
Annual PV Production Variation (GWh/year)	291.79	318.90	304.33

The UBEM results (section 4.2) benefits from a lower PV production than the one provided in the PVG Tool. The tariff results will show a higher electricity demand from the grid, which will also reduce the self-consumption used.

The results for the second scenario are in Table 9. It is an optimum scenario in which all the PVs are oriented south. The annual PV production in this scenario is 317.10 GWh which can be considered as the best case scenario.

The third scenario (Figure 33) analyzes the annual PV production variation through historical data to calculate the hourly PV produced from 2005 to 2020 in a combined scenario with south and east PVs installed as in the first scenario. Although the UBEM results are within the minimum range of PV production, it is not assumed to be the minimum, since the UBEM considers the average PV production for the calculation. However, the variation throughout the years is 3.15%.

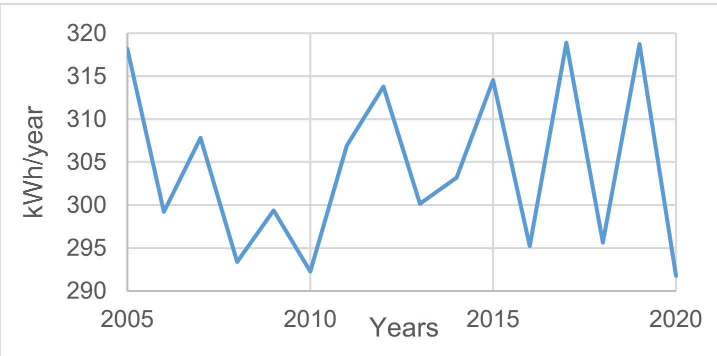


Figure 33. Annual PV production variation.

4.4. PV Electricity Self-Consumption Result

In the scenario where the PV electricity is consumed within the REC, the priority is to consume the electricity generated, and the surplus feed it to the electric grid. Although there is enough PV production to satisfy the electricity demand, the consumption is low and has to be fed to the grid when it is produced. When there is no PV production, RIVAS still consumes electricity that has

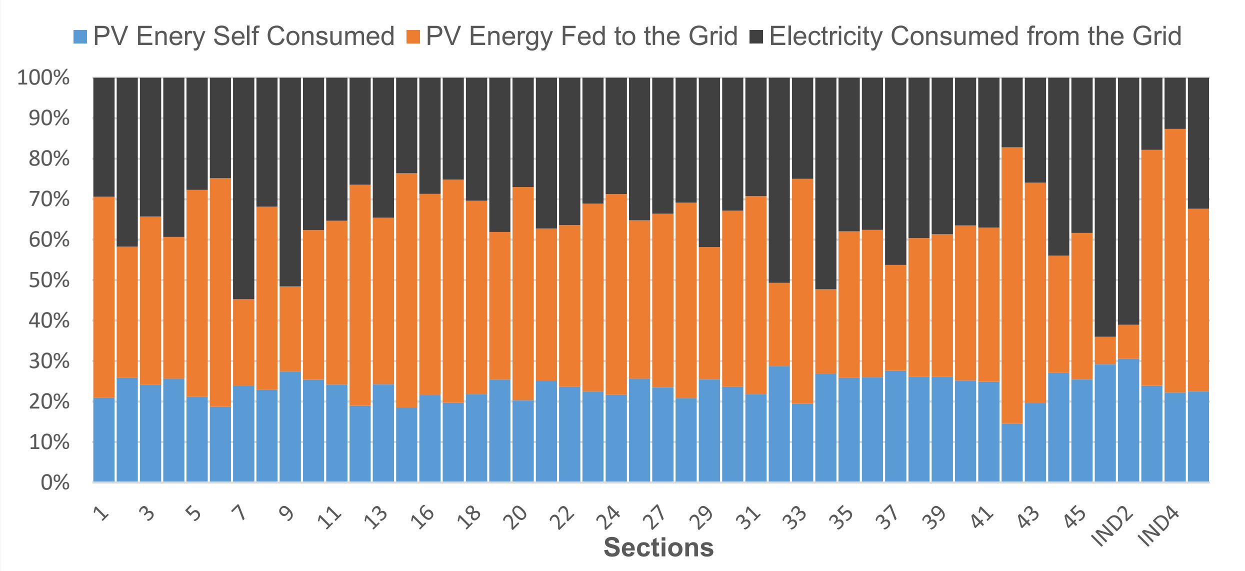


Figure 35. Ratio of total electricity usage.

to be taken from the grid. RIVAS has a PV self-consumption of **38%** and a self-sufficiency of **41%.** Self-sufficiency is the amount of the electric demand that is covered by PV. Figure 34 shows the total electricity usage per section composed of the PV self-consumed, the PV fed to the grid, and the electricity consumed from the grid for each section. From this result, 30 sections out of the 48 has the possibility to be self-sufficient if storing the overproduction is economically feasible. Figure 35 shows that **62%** of the PV generated by RIVAS is fed into the grid and not used by the REC.

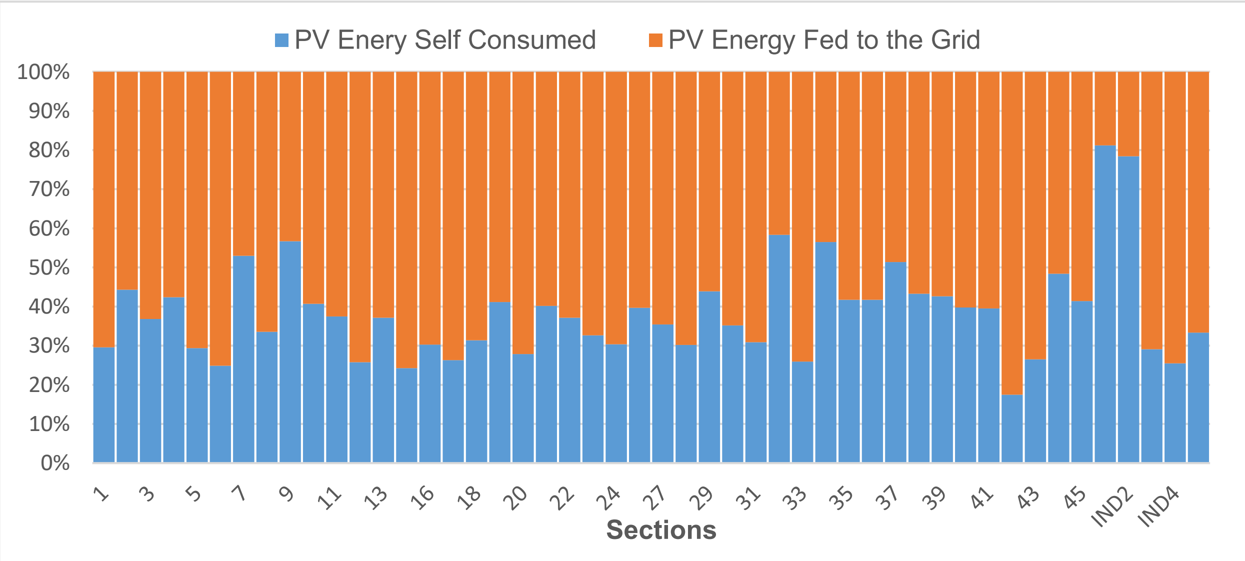


Figure 34. Annual PV End use.

4.5. PV Electricity Self-Consumption per Sector

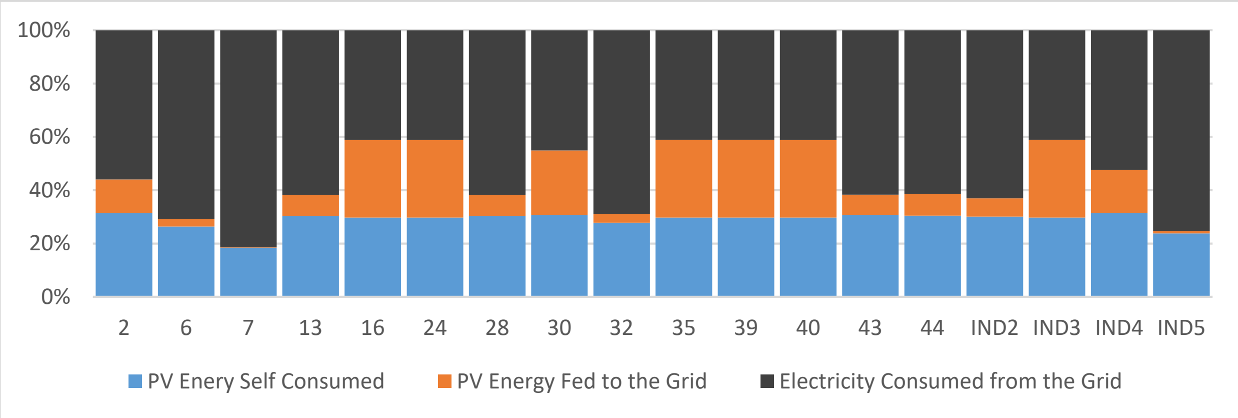


Figure 36. Commercial total electricity use.

The potential to harness the PV electricity overproduction per sector is shown through Figure 36 to Figure 39. The ratio of PV overproduction to net demand can be used to define the potential to further store the overproduction for a later use, sell it to the grid, or exchange it within other members of the REC. In this study, this ratio is also called solar ratio. The residential sector has a solar ratio of 145%. The commercial sector has a solar ratio of 20%. The tertiary sector has a solar ratio of 39%. Finally, the industrial sector has a solar ratio of 327%. When the solar ratio is higher than 100%, the overproduction could satisfy the demand if stored and still be sold to the grid.

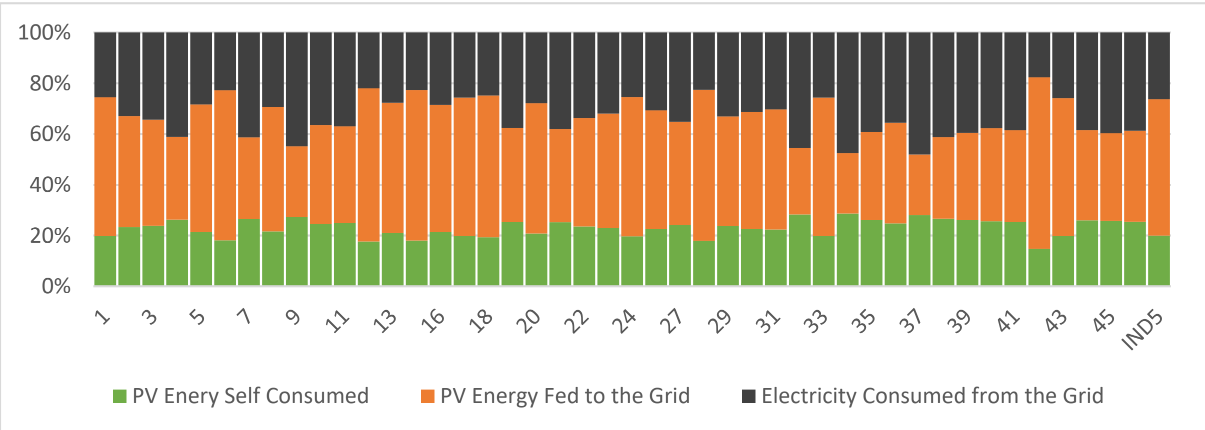


Figure 37. Residential total electricity use.

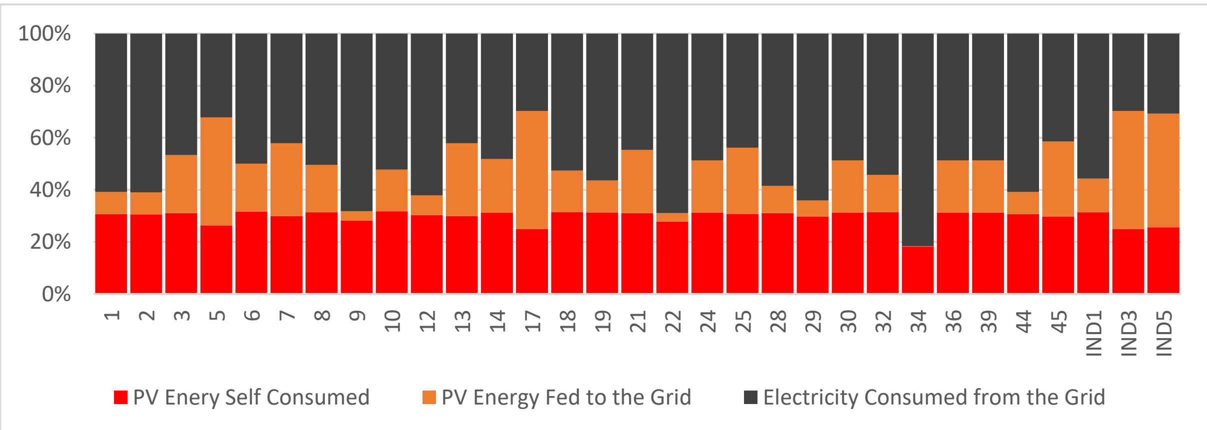


Figure 38. Tertiary total electricity use.

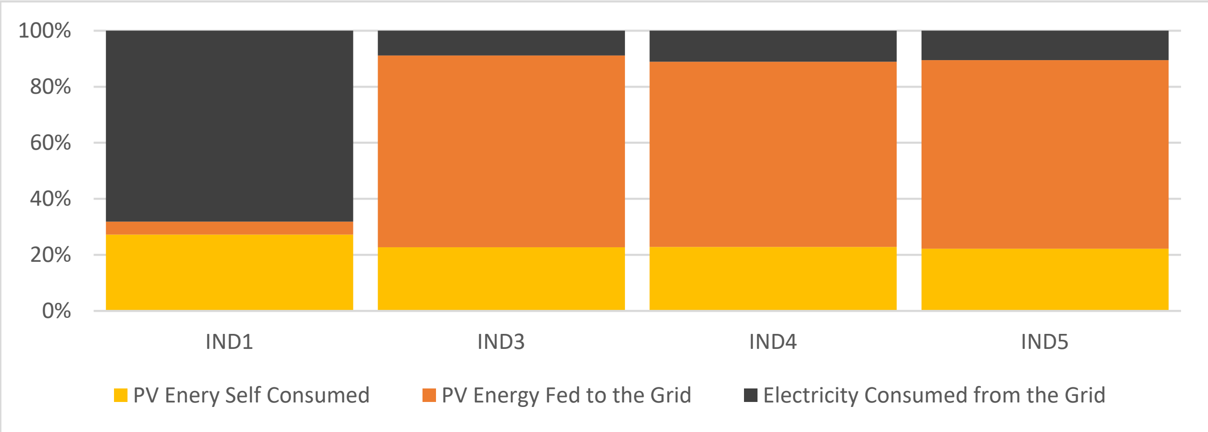


Figure 39. Industrial total electricity use.

The industrial energy usage is shown in Figure 39 and it is important to note the difference between the industrial section 1 to the rest of them. The industrial buildings have low space availability to install PV, so the PV production is less than in other districts. Its solar ratio is 8% vs. the rest of them that is above 600%.

4.6. Electricity Demand Total Costs

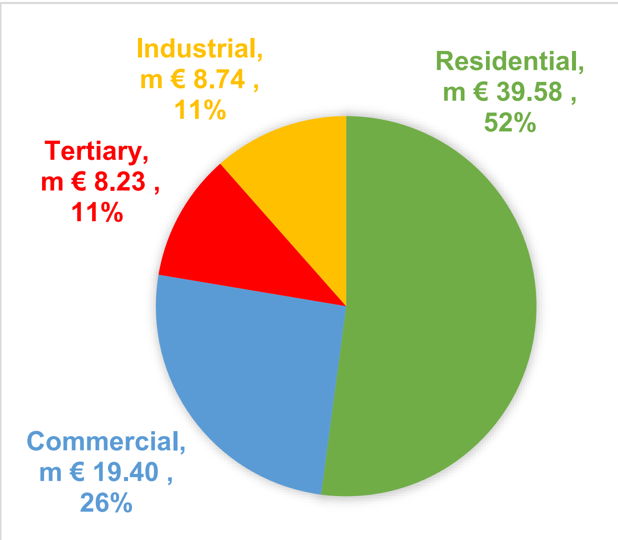


Figure 40. Total electricity costs for RIVAS.

The baseline electricity cost for RIVAS, where no PV is installed, is of **m € 75.96 per year**. The tariff results are directly proportional to the electricity demand results in chapter 4.1. The residential sector still represents the highest costs, amounting to 52% of the total costs. The commercial sector represents the second highest costs with 26%, as the electricity demand results showed. These results represent the baseline of the total costs. The PV installation aims to capture the value present in the electricity demand to develop and sustain the energy community.

4.7. Self-Consumption Tariff Results

The cost analysis of the self-consumption scenario shows a **42% reduction** in the total electricity bill for RIVAS. The bill is reduced from **m € 75.96 to m € 44.30** . The sector that experiences the highest savings is the industrial sector with a 56% reduction in its bill. This is due its demand profile is similar to its PV production profile, most of the PV generated is self-consumed requiring less electricity from the grid. The residential, commercial, and tertiary sectors have savings of 43%, 34%, and 38%, respectively.

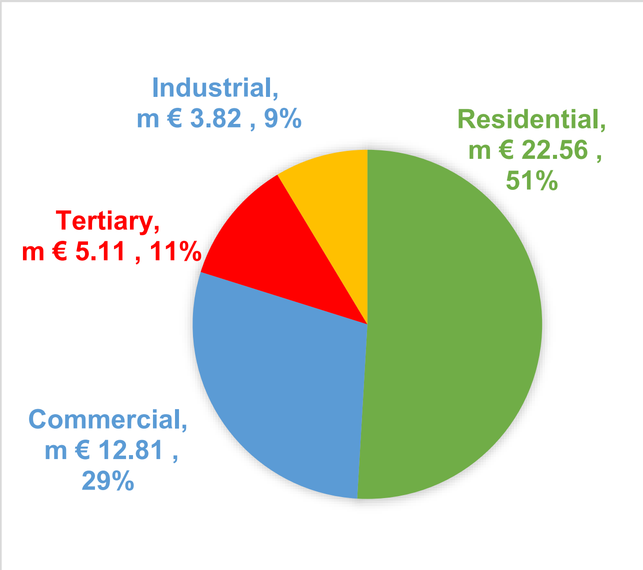


Figure 41. Cost distribution of electricity from the grid.

This scenario considers that each member will be paid for the electricity the PV panels installed in their building produces. The balance of energy is made according to the tariff period in which the PV production is done. The REC makes the energy balance each month. If there is a surplus of electricity, it is not passed on for the next month. In this case, the REC can sell the PV overproduction in the energy market and obtain a profit of it. Depending on the stage of development, the income can be used to expand the energy community or further reduce the electricity bill for the member of the REC.

The REC benefitted from the electricity produced as income for the community. Although these are not shown individually, the whole community saves **m € 31.66** from the PV self-consumed. The overproduction is then sold in the energy market, generating an income of **m € 20.86** . The REC obtains total savings of **m € 52.52** .

The residential sector has a baseline annual electricity cost of **m € 39.58** . The electric bill is reduced to **m € 22.56** , representing savings of **m € 17.02** due to the electricity being self-consumed during production hours. The residential overproduction is sold in the electricity market and provides an additional income of **m € 15.41** , resulting in total savings of **m € 32.43** .

The commercial sector has a baseline annual electricity cost of **m € 19.40** . The electric bill is reduced to **m € 12.81** , representing savings of **m € 6.59** due to the electricity being self-consumed during production hours. The commercial overproduction is sold in the electricity market and provides an additional income of **m € 0.95** , resulting in total savings of **m € 7.54** .

The tertiary sector has a baseline annual electricity cost of **m € 8.23** . The electric bill is reduced to **m € 5.11** , representing savings of **m € 3.12** due to the electricity being self-consumed during production hours. The tertiary overproduction is sold in the electricity market and provides an additional income of **m € 0.74** , resulting in total savings of **m € 3.87** .

The industrial sector has a baseline annual electricity cost of **m € 8.74** . The electric bill is reduced to **m € 3.82** , representing savings of **m € 4.93** due to the electricity being self-consumed during production hours. The industrial overproduction is sold in the electricity market and provides an additional income of **m € 3.76** , resulting in a final total savings of **m € 8.69** .

The previous results are calculated monthly, and each sector experiences different costs and savings throughout the year. Figure 42 shows the cost to satisfy the net demand throughout the year. The summer months have lower electricity bills due to the higher PV production. The reduction is more evident in the residential sector. Figure 43 shows the lack of savings during the winter months, but it is compensated for the PV production during the summer months. The savings are shown as negative.

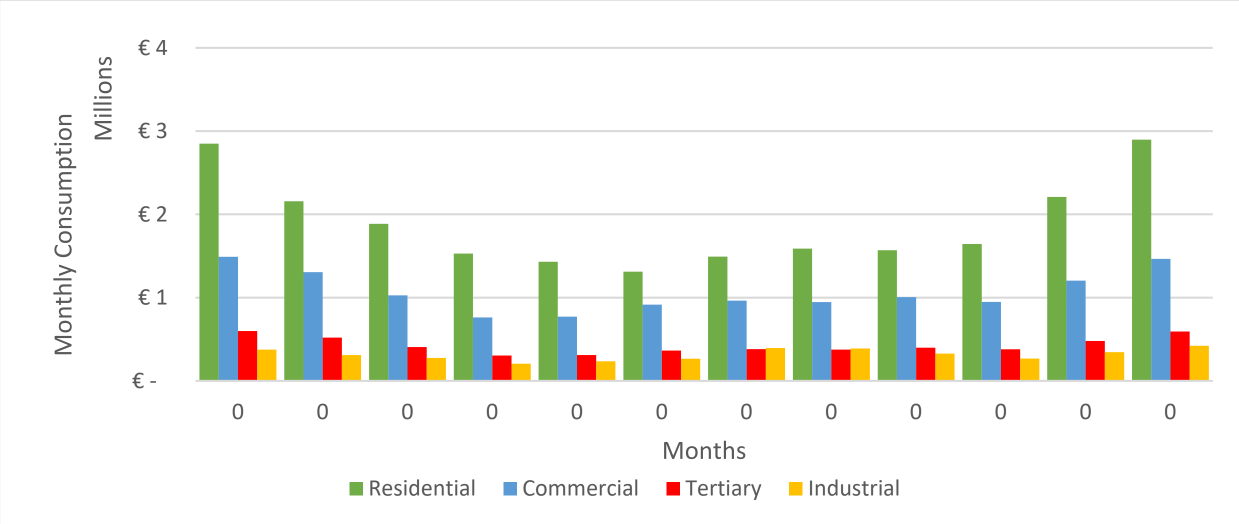


Figure 42. Monthly cost of electricity consumed to satisfy net demand.

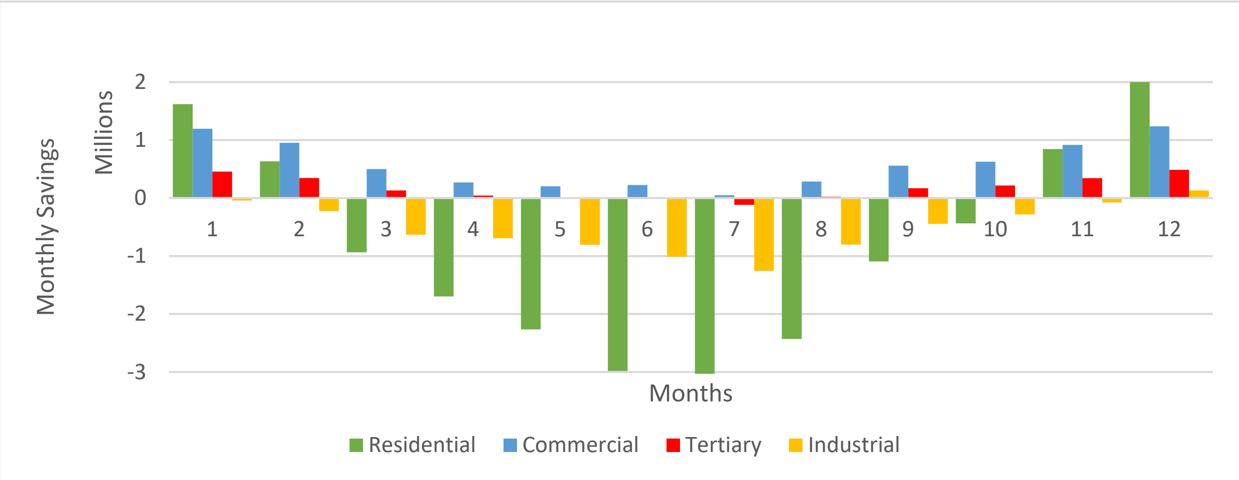


Figure 43. Monthly savings.

The savings are calculated according to Equation 2.

Equation 2. Total savings.

$$Savings = Electricity\ cost\ baseline - (Net\ demand\ cost + Overproduction\ profit + REC\ membership\ fee)$$

The costs shown are related to the electricity costs. The power term is not considered in these calculations since it is estimated that the power term will still be paid. Additional access costs and taxes are not included in the calculations. Each REC member has to paid a membership fee to participate in the energy community.

4.8. Tariff 2.0TD Results Case

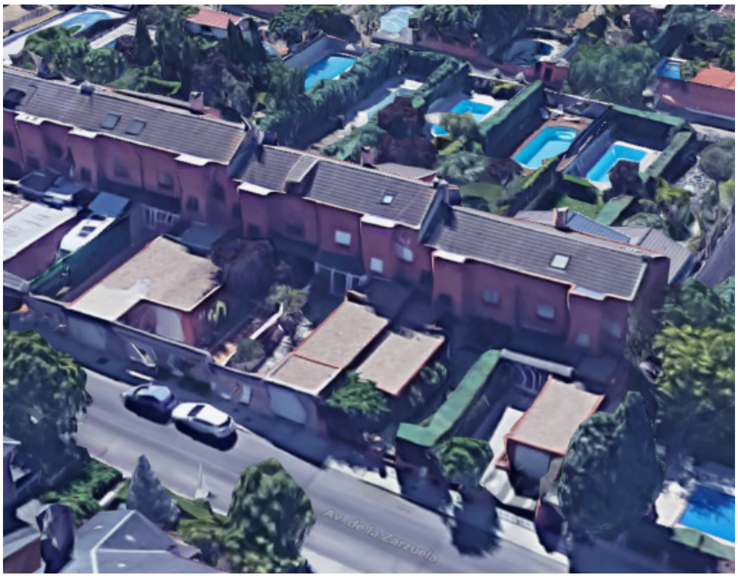


Figure 44. Household case analysis.

The results provided in this chapter show the individual case of a residential house. The house described has a total area of 110.20 m2 , with a PV area available of 17.08 m2 . An electric demand of 3,043 kWh/year is calculated, representing a daily average electricity consumption of 8 kWh/day . The results show an annual electric bill of € 1,213.17 . After being a member of RIVAS REC and having PVs installed for its self-consumption, this household would pay for its electric bill € 516.64 .

Figure 45 presents the total monthly costs, including access costs, taxes, and membership for participating in the REC. The electricity consumed represents the cost of the electricity that the household consumes each month after self-consumption. For the months in which it is negative, these values represent the income for the energy community since the balance in favor of the member is not passed on to the next month. The household pays a minimum fee while the electricity consumed is negative.

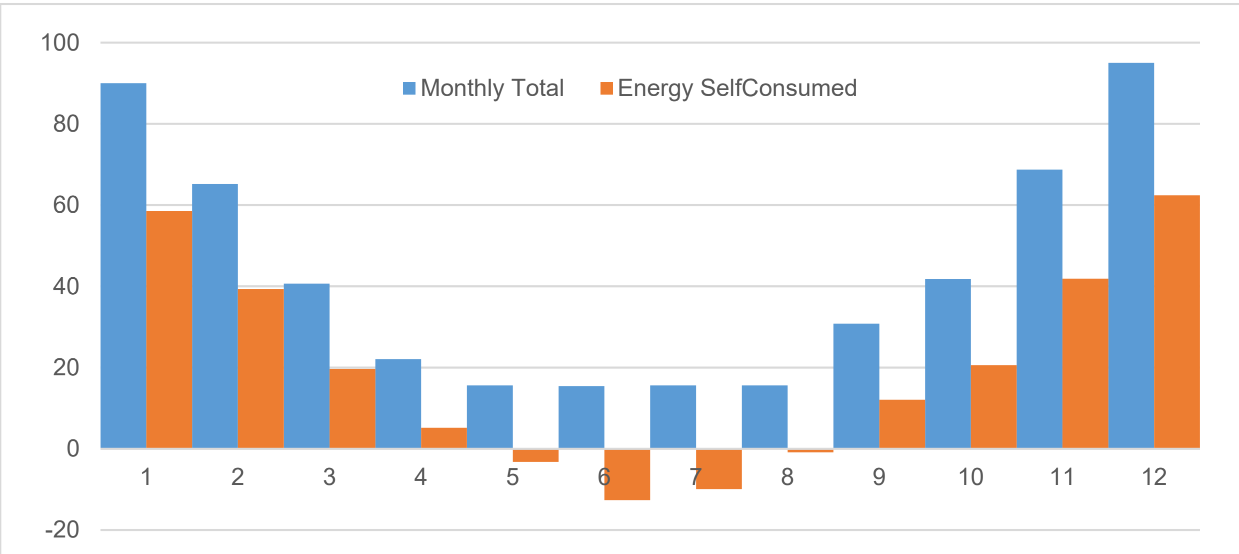


Figure 45. Residential monthly electric bills.

4.9. Capital Investment Cost

The PV installed capacity for RIVAS is **196.19 MWp**. The average cost of kW installed in Spain, considering a large-scale deployment, assumed to be obtained through a bulk installation, is **1,100 €/kW** [32]. The investment required to complete the RIVAS PV installation is **€ 215,808,364** . Figure 46 shows the distribution of the installation costs for each sector.

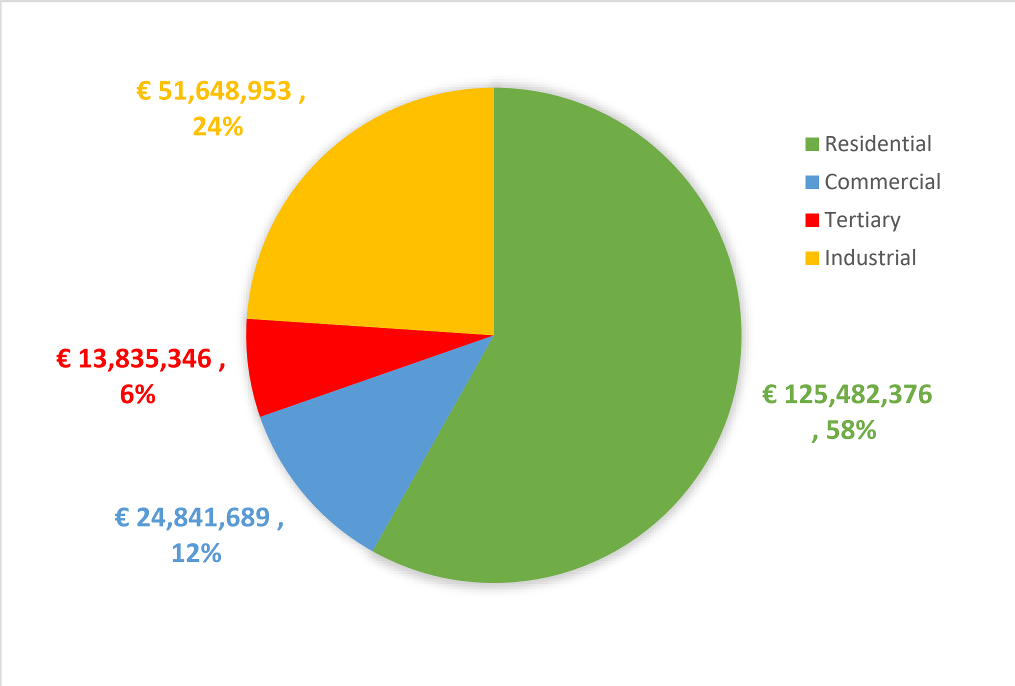


Figure 46. Distribution of capital investment costs per sector.

4.10. CO2 Savings Results

The installation of PV panels allows the reduction of the consumption of electricity from the grid. The Spanish grid considers a carbon footprint of 0.357 kg CO2/kWh. After the implementation of 196.19 MWp in the renewable energy community of RIVAS, it is possible to offset 104,534 tons of CO_2 each year. It is also equivalent to planting 3,240,559 trees to offset the CO_2 emissions by the electricity produced [33]. This reduction will be proportional to the deployment of the REC. The residential sector contributes 59%, the commercial sector with 11%, the tertiary sector with 6%, and the industrial sector contributes 23% of the reduction in emissions.

4.11. RIVAS Energy Community Development

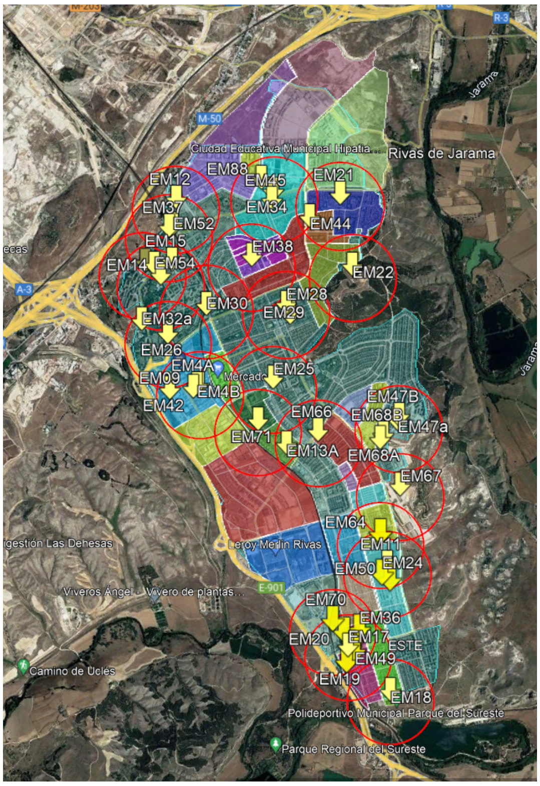


Figure 47. RIVAS community buildings location.

RIVAS goal is to define a strategy to implement a municipal-wide energy community in a sustainable way. It plans to install PVs in its municipal buildings and serve as seeds for each community. The municipal buildings will be clustered, according to their proximity, in smaller energy communities named as "EC##".

The energy management strategy consists in self-consume the PV production and feed the overproduction to the grid. As a REC, they will be able to share their overproduction with other members within a 500 m radius of the PV installation. Figure 47 shows the buildings' location and their respective radius. This distribution covers most of the municipality. The ECs have residential buildings adjacent that could take advantage of the overproduction.

The PV systems were designed for the 96 buildings to define the exact amount of PVs that could be installed according to the area available on their roofs. This difers with the methodology employed to create the UBEM for RIVAS, which considered a percentage of the roof as the area available for PVs. The PV installed capacity is **771.48 kWp** out of **196.19 MWp,** which is the potential capacity installed indicated in section 4.9. The initial investment for the PVs for the energy communities is **€ 848,625** .

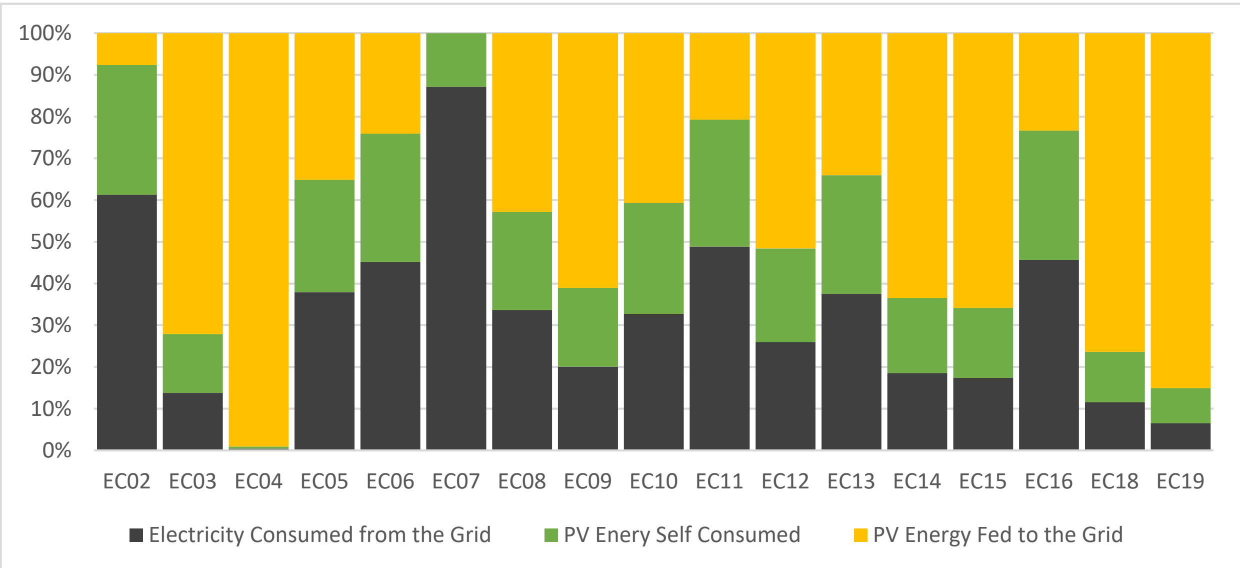


Figure 48. Total electricity usage for the energy communities.

The 96 buildings were clustered in 17 RECs. Figure 48 shows the total usage of the electricity consumed and produced. 68% of the PV produced is fed to the grid, and 32% is self-consumed. However, not all of these sections have these rates. EC02 self-consumes 80% of the PV produced, leaving 48,288 kWh/year for the REC. Considering the residential example in section 4.8, with an annual demand of 3,043 kWh/year , the overproduction could incorporate 15 houses as members of the REC. The calculation is not as straightforward since electricity is consumed in real-time; thus more members have to be incorporated in EC02 to consume the overproduction optimally.

The electricity demand for the 96 buildings is calculated to be **3.797 GWh/year**. The solar PV produced is **5.031 GWh/year**. The surplus electricity is equivalent to **3.434 GWh/year**. The benefits for participating in the REC for municipal buildings are to receive a reduction in their electricity bill. The surplus electricity is sold to residential members to obtain a profit. According to the results in section 4.1, the residential sector has a demand baseline of **137.49 GWh/year,** having enough demand to use the PV produced. The task for the REC is to incorporate enough members to use it.

4.11.1. RIVAS Business Model Considerations

Section 4.11 shows the potential and economic benefits of developing a REC. Most importantly, it shows how they can be self-sustainable during their development phase and grow by themselves. One crucial aspect that will need to be considered by the stakeholder in this scenario is how to manage the savings obtained during the seed phase.

According to the municipality's long-term planning, its authorities would need to consider three economic items to decide upon.

1. Savings from self-consumption.
2. Reinvestment of electricity sold to REC members.
3. Debt payment for initial investment.

The first item relates to the annual baseline electricity cost. The savings from the self-consumption allows them to have a budget of **€ 455,236** which can be used to carry out public works in the municipality. It can also be destined to increase the PV capacity.

The second item relates to the amount of reinvestment the REC will focus on increasing its PV capacity. It could focus some of the income generated to reduce the electricity tariff of the current members. However, it is not recommended since the best strategy focuses on increasing the PV capacity to achieve its full potential in the short term. Once the REC has achieved its full potential or as the surplus of electricity exceeds its self-consumption, the income can be used to lower the electricity tariff for its members.

The third item relates to the financing of the initial PV infrastructure. The municipality can generate debt to finance the installation. In this case, a ratio of the income generated would be used to pay back the debt. Another alternative is for the municipality to use its budget or apply for economic support from IDAE.

4.11.2. RIVAS REC Baseline

In economic terms, the municipal buildings have a baseline electricity cost of **€ 1,049,616** . As members of the REC, their electric bill is reduced to **€ 594,380** , obtaining savings of 43%. The REC, in turn, will sell the **3.434 GWh/year** overproduced for an annual income of **€ 1,031,370** .

The annual income is then reinvested in continuing to deploy additional PVs. One key variable is the operating cost for the REC which will determine the cash flows at the end of the year. These costs include the management, new members acquisition activities, installation costs, and grid management fees. The REC cash flow can be represented as a percentage of the income. Figure 49 shows three scenarios with different cash flow margins. A high margin represents that the costs were low, which lead to a higher reinvestment to deploy more PVs. If the operating costs are higher, the cash flow margin will be reduced, slowing the PV deployment. Best case scenario would allow the REC to achieve its completion by the tenth year. In the worst case, it would require 17 years.

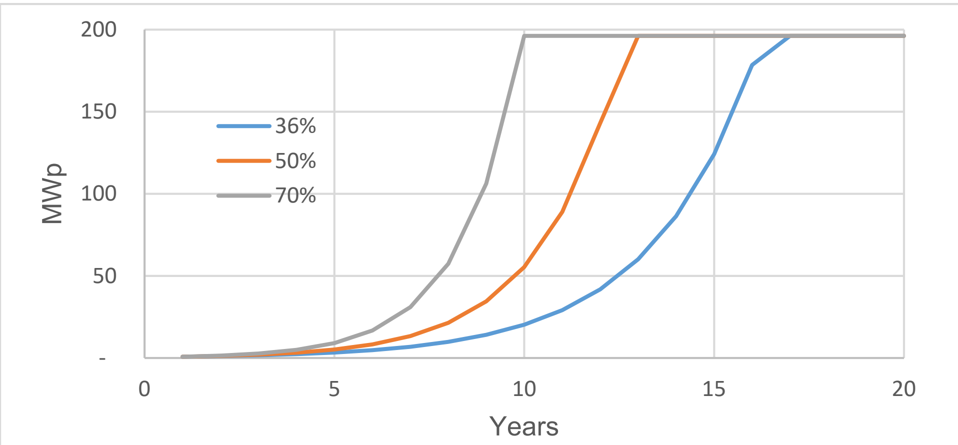


Figure 49. PV Capacity growth.

5. Sensitivity Analysis

The UBEM created has different variables that were assumed. The variables analyzed in the sensitivity analysis are:

1. REC's deployment rate
2. Availability of flat roof
3. Availability of hipped and gable roof
4. PV South/East orientation

The accuracy of the roofs' measurements is analyzed through the REC deployment analysis. Even so, this value is analyzed using different tools to obtain the roof measurements, such as LIDAR and OSM.

The results analyzed in the sensitivity analysis are:

1. Tariff cost. This value represents the total amount the community will pay for the electricity from the grid. Although the REC is fully deployed, it needs grid electricity to satisfy its demand.
2. Savings. This value is dependent on the tariff cost. It takes into account the total electricity cost without PV.
3. PV production. It is the amount of PV electricity produced in the REC.
4. PV self-consumed. It is the amount of PV electricity self-consumed within the REC.
5. Electricity demand covered by PV. It is the percentage of the consumption satisfied with PV.
6. PV Energy to grid vs net demand. It represents the amount of PV electricity fed to the grid by comparing it to the community's demand.
7. PV Installed. It is the PV capacity installed in the REC.

The sensitivity analysis is performed for these results by obtaining the variation coefficient. It is calculated according to the formula:

$$Variation\ coefficient\ = \frac{standard\ deviation}{baseline\ value}$$

Equation 3. Variation coefficient.

5.1. REC's Deployment Rate

The results in Table 10 show the baseline scenario without PV installed (0%) shown in section 4.6 and the ones with a full REC (100%) shown in section 4.7.

Table 10. Variation of Energy Communities Deployment.

	Sensitivity Analysis Variation of Energy Communities Deployment						
REC Deployment	**Self Consumption Cost**	**Savings**	**PV Production (GWh)**	**PV Self Consumed**	**Electricity demand covered by PV**	**PV Energy to grid vs net demand**	**PV MWp installed simulation**
0%	€ 75,952,906	0%	0.00	0%	0%	0%	0.00
20%	€ 60,799,861	20%	58.56	18%	19%	3%	39.24
40%	€ 53,106,213	30%	117.13	27%	29%	20%	78.48
60%	€ 48,897,247	36%	175.69	32%	35%	46%	117.71
80%	€ 46,196,326	39%	234.25	35%	38%	78%	156.95
100%	€ 44,296,539	42%	292.81	38%	41%	113%	196.19
Stdev	€ 10,843,335	14%	100.01	13%	14%	41%	67.01
Variation Coefficient	24.48%	34.25%	34.16%	34.26%	34.26%	36.36%	34.16%
Ave	€ 54,874,849	28%	146.41	25%	27%	43%	98.09
Min	€ 44,296,539	0%	0.00	0%	0%	0%	0.00
Max	€ 75,952,906	42%	292.81	38%	41%	113%	196.19

5.2. Availability of Flat Roof

The model considered a flat rooftop availability of 48%, as expressed at the end of section 3.3.6. Table 11 shows the results of increasing the PV capacity. The PV production increases proportionally as more PV is installed on flat roofs. The PV electricity cannot satisfy the community demand in the same proportion and must be fed to the grid.

Table 11. Variation of flat roof available area.

	Sensitivity Analysis Variation of Flat Roof Available Area						
Reduction Factor Flat Roofs	**Self Consumption Cost**	**Savings**	**PV Production (GWh)**	**PV Self Consumed**	**Electricity demand covered by PV**	**PV Energy to grid vs net demand**	**PV MWp installed simulation**
48%	€ 44,296,539	42%	292.81	38%	41%	113%	196.19
57%	€ 43,207,909	43%	326.56	35%	42%	135%	219.24
66%	€ 42,330,130	44%	360.31	32%	43%	158%	242.29
75%	€ 41,612,334	45%	394.05	30%	44%	181%	265.34
80%	€ 41,267,025	46%	412.80	29%	45%	194%	278.15
90%	€ 40,669,595	46%	450.30	27%	45%	221%	303.76
100%	€ 40,169,888	47%	487.79	26%	46%	248%	329.37
Stdev	€ 1,342,729	2%	63.34	4%	2%	44%	43.26
Variation Coefficient	3.03%	4.24%	21.63%	10.45%	4.28%	38.54%	22.05%
Ave	€ 41,936,203	45%	389.23	31%	44%	178%	262.05
Min	€ 40,169,888	42%	292.81	26%	41%	113%	196.19
Max	€ 44,296,539	47%	487.79	38%	46%	248%	329.37

5.3. Availability of Hipped and Gable Roof

The model considered a hipped/gable rooftop availability of 31%, as expressed at the end of section 3.3.6. Table 12 shows the results of increasing the PV capacity up to 60%. This value is considered a limit since it would exceed the defined constraint of only installing PVs in half of the roof available, taking advantage of the south and not the north roof. The increased PV production has the same effects as the analysis in the previous section, 5.2. It leads to more PV electricity being available to sell to the grid without significant savings for the self-consumption of electricity.

Table 12. Variation of hipped/gable roof available area.

	Sensitivity Analysis Variation of Hip Roof Available Area						
Reduction factor Hip roofs	**Self Consumption Cost**	**Savings**	**PV Production (GWh)**	**PV Self Consumed**	**Electricity demand covered by PV**	**PV Energy to grid vs net demand**	**PV MWp installed simulation**
31%	€ 44,296,539	42%	292.81	38%	41%	113%	196.19
35%	€ 44,095,934	42%	307.37	36%	41%	122%	205.64
40%	€ 43,880,284	42%	325.57	34%	41%	134%	217.46
46%	€ 43,662,757	43%	347.41	32%	41%	148%	231.63
50%	€ 43,536,348	43%	361.97	31%	42%	157%	241.09
60%	€ 43,268,268	43%	398.37	29%	42%	181%	264.72
Stdev	€ 344,254	0%	35.20	3%	0%	22%	22.86
Variation Coefficient	0.78%	1.09%	12.02%	8.07%	1.09%	19.81%	11.65%
Ave	€ 43,790,022	42%	338.92	33%	41%	143%	226.12
Min	€ 43,268,268	42%	292.81	29%	41%	113%	196.19
Max	€ 44,296,539	43%	398.37	38%	42%	181%	264.72

5.4. Baseline vs combined scenario

The combined effects of using 100% of flat roof space available and 48% of hipped and gable roof available lead to a total PV production of **542.39 GWh/year** instead of the **292.81 GWh per year** calculated in section 4.2. The KPIs change is presented in Table 13.

Table 13. Baseline vs. combined scenarios

KPI	Baseline Scenario	Combined Scenario
PV Electricity Production	292.81 GWh	542.39 GWh/year
PV Self-consumed	38%	23%
PV Generated to Grid	62%	77%
Demand covered by PV	41%	47%
PV Energy to grid vs net demand	113%	287%

5.5. PV South/East Orientation

The buildings were set in two directions, south, and east, where the PV panels would be installed during the archetype characterization. However, this procedure could leave buildings that were oriented in any orientation within this range. The values could be 90° for the east and 180° for the south, but buildings were found in many ranges. Even some that could be defined with a predominant west orientation for PVs.

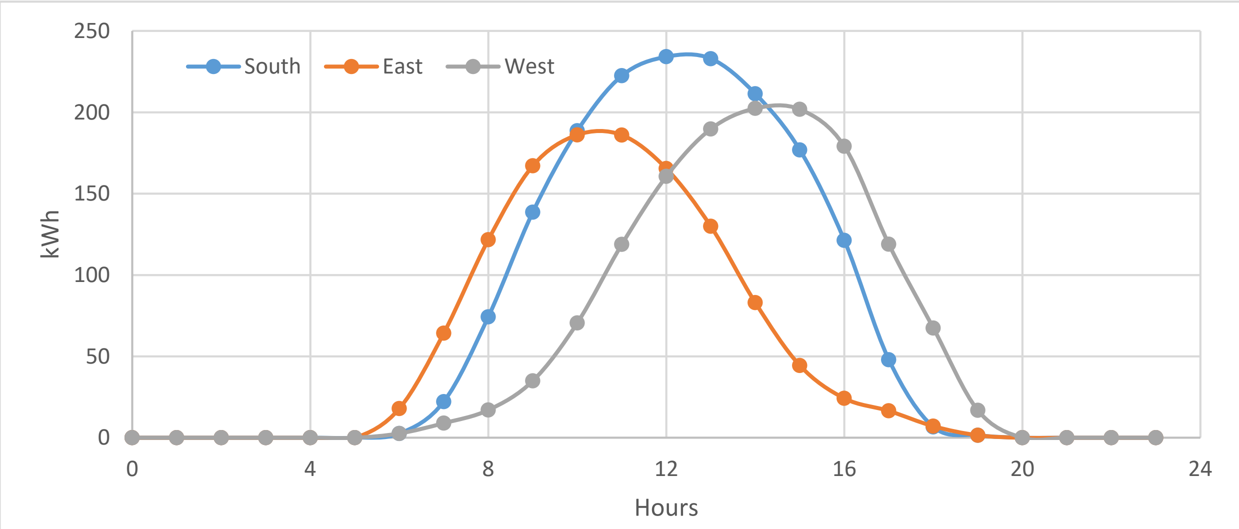


Figure 50. Annual hourly PV production

The analysis evaluated the performance of a 1 kWp PV installation according to these three orientations. The "Photovoltaic Geographical Information System" [31] calculates the PV production in this scenario and the solar tariffs from section 2.3.3 to obtain the income.

Figure 50 shows the variance in the hourly PV production. The PVs oriented south produce the highest energy. The systems oriented to the east and the west reach different peak values earlier or later during the day. These differences do not present an opportunity and take advantage of this orientation to produce electricity at peak hours.

Figure 51 shows the monthly income for the three orientations. It is highest for the PVs oriented south for ten months. The east orientation has the lowest income out of the three scenarios. The total income for each scenario is shown in Table 14.

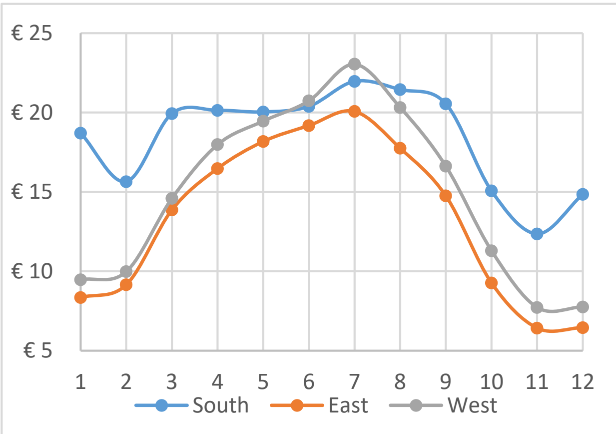


Figure 51. Monthly income for different orientations.

Table 14. Total income for different orientations.

Orientation	Total Income (€)
South	221
East	160
West	149

6. Discussion and Conclusions

6.1. Discussion

The RIVAS Renewable Energy Community has meaningful impacts in different aspects.

Regarding social and economic aspects, members of the REC will be incentivized to participate in and support this incentive. Homeowners can immediately benefit from saving up to 57% on their electricity bill. Previously, grid-connected systems benefitted from a reduction of their CAPEX for their installation. However, upfront costs and extended return of investment periods still slowed down its adoption. While interviewing a dry cleaner owner about the possibility of installing PVs in his business, the answer was negative due to the initial investment. This interview is an example of how CAPEX plays an important role, although they had already installed PVs in another establishment and witnessed the savings in the electric bill. As a REC member, he can offset the initial investment and participate in savings in their electricity bill.

The model proposed to develop the energy community is a sustainable one. The municipality intends to transform its buildings into the seeds of energy communities. The analysis shows how the buildings can create an electricity surplus that will be transferred to the immediate buildings. The Spanish law considers a limit to this interconnectivity, defined by distance. This mean that the prosumer and the consumer can be separated by a maximum of 500 meters. This is not a real barrier for RIVAS for three different reasons. The first is that it has a diverse number of municipal buildings that can be connected within this range. The second reason is that IDAE published standard practices to be implemented for energy communities, establishing that the distance limit for municipalities could not apply. The third reason is that physically this distance is not relevant due to the size of the municipality.

The analysis showed KPIs that can be used to define which sections of the municipality should be focused on to develop the REC.

6.1.1. Solar ratio.

In this study, the solar ratio is the PV overproduction fed to the grid to the net demand. This KPI evaluates the surplus electricity a building or section has concerning the electricity it needs to satisfy its electric demand during periods of no PV production. First, this value represents the electricity fed into the grid during the flat and peak energy periods and the electricity consumed during the valley period. In essence, the building produces electricity when it is expensive and consumes it when it is cheap.

Typically, this is of little relevance for a single user since the feed-in ratio punishes electricity generation by 40%. However, as a REC, the electricity one member produces is consumed by another member during the development phase. This exchange, in turn, is a feed-in ratio of 1:1 for the energy community. The members are still penalized by the feed-in ratio of 1:2.1, meaning that they will be paid less for the PV fed to the grid, but the economic benefit stays in the REC and allows the savings to maintain their capacity for growth. In other words, the savings are invested in the community and will not account for a profit for the utility company.

This KPI also serves as an indicator for future grid services, such as balancing services such as battery implementation for the REC operation. When the value for the section is less than 100%, it can only produce electricity for its use during the night periods. When the value is above 100%, the REC can use the electricity and sell it in an energy market to further reduce the tariff of the whole community. The sections that have the highest values are candidates to initiate the REC.

6.1.2. PV Self-Consumed

This KPI evaluates the amount of electricity produced in the REC and is self-consumed by the producer. The initial stage of PV production is for self-consumption by the household with the PV installation. The overproduction is then consumed by the next-door neighbor in the same time frame. At certain times of the day, for example at noon, when the overproduction is highest, one building could share its surplus to more than one consumer. Once the REC is fully developed, the results show that most of the PV produced is not self-consumed, but fed to the grid. The results changed by sector, from 28% to 71%. This range is due to the number of users in each sector. The REC has a total PV self-consumed of 38%.

This KPI can be used to design the REC to optimize the initial development of the whole community. One milestone can be set to achieve a 100% of PV self-consumed. This strategy results in optimizing the investment required to implement the REC. In this scenario, there would still be a need for electricity from the grid during the night, but it can achieve savings of up to 42% in the scenario calculated. Further savings can be obtained by selling the electricity on energy markets, but an additional investment would be required.

6.1.3. Socio-economic KPIs

RIVAS has a size of 1400 hectares and a population of 92,925 habitats. It has 6,646 active businesses.

The KPIs that define the REC PV installed capacity are 2.11 kW/habitant, 29.52 Kw/business, and 140 kW/ha. Although they require to be compared to other studies or REC already implemented, these values can be used to estimate the potential PV production for other REC in suburban scenarios.

6.1.4. Rate of deployment

The rate of deployment will affect where the REC benefits are achieved. In general terms, the bigger the energy community related to its PV production, the greater its benefits for reducing the electricity costs, increasing profits and environmental benefits. However, during an initial deployment stage, the benefits are received due a higher self-consumption. The overproduction can be shared within other members providing an income for the REC. Figure 52 shows how the savings obtained from only the self-consumption of electricity are significant during the initial deployment phases. As the electricity produced is no longer self-consumed by the REC, it is available to sell to the electricity market, and the REC would experience a change in its business model.

Stakeholders can consider this value to optimize the deployment of the REC and focus their strategy from a self-consumption business model to one in which the overproduction is sold in electricity markets.

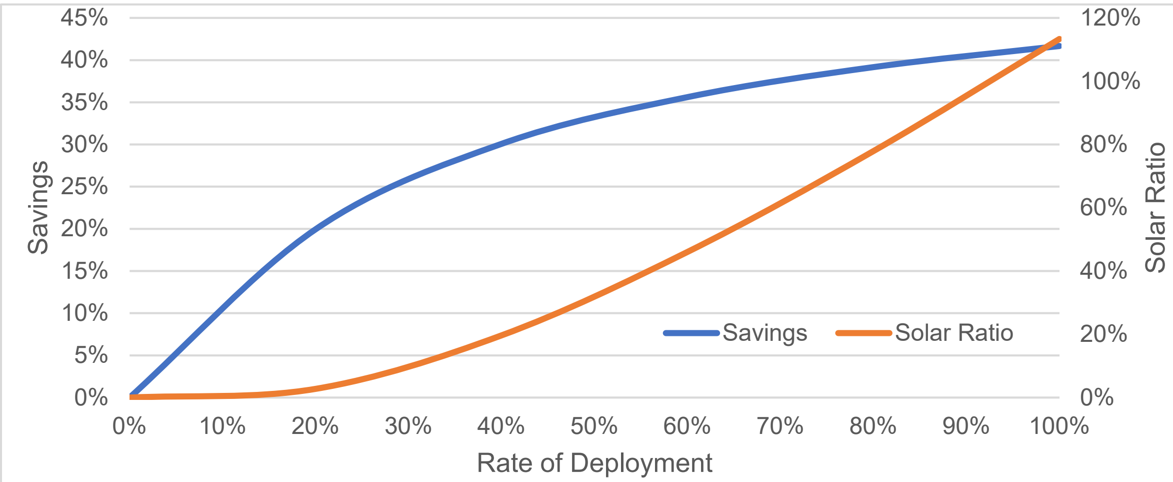


Figure 52. Savings and PV Energy to grid vs net demand according to REC deployment.

6.1.5. Profits and Margins

The economic benefit of creating a REC lies in the ability to capitalize on its energy. Previously, this benefit was taken by the DSO or another REC that works as an aggregator. Taking SOM Energy tariffs [34], its consumption tariff is 0.357 €/kWh and its generation compensation is 0.170

€/kWh, which represents a profit of 110%. Using the same business model in the simulation results in a net margin of 190%. Table 15 shows the analysis of the tariffs offered by Som Energy. These values help to explain the income from selling the surplus PV to other members in the REC, as seen in section 4.11. RIVAS needs to create the REC to manage the PV produced at the creation of the REC. It could hire an aggregator to handle the administrative process, but most of its benefits would be lost to increase its capacity.

Table 15. Profits and Margins for Tariffs 2.0TD and 3.0TD

Tariff 2	Cost	Generation Price	Profit	Margin
Valley Energy	€ 0.2410	€ 0.096	€ 0.15	151%
Flat Energy	€ 0.2930	€ 0.120	€ 0.17	144%
Peak Energy	€ 0.3570	€ 0.170	€ 0.19	110%
Tariff 3	**Cost**	**Generation Price**	**Profit**	**Margin**
P1	€ 0.3550	€ 0.142	€ 0.21	150%
P2	€ 0.3240	€ 0.130	€ 0.19	149%
P3	€ 0.2960	€ 0.107	€ 0.19	177%
P4	€ 0.2690	€ 0.095	€ 0.17	183%
P5	€ 0.2460	€ 0.083	€ 0.16	196%
P6	€ 0.2390	€ 0.091	€ 0.15	163%

6.2. Conclusions

The conclusions presented summarize the work done and are presented by answering the research questions in section 1.1.

1. The results show that the municipality Rivas-Vaciamadrid has the potential to implement an energy community that can produce 292.81 GWh per year. 38% of the PV generated is self-consumed and the rest is fed to the grid. The collective capacity of the PVs is of 196.19 MWp. The size of this REC can be compared La Mula solar farm in Spain. It is one of the biggest solar farms in Europe, with a rated power of 494 MWp distributed in 1,000 hectares. RIVAS REC has the potential of being 40% this size.

2. The PV electricity produced is self-consumed by its members. The surplus electricity can then be sold in electricity markets or stored to provide ancillary services within the community or the energy market. The first economic benefit the REC members receive is the savings provided by the PVs installed in their roofs. The REC receives the economic

benefits provided by selling the electricity produced within the community to members that do not have the infrastructure installed and by selling the surplus electricity in energy markets. At the end of the year the REC can reimburse the members according to the PVs installed on each roof. Other members can also benefit from lower tariffs if applicable and receive the benefit as reimbursement.

3. There are a number of KPIs that were identified as relevant to assess other communities' potential as a REC. The PV Energy fed to the grid and PV energy self-consumed defines the solar end use. These can be identified as a community or by sector. The grid and PV utilization KPIs define how the electricity demand is covered within the community. The PV Energy to grid KPI can be used to assess the potential usage of the PV generated and implement it for other usages such as energy storage or selling it in electricity markets. In analysis in which not enough information is available or to perform a fast estimate, the socio-economic KPIs can be used according to the population and business density or the size of the community. The values for these KPIs are in appendix A-2.

4. The first challenge is to secure the investment to kick start the REC. This is important because it defines who is the owner of the PVs installed and how the economic benefits are implemented. In this case, the municipality of RIVAS, which is the leading promoter of the REC, is ready to secure the initial investment to implement the seeds for the RECs. The energy community still has to be created, and the municipality will be a member. The installation of PVs is done in the municipality buildings. They will serve as hubs and sell the surplus electricity between the members of the REC. The business model proposed identifies the residential sector near these hubs to be the first members of the REC and sell the surplus PV electricity.

   The literature review showed that one challenge to create a REC lies in the organization of a group of people and then elaborate the project. The learned experiences from pilot programs show that it is necessary a leader organization or enterprise to guide the process during its creation. In this case the municipality of RIVAS is leading the effort and will set up the infrastructure in order to promote the REC and incorporate new members. RIVAS can also lobby the expansion of the RECs in the industrial sector due to its high PV energy to grid vs net demand ratio. This can be useful to expand the REC in sections where there is not a municipal building to serve as a hub.

   The RIVAS REC requires a structure to operate. At first, it will work closely with the local DSO to manage the exchange of electricity between its members. Installation and management can be outsourced through tendering processes. RIVAS has the window of opportunity to generate profits from the beginning of its operation and use it to deploy additional PVs. Further down the line, RIVAS can perform additional actions to improve its operation and obtain additional profits for the REC. One of this actions is the acquisition of the distribution grid. The REC has also the potential to hire its own personnel and create jobs to support the installation and maintenance of the infrastructure, management of the electricity flows between the members and the DSO. According to the margins in section 4.11.2, it has the opportunity to hire up to 10 people in the first year and increase its organization according to the REC size. The jobs that can be created range from specialized technicians, engineers, energy traders, and customer service agents. It could create up to 100 jobs once the REC is fully deployed.

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Appendix A. Electricity Demand and Solar PV

A-1. Baseline Results

Baseline Scenario

	Electricity Demand (kWh/month)									
Month	Residential		Commercial		Tertiary		Industrial		Monthly Consumed	
1	14,278,350	10%	6,143,877	9%	2,607,992	9%	2,323,409	7%	25,353,628	9%
2	11,952,820	9%	5,746,883	8%	2,439,483	8%	2,167,254	6%	22,306,441	8%
3	12,005,428	9%	5,711,917	8%	2,424,710	8%	2,473,184	7%	22,615,240	8%
4	10,571,571	8%	5,225,380	7%	2,218,136	7%	2,389,876	7%	20,404,963	8%
5	9,851,633	7%	5,416,978	8%	2,299,442	8%	2,742,769	8%	20,310,822	7%
6	9,803,202	7%	6,462,403	9%	2,743,259	9%	3,249,139	10%	22,258,003	8%
7	11,725,789	9%	6,556,270	9%	2,783,066	9%	4,138,436	12%	25,203,561	9%
8	11,862,718	9%	6,399,196	9%	2,716,450	9%	4,144,516	12%	25,122,880	9%
9	10,077,758	7%	5,845,896	8%	2,481,570	8%	3,012,650	9%	21,417,874	8%
10	10,023,985	7%	5,449,555	8%	2,313,318	8%	2,415,713	7%	20,202,571	7%
11	11,729,219	9%	5,479,107	8%	2,325,841	8%	2,370,194	7%	21,904,361	8%
12	13,588,344	10%	5,748,995	8%	2,440,433	8%	2,415,454	7%	24,193,226	9%
Total	137,470,816		70,186,456		29,793,702		33,842,595		271,293,569	

	Cost of Electricity Consumed from the Grid (Euros)									
Month	Residential		Commercial		Tertiary		Industrial		Monthly Consumed	
1	€ 4,083,185	10%	€ 1,836,896	9%	€ 779,736	9%	€ 649,990	7%	€ 7,349,809	10%
2	€ 3,441,158	9%	€ 1,731,994	9%	€ 735,206	9%	€ 609,164	7%	€ 6,517,522	9%
3	€ 3,478,169	9%	€ 1,618,413	8%	€ 687,016	8%	€ 656,962	8%	€ 6,440,560	8%
4	€ 3,036,285	8%	€ 1,308,258	7%	€ 555,344	7%	€ 554,056	6%	€ 5,453,943	7%
5	€ 2,832,444	7%	€ 1,357,357	7%	€ 576,181	7%	€ 637,633	7%	€ 5,403,615	7%
6	€ 2,829,253	7%	€ 1,715,493	9%	€ 728,215	9%	€ 814,171	9%	€ 6,087,132	8%
7	€ 3,350,950	8%	€ 1,938,090	10%	€ 822,690	10%	€ 1,164,790	13%	€ 7,276,520	10%
8	€ 3,431,350	9%	€ 1,699,129	9%	€ 721,276	9%	€ 1,036,678	12%	€ 6,888,432	9%
9	€ 2,914,153	7%	€ 1,554,758	8%	€ 659,989	8%	€ 753,419	9%	€ 5,882,318	8%
10	€ 2,866,339	7%	€ 1,363,474	7%	€ 578,788	7%	€ 560,071	6%	€ 5,368,673	7%
11	€ 3,399,675	9%	€ 1,554,814	8%	€ 660,005	8%	€ 629,056	7%	€ 6,243,549	8%
12	€ 3,915,051	10%	€ 1,719,147	9%	€ 729,767	9%	€ 676,868	8%	€ 7,040,833	9%
Total	39,578,013		19,397,822		8,234,213		8,742,858		75,952,906	

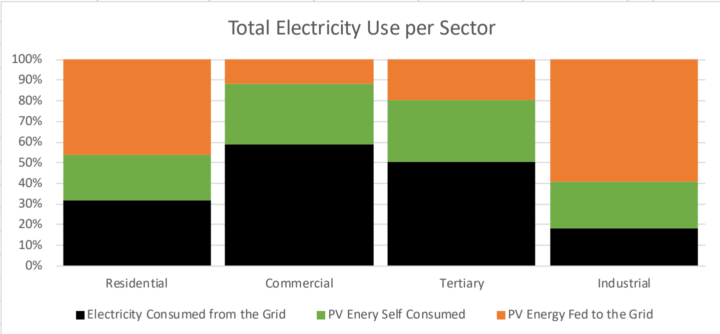
A-2. Electricity Demand and Solar PV

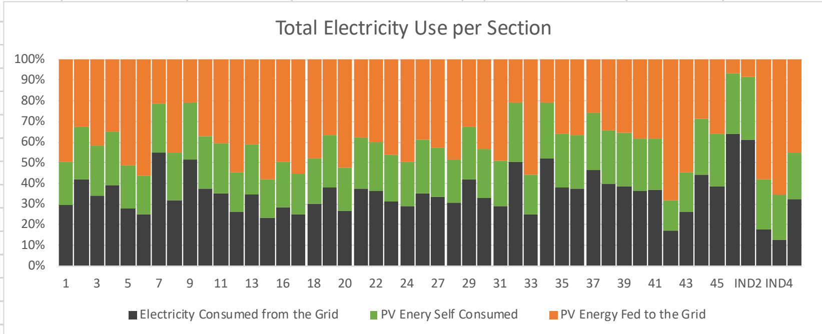
Electricity Results per Sector (GWh)

	Electricity Demand (GWh)	PV Production (GWh)	PV Energy Fed to the Grid (GWh)	PV Enery Self Consumed (GWh)	Electricity Consumed from the Grid (GWh)	PV Self Consumed	PV Generated to the grid	Electricity demand covered by PV	PV Energy to grid vs net demand	Energy fed to grid over demand covered or required to satisfy demand.	PV MWp installed simulation	Capacity Factor	Ton CO2 Savings
Residential	137.49	173.71	116.64	57.06	80.42	33%	67%	42%	145%	0%	114.07	17%	62,013
Commercial	70.19	32.74	9.43	23.31	46.89	71%	29%	33%	20%	0%	22.58	17%	11,688
Tertiary	29.80	18.32	7.31	11.02	18.78	60%	40%	37%	39%	0%	12.58	17%	6,542
Industrial	33.84	68.04	49.24	18.80	15.04	28%	72%	56%	327%	0%	46.95	17%	24,291
Total (GWh)	**271.32**	**292.81**	**182.62**	**110.19**	**161.13**	**38%**	**62%**	**41%**	**113%**	**13%**	**196.19**	**17%**	**104,534.17**
Average (GWh)	67.83	73.20	45.66	27.55	40.28								

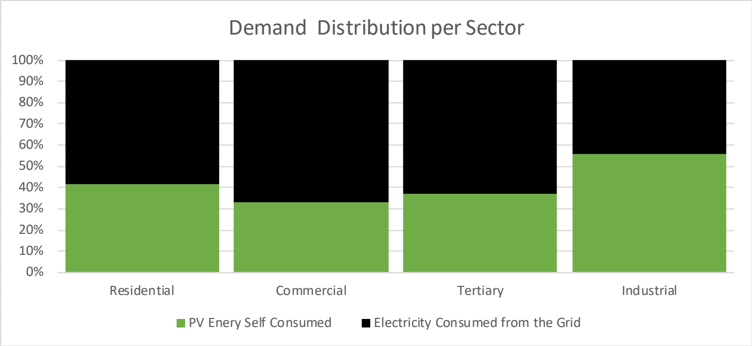
Electricity Distribution per Sector

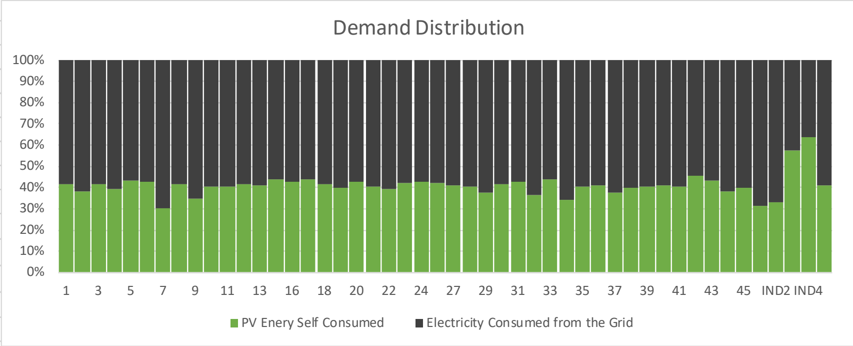
	Demand Coverage		Total Demand Coverage			Solar End Use		Total Solar End Use						
	Grid	PV	Grid	PV	Electricity Demand	PV Energy Fed to the Grid	PV Enery Self Consumed	PV Generated to the grid	PV Self Consumed	PV Production	PV Energy to grid vs net demand		% PV MWp installed simulation	Ton CO2 Savings
Residential	58%	42%	30%	21%	51%	67%	33%	40%	19%	59%	145%		58%	59%
Commercial	67%	33%	17%	9%	26%	29%	71%	3%	8%	11%	20%		12%	11%
Tertiary	63%	37%	7%	4%	11%	40%	60%	2%	4%	6%	39%		6%	6%
Industrial	44%	56%	6%	7%	12%	72%	28%	17%	6%	23%	327%		24%	23%
Total	59%	41%	59%	41%	100%	62%	38%	62%	38%	100%	113%		100%	100%



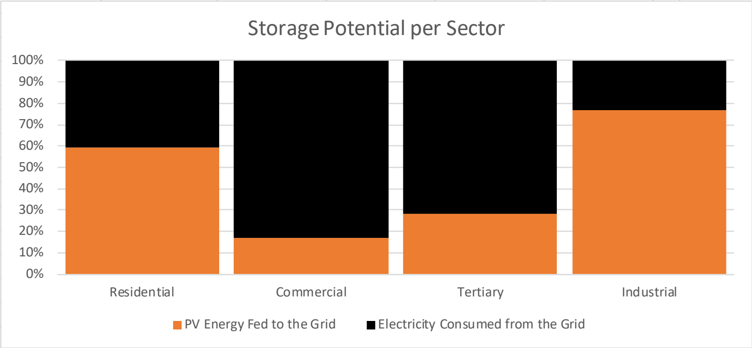


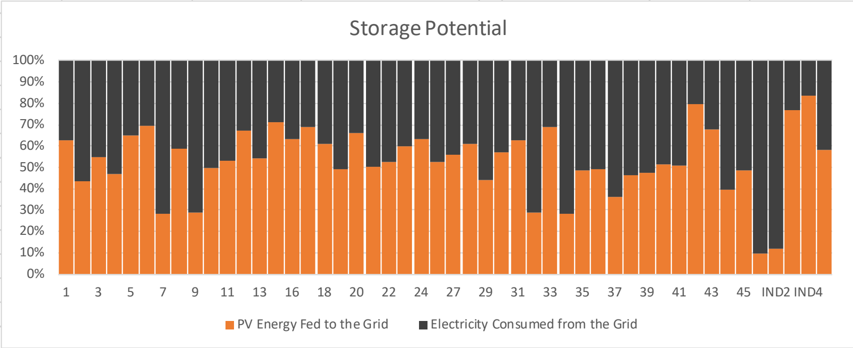
Energy matrix to satisfy electricity demand.



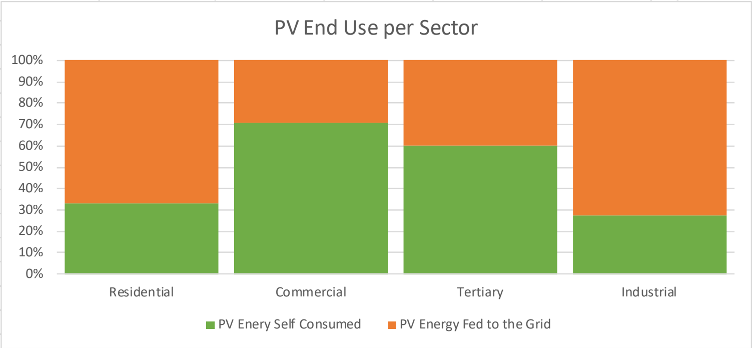


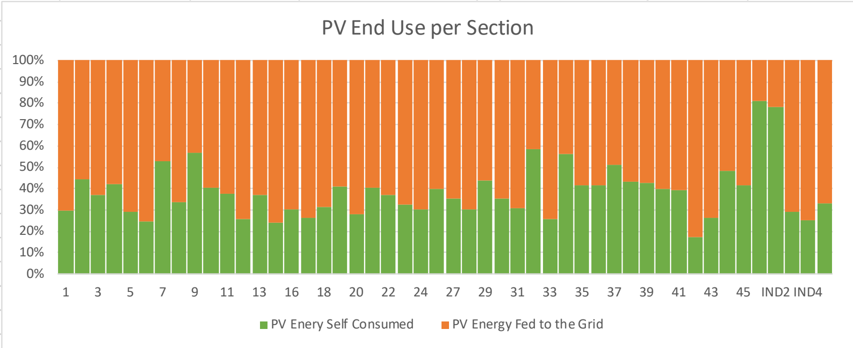
Ratio abouat the available PV production to be stored and reduce the net demand from the grid.





Ratio of PV production from the PV Self consumed and the PV Fed to the Grid. Defines how much electricity is self-consumed and how much is fed to the grid.





Electricity Distribution per Sector

	Total Demand Coverage			Total Solar End Use								
	Grid	PV	Electricity Demand	PV fed to Grid	PV Self-Consumed	PV Production	PV Self-Consumed	PV Fed to Grid	Demand Covered by PV	PV Energy to Grid vs. Net Demand	PV MWp installed simulation	Ton CO2 Savings
1	1.86	1.32	3.18	3.15	1.32	4.47	30%	70%	42%	169%	2.88	1,596
2	1.82	1.13	2.95	1.42	1.13	2.55	44%	56%	38%	78%	1.76	909
3	1.91	1.35	3.27	2.32	1.35	3.67	37%	63%	41%	121%	2.51	1,310
4	2.68	1.75	4.43	2.38	1.75	4.13	42%	58%	40%	89%	2.85	1,474
5	1.57	1.20	2.77	2.89	1.20	4.09	29%	71%	43%	184%	2.68	1,460
6	2.34	1.77	4.11	5.34	1.77	7.11	25%	75%	43%	228%	4.47	2,537
7	3.84	1.68	5.53	1.50	1.68	3.18	53%	47%	30%	39%	2.16	1,135
8	1.35	0.97	2.32	1.92	0.97	2.89	34%	66%	42%	142%	1.98	1,030
9	2.75	1.47	4.22	1.12	1.47	2.59	57%	43%	35%	41%	1.79	924
10	1.52	1.02	2.54	1.49	1.02	2.51	41%	59%	40%	98%	1.73	897
11	0.82	0.56	1.37	0.93	0.56	1.49	37%	63%	41%	114%	1.03	533
12	1.65	1.18	2.84	3.41	1.18	4.59	26%	74%	42%	206%	2.91	1,640
13	4.06	2.85	6.92	4.83	2.85	7.68	37%	63%	41%	119%	5.12	2,743
14	1.75	1.38	3.13	4.29	1.38	5.67	24%	76%	44%	245%	3.61	2,024
16	1.55	1.16	2.71	2.68	1.16	3.84	30%	70%	43%	173%	2.41	1,371
17	2.39	1.88	4.27	5.26	1.88	7.14	26%	74%	44%	220%	4.63	2,548
18	1.69	1.22	2.91	2.66	1.22	3.87	31%	69%	42%	157%	2.46	1,383
19	3.21	2.15	5.36	3.07	2.15	5.22	41%	59%	40%	96%	3.54	1,863
20	1.24	0.94	2.18	2.43	0.94	3.37	28%	72%	43%	195%	2.32	1,202
21	2.27	1.54	3.81	2.29	1.54	3.83	40%	60%	40%	101%	2.64	1,368
22	1.71	1.11	2.82	1.88	1.11	2.99	37%	63%	39%	110%	2.06	1,067
23	1.98	1.43	3.42	2.96	1.43	4.39	33%	67%	42%	149%	2.77	1,568
24	1.56	1.18	2.74	2.70	1.18	3.88	30%	70%	43%	173%	2.49	1,384
25	2.77	2.02	4.79	3.07	2.02	5.10	40%	60%	42%	111%	3.27	1,819
27	0.76	0.53	1.29	0.97	0.53	1.51	35%	65%	41%	128%	1.04	537
28	1.66	1.12	2.78	2.59	1.12	3.72	30%	70%	40%	156%	2.50	1,326
29	4.83	2.95	7.78	3.77	2.95	6.72	44%	56%	38%	78%	4.37	2,398
30	2.16	1.55	3.71	2.86	1.55	4.41	35%	65%	42%	132%	3.03	1,576
31	0.64	0.48	1.12	1.07	0.48	1.55	31%	69%	43%	167%	0.99	555
32	4.60	2.61	7.21	1.87	2.61	4.48	58%	42%	36%	41%	2.93	1,599
33	3.61	2.81	6.42	8.02	2.81	10.83	26%	74%	44%	222%	7.01	3,868
34	4.00	2.06	6.06	1.59	2.06	3.65	56%	44%	34%	40%	2.37	1,303
35	2.81	1.92	4.72	2.67	1.92	4.59	42%	58%	41%	95%	3.03	1,639
36	3.83	2.65	6.49	3.71	2.65	6.36	42%	58%	41%	97%	4.22	2,271
37	1.87	1.12	2.99	1.06	1.12	2.18	51%	49%	37%	57%	1.50	777
38	3.91	2.58	6.49	3.38	2.58	5.96	43%	57%	40%	86%	3.99	2,129
39	4.08	2.76	6.84	3.72	2.76	6.48	43%	57%	40%	91%	4.33	2,313
40	3.94	2.73	6.67	4.14	2.73	6.87	40%	60%	41%	105%	4.54	2,451
41	1.23	0.83	2.06	1.27	0.83	2.09	40%	60%	40%	103%	1.45	747
42	1.35	1.14	2.49	5.37	1.14	6.51	17%	83%	46%	398%	4.12	2,324
43	1.80	1.37	3.17	3.79	1.37	5.16	27%	73%	43%	210%	3.24	1,842
44	2.77	1.71	4.48	1.82	1.71	3.54	48%	52%	38%	66%	2.34	1,262
45	4.06	2.70	6.76	3.82	2.70	6.53	41%	59%	40%	94%	4.51	2,330
IND1	9.94	4.54	14.48	1.05	4.54	5.60	81%	19%	31%	11%	3.83	1,998
IND2	27.04	13.52	40.57	3.72	13.52	17.25	78%	22%	33%	14%	11.89	6,158
IND3	7.18	9.64	16.82	23.49	9.64	33.13	29%	71%	57%	327%	22.88	11,828
IND4	3.49	6.16	9.66	18.03	6.16	24.19	25%	75%	64%	516%	16.71	8,637
IND5	9.23	6.42	15.65	12.85	6.42	19.28	33%	67%	41%	139%	13.31	6,881
Total	161.13	110.19	271.32	182.62	110.19	292.81	38%	62%	41%	113%	196.19	104,534