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Neighborhood decarbonization based on electrification and implementation of renewable energies. Case study: Benicalap, Spain.

Master's Thesis

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Final Master Thesis

NEIGHBORHOOD DECARBONIZATION BASED ON ELECTRIFICATION AND IMPLEMENTATION OF RENEWABLE ENERGIES. CASE TO STUDY: BENICALAP,SPAIN

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ABSTRACT

The growing environmental concerns associated with the use of fossil fuels require a transition to renewable energy sources. In this context, the National Integrated Energy and Climate Plan 2021-2030 (PNIEC) and the Sustainable Development Goals (SDGs) have been designed to reduce dependence on fossil fuels and facilitate the realization of a global emissions-free environment. Addressing decarbonization scenarios requires focusing on high-consumption areas such as cities, which account for approximately 70% of global emissions.

This project aims to develop a series of action plans based on electrification and the implementation of renewable energies for the decarbonization of the Benicalap neighborhood, located in the city of Valencia. This neighborhood is recognized for its substantial potential to improve energy efficiency in buildings and its low utilization of renewable energy resources.

The project begins with an overview of relevant topics contributing to carbon neutrality. Subsequently, a sectoral analysis of the neighborhood is carried out to synthesize data and identify potential areas for intervention. A set of action plans accompanied by relevant measures is proposed and developed. These measures include the installation of heat pumps, induction cooktops, photovoltaic installation on the neighborhood's rooftops, and an energy storage system in each building of the neighborhood. These actions are evaluated from energy, environmental, and economic perspectives to determine their contribution to the decarbonization of the neighborhood. Additionally, an assessment of the synergistic effects of the proposed measures with existing initiatives is conducted to determine the collective impact of all measures.

After the implementation of the proposed measures, the Benicalap neighborhood would achieve an annual energy consumption saving of 72,483.86 MWh, equivalent to a reduction of 13,662.20 tCO2e. Furthermore, the application of these measures in a representative building in Benicalap results in annual energy consumption savings of 51.34 MWh and 10 tCO2e. As a result, these initiatives would eliminate the use of fossil fuels in the residential sector and contribute to the decarbonization goals of the Benicalap neighborhood.

Keywords: Carbon neutrality, decarbonization, neighborhood, electrification, GHG emissions, scopes, sectors, renewable energies, efficiency, heat pump, storage energy.

RESUMEN

Las crecientes preocupaciones ambientales asociadas al uso de los combustibles fósiles requieren una transición hacia fuentes de energía renovable. En este contexto, se han diseñado el Plan Nacional Integrado de Energía y Clima 2021-2030 (PNIEC) y los Objetivos de Desarrollo Sostenible (ODS) para disminuir la dependencia de los combustibles fósiles y facilitar la realización de un entorno global libre de emisiones. Abordar los escenarios de descarbonización requiere centrarse en áreas de alto consumo, como las ciudades, que representan aproximadamente el 70% de las emisiones globales.

Este proyecto tiene como objetivo desarrollar una serie de líneas de acción basadas en la electrificación y la implementación de energías renovables para la descarbonización del barrio de Benicalap, ubicado en la ciudad de Valencia. Este barrio, se reconoce por su potencial sustancial para mejorar la eficiencia energética en edificios y su baja utilización de recursos de energía renovable.

El proyecto comienza con una visión general de los temas pertinentes que contribuyen a la neutralidad de carbono. Posteriormente, se lleva a cabo un análisis sectorial del barrio para sintetizar datos e identificar áreas potenciales de intervención. Se propone y desarrolla un conjunto de planes de acción, acompañados de medidas relevantes. Entre dichas medidas se encuentran la instalación de bombas de calor, de cocinas de inducción, instalación fotovoltaica en los tejados del barrio y un sistema de almacenamiento energético en cada edificio del barrio. Estas acciones se evalúan desde perspectivas energéticas, ambientales y económicas para determinar su contribución a la descarbonización del barrio. Además, se realiza una evaluación de los efectos sinérgicos de las medidas propuestas con las iniciativas existentes para determinar el impacto colectivo de todas ellas.

Tras la implementación de las medidas propuestas, el barrio de Benicalap lograría un ahorro anual de consumo de energía de 72.483,86 MWh, equivalente a una reducción de 13.662,20 tCO2e. Además, la aplicación de estas medidas en un edificio representativo en Benicalap conduce a ahorros anuales de consumo de 51,34 MWh y 10 tCO2e. Como resultado, estas iniciativas eliminarían el consumo de combustibles fósiles en el sector residencial y contribuirían a los objetivos de descarbonización del barrio de Benicalap.

Palabras clave: Neutralidad de carbono, descarbonización, barrio, electrificación, emisiones de gases de efecto invernadero, alcance, sectores, energías renovables, eficiencia, bomba de calor, almacenamiento de energía.

RESUM

Les creixents preocupacions ambientals associades a l'ús dels combustibles fòssils requereixen una transició cap a fonts d'energia renovable. En aquest context, s'han dissenyat el Pla Nacional Integrat d'Energia i Clima 2021-2030 (*PNIEC) i els Objectius de Desenvolupament Sostenible (*ODS) per a disminuir la dependència dels combustibles fòssils i facilitar la realització d'un entorn global lliure d'emissions. Abordar els escenaris de descarbonització requereix centrar-se en àrees d'alt consum, com les ciutats, que representen aproximadament el 70% de les emissions globals.

Aquest projecte té com a objectiu desenvolupar una sèrie de línies d'acció basades en l'electrificació i la implementació d'energies renovables per a la descarbonització del barri de *Benicalap, situat a la ciutat de València. Aquest barri, es reconeix pel seu potencial substancial per a millorar l'eficiència energètica en edificis i la seua baixa utilització de recursos d'energia renovable.

El projecte comença amb una visió general dels temes pertinents que contribueixen a la neutralitat de carboni. Posteriorment, es duu a terme una anàlisi sectorial del barri per a sintetitzar dades i identificar àrees potencials d'intervenció. Es proposa i desenvolupa un conjunt de plans d'acció, acompanyats de mesures rellevants. Entre aquestes mesures es troben la instal·lació de bombes de calor, de cuines d'inducció, instal·lació fotovoltaica en les teulades del barri i un sistema d'emmagatzematge energètic en cada edifici del barri. Aquestes accions s'avaluen des de perspectives energètiques, ambientals i econòmiques per a determinar la seua contribució a la descarbonització del barri. A més, es realitza una avaluació dels efectes sinèrgics de les mesures proposades amb les iniciatives existents per a determinar l'impacte col·lectiu de totes elles.

Després de la implementació de les mesures proposades, el barri de *Benicalap aconseguiria un estalvi anual de consum d'energia de 72.483,86 *MWh, equivalent a una reducció de 13.662,20 *tCO2e. A més, l'aplicació d'aquestes mesures en un edifici representatiu en *Benicalap condueix a estalvis anuals de consum de 51,34 *MWh i 10 *tCO2e. Com a resultat, aquestes iniciatives eliminarien el consum de combustibles fòssils en el sector residencial i contribuirien als objectius de descarbonització del barri de *Benicalap

Paraules clau: Neutralitat de carboni, descarbonització, barri, electrificació, emissions de gasos d'efecte d'hivernacle, abast, sectors, energies renovables, eficiència, bomba de calor, emmagatzematge d'energia.

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ACRONYMS

GHG	Greenhouse gases
NECP	National Energy and Climate Plan
SDG	Sustainable Development Goals
CO_2	Carbon Dioxide
PV	Photovoltaic
HP	Heat pump
ZED	Zero Energy District
NZEB	Nearly Zero Energy Building
PB	Payback
NPV	Net Present Value
IRR	Internal Rate of Return
REE	Red Eléctrica de España
DHW	Domestic Hot Water
COP	Coefficient Of Performance
SCOP	Seasonal Coefficient Of Performance
SEER	Seasonal Energy Efficiency Ratio
LCOE	Levelized Cost Of Energy

1 INTRODUCTION

1.1 Background

Currently, most of the energy supply and demand in Spain continue to be satisfied with fossil fuels. According to the International Energy Agency, only 72% of the final energy supply was of fossil origin, and only 32% of final energy consumption came from non-fossil sources in 2019. Another potentially bleak statistic could be that only a quarter of the total energy supply was produced domestically in 2019; the rest was imported, which shows us how dependent our country is currently on the outside [1].

Over 75 % of global greenhouse gas (GHG) emissions and nearly 90 % of all carbon dioxide (CO_2) emissions have been produced by burning fossil fuels, one of the main causes of climate change. This produced temperature rises from 2011 to 2020, the greatest warming date recorded, provoking a rise in sea level and further warming of water, as well as the disappearance of species, increased natural disasters, food shortages, more health risks, and even more poverty [2].

However, not all outlook is bleak; for example, in 2019 about 55% of the energy produced in Spain came from renewable energies [1]. Complementary to this data, to reduce the consumption of this fuel, which implies an emission reduction, the European Union requires each state to develop a National Energy and Climate Plan (NECP). Among others, the objectives of these plans are to reduce GHG emissions by 40% compared to 1990, achieve at least 32% of total gross final energy consumption from renewable sources, and improve energy efficiency by 32.5% [3]. Moreover, in 2015, the members of the United Nations set 17 Sustainable Development Goals (SDG) to make this transition in a way that protects the planet and improves the lives of all, reducing poverty. The main points of analysis should be directed at the points of greatest consumption and, therefore, of greatest GHG emissions. A clear example would be cities, which are responsible for about 70% of global carbon emissions and more than 60% of resource use [3]. In 2007, more than half of the world's population lived in cities, but today this is still increasing; rapid urbanization results in growing poverty, inadequate services and increased urban pollution [4].

For its part, the city of Valencia, through the Valencia 2030 Climate Mission program, has set itself the ambitious goal of becoming a carbon-neutral city by 2030, contributing to the achievement of European objectives. In this plan, they are committed, among others, to a fair and inclusive energy transition favouring local energy production, energy efficiency, energy culture and the right to energy [5].

1.2 Motivation and justification

The creation and analysis of studies on decarbonization proposals are key to achieving the goals by 2030. As well as locating the major consumption and emissions points, studies at the local level are also very important to determine the individualities of each place and to carry out the study in a more accurate and realistic way.

In addition, local policies can encourage greater citizen involvement, which translates, whether in the form of self-consumption or collective generation, into significant environmental, energy or even economic benefits for society and the planet.

After a previous study [6] carried out on the neighborhoods of Valencia, finally, Benicalap has been defined as a neighborhood with a high potential for the improvement of energy efficiency in buildings and for its low potential of renewable energy resources, which justifies the choice of this neighborhood as the object of study. The study at the neighborhood level will allow us to realistically and effectively the neighborhood's situation, adapting the lines of action to the characteristics of the neighborhood in a more precise way to contribute to forming a carbon-free neighborhood.

1.3 Objectives

This master thesis aims to develop a methodology to estimate the decarbonization potential through electrification at the neighborhood level and the roadmap to achieve it for the Benicalap neighborhood in the city of Valencia.

This research study's specific main goals are:

- Study and analyze the sectors of the neighborhoods where quantitative and efficient electrification can be carried out.
- Build a methodology to estimate equipment by fuel type and quantify its contribution to the neighborhood.
- Implementation of more efficient equipment to quantify the impact on the final situation of the neighborhood.
- Perform a techno-economic analysis of electrical energy production based on PV and storage systems.
- Study the impact of the measures over the years, comparing it with the initial state of the neighborhood.
- Analyze and detail future actions and directions to improve and complete the study.

1.4 Methodology and structure

The study is organized into twelve chapters to ensure a systematic and coherent approach. The chapters are structured as follows:

Chapter 1: Introduction. This chapter provides a comprehensive overview of the study, including its background, motivation, and justification. It outlines the objectives and provides a brief overview of the overall organization of the research.

Chapter 2: State-of-the-Art. The focus of this chapter is to explore the current state-of-the-art in the fields of electrification, renewable energies, and energy storage. It examines how these technologies can contribute to the decarbonization of cities and the reduction of emissions.

Chapter 3: Tools and Methodology. This chapter provides a concise explanation of the tools employed in the study and their significance in the research process.

Chapter 4: Methodology. Here, the methodology adopted for the project's development is elucidated in detail.

Chapter 5: Neighborhood Study. This chapter is dedicated to a thorough examination of the target neighborhood, showcasing the development of the identified lines of action.

Chapter 6: Results and Analysis. The results obtained from the implemented lines of action are presented and subjected to comprehensive analysis in this chapter.

Chapter 7: Emissions Analysis. This chapter conducts an in-depth analysis of the initial and final emissions situation, focusing on the evolution of energy consumption and CO2 emissions over time.

Chapter 8: Economic Evaluation. The evaluation of different lines of development from various economic aspects takes center stage in this chapter, shedding light on their financial implications.

Chapter 9: Synergy and Future Directions. Examining the synergy between previously implemented measures and new initiatives, this chapter proposes future improvements and directions for further study.

Chapter 10: Conclusions. The main conclusions drawn from the study are presented in this chapter, summarizing the key findings and their implications.

Chapter 11: References. This chapter lists the bibliographic citations consulted during the development of the study.

Chapter 12: Appendices. The final chapter comprises annexes containing detailed information on the project's development.

Each chapter serves a distinct purpose, contributing to the overall understanding and analysis of the research topic.

2 STATE OF THE ART

As a previous step to the elaboration of the project, it is important to know the current state of the art of the subject on which the project will be based. State-of-the-art has been developed through the collection of documents, bibliographic sources, opinions, and existing research related to the decarbonization of neighborhoods.

2.1 Carbon Neutral Neighborhood

The first step is to find the right definition of a Carbon Neutral Neighborhood, as this will be the main topic on which the project will be based. A carbon-neutral neighborhood means that the net CO_2 emissions from the neighborhood are zero.

The term ZED has been created, whose one of its ultimate goals is to achieve CO_2 neutrality in neighborhoods by achieving zero or positive energy as can be seen in figure 2.1. Primarily, a ZED is a group of buildings, such as an urban district, a community, a village, a cluster of buildings, or a grouping of buildings or campuses, producing at least as much energy as they demand, and whose reduced energy demand is produced by on-site or nearby renewable energy [7]. In order to achieve neutrality in the different districts, intensive individual investigations are required, studying the best route based on the available resources and the location of each district.

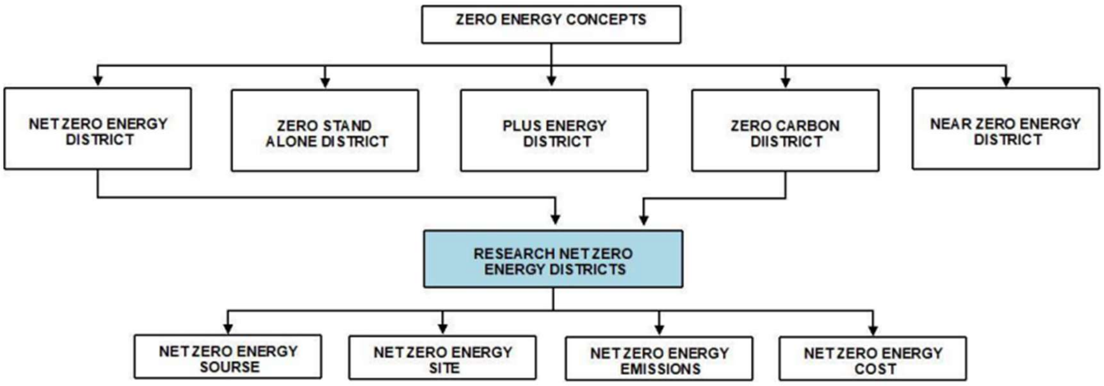


Figure 2.1 Zero Energy District Concepts **[7]**

2.2 New lines to achieve carbon neutrality

Although most solutions for GHG emissions reduction have been developed primarily at larger scales, the main advantage of developing intermediate-scale measures focused on city neighborhoods is that they have a greater potential for implementing measures [8]**.**

There are many ways to achieve neutrality, in this case, the measures proposed have been based on some solutions within the following methods [8]:

- **Energy savings:** in buildings through passive systems or other technologies, improved thermal insulation, efficient lighting, sustainable mobility by encouraging cycling and public transportation.
- **Local exploitation of renewable energy sources**: it is based on combining solutions to generate energy from renewable sources, including heat and electricity. The installation could be done progressively over a reasonable time interval, considering first the energy retrofitting of the neighborhood (short term) and then the transition to electric systems (long term).
- **Transition to electric systems to replace residual fuels:** as a desirable vision of future city neighborhoods, the simulated policies envision a transition to electric systems in buildings, including heating and cooking. In addition, a transition to sustainable mobility based on the replacement of fossil fuels with electric cars or renewable hybrids is foreseen, as well as the promotion of bicycles and public transportation.
- **Carbon sequestration by vegetation:** Urban forestry is one of the recommended actions to achieve carbon neutrality.

Buildings play a key role in the decarbonization of neighborhoods. The term NZEB is defined as a "building that has a very high energy performance… the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" [7]. Building systems can be specifically designed and have tailored load profiles that allow high penetration of carbon-free renewable sources, such as PV, to cover electricity and heat pumps for heating and cooling demands. In addition, if measures aimed at energy cooperation are implemented, communities can possess their own energy, thus promoting energy savings [7].

To achieve a ZED, it is necessary to focus some of the above measures on buildings to make them NZEB. Focusing on energy efficiency measures focused on individual buildings will allow us to reduce overall neighborhood demand and, if combined with technologies based on renewable systems and energy storage, can offer cost-effective overall solutions [7].

Renewable HP can meet domestic heating, DHW and cooling demand. This equipment for domestic heating and hot water supply is currently a niche technology in many European countries but is expected to play an increasingly important role in a low-carbon future, as the use of electricity through HPs is one of the least polluting heating options. In addition, the cost for HPs has been estimated to be about 30-40% lower for heat services by 2050 [9]. However, in Spain for 2014, only 17% of that are used as a heating system and met the specifications determined considered renewable heat pumps [10].

The most correct way to meet the decarbonization objective is to cover the electricity demand, including the energy necessary for the operation of the HP or new efficient equipment that consumes electricity in a renewable way. The photovoltaic system has been chosen because of the simplicity of its implementation due to the advancement of technology, the reduction of material costs and the government's support in producing electricity employing this technology [11]. Complementing the PV generation system with an energy storage system reduces GHG emissions by consuming less electricity from external sources and reduces the system's cost of energy [9]. Among commercial battery-based electrical energy storage systems, lithium-ion batteries offer the highest efficiency and longest cycle life [12].

However, achieving ZED is a challenge due to cities' current lack of capacity and commitment to implement these transformative changes. This decarbonization process must be carried out in a fractional, orderly, and fair manner for all, with the cooperation of all bodies, so that there is a single direction that favours the planet.

2.3 How renewable electrification can achieve carbon neutrality

Electricity from renewable sources has been growing in recent years, which is considered a valuable opportunity to transition from fossil fuels to renewable energies. For example, oil and gas boilers could be converted to electric heating by HP, or oil in transportation could be replaced by electricity, hydrogen, or electric fuels [13]. The Roadmap for Valencia's energy strategy 2020-2030 [14] defines electrification as the only way to achieve a sustainable future based on efficiency, equity, and environmental respect.

Electrification of energy demand improves air quality in cities if electricity is consumed where it is generated, facilitates the penetration of renewable energies, and is a step towards the management and independence of citizens [14].

Substitution of efficient electricity equipment for conventional fossil equipment can lead to a large reduction in GHG emissions. Full deployment of HP can lead to a reduction in total EU27+UK emissions of up to 17% in the extreme case of full electrification, and the demand for heat pumps is met by carbon-free energies such as renewables or nuclear [15].

Heat pumps can cover the demand for heating, cooling, and DHW in homes; however, another system based on electrical efficiency must be sought for cooking. In some studies, implementing an induction stove has resulted in savings of up to 30% within the cooking sector [16] , as this is the most efficient electrical option in the kitchen sector.

Electrification also means an increase in the electricity demand. However, this is not a problem if the electricity comes from renewable energies, and this demand reduces fossil fuel consumption. The significant progressive reduction of emissions from the power grid in recent years makes electrification feasible for local energy decarbonization. For instance, thanks to major advances in the electricity system, the share of emissions from electricity in the UK has been reduced by 27% by 2020 [17].

Regarding heat demand, implementing HPs is a step towards high-efficiency systems, which reduces annual electricity demand compared to electrification with less efficient equipment. It is estimated that in some countries, the peak electricity demand will grow three to five times if traditional electricity equipment is used. However, if HPs were installed to cover the heating demand, it would only increase by 40% to 110% [13]. However, the heat demand in the industrial sector is unear how it will evolve and what proportion could be electrified [13].

2.4 Emissions scopes

For environmental quantification, making a distinction based on the origin of the emissions is important. To complement the GHG emissions inventory carried out previously [6] and to see in a complementary way how the measures would affect the inventory and, therefore, the new environmental status of the neighborhood.

The division of emissions will be made following the scopes determined by the EPA, shown in the following table:

Table 2.1 Emissions scopes **[18] [19]**

Emission type	Scope	Definition	Examples
Direct emissions	Scope 1	Direct GHG emissions from sources controlled or owned by an organization of a reporting company.	Emissions associated with fuel combustion in boilers, furnaces, and vehicles).
Indirect emissions	Scope 2	Indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling.	Emissions resulting from the purchase of electricity, steam, heat, or cooling.

Indirect emissions	Scope 3	These are emissions that do not fall within an organization's scope 1 and 2 boundaries. These are the result of activities of assets that are not owned or controlled by the reporting organization but are indirectly affected by the organization in its value chain.	Purchased goods and services. Upstream and downstream transportation and distribution. Waste generated in operations.

3 TOOLS

This section will briefly explain the usefulness of the programs used to develop the project.

3.1 Microsoft Excel

Microsoft Excel is a spreadsheet tool used during practically all stages of the project. The specific functions that this tool has allowed us to perform are detailed below:

- Data collection and organization, using its search and reference functions. Allowing to optimize the rest of the processes.
- Calculation tool using its statistical, logical, and mathematical functions.
- Analytical and graphical analysis tool. To choose the most favorable option according to the criteria established at each moment.
- Facilitate the economic calculation during the lifetime of the project year by year through its financial functions such as NPV or IIR.
- To create energy and environmental balances. This will help us check the project's variation concerning its initial state.

3.2 Datadis

Datadis is an online tool that allows us to consult historical daily consumption, the types of tariffs contracted, power peaks, etc. For the project's development, only the data on daily consumption during 2019 for Benicalap has been used.

3.3 QGIS

QGIS is an Open-Source Geographic Information System software used to obtain the average number of dwellings in a block of buildings in the neighborhood, as well as the distribution of floors of the dwellings in Benicalap.

3.4 PVGIS

PVGIS (Photovoltaic Geographical Information System) is an online tool developed by JRC (Joint Research Centre) from the European Commission that provides information about solar radiation for any location in Europe. The hourly radiation data for the year 2019 in Benicalap has been extracted from this tool.

3.5 Homer

HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a software initially developed at the National Renewable Energy Laboratory and enhanced and distributed by HOMER Energy. It allows simulation of the operation of a hybrid microgrid for a whole year, in time steps from one minute to one hour.

HOMER has allowed us to create a hybrid system where we can enter the measurements and see their evolution over time, as well as all possible combinations of system types and depending on the chosen variable.

4 METHODOLOGY

This section will detail the methodology followed for the development of the study.

4.1 General procedure

The general procedure followed is shown in the figure 4.1.

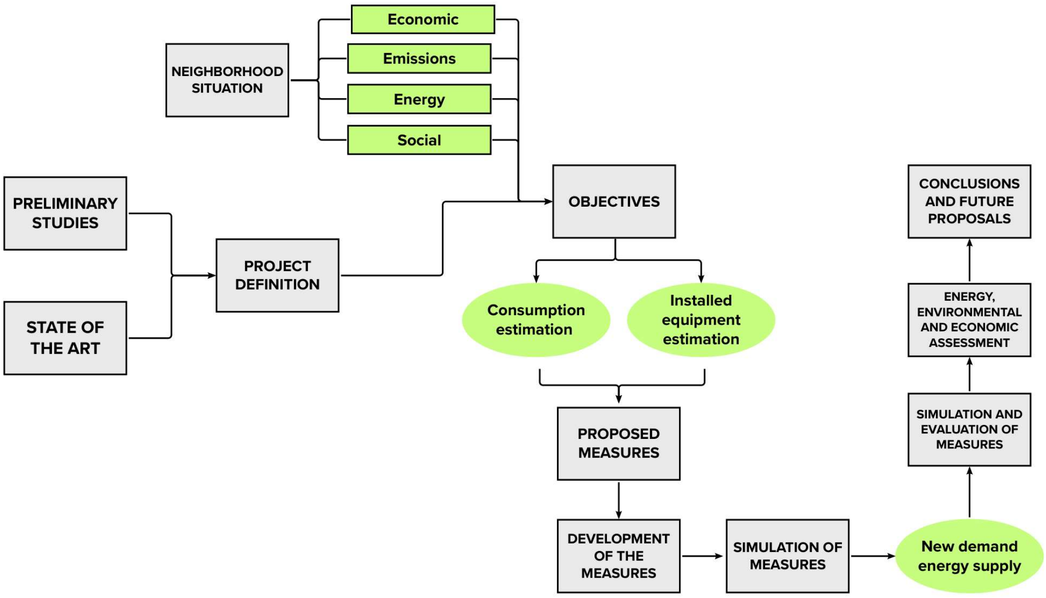


Figure 4.1 Scheme of general procedure methodology

Preliminary studies

The preliminary study has been based on seeking information about which neighborhoods in the municipality of Valencia have the greatest potential for improvement.

In the study on the creation of a methodology to estimate the decarbonization potential at neighborhood level, it was estimated that this neighborhood was one of them [6], so it has been decided to continue with its improvement and this study has been used as a "starting point". The main idea is to complement its work with different lines of action, deepening the concept of electrification and the implementation of renewable energies and their possible storage, with the common goal of making the neighborhood of Benicalap a carbon-free neighborhood.

State of the art

Parallel to the preliminary study of the situation of the neighborhoods of Valencia, the state of the art has been developed.

In this section, concepts that will deal with terms of decarbonization have been defined and studied. The general objective is to know the status of the concepts used during the project to see the positive and negative points to later estimate how they can influence the development of the measures.

Project definition

A fundamental part is to be clear about what the project will be about.

In a simplified way, the project can be summarized as: "with the available information about the Benicalap neighborhood, create a way to help decarbonization most efficiently and realistically possible". This pathway will be defined in the following points, having as a premise the search for answers to the questions of point 2.2, the information collected in the preliminary study and in different topics on decarbonization collected in the study of state of the art.

The approach for the project analysis has been to use the following indicators:

- In the energy analysis: MWh/year saved, % grid independence, % electrification of demand.
- Environmental analysis: tCO_2/year saved, tCO_2/MWh.
- Economic analysis: €/kWh, €/tCO_2, years of return on investment, Net Present Value (NPV), Interest Rate of Return (IRR).

Neighborhood situation

After defining what the project is going to be about, an analysis of the initial situation of the neighborhood was carried out. In this analysis, data on the characteristics of the neighborhood such as the number of inhabitants, number of buildings, electricity consumption by use, etc. were obtained. At the environmental level, the previously developed environmental inventory by sector has been used [6] to get an idea of the magnitude of emissions in the neighborhood.

Throughout the project, it will be explained what the data from this initial analysis have been used for and, together with the previous sections, how they have been used to define the objectives.

Objectives & proposed measures

Once the project has been defined and the analysis of data availability has been made, the objectives have been set. The objectives have been defined to be fulfilled as realistically as possible, contributing to the objectives set by the city of Valencia.

The following measures have been designed to meet the objectives outlined in section 1.3:

- Replacement of fossil fuels by heat pumps in residential heating.
- Replacement of gas stoves with induction stoves.
- Photovoltaic power generation.
- Energy storage.

These measures have required the estimation of consumption by energy source and the estimation of installed equipment. How this data was obtained is explained below.

Simulation & evaluation of the measures

Manually quantifying the impact, the measures can have on the neighborhood can be difficult and lead to errors if done manually. Several simulations have been carried out in the HOMER program to avoid such problems.

The following sensitivity variables were considered in the model:

- Annual consumption increase.
- Electricity price.
- Equipment replacement.

Mainly energy and economic information has been extracted from the model. To evaluate the simulations and choose the best scenario, a technical-economic analysis has been carried out, considering variables such as the renewable fraction, economic limitation in the sale of surpluses, independence from the grid, and finally, the amount of electricity bought and sold.

Energy and environmental assessment. Initial vs final state

Once the best scenario has been chosen, the impact of the different measures on the neighborhood is evaluated. This analysis will be carried out mainly using energy and CO_2 balances, applying the indicators defined in the "Project definition" section as evaluative variables, allowing us to know to what extent the objectives proposed for the project have been achieved.

Conclusions and future proposals

After the different types of analysis, conclusions have been developed from different points of view. In addition to these conclusions, a series of future proposals will be made as to how the measures developed could be further developed, how they could be extrapolated to other neighborhoods, or will last into the future.

4.2 Methodology for estimating installed equipment

For the development of the measure to electrify the residential sector it is important to specify the equipment installed about Benicalap and the source of energy they use. Unfortunately, there is no direct data to quantify the weight of each team and other methods have had to be used to estimate them.

Due to the lack of data on installed equipment at the municipal and provincial levels, it has been decided to use the data provided in the SPAHOUSE II document [20], which indicates the types of systems by climate zone in the residential sector. The absence of solid and recent data on the equipment used for heating in the rest of the uses has been the main reason why the measure to electrify heating has focused on the residential sector.

To estimate the equipment installed in the Benicalap neighborhood, the methodology detailed in Figure 4.2 has been followed. It has been considered that this is the best way with real data to estimate each equipment according to the climatic zone. The results of this estimation can be found in section 5.3 in the case study.

This methodology shows how, using data from the Mediterranean area extracted from national reports and the characteristics of the Benicalap neighborhood, an estimate of the installed equipment can be made.

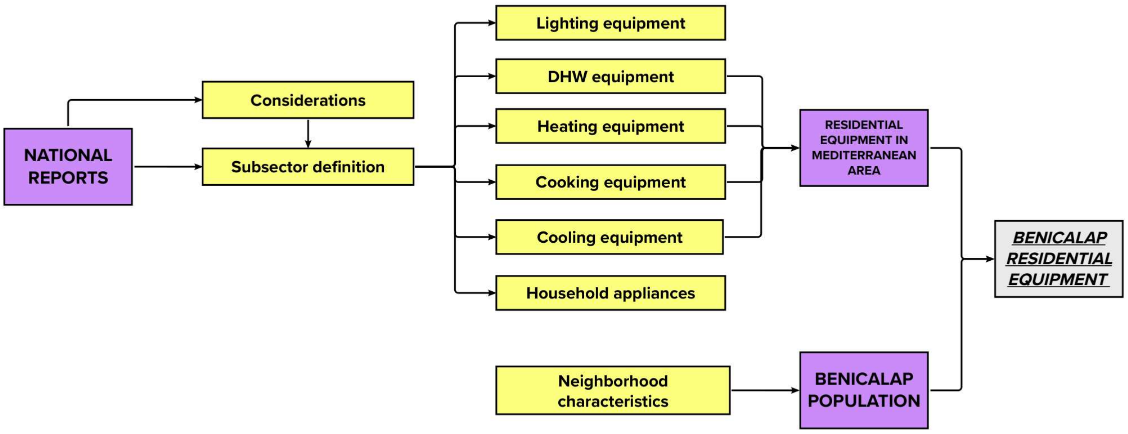


Figure 4.2. Methodology for estimating the equipment installed in the Benicalap neighborhood

Prior to the estimation of the equipment installed in the Mediterranean area, it is necessary to define the installed equipment that make up the sub-sectors of the national reports. For this purpose, the national document “actualización 2020 de la estrategia a largo plazo para la rehabilitación energética en el sector de la edificación en España” [21] which is based, among others, on the following documents SPAHOUSE I [22] and SPAHOUSE II [20]. In addition, in this document, for greater precision in the quantification of the equipment, we find the fact that within the multi-family homes in the Mediterranean area, a distinction has been made between individual and collective equipment.

Although an attempt has been made to make as few considerations as possible and to focus on real data, it has not been possible due to the lack of data. The considerations have been:

- Condensing boilers using only natural gas as fuel.
- Quantification of portable electric equipment in the "others" section with the remaining % in heating.

The residential sector is divided into heating, DHW, cooling, cooking, lighting, and household appliances. Focusing on each domestic sub-sector within the Mediterranean area, to which Valencia belongs, the division is made into multi-family dwellings which constitute 96.8% of the dwellings in the neighborhood of Benicalp and single-family dwellings, constituting only 3.2% of the total number of dwellings in the neighborhood according to the city council of Valencia [23]. As well as it has been extracted from the regional data that 88.01% of the population of the district of Benicalap has some kind of heating system.

Finally, with the characteristics of the neighborhood and the domestic equipment in the Mediterranean area defined, an estimate of the equipment installed in the Benicalap neighborhood can be made.

4.3 Methodology for estimating energy consumption

4.3.1 Electric consumption

The electricity consumption for the Benicalp neighborhood has been calculated based on data from the Valencia City Council [23] for calculating the annual electricity consumption and from the daily data provided by Datadis [24] with REE profiles.

Hourly consumption

In order to estimate the daily electricity consumption in the Benicalap neighborhood, the methodology shown in figure 4.3 has been used.

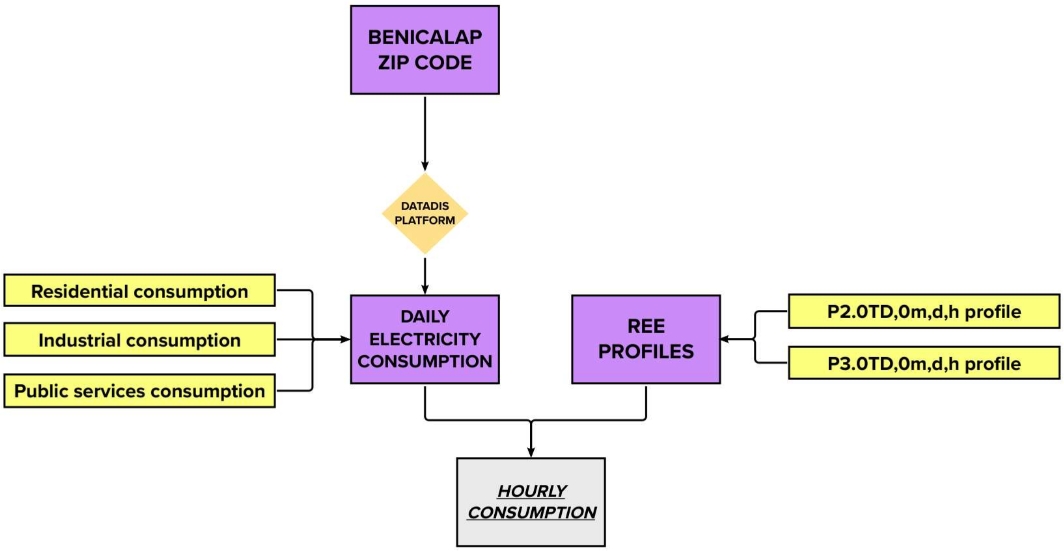


Figure 4.3. Methodology for estimating the hourly consumption in the Benicalap neighhborhood

To obtain the hourly values, the daily values must first be obtained. For this purpose, we have used the Datadis platform [24] which provides electricity consumption data and number of customers according to the zip code of the Benicalap neighborhood. The zip code 46022, that corresponding with Benicalap, is entered in the web and the daily values in kWh for each sector (residential, industrial, and public services) for the year 2019 are obtained. The choice of this year and not later years has been since these years may be influenced by the COVID-19 crisis and by the war in Ukraine.

Once the daily values have been obtained, the hourly values have been obtained from the consumption profiles provided by REE [25] for values lower than 15 kW, profile P2.0TD,0m,d,h have been established for residential use and values between 15 and 50 kW, profile P3.0TD,0m,d,h has been established, corresponding to industrial and service uses.

The calculation process has been to multiply each daily value obtained from Datadis by the sum of the corresponding profile each day and divide it by the schedule for each hour, as shown in the equation #3 of the annexe B.

Annual consumption

To obtain the annual value for the neighborhood of Benicalap, the annual data of electric energy billed in the municipality of Valencia has been taken and extrapolated to the neighborhood of Benicalap. However, only the annual residential electricity consumption has been used as data due to what explain which in the following section.

The calculation method has been to use the starting data from the city council of 580,798 MWh of total electricity energy billed for the domestic sector and from the total number of buildings in Valencia and those in the Benicalap neighborhood, as indicated in equation #4 in Annex B.

4.3.2 Fossil fuel consumption

Estimating the annual consumption of fossil fuels has not been easy, since we do not have direct data to rely on, except for Natural Gas and packaged butane and propane. Those consumptions can be seen in table 12.6 of section E of the annexes.

Gas natural consumption

As was done to obtain the annual electricity consumption, the city council of Valencia also provided data on the Natural Gas billed in the municipality of Valencia. Starting from this base data, would have to be extrapolated to the Benicalap neighborhood, following the same equation used for electricity.

Oil products consumption

The data for packaged butane and propane are known thanks to the city council of Valencia; however, insufficient data are available to estimate fuel oil consumption. For the calculation of the latter, the data of the installed equipment has been used.

The values provided by Valencia city council for electricity, natural gas, butane and propane packaged have been fixed. These values have been determined based on the percentage of equipment that consumes gasoil in each subsector of the residential sector, a simple rule of three is performed. 2.8% of the installed equipment consumes diesel and slightly more than 94% of the equipment consumes electricity, natural gas, butane, or propane; this 94% is a value that is given by the city council and from this data the unknown diesel consumption is calculated.

Coal consumption

There is also no data available on coal consumption in the neighborhood, so the same procedure has been carried out as with diesel fuel for a residential use. However, in this case, the equipment using coal is smaller.

4.3.3 Renewable resource consumption

Only equipment providing direct energy such as radiant underfloor heating, solar panels or biomass has been considered as a renewable resource. The calculation procedure has been the same as the one used to estimate coal and gas-oil consumption. As in the previous cases, this estimate will be used for the residential sector since data on installed equipment for other sectors are not available.

4.4 Methodology for estimating consumption by energy source in residential sector

For the quantification of consumption by energy source in heating, DHW, cooling, cooking, lighting and household appliances in the residential sector, other than electricity, natural gas, butane or propane, it has proceeded to use the data of the percentage of consumption in the Mediterranean area in the residential sector of the document SPAHOUSEC I [22]. This initial division has been as follows:

Table 4.1 Initial distribution of consumption in the residential sector in the Mediterranean area **[22]**

Consumption by use	***%***
DHW	**19.60%**
Heating	**40.90%**
Cooking	**7.10%**
Cooling	**1.10%**
Lighting	**5.70%**
Household appliances	**25.60%**

This division was created in 2011, so it is easy to believe that it may have varied over the years. However, according to more recent documents such as the Energy Book in Spain of 2019 [26] and the Energy Policy Review of Spain in 2021 by the International Energy Agency (IEA) [27], these percentages have not significantly changed in recent years.

Following the initial consumption proposal, it has been decided to adjust these percentages based on the average heating and cooling demands specific to the climatic zone of Valencia, specifically referred to as zone B3 [28]. This adjustment will rely on data extracted from the Spanish government's document that outlines the Energy Efficiency Rating of Buildings [29], where average values for thermal comfort and cooling requirements for both single-family dwellings and apartment buildings can be obtained. The table 4.2 shows the average annual comfort conditions according to the type of dwellings in the Benicalap neighborhood.

Table 4.2 Average annual comfort conditions according to the type of dwellings for the Benicalap neighborhood **[30]**

	Average annual thermal comfort value ($\frac{kWh}{m^2}/year$)	**Average annual cooling comfort value ($\frac{kWh}{m^2}/year$)**
Single dwellings	58.50	25.79
Block dwellings	42.60	20.62

According to this source, it is noted that the cooling demand is two times lower than the heating demand for residences within this climatic zone. By applying the efficiencies of the installed heating and cooling systems, the corresponding consumption for these two aspects can be calculated.

Although not everyone in the Benicalap neighborhood has the desired thermal comfort in their homes, it is possible to establish a scenario where heat pumps help to achieve this comfort. Determining thermal comfort contributes to improving the energy efficiency of buildings by optimizing the design and use of air conditioning and heating systems, resulting in reduced energy consumption and greenhouse gas emissions. In addition, achieving this comfort avoids health problems that can affect people's quality of life.

Using tables III.6 and III.7 from the Spanish government's document that establishes the Energy Efficiency Rating of Buildings [30], average values for thermal comfort and cooling requirements for both single-family dwellings and apartments in buildings can be obtained. According to the classification established in the Código Técnico de la Edificación (CTE); Valencia corresponds to climate zone B3 [28], which means that Benicalap also corresponds to this climate zone. In Benicalap the 96.8% of the dwellings are located in a building and only 3.2% are single-family dwellings, the significance of buildings within the neighborhood study is highly relevant. The average values required to achieve comfort in the different dwellings within the Benicalap neighborhood are presented in the table 5.8; this averages the comfort required in new and existing private residential buildings.

However, due to the availability of official data from the city council of Valencia, it has been decided that these data should take precedence over the previous percentages, as they are more recent and specific to the municipality of Valencia. This will allow for a more accurate estimation to be made for the Benicalap neighborhood. Consequently, these chosen data have caused variations in the percentages presented. Furthermore, the division has also been influenced by estimating the consumption of energy resources, particularly in the cooking subsector, where official data is not available. In this calculation, energy data from the Comunitat Valenciana for the year 2019 has been utilized [31].

Taking all these factors into consideration, the final consumption figures for the Benicalap neighborhood can be found in the following sections of the case study.

5 CASE STUDY

5.1 The situation in the Benicalp neighborhood

Benicalap is the largest neighborhood within district 16 of Valencia, Spain, situated in the northwest region of the city. It encompasses two specific neighborhoods: Ciutat Fallera and Benicalap. The precise geographical location of the neighborhood within Valencia can be seen in the figure below, highlighted in blue.

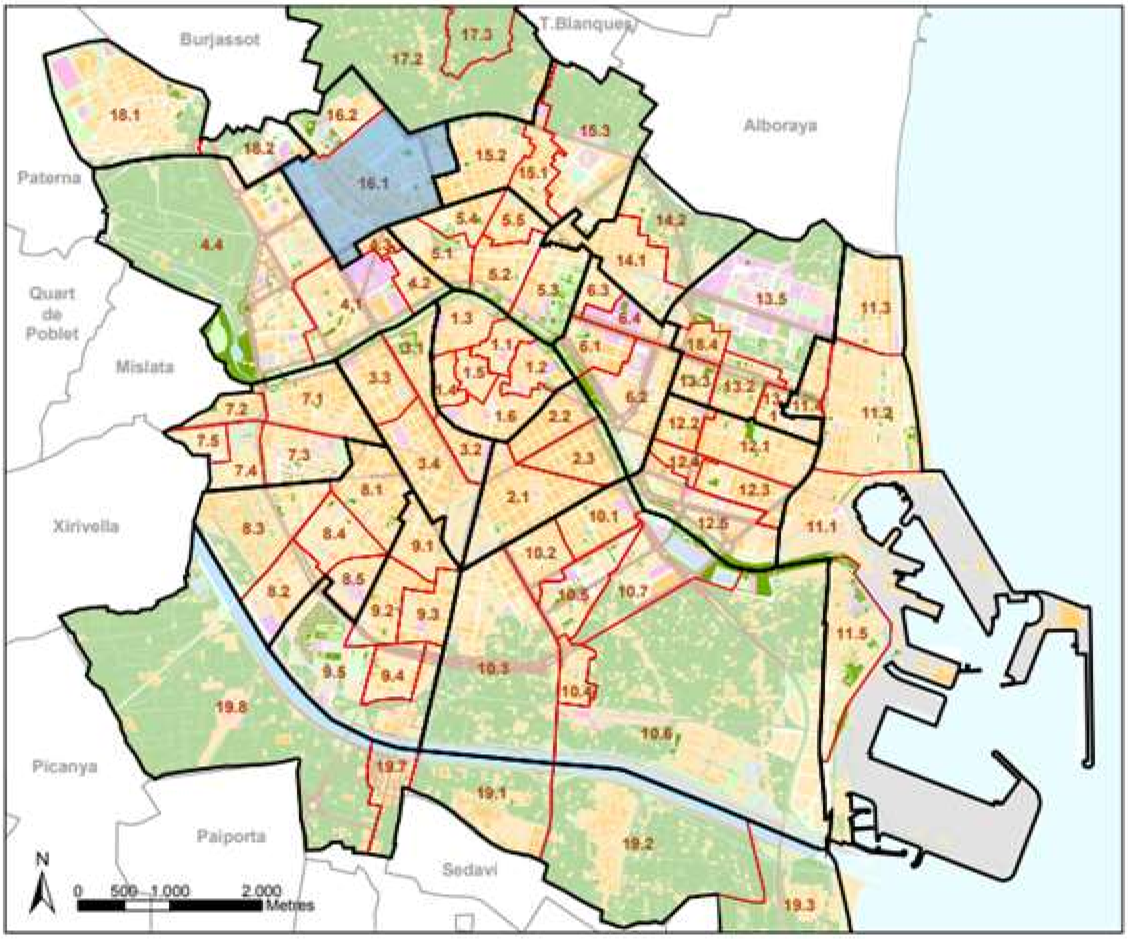


Figure 5.1 Geographical location of Benicalap. Modified from **[23]**

The statistical base of the city council has provided basic data for the Benicalap neighborhood for the year 2021. These data are shown in Table 5.1.

Table 5.1 Basic data of Benicalap **[23]**

Population (number on inhabitants)	41,483
Surface (km^2)	1.72
Density of population (inhab/km^2)	24,132

For the development of the project, it has also been used data on the number of properties in the neighborhood in the year 2021. In total Benicalap consists of 33,585 real estate properties, broken down according to the use of the property in table 5.2.

Table 5.2 Number of properties in the Benicalap neighborhood in 2021 **[23]**

Properties in Benicalap	
Residential	**18,975**
Commercial	**1,253**
Office	**114**
Industrial	**213**
Others	**279**

From the 1053 cadastral values obtained from QGIS for the resindecial sector, it has been calculated that there are approximately 1020 blocks of buildings which is equivalent to 19,096 dwellings, obtaining a very similar number to the one provided by the Valencia city council. This small difference shows the reliability of the data extracted from QGIS; although for the calculations used in the project the number published by the city council of Valencia will be used.

Likewise, from the results extracted from the program it can be obtained that the average number of dwellings per building is 18 and most of the properties have 7 floors, as shown in Figure 5.2. The measures focused on the residential sector will use these data as a reference for their development. The average surface area per residential property after 1800 is 103.3 m2, according to data from the Valencia City Council.

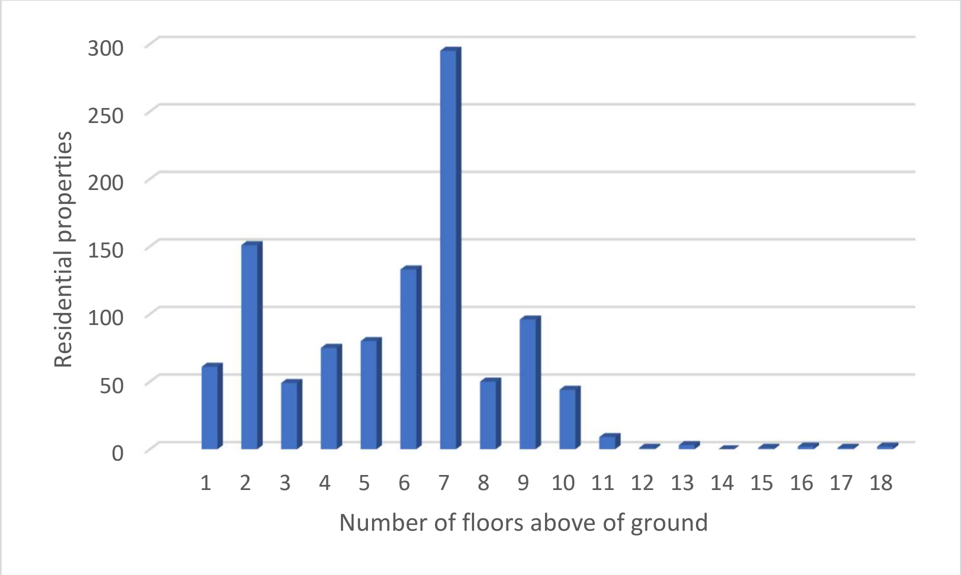


Figure 5.2 Number of floors above ground of residential buildings

For a comprehensive analysis of the neighborhood and the proper execution of the project, a thorough examination of the neighborhood's conditions is necessary. The alignment of the measures with the neighborhood's conditions facilitates their practical implementation. To this end, a concise analysis will be conducted on the social, economic, energy, and environmental data deemed most pertinent.

5.1.1 Social situation

The social situation of the neighborhood can be used to perform a qualitative analysis and to approach the measures from a different point of view.

The population's level of education can be one of the positive aspects to understanding this project's lines of work and knowing how to value the contribution of these on the different aspects of environmental, economic, and energy savings. The following figure shows the population in family dwellings over 16 years of age by educational level.

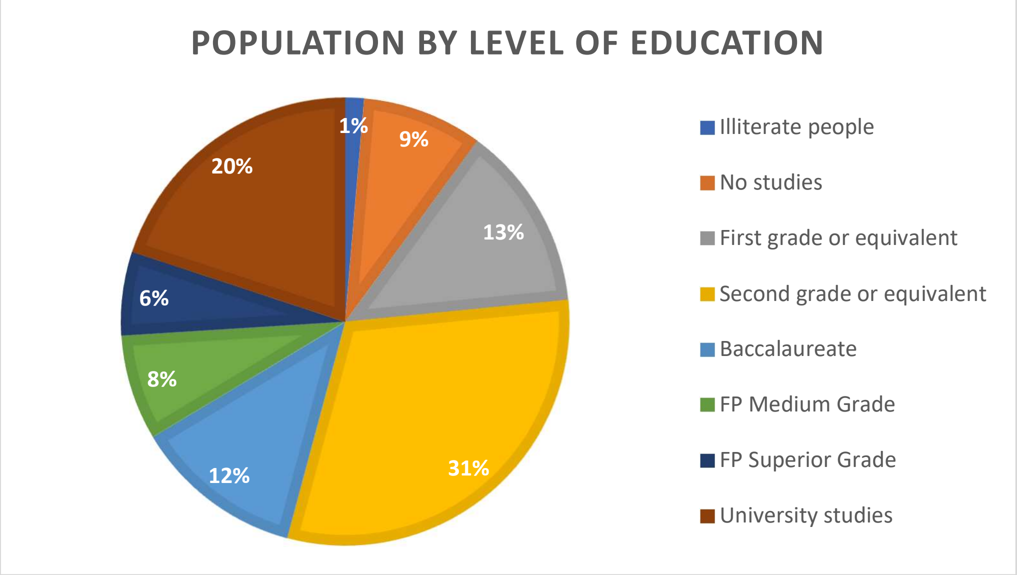


Figure 5.3 Population in family dwellings aged 16 and over by level of education (2011) **[23]**

In the district of Benicalap the birth rate in 2020-2021 is quite high compared to most of the districts of the city of Valencia. On the other hand, the mortality rate in these years is the second lowest of the districts. This means that more people are born and die less on average than the rest of the districts of the city of Valencia, which may lead to a greater variation in consumption. These results are reflected in figure 5.4.

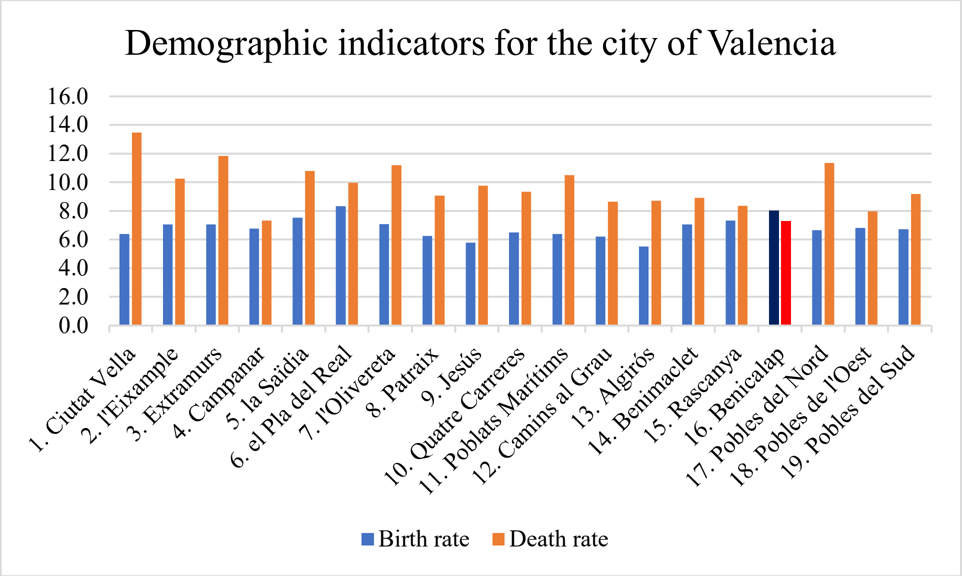


Figure 5.4 Demographic indicators for the city of Valencia 2020-2021 **[23]**

5.1.2 *Economic situation*

The economic situation of the people living in Benicalap neighborhood is very important, since much of the economic expenditure, if not the total in some cases, of the measures must be assumed by the population. To a large extent it helps us to formalize a qualitative analysis of the study.

A basic economic data would be the income of people. The following table shows the average annual income in the neighborhood of Benicalap in 2017, seeing how it is lower than the average income of the average of the city of Valencia, which reflects a somewhat bleak data.

Table 5.3 Annual mean 2017 **[23]**

Benicalap district	26,519 €	10,265 €	15,373 €
Valencia city	31,142 €	12,349 €	18,348 €
	-17.4%	-20.3%	-19.4%

Another interesting data might be to see in which economic activities people work in the neighborhood, although the data has been extracted at the district level, it is useful to get a close idea. From figure 5.5 it can be seen that the main economic activity in Benicalap comes from commerce, financial institutions and insurance, and industrial activities.

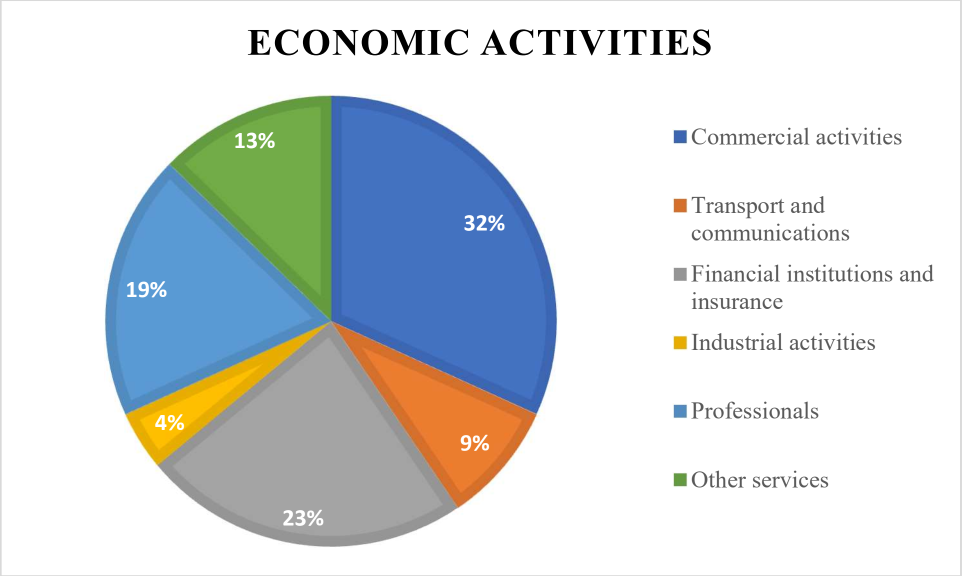


Figure 5.5 Distribution of economic activities in Benicalap.

In the case of the active population, almost 70% of the population has a job. This data directly impacts the economy since a stable job can contribute to and encourage investment in new measures.

Related to the characteristics of the land in the neighborhood, table 5.4 it is presented the average value per m2 is higher in Benicalap than in the city of Valencia in general.

Table 5.4 Land values in 2021 **[23]**

	Average surface area (m^2)	Average value (€)	Average value per m^2 (€)
Benicalap	1,588.8	174,416.21	109.73
Valencia	1,165.0	123,653.11	106.13

Finally, related to the age of the properties in the neighborhood of Benicalap has been represented in figure 5.6. The state of the properties can have repercussions in more energy losses due to less thermal insulation, and more maintenance, which means a higher cost.

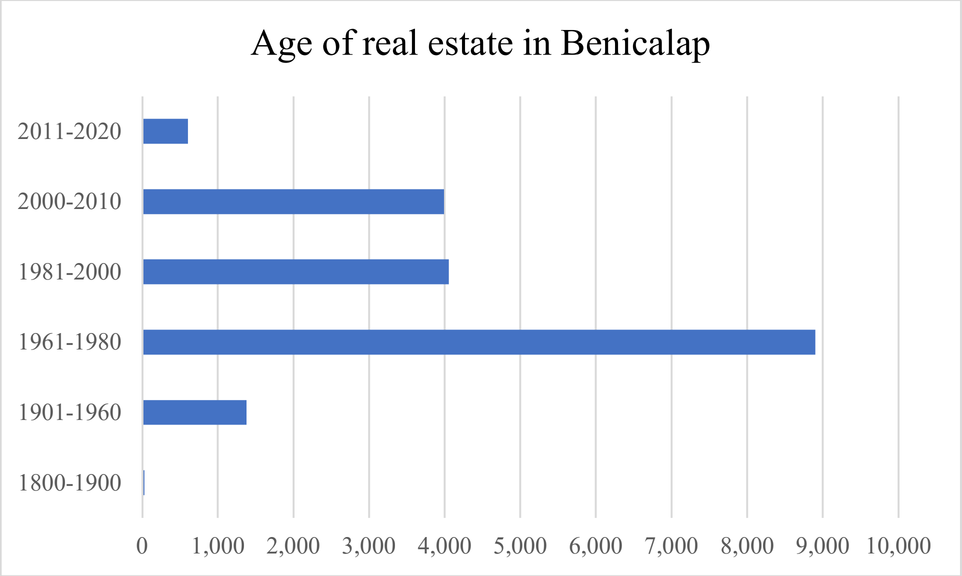


Figure 5.6 Age range in Benicalap **[23]**

5.1.3 Energy situation

The energy situation analysis is the most determining factor for the development of the work since a large part of the measures implemented, and the environmental study depends on it.

At the neighborhood level, consumption data by fuel type are not available, for which extrapolations of the energy bill in the city of Valencia [8] have been used.; shown in the table 5.5.

Table 5.5 Total consumption in MWh in the City of Valencia for 2019 **[23]**

Electricity consumption	2,548,179	MWh
Gas Natural consumption	939,008	MWh
Butane Packaged consumption	132,506	MWh
Propane packaged consumption	20,910	MWh

The electricity consumption energy from Datadis data in the different sectors is shown in figure 5.7**.** The sum of all sectors is equivalent to an electricity consumption of 77,085 MWh per year.

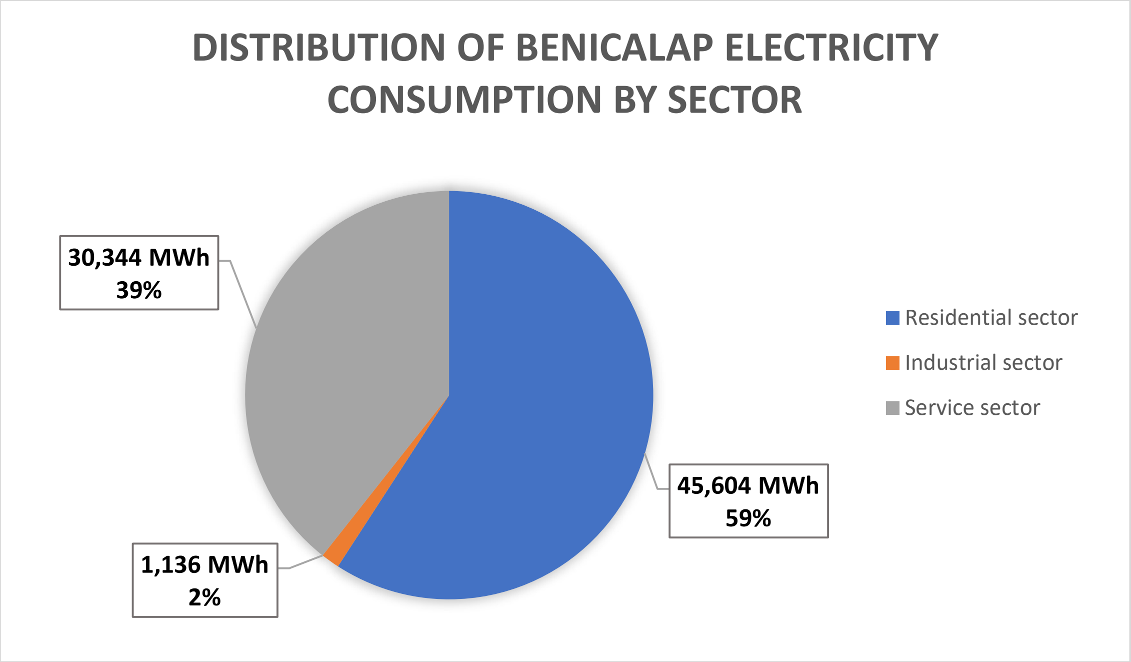


Figure 5.7 Distribution of Benicalap electric consumption by sectors in 2021 based on Datadis data **[24]**

The starting energy data are those shown above, in addition to the annual consumption of natural gas by sector in the city of Valencia. However, this data has not provided information for the development of the work because it is not possible to make a quantitative classification of natural gas consumption in the subsectors of the industrial and services sector.

As mentioned above, the scarcity of data on the quantification of fossil fuel consumption within each subsector has led us to focus on the residential sector. The situation within this sector is shown in the following section.

Residential sector

Using the calculation method based on city council data for electricity consumption in the residential sector we obtain a value of 45,561 MWh per year; observing only a percentage error of 0.09% concerning the Datadis result. As shown in the table 5.6.

Table 5.6 Total annual consumption (MWh) in Benicalap residential sector by different calculation method.

Datadis data	45,604	MWh
City Council data	45,561	MWh

After applying the methodology explained in sections 4.3 and 4.4, the following distribution of consumption in the residential sector in the Benicalp neighborhood for the year 2021 has been obtained. It can be seen that electricity is at the top of this distribution. However, almost 42% of consumption comes from renewable sources for the residential sector.

Table 5.7 Consumption of the residential sector of Benicalap by energy source in 2021

Energy Source	Consumption (MWh)	Percentage
Oil products	7,181	9.02%
Natural gas	25,408	31.94%
Renewable resources	796	1.00%
Coal	536	0.67%
Electricity	45,715	57.40%

If the distinction is made between renewable sources, electricity or fossil fuels, the distribution would be as follows:

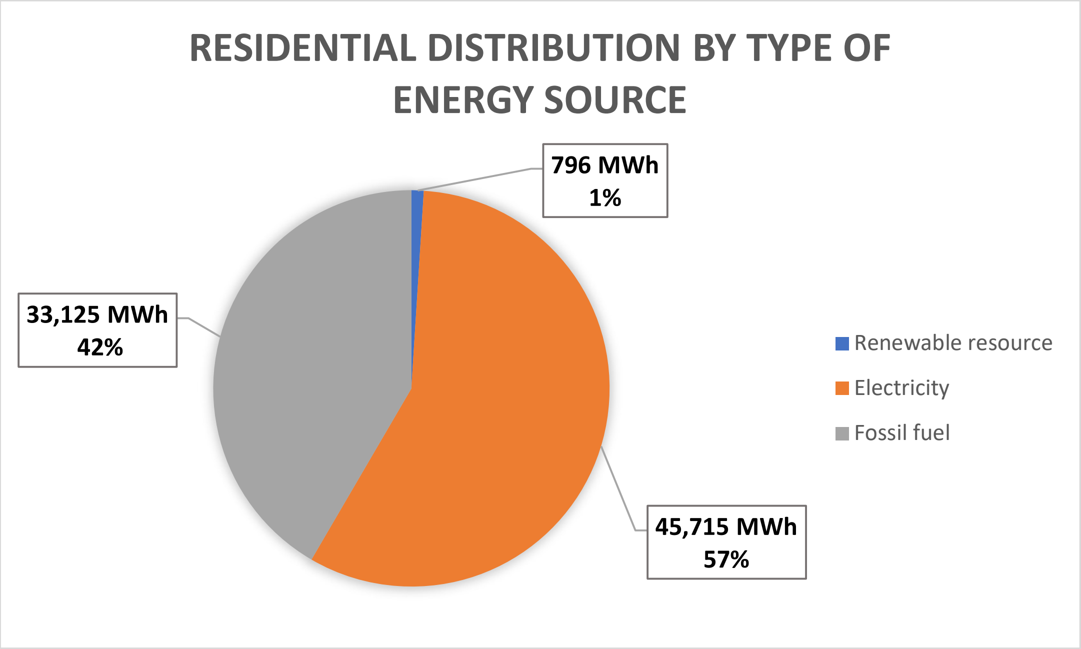


Figure 5.8 Residential distribution by type of energy source in the Benicalap neighborhood in 2021

The distribution of consumption in this sector is shown in graph 5.8. Heating occupies the first place, followed by household appliances and DHW.

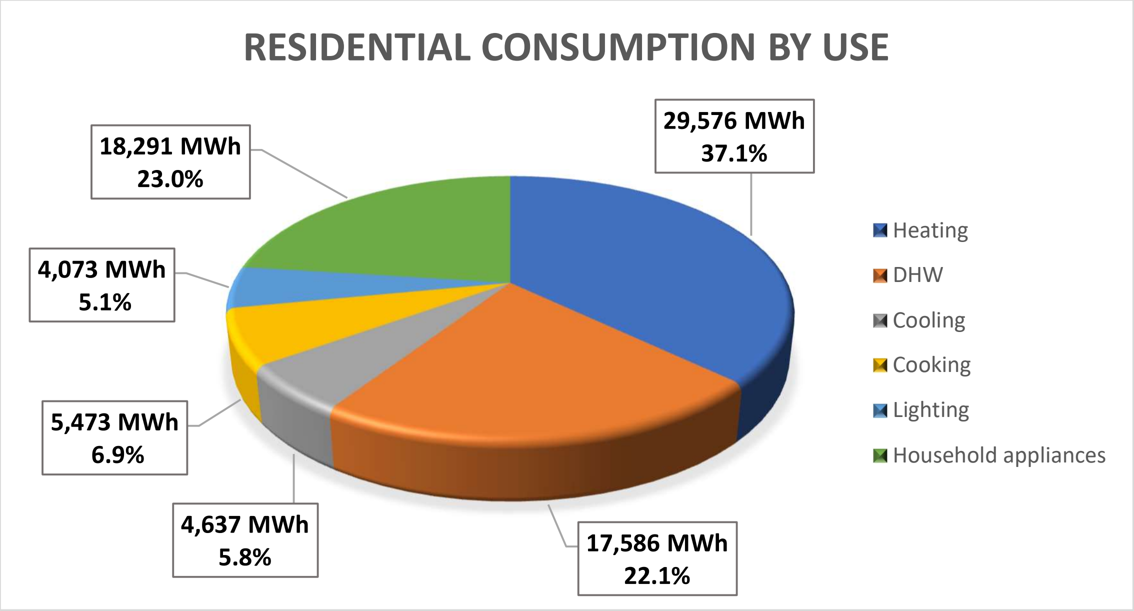


Figure 5.9 Distribution of consumption in the residential sector in the Benicalap neighborhood in 2021

Another relevant data for the study is to determine the average built surface of the real estate properties with residential use in the Benicalap neighborhood. In this case, the information provided by the city council shows that the average built-up area is 103.3 m2, resulting in it being very similar to the Valencian average.

Based on the information provided and the distribution shown in Figure 5.9, the total annual consumption per building in the neighborhood is estimated to be 75.58 MWh.

5.1.4 Neighborhood emissions

To study the initial situation, a GHG emissions inventory of the Benicalap neighborhood has been carried out in a previous work [6]. Although it is worth mentioning that only the emissions generated by electricity in terms of buildings were quantified, which is the substantial burden of application of our measures.

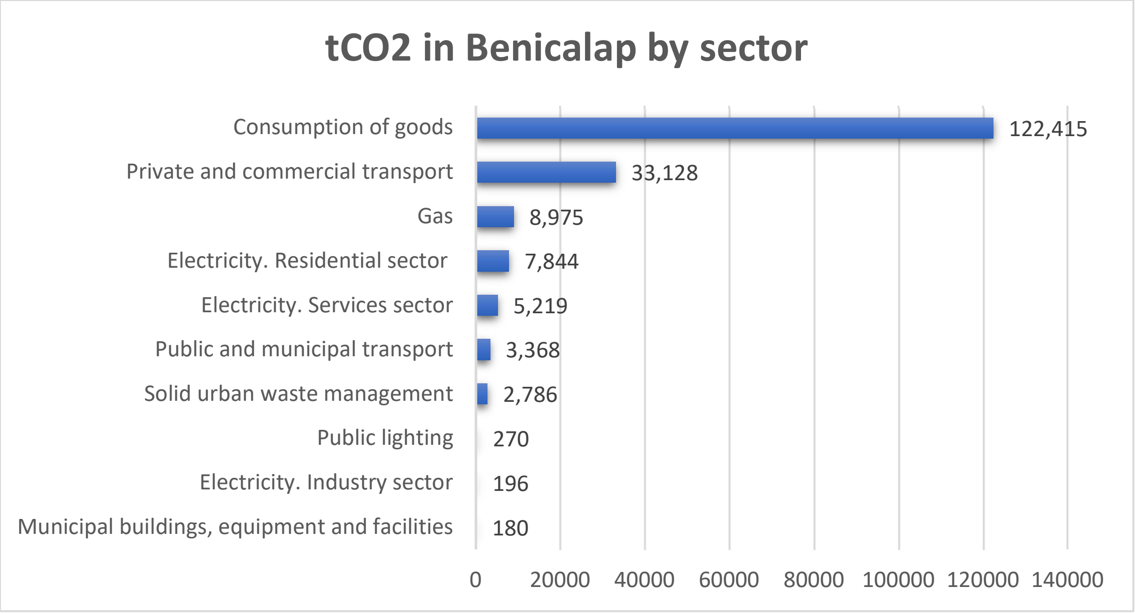


Figure 5.10 Summary of GHG inventory for Benicalap by sector **[6]**

The highest emissions come from the consumption of goods, followed by private and commercial transportation. Natural gas consumption and residential electricity consumption rank third and fourth, respectively.

The figure 5.11 shows the distribution of these emissions in the three scopes defined in section 2.5.

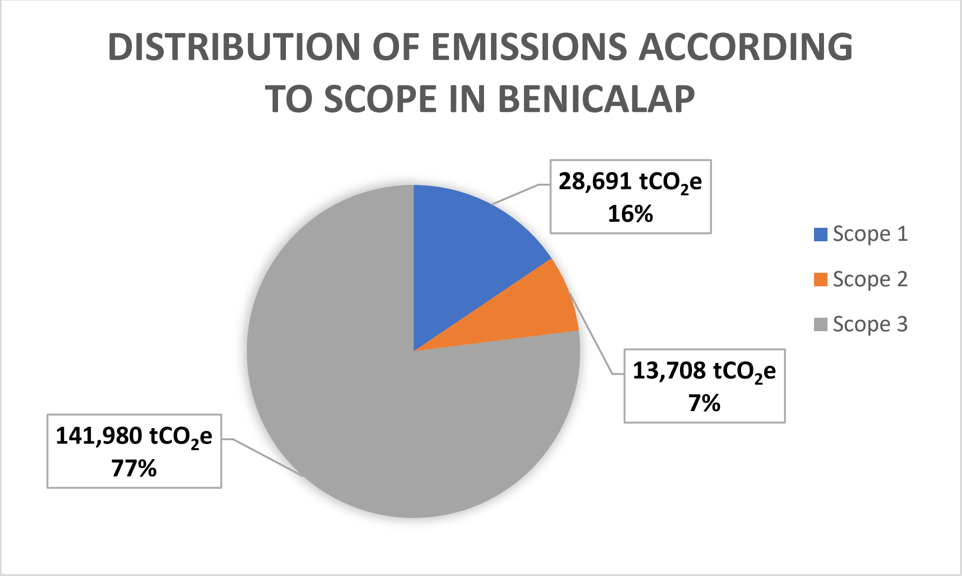


Figure 5.11 tCO_2e emissions distribution by scopes in Benicalap neighborhood **[6]**

It can be seen how most of the emissions come from Scope 3, since the consumption of goods belongs to it. As for Scope 1, fuel consumption from vehicles makes it the scope with the second highest CO_2 emissions. Finally, scope 2 is the least polluting of all. The total emissions from all scopes would be 184,379.32 tCO_2e. The estimated emissions per building would be 14.08 tCO2e.

5.2 Justification for the selection of this neighborhood and the applied measures

As previously mentioned, Benicalap is one of the neighborhoods with the greatest decarbonization potential due to its low potential for renewable energy resources and the high potential for improving the energy efficiency of buildings [6], [32]. From the social aspect considering the results of the surveys conducted on Fuel poverty as a percentage of total first residences [33], the Benicalap neighborhood is among the districts with the highest average rate of Fuel poverty. In addition, the results are related to median income, where Benicalap is also among those with the lowest median income [33].

These data have led to the demand for measures to improve the quality of life of the inhabitants at the neighborhood level.

Since the residential sector is the sector that offers the most representative data and where it is easier to implement measures due to its homogeneity, it has been decided to focus most of the measures on this sector.

The installation of residential heat pumps would result in a significant decrease in carbon emissions compared to general production methods, such as a conventional natural gas boiler [16]. Similarly, improvements in more efficient cooking equipment, such as induction stoves, resulting in lower net consumption and emissions savings. Similarly, the installation of solar photovoltaic panels on rooftops would mean a reduction in the amount of electricity taken from the grid and thus a reduction in CO_2 emissions [16], which, in turn, the system can cover much of the electricity demand from the replacement of conventional equipment with more efficient electrical equipment. If an energy storage system is added, the result would be even greater emissions savings and independence from the grid.

Another justification for the installation of heat pumps could be, as shown in Figure 5.11, that the highest electricity consumption in the Benicalap neighborhood occurs during the winter months, due to the great weight of heating during these months and the low passive thermal comfort provided by the old buildings in the neighborhood.

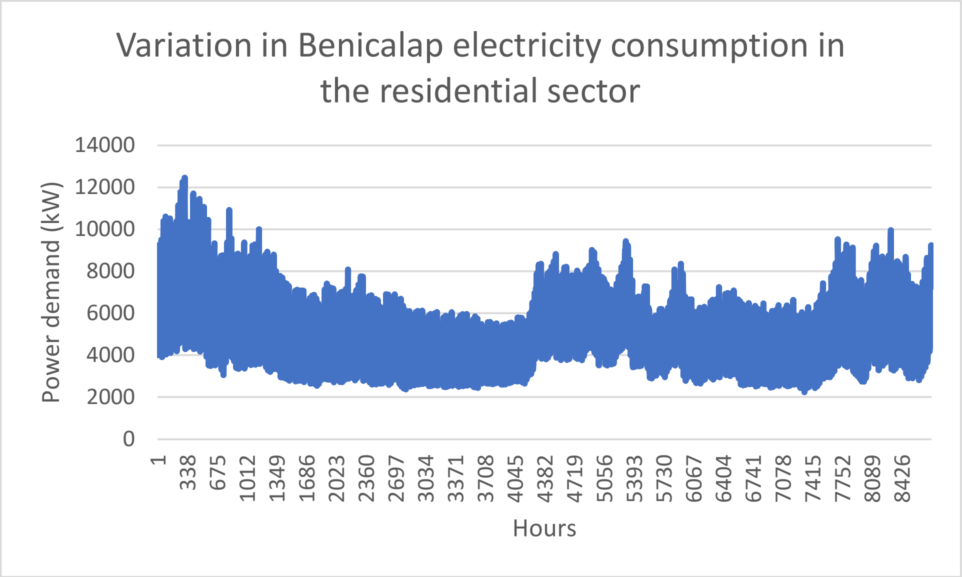


Figure 5.12 Variation in Benicalap electricity consumption in the residential sector in 2021

Another measure studied was the installation of biomass to cover thermal demand in the residential sector as a source of zero net emissions. However, in the “plan integral de fomento de la biomasa residual agrícola y forestal para uso térmico” [34] the agricultural and forestry resource in the district of Valencia is observed; and to satisfy the residential thermal demand of Benicalap it is necessary to consume about 1% of the annual biomass resource in the district and a storage site for the biomass resource. Faced with these drawbacks, it has been decided to bet on other lines to achieve carbon neutrality in the neighborhood of Benicalap.

5.3 Development of defined lines to achieve carbon neutrality

Based on the main objective of the project to achieve a carbon-neutral neighborhood and in the most quantifiable and realistic way possible, the best line of action developed is the electrification of the residential sector through the installation of more efficient electrical equipment in the residential sector (heat pumps and induction stoves), photovoltaic electricity generation and storage of this to cover the new total electricity demand.

5.3.1 Electrification of heating demand in the residential sector

The initial stage in the electrification of the heating demand involves determining the quantity of existing equipment within the Benicalap neighborhood's subsector, in order to proceed with its complete replacement. The subsequent table illustrates the equipment present in the subsector, subsequent to its full replacement.

Table 5.8 Current distribution of heating equipment in the residential sector of the Benicalap neighborhood

Heating equipment		
Conventional boiler	Biomass	0.46%
	Natural gas	18.75%
	Oil products	7.29%
	Coal	0.01%
Condensing boiler		0.99%
Reversible heat pump		17.99%
Radiator/electric convector		22.47%
Solar panels		0.05%
Underfloor heating		0.10%
Others	Natural Gas convectors and stoves	8.62%
	LPG stoves	10.92%
	Non-reversible heat pumps	0.13%
	Coal	1.81%
	Biomass burning	1.33%
	Portable electrical equipment	9.07%

It can be deduced that 48.82% of the equipment uses fossil fuels. Therefore, this equipment must be replaced to electrify the heating of the residential sector.

Applying the methodology explained in point 4.3, the following consumption for heating has been obtained:

Table 5.9 Current distribution of fuel consumption in heating of the residential sector in Benicalap neighborhood

Fuel source	***Heating (MWh)***
Oil products	5,602
Natural gas	10,104
Renewable resource	561
Coal	536
Electricity	12,773

These data represent an annual consumption of 29,576 MWh, of which 16,242 MWh correspond to fossil fuels, which means that more than half of the consumption coming from this sector emits a large amount of greenhouse gases.

Based on these consumption values and the efficiencies from table 12.4 in appendix D, it can be determined that the thermal demand for the Benicalap neighborhood is 43,070 MWh. Of the total heating demand, 41,692 MWh would be attributed to the set of buildings and the remainder to single-family homes, indicating a total of 40.87 MWh per building in the neighborhood and 2.27 for single dwellings. This demand will be covered using renewable reversible air-source heat pumps.

Replacing residential equipment with heat pumps is a good option for various technical reasons. Firstly, heat pumps are highly efficient systems that transfer heat from the environment instead of generating it, resulting in significant energy savings and reduced carbon emissions. This is achieved using refrigerants and compressor technology, which allows heat pumps to operate at high efficiencies even at low outdoor temperatures. Secondly, heat pumps provide both heating and cooling capabilities, making them a versatile option that can be used year-round, reducing the need for separate heating and cooling systems. Additionally, heat pumps are safer and more reliable than combustion-based systems, as they do not produce any harmful emissions or require flammable fuels. This also results in a lower risk of equipment failure and the need for regular maintenance. Finally, the installation of heat pumps can increase the value of a property and provide a healthier living environment for its occupants by maintaining comfortable and consistent indoor temperatures, reducing humidity levels, and improving indoor air quality.

However, not all heat pumps can meet the green objective set out for the study. To consider this measure as green, the following two points have been considered.

1. The chosen heat pump is considered renewable under European standards.
2. Most, if not all, of the electricity required by the heat pump will be from renewable sources.

For a heat pump to be considered of renewable origin, according to IDAE, it must have a Seasonal Performance Factor (SPF) estimate of greater than 2.5 [10]. For heating, the Seasonal Coefficient of Performance (SCOP) will be used. This efficiency estimates the energy that the heat pumps can provide to meet this demand, as this efficiency considers seasonal climatic variations throughout the year.

The heat pump chosen for implementation is the Vaillant aroTHERM plus heat pump commercial model 12. The choice of this heat pump is justified in section C of the annexes.

To meet the demand per building, 5 heat pumps will be used, and for single-family homes, only one unit will be required. The nominal power of each heat pump for this model is 12.

The air-to-water heat pump model has a SCOP of 6.48. Heat losses due to the transportation of hot fluid from the heat pump to heat emitters throughout a building are influenced by various factors, such as distance, pipe diameter, insulation, and fluid flow rate. To accurately calculate these losses, a detailed heat loss calculation is required for each building, considering size, shape, orientation, construction materials, and environmental conditions, as well as the heating requirements of each unit or zone. Despite this, a general percentage of heat transfer losses has been used, based on a study showing the percentage of days depending on temperature for a district heating system using a heat pump [35]. Annex C shows how the losses have been calculated for a building with climatic characteristics similar to those of Valencia. These losses were determined to be 14.2%, resulting in an overall heating performance of 5.56.

HP results for heating

Table 5.10 presents the comparison between the old annual consumption and the new annual consumption after the implementation of the heat pump measure in heating mode for the Benicalap neighborhood.

Table 5.10 New consumption and savings applying the HP measure in heating mode for residential sector in Benicalap neighborhood

	MWh/year
Old annual consumption	29,576.38
New annual consumption	7,746.63
Annual savings	-21,829.75

The results demonstrate a substantial decrease in energy consumption following the implementation of the heat pump measure, resulting in an approximate 73.80% reduction in energy consumption. By replacing all fossil fuel consumption and improving energy efficiency through the substitution of less efficient equipment with heat pumps, the mentioned reduction is achieved.

Here is a table that shows the results obtained when applying the heat pump measure in the Benicalap neighborhood, classified by type of property.

Table 5.11 Energy results of the heat pump measure in heating mode according to the type of property

	Building	**Single-family dwelling**
Old annual consumption (MWh/year)	29.00	1.56
New annual consumption (MWh/year)	7.59	0.41
Annual savings (MWh/year)	-21.40	-1.15

These results highlight the effectiveness of the implemented measure in achieving significant energy savings and promoting energy efficiency in both the building and single-family dwelling sectors.

From the environmental point of view, CO_2 emissions have been calculated considering the emission factors established in annex A. The small polluting value contributed by the natural refrigerant gas R290 has also been considered.

Table 5.12 CO_2 savings results applying the HP measure in heating mode for residential sector in Benicalap neighborhood

	tCO_2e/year
Old annual CO_2 emissions	5,758.40
New annual CO_2 emissions	1,332.43
Annual savings	-4,425.97

This represents a reduction of approximately 76.9% in heating CO2 emissions. These results demonstrate the significant positive impact of the implemented measures in reducing greenhouse gas emissions and contributing to environmental sustainability.

The environmental results for this sector, classified by type of property, are presented in Table 5.13.

Table 5.13 CO_2e savings results of the heat pump measure in heating mode according to the type of property

	Building	**Single-family dwelling**
Old annual CO_2 emissions (tCO_2e/year)	5.65	0.30
New annual CO_2 emissions (tCO_2e/year)	1.31	0.07
Annual savings (tCO_2e/year)	-4.34	-0.23

These results underscore the significant environmental benefits achieved by implementing the heat pump measure in heating mode for both buildings and single-family dwellings. The substantial reductions in CO2 emissions, approximately 76.86% for buildings.

5.3.2 Electrification of DHW demand in the residential sector

As done with heating, the first step to electrify the DHW demand is to determine which equipment uses fossil fuels for their subsequent replacement. This estimated distribution of the equipment used for DHW is shown in Table 5.14.

Table 5.14 Current distribution of DHW equipment in the residential sector in the Benicalap neighborhood

DHW equipment		
Conventional boiler	Biomass	0.09%
	Natural gas	29.02%
	Oil products	5.92%
Condensing boiler		1.42%
Electric water heater		24.65%
Natural gas wáter heater		36.82%
Solar panels		0.59%
Others	Renewable gases	0.50%
	Heat pump	1.00%

This translates to 73.2% of the equipment used to produce DHW is fueled by fossil fuels. As mentioned above, this fossil fuel-fired equipment will be replaced by the proposed heat pump.

Table 5.15 shows the distribution by energy source of residential consumption to meet DHW demand.

Table 5.15 Current distribution of fuel consumption in DHW of the residential sector in Benicalap neighborhood

Fuel source	***DHW (MWh)***
Oil products	766
Natural gas	13,041
Renewable resource	187
Coal	0
Electricity	3,592

The total annual energy consumption used in the Benicalap neighborhood is 17,586 MWh, of which 13,807 are from fossil fuels, indicating that around 78.51% of the energy consumed for hot water production uses polluting technologies.

Applying the efficiencies shown in Table 12.4 of Annex D, a demand of 20,763 MWh per year is obtained, which, when extrapolated by buildings, means an annual demand of 20.056 MWh per building and 1.09 MWh per single dwellings.

The average consumption of hot water in a household in Benicalap can vary depending on various factors such as the number of occupants, hot water usage habits, and the type of water heating system utilized. For our analysis, national average data will be used. According to IDAE, the average water consumption per person in a multi-family household is 22 liters per day, and in a single-family household, it is 30 liters per day [36].

To satisfy the hot water demand, the heat produced by the heat pumps will be used, then the installation will have the same power as in heating mode. In case of block of dwelling, the DHW demand will be 418 liters per building, which will require two hydraulic modules and two DHW accumulators. The uniSTOR VIH R/6B DHW accumulator [37] model has a capacity of up to 184 liters, and two units are sufficient to cover the daily demand even on the most demanding days for. This system has a SCOP of 5.63, which, including the previously mentioned losses, results in a SCOP of 4.83.

On the other hand, for single-family homes, about 30 liters of DHW per day are required. By using the same heat pump that covers the heating demand, enough energy will be generated to meet this demand as well. A small wall-mounted tank, the actoSTOR VIH CL 20 model, from the manufacturer Valliant with a capacity of up to 20 liters will be used to provide DHW in exceptional circumstances. The SCOP estimated for this technology will be of 4.24, including heat losses.

HP results for DHW

The table 5.16 displays the comparison between the old annual consumption and the new annual consumption after implementing the HP measure in DHW.

Table 5.16 New consumption and savings applying the HP measure in DHW for residential sector in Benicalap neighborhood

	MWh/year
Old annual consumption	17,586.00
New annual consumption	4,298.22
Annual savings	-13,287.78

These measures achieve an energy savings rate of approximately 75.56%. If these savings are extrapolated according to the type of property, the results would be as follows:

Table 5.17. Energetic results of the heat pump measure to produce DHW according to the type of property

	Building	**Single-family dwelling**
Old annual consumption (MWh/year)	17.24	0.93
New annual consumption (MWh/year)	4.21	0.23
Annual savings (MWh/year)	-13.03	-0.70

From the environmental point of view, CO_2 emissions have been calculated considering the emission factors established in annex A.

Table 5.18 CO_2 savings results applying the HP measure in DHW for residential sector in Benicalap neighborhood

	tCO_2e/year
Old annual CO_2 emissions	3,422.57
New annual CO_2 emissions	793.30
Annual savings	-2,683.27

This represents a reduction of approximately 78.4% in CO2 emissions. On the other hand, according to the type of property, the results would be as follows:

Table 5.19. CO_2e savings results of the heat pump measure to produce DHW according to the type of property

	Building	**Single-family dwelling**
Old annual CO_2 emissions (tCO_2e/year)	3.36	0.18
New annual CO_2 emissions (tCO_2e/year)	0.72	0.04
Annual savings (tCO_2e/year)	-2.63	-0.14

5.3.3 Electrification of cooling demand in the residential sector

The type of refrigeration technology and equipment used can significantly influence energy consumption and demand in the region. Therefore, it is crucial to promote responsible refrigeration practices that are energy-efficient to minimize the environmental impact and enhance energy sustainability. Although refrigeration has the lowest energy consumption within the residential subsectors, it is important to scrutinize this area because implementing energy-efficient measures is relatively straightforward in the residential sector.

Table 5.20 shows the distribution of equipment used to cool homes in the Benicalap neighborhood.

Table 5.20 Current distribution of refrigeration equipment in the residential sector of the Benicalap neighborhood

Cooling equipment	
Portable air conditioning	7.14%
Reversible heat pump	79.39%
Non-reversible heat pump	13.48%

As all equipment in this subsector uses electricity as its energy source, it can be classified as fully electrified. However, to achieve energy efficiency, it is recommended to replace old equipment with newer models that offer superior performance. In this case, all the equipment will be replaced by the proposed heat pump, which can cover the cooling demand as well, given that it is a reversible heat pump.

The Heat pump proposed can cover the cooling demand, using the same commercial model employed for heating and DHW, with the only difference being that this heat pump has a nominal power of 10 kW and SEER of 4.61 when operating in cooling mode.

The annual demand that needs to be met is 13,942 MWh, consisting of 13,496 MWh from buildings and 446.15 MWh from single-family homes. The annual demand per building is 13.231 MWh and per dwelling 0.73 MWh. The demand for energy is low due to the advanced technology employed in electric equipment used for refrigeration, which maximizes heat transfer and minimizes energy losses during the cooling process. These energy-efficient equipments are designed to provide greater cooling capacity with lower electricity consumption.

HP results for cooling

Table 5.21 presents the comparison between the old annual consumption and the new annual consumption after the implementation of the heat pump measure in cooling mode.

Table 5.21 New consumption and savings applying the HP measure in cooling mode for residential sector in Benicalap neighborhood

	MWh/year
Old annual consumption	4,637.00
New annual consumption	3,024.35
Annual savings	-1,612.65

This represents a notable energy savings rate of approximately 34.78%. Moreover, these energy savings by type of property are shown in Table 5.22.

Table 5.22 Energetic results of the heat pump measure in cooling mode according to the type of property

	Building	**Single-family dwelling**
Old annual consumption (MWh/year)	4.55	0.24
New annual consumption (MWh/year)	2.97	0.16
Annual savings (MWh/year)	-1.58	-0.08

From the environmental point of view, CO_2 emissions have been calculated considering the emission factors established in annex A.

Table 5.23 CO_2 savings results applying the HP measure in cooling mode for residential sector in Benicalap neighborhood

	tCO_2e/year
Old annual CO_2 emissions	520.20
New annual CO_2 emissions	797.56
Annual savings	-277.37

This implementation has resulted in annual savings of -277.37 tCO2e/year, which means an approximate reduction of 34.8% in CO2 emissions. While calculating these emissions savings for each type of property, the results would be as follows:

Table 5.24 CO_2e savings results of the heat pump measure in cooling mode according to the type of property

	Building	**Single-family dwelling**
Old annual CO_2 emissions (tCO_2e/year)	0.78	0.042
New annual CO_2 emissions (tCO_2e/year)	0.51	0.027
Annual savings (tCO_2e/year)	-0.27	-0.015

It is not as noticeable as the savings achieved for heating and DHW production, but it manages to reduce CO2 emissions, which is one of the main objectives of the implementation of heat pumps in this project.

5.3.4 Kitchen electrification in the residential sector

The first step in the development of this measure has been the quantification of the equipment installed in the kitchens of the Benicalp neighborhood, as has been done previously.

Table 5.25 Current distribution of kitchen equipment in the residential sector in the Benicalap neighborhood

Kitchen equipment		
Gas	Natural Gas	30.41%
	Oil products	20.08%
Electric ceramic hob		41.26%
Gas ceramic hob		1.22%
Induction stove		3.57%
Mixed (glass ceramic - induction)		0.32%
Firewood		0.02%
Mixed (gas-eléctric)	Natural Gas	0.58%
	Oil products	0.58%
	Electricity	1.16%

The table shows that 46.31% of the equipment uses electricity, 52.87% of the equipment uses fossil fuel as an energy resource and the remaining % uses biomass resources.

Based on the methodology explained above, the consumption in the kitchen subsector shown in table 5.26 has been obtained.

Table 5.26 Current distribution of fuel consumption in kitchen of the residential sector in Benicalap neighborhood

MWh	
Oil products	814
Natural gas	2,262
Renewable resource	48
Electricity	2,349

Observing a total consumption for this subsector of 5,473 MWh and Applying the efficiencies for each fossil fuel equipment shown in the table in Annex C, it has been obtained that the thermal demand satisfied by fossil fuels, in other words, that which is intended to be satisfied with electric energy equipment, would be 8,616 MWh for these two subsectors.

According to IDAE, the most efficient equipment in the kitchen would be gas stoves [38]. However, this data is from 2011 considering an energy mix of electricity production where fossil fuels predominate; also, in our case most of the energy will be generated by the PV system, that will be explained in the next section, and this will be self-consumed and will not have the losses equivalent to the cycle of transformation of gas to electricity and the distribution of this.

Having clarified this, induction cooktops have been chosen as the most efficient equipment to achieve carbon neutrality targets. According to IDAE, this system consumes 20% less electricity than conventional glass-ceramic hobs. Induction stoves heat food by generating magnetic fields faster and more efficient than conventional stoves.

Induction stoves results

As with the measure heat pumps, the main objective is to follow the same installation schedule. Basically, to progressively install induction stoves every year until the conventional gas stoves are completely replaced, which will simultaneously affect the annual demand. The assumed useful life for the development of the project for a conventional induction stove was 10 years. [39] and therefore, the replacement pattern will be the same as the installation pattern.

The energetic results have been shown in table 5.27 and 5.28.

Table 5.27 New consumption and savings applying the measure of induction stoves in the kitchens of the residential sector in Benicalap neighborhood

	MWh/year
Induction stove consumption	5,472.95
New annual consumption	3,836.91
Annual savings	-1,636.05

This measure shows a 29.89% reduction in consumption in this sector, which demonstrates the effectiveness of the induction stove and achieve the objective of electrifying the entire kitchen sector. On the other hand, the result of the implementation of this technology by type of property shows the following savings:

Table 5.28 Energy results of the induction stove measure in cooling mode according to the type of property

	Building	**Single-family dwelling**
Old annual consumption (MWh/year)	5.37	0.29
New annual consumption (MWh/year)	3.76	0.20
Annual savings (MWh/year)	-1.60	-0.09

The results reflect a significant change in energy consumption after transitioning from an induction stove to a different type of stove.

From an environmental point of view, the new CO_2 emissions, and savings from the substitution of fossil-fuel conventional stoves for induction stoves are shown in the following table:

Table 5.29 New emissions and savings applying induction stove measure in the kitchens of the residential sector in Benicalap neighborhood

	tCO_2
Induction stove CO_2 emissions	247.66
New annual CO_2 emissions	651.69
CO_2 saved per year	-407.45

Considering the old emissions, before the implementation of this measure, compared to the new ones, a reduction of -38.47% was obtained in the emissions of the cooking subsector. As with consumption savings by property type, the environmental results are as follows:

Table 5.30 CO_2e savings results of the induction stove measure according to the type of property

	Building	**Single-family dwelling**
Old annual CO_2 emissions (tCO_2e/year)	1.04	0.06
New annual CO_2 emissions (tCO_2e/year)	0.64	0.03
Annual savings (tCO_2e/year)	-0.40	-0.02

Both the building sector and single-family dwellings have significantly contributed to reducing their carbon footprint and working towards a greener future.

5.3.5 PV generation

Photovoltaic energy is predominantly employed as the primary form of energy generation due to its renewable nature, declining costs, modularity, accessibility, positive environmental impact, and ability to provide energy independence. These factors have driven its global adoption as a clean and sustainable energy source.

In this study, the main objective of photovoltaic energy is to fulfill the electricity demand of the Benicalap area. The installation of photovoltaic systems aims to provide a reliable and sustainable source of electricity specifically tailored to the needs of the Benicalap community. By harnessing solar power, photovoltaic panels will convert sunlight into electricity, directly supplying it to the local grid or storing it in batteries for later use. This localized generation of clean energy not only reduces dependence on traditional fossil fuel-based electricity but also contributes to a decrease in greenhouse gas emissions and the mitigation of climate change. By covering Benicalap electrical demand with photovoltaic energy, the study seeks to establish a resilient and environmentally friendly energy supply that aligns with sustainability and energy independence goals.

The system has been designed based on a reduction of 5.62% in the total electricity demand of the neighborhood, thanks to the effectiveness of heat pump measures and the use of induction cooking. The combination of these measures significantly contributes to the overall energy savings, allowing the photovoltaic system to cover a substantial portion of the reduced demand.

After the study carried out on the maximum installation capacity of photovoltaic panels on the useful surfaces of the roofs of the Benicalap neighborhood [6], it has been decided to install a capacity of 52.5 MW of photovoltaic energy with an inclination of 15º. This installation has entailed a cost of 56,700,000€ amortized over the 25-year useful life of the system.

The results of the photovoltaic system have been obtained through simulation using HOMER PRO software, considering the reduction in electricity consumption resulting from the installation of efficient technologies in the residential sector. The technical input variables for this study have been defined in Annex F.

Figure 5.13 represents the daily variation of PV power output in the Benicalap neighborhood. The graph shows that the highest production of photovoltaic energy occurs during the spring and summer months, attributed to the increased solar radiation in the region during that time of year. The longer daylight hours, intensified solar radiation, and favorable climatic conditions contribute to a greater amount of energy generated by the photovoltaic panels. Additionally, the peak hours of photovoltaic energy production typically occur around midday and early afternoon, generally between 10:00 AM and 4:00 PM. During this period, the sun is at its highest point in the sky, providing more intense and direct solar radiation onto the photovoltaic panels. These hours are considered to have the highest solar irradiation and consequently result in a greater production of photovoltaic energy.

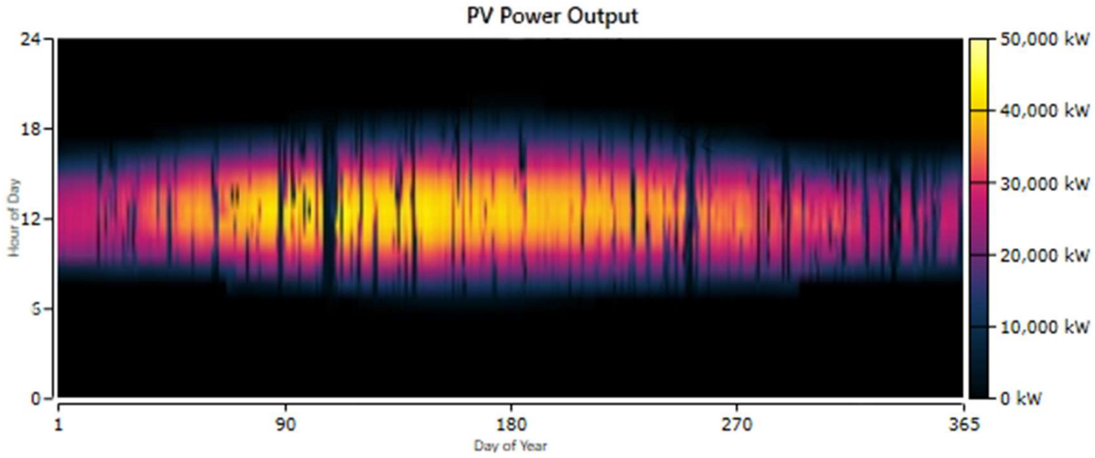


Figure 5.13 PV Daily Variation of Power Output of Benicalap neighborhood: Daily Variation

The following curves provide a comprehensive overview of the interplay between photovoltaic generation, energy consumption, grid interaction, and energy storage, thereby offering valuable insights into the energy system's performance and efficiency. Analyzing these curves allows us to identify patterns, trends, and optimize strategies for decision-making. It is worth mentioning that the simulated system includes residential battery systems installed in each building within the neighborhood, specifically 1020 batteries. Further details regarding this data will be explained in the subsequent section.

As previously discussed, the winter season is not the most favorable period for the photovoltaic system. Nevertheless, it is still capable of sufficiently meeting the electricity demand for the majority of the day. The system commences electricity generation around 7 AM and concludes around 5 PM. However, during the hours of 8 AM to 4 PM, it is able to cover the entire electricity demand at a 100% level, albeit with the assistance of the complementary battery system.

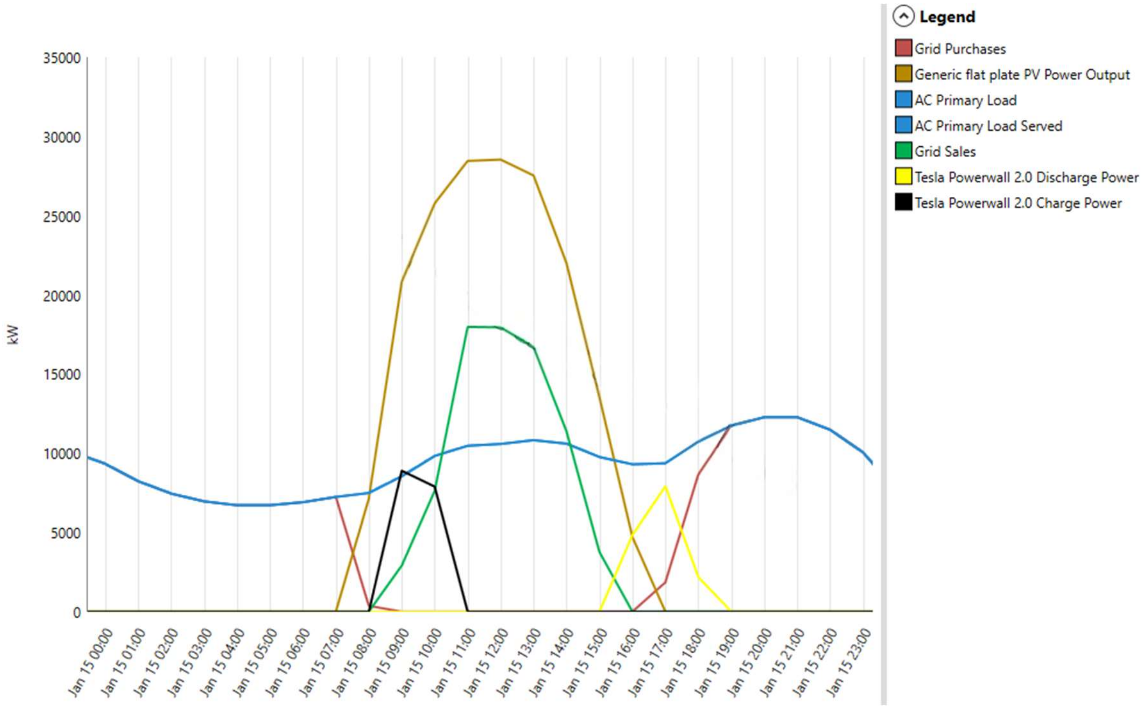


Figure 5.14 Power Generation Curve for Benicalap neighborhood on a January day: Simulation Results

On the other hand, as previously mentioned, the summer month stands out as having optimal conditions for energy generation. The system starts generating electricity from the early hours of the morning until around 7 PM, or slightly later. During this period, the electricity demand can be fully covered by the generation and storage system, typically between approximately 7 AM and 6 PM.

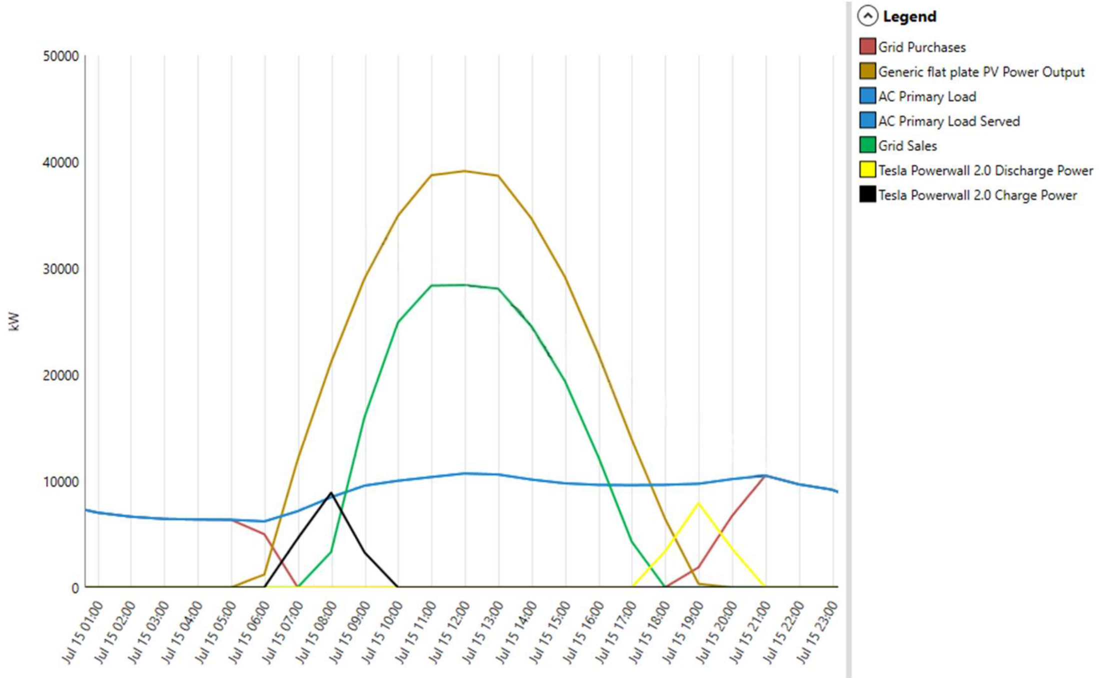


Figure 5.15 Power Generation Curve for Benicalap neighborhood on a July day: Simulation Results

The simulation conducted with the maximum installed power demonstrates a total annual production of 82,706 MWh. However, out of this total, only 34,483 MWh are utilized to meet the electricity demand and the remainder is sold to the grid. The capacity factor of the photovoltaic system in this scenario is approximately 18%, which is a common value observed in the Valencian Community for similar installations [40]. This level of generation implies that the photovoltaic system fulfills approximately 54.29% of the total electricity demand. The capacity factor indicates that the photovoltaic system operates for 4,079 hours per year, accounting for approximately 46.5% of the total hours in a year.

From an environmental standpoint, it is important to distinguish between the savings achieved through the installed capacity and the additional savings obtained by covering the electricity demand in the neighborhood.

The electricity generated to meet the neighborhood's electricity demand leads to a separate savings of 5,931.02 tCO_2 equivalent per year. These savings directly contribute to reducing emissions within the neighborhood.

The photovoltaic system's maximum installed capacity generates 82,706 MWh per year of emission-free electricity. This electricity is not derived from the energy mix, resulting in a total savings of 14,225.43 tCO_2, including the electricity that remains unused and is sold instead.

Installation applied to building

The calculation of the photovoltaic capacity in the Benicalap neighborhood's building blocks was derived from the peak power estimation of 6.17 kW. Through simulations presented in Table 12.13 in Annex F, an optimal option was determined based on the ratio of purchased electricity from the grid to electricity sold. Consequently, the decision was made to install a capacity of 14.8 kW for each building in order to maximize efficiency and minimize energy waste.

This would occupy an area of approximately 87.33 m². However, considering that the average available surface area is 388.88 m², the solar installation would only occupy around 22.5% of that surface area. This leaves enough space available for other equipment or purposes in the building. These calculations are based on the data and dimensioning performed in Annex F and demonstrate that there is sufficient surface area available for the installation of solar panels without compromising space for other equipment or unrelated purposes. This relationship between installed power and occupied surface area is crucial in determining the feasibility and efficiency of the solar installation in the building.

Figure 5.16 presents the same information as Figure 5.13 but applied specifically to the building. The time range, the months of peak utilization, and the total operating hours of the system are practically the same as those shown in the mentioned figure; the only difference is the generated power due to the installation of a lower capacity.

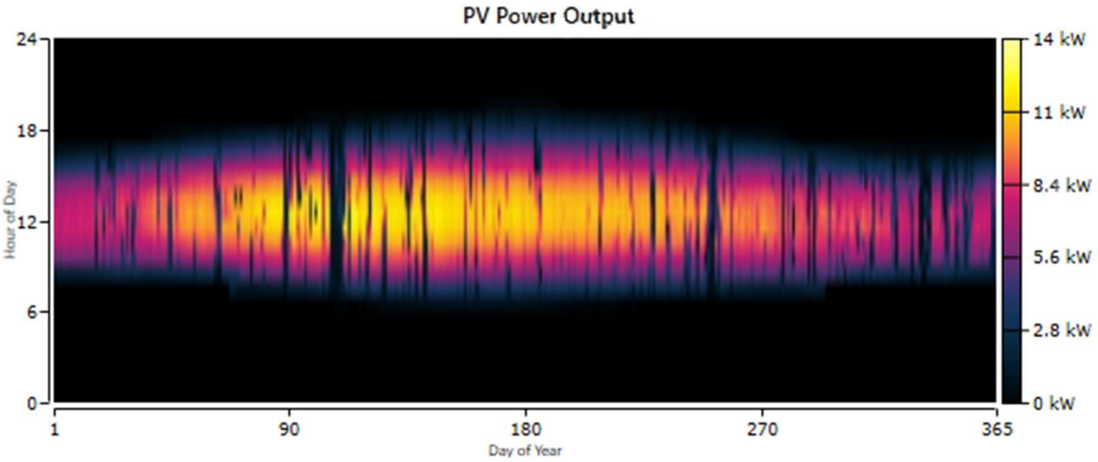


Figure 5.16 Daily Variation of Power Output in the Benicalap Neighborhood Building: Simulation Results

On the other hand, Figures 5.17 and 5.18 depict the generation curve of the PV system, illustrating the parameters related to the purchase and sale of electricity from the grid, as well as the storage system that will be implemented to meet the hourly demand. These figures provide a comprehensive overview of the system operation, showcasing the interplay between the PV generation, grid interactions, and energy storage, highlighting the balance between energy consumption and production throughout different time intervals.

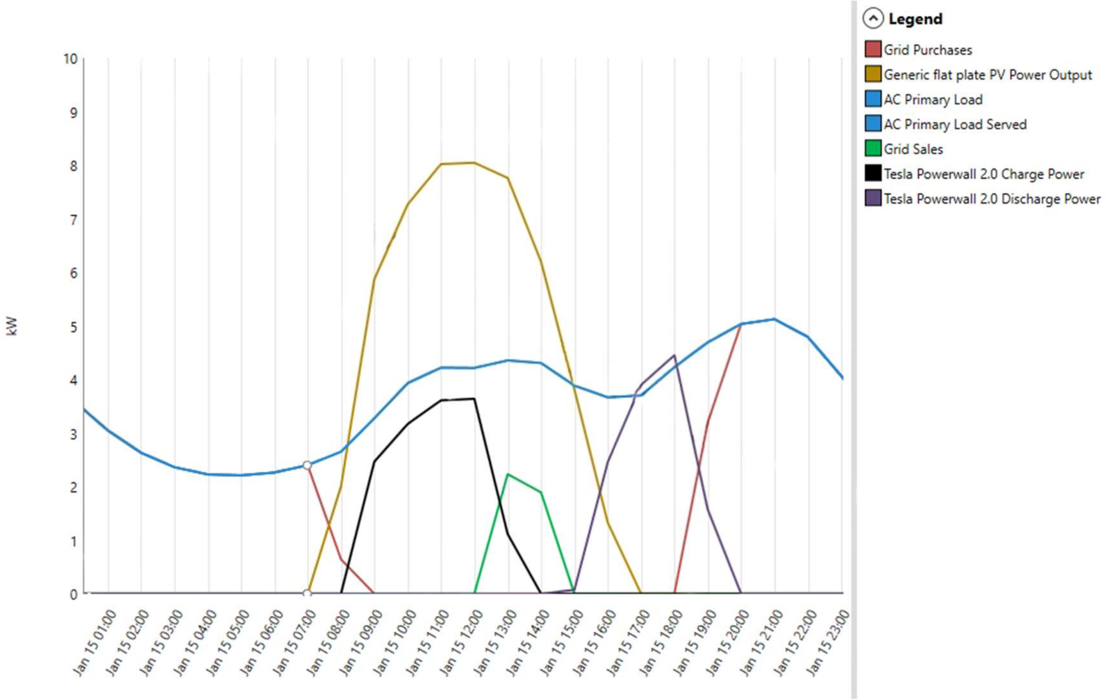


Figure 5.17 Power Generation Curve for Benicalap neighborhood building on a January day: Simulation Results

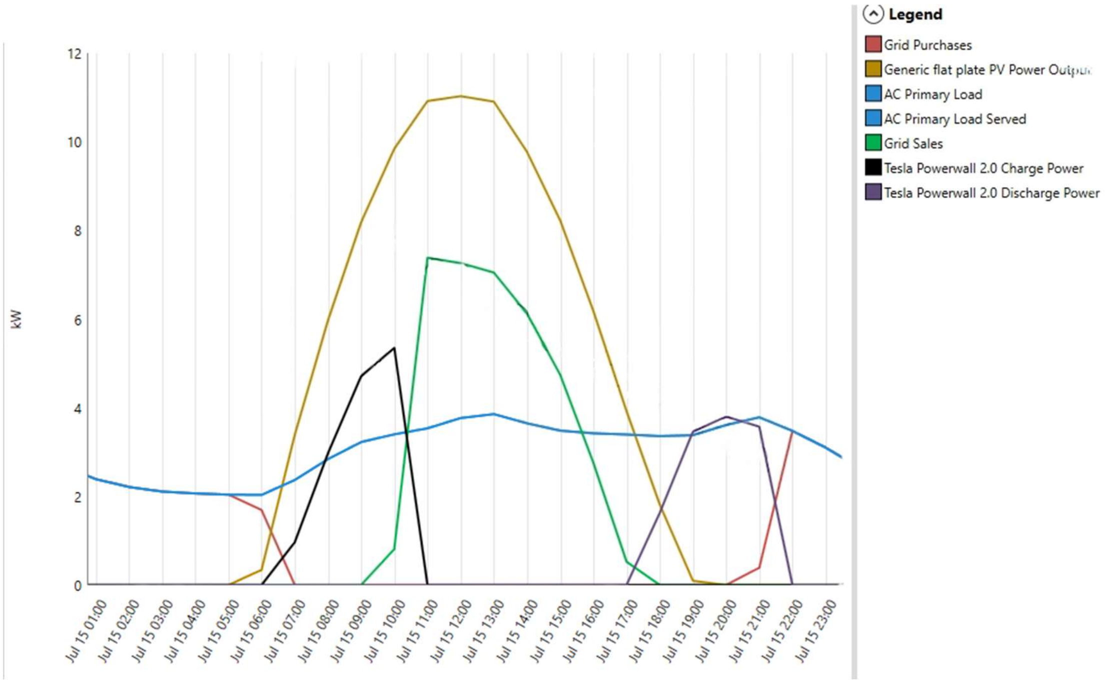


Figure 5.18 Power Generation Curve for Benicalap neighborhood building on a July day: Simulation Results

Overall, the photovoltaic system has the capacity to generate 23,315 kWh of electricity per building annually. Out of this, only 13,725 kWh are utilized to meet the energy demand of the building, while the remainder is either sold back to the grid or stored in the battery system. This means that the system is capable of covering approximately 60.7% of the total energy demand.

From an environmental perspective, the system results in savings of 2,360.70 kg of CO_2e emissions per year.

In economic terms, the photovoltaic installation will represent an investment of €15,984 and an annual O&M cost of €444.

5.3.6 Energy storage

Energy storage employing batteries helps us to achieve the objectives of decarbonization and maximize energy savings. The energy that will be stored will be the surplus energy from photovoltaic generation, so the consumption from the grid will be lower and a greater energy independence will be obtained in terms of electricity price variations.

As observed in figures 5.14, 5.15, 5.17 and 5.18; photovoltaic energy meets the majority of the electricity demand during production hours. However, outside of these hours when solar energy cannot be utilized, the electrical energy needs to be sourced from the grid. To mitigate this reliance on grid electricity and optimize the efficiency of the PV system, a battery system has been strategically designed. This battery system aims to minimize grid purchases and enhance the overall performance of the PV system, ensuring optimal utilization of renewable energy and reducing dependency on external power sources. The integration of a battery system allows for the storage of excess energy generated during peak production periods, which can then be utilized during non-production hours, enabling a more sustainable and self-sufficient energy supply for the system.

The implementation of the battery system aims to enhance the performance of the photovoltaic system within each residential building block. Following the power selection criteria outlined in Annex F, it has been determined that a 13.2 kWh battery will be installed in each building. This power capacity has been carefully chosen to align with the energy requirements and optimize the storage capabilities of each individual building. The installed battery system contributes a total of 4,227 kWh annually to the grid, signifying that this energy is being utilized to maximize the photovoltaic generation system, achieve energy and environmental savings, and reduce dependence on the grid.

Considering the installation of the selected 13.2 kWh model in each building, a total battery system with a nominal capacity of 13.46 MWh will be deployed in the neighborhood. This battery system is designed to have a useful life of 10 years, providing long-term energy storage capabilities. The investment cost associated with implementing this battery system amounts to 12,240,000 €.

Justification for the implementation of the battery system

The utilization of the PV system with a storage system, compared to the PV system without storage, indeed results in significant energy and environmental savings. However, it is important to note that in Section 8, a separate economic feasibility study has been conducted. While this study evaluates the financial aspects of the system implementation, it is secondary in importance compared to the primary objectives of achieving energy and environmental savings proposed in this study.

The comparison between using a battery system or not is presented in Table 5.31. This comparison has been made for the building block, since, as mentioned above, this measure is intended to be implemented in the residential sector.

The energy and environmental savings achieved with the implementation of a storage system reach up to 60.81%, whereas without a storage system, the savings would be 42.99%. This difference is a crucial factor in attaining the Sustainable Development Goals (SDGs), National Energy and Climate Plans (NECPs), and the goal of making the city of Valencia carbon neutral by 2030.

Table 5.31 Analysis of PV system performance in a residential building block: Comparison between system with and without storage

	Energy purchase (MWh/year)	***Energy savings (MWh/year)***	***tCO_2 eq produced/year***	***tCO_2 savings/year***
PV with storage system	8.854	-13.725	1.523	-2.361
PV without storage system	12.869	-9.710	2.214	-1.670

The percentage of independence from the grid or the part of the installation that covers the demand of the neighborhood with the battery system would correspond to 72.5%; While without using any storage system this percentage would be reduced to 64.4%. This means a more independent system from the grid and an optimization of the photovoltaic system.

From a renewable energy perspective, the inclusion of the battery system has been studied and found to contribute to a higher renewable energy factor. Specifically, it increases the renewable energy factor from 59.8% to 66.6%. This improvement signifies a significant increase in the proportion of renewable energy utilized within the overall energy mix of the system.

Battery operating state

For the simulation, a working regime of the battery system has been established to meet the established energy and environmental criteria.

1. Charge only with the surplus from the PV system, with no load from the grid.
2. Discharge when the photovoltaic system cannot supply the electric demand.

Without these basic parameters the system considers economic criteria, and the system may no longer be viable to meet the project objectives.

Figure 5.19 show the state of charge and discharge of the battery, under the previously mentioned criteria. These figures show how the system only charges when there is a surplus of photovoltaic energy and begins to discharge when the photovoltaic system is not able to supply the demand on its own.

It is also observed that the battery system is more efficient during the summer months since in this season there are more hours of solar radiation, as shown in figure 12.4 of Annex E. More hours of solar radiation mean more photovoltaic energy production in periods of higher demand and the battery system can be extended for a longer period, which means less consumption from the grid with the corresponding energy and environmental savings. In turn, it is also economically more profitable in these months because the battery system covers the electricity demand during more hours when the price of electricity is at its peak.

The relationship between the above information and the state of charge of the battery can be visualized more clearly in the following image. The image depicts the battery state of charge for the building. It shows that the highest state of charge is reached between 12 and 18 hours, indicating that the battery is being charged during that period. Furthermore, it is evident that during months with higher radiation, such as May and June, the battery is charged more frequently. Conversely, during December and January, which are months with lower radiation, the battery is more frequently discharged.

Figure 5.19 Annual variation of the state of charge of the battery system for Benicalap neighborhood building: Simulation Results

6 Results and analysis

First, the impact of the measures on the residential sector was analyzed, followed by an analysis of all the measures at the overall level of the neighborhood.

Residential sector results

The heat pump has replaced all the equipment installed for heating, DHW, and cooling production. Table 6.1 shows the representation of heat pumps, both reversible and non-reversible, among the installed equipment.

Table 6.1. Percentage of Heat Pump Integration Before and After Measure Implementation

	Before measure implementation	*After measure implementation*
HP% in Heating equipment	18.12%	100%
HP% in DHW equipment	1%	100%
HP% in Cooling equipment	92.87%	100%

On the other hand, there has been a new distribution within the kitchen subsector, which has resulted in the replacement of conventional stoves with induction cooktops. This new distribution can be observed in Table 6.2.

Table 6.2 New distribution of kitchen equipment in Benicalap neighborhood

KITCHEN EQUIPMENT	
Electric ceramic hob	41.26%
Induction cooktop	57.60%
Mixed (glass ceramic - induction)	0.32%
Firewood	0.02%

The installation of induction-only stoves in Benicalap homes has increased from 3.57% to 57.60%. This replacement signifies the complete electrification of equipment within the kitchen subsector.

Furthermore, within the residential sector, there has been a notable shift in energy consumption. The current consumption stands at 41,444 MWh, reflecting a significant saving of -38,098 MWh compared to pre-measure implementation levels. The updated distribution can be visually observed in the accompanying figure.

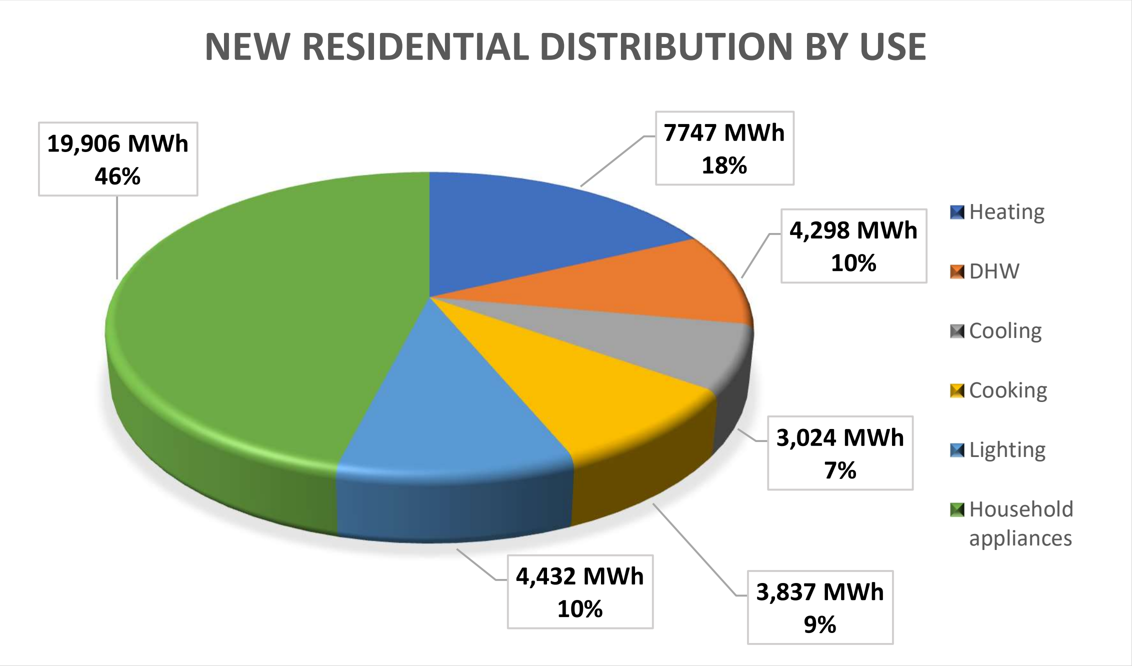


Figure 6.1 New residential consumption by use after implementation of the measures.

After eliminating all consumption of fossil fuels and less efficiency energy consumption, only electricity consumption would remain.

The implementation of a photovoltaic system along with a battery system has enabled more efficient coverage of energy demand, maximizing the utilization of solar energy and providing backup in case of disruptions in the power supply.

The graph 6.2 illustrates the monthly energy production, distinguishing between the contributions from the photovoltaic system and the grid. This graph provides a visual representation of the monthly energy production in the context of the Benicalap neighborhood building. It is evident that the predominant source of energy generation is the photovoltaic system, apart from December when grid electricity consumption marginally exceeds it. As previously mentioned, the photovoltaic system accounts for 72.5% of the overall production.

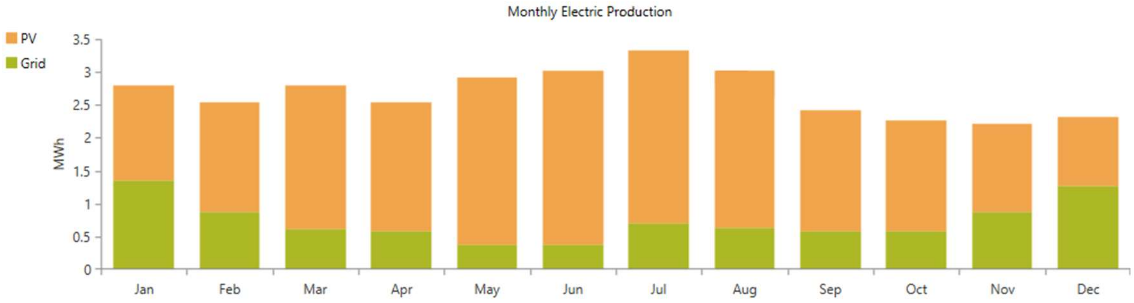


Figure 6.2 Monthly residential neighborhood building electric production by energy generation method: Simulation results

Figures 6.3 and 6.4 show a direct relationship representing the network dependence of the building. The figures reveal that the majority of electricity sales occur during hours with solar resource availability. Specifically, the months from April to June exhibit higher sales volumes, indicating reduced reliance on grid electricity purchases. In contrast, during the winter months, the photovoltaic system operates with lower efficiency, resulting in increased grid electricity purchases.

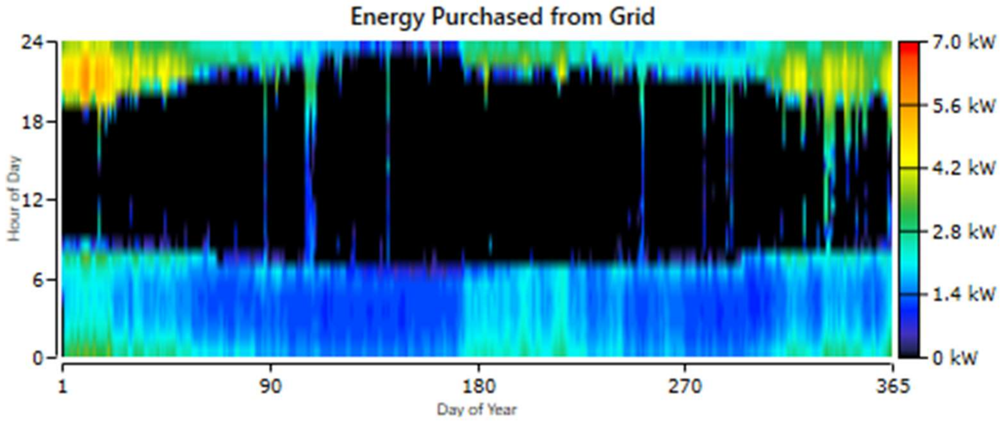


Figure 6.3 Residential neighborhood building energy purchased from grid: Simulation results

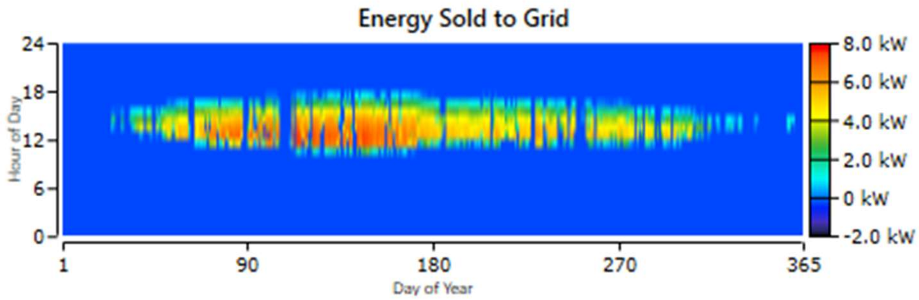


Figure 6.4 Residential neighborhood building energy sold to grid: Simulation results

Table 6.3 provides a summary of the annual savings achieved in the Benicalap neighborhood building through the implementation of various measures. These results highlight the effectiveness of the implemented measures in achieving substantial energy savings and emissions reductions in the Benicalap neighborhood building.

Table 6.3 Residential annual savings summary for Benicalap neighborhood building

Measure	**Annual energy savings (MWh/year)**	**Total emissions savings (tCO_2e/year)**
Heat Pump	-36.01	-7.24
Induction Stove	-1.6	-0.4
PV generation with batteries storage	-13.73	-2.36
TOTAL	***-51.34***	***-10.00***

The Heat Pump exhibits the highest energy savings and emissions reductions in the Benicalap neighborhood building. This is because it replaces fossil fuel-based technologies that are less efficient and more polluting. Furthermore, this measure encompasses sectors with higher energy demands in the neighborhood, resulting in greater overall savings.

On the other hand, PV generation with battery storage achieves considerable savings, even though it might be assumed to only save on electricity consumption. In this case, the ratio is 1:1, meaning that the energy produced by the PV system is directly utilized, resulting in significant energy savings. Moreover, in terms of emissions, this measure also contributes to lower emissions savings due to the lower emission factor of the generated electricity.

In contrast, the Induction Stove is specifically targeted for the cooking sector, which represents a small subsector, accounting for only 6.87% of the total energy consumption in the residential sector. While the Induction Stove is one of the most efficient technologies available for cooking, it falls behind Heat Pumps in terms of the efficiency ratio. As a result, the energy savings achieved with the Induction Stove are relatively smaller compared to the other two proposed measures. However, it is important to note that this does not mean the Induction Stove is an inefficient measure. On the contrary, it successfully electrifies the cooking sector with one of the most efficient and environmentally friendly technologies available.

In summary, the Heat Pump and PV generation with battery storage demonstrate the highest energy savings and emissions reductions in the Benicalap neighborhood building, mainly due to their wider application and more efficient performance. These results demonstrate the positive impact of each measure in terms of energy savings and emissions reduction, providing valuable insights into the effectiveness of implemented actions within the residential sector.

Results at neighborhood level

The successful implementation of measures involving heat pumps and induction cooktops has resulted in an annual decline in electricity annual demand by -4,335 MWh, representing a reduction of 5.63%. This annual decrease has been accounted for in the 25-year simulation, as detailed in the annexes. The resultant changes in electricity consumption distribution are summarized in the following table.

Table 6.4 New Benicalap electricity consumption after implementation of all measures

Electricity consumption by sectors (MWh/year)			
Residential	Industry	Services	Total
41,270	1,136	30,344	72,750

Due to the photovoltaic system and the battery system, it can be seen in the figure 6.6 that the hours where most purchases occur is from 24h. In the winter months, purchases are made from 9 pm to approximately 8 am, while in the summer, electricity is usually purchased only in the early morning hours. Being the purchases of greater intensity in the last hours of the night that is when the photovoltaic system does not produce, and the batteries are discharged. In addition, throughout the year there are occasional purchases on certain days, this is because the photovoltaic system does not generate energy due to climatic factors that prevent the incidence of solar radiation on the panels.

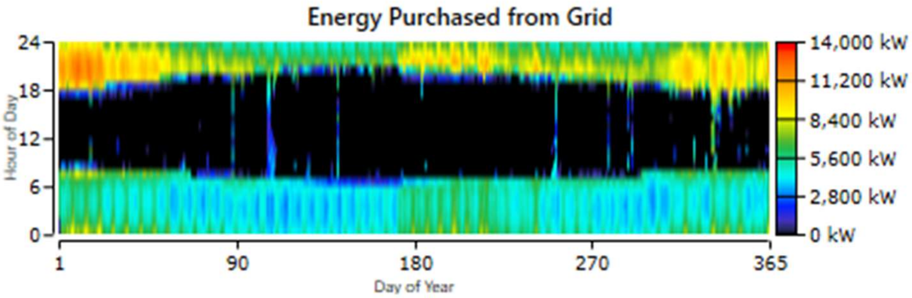


Figure 6.5 Energy purchased from the grid after implementation of all measures: Simulation Results

The energy purchase schedule coincides inversely with the energy sold, with sales occurring mostly during peak PV production hours.

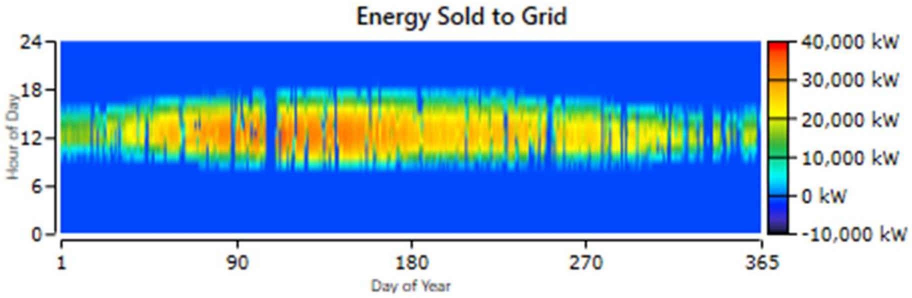


Figure 6.6 Energy purchased from the grid after implementation of all measures: Simulation Results

Similarly to Figure 6.2, which focuses on the residential building example, Figure 6.7 illustrates the contributions from the photovoltaic system and the grid to the overall electricity production of the neighborhood. In this case, we observe that 74.2% of the total electricity production comes from the photovoltaic system. However, out of this 74.2%, only 54.30% is utilized to meet the electricity demand of the neighborhood. The remaining electricity demand is covered by the grid.

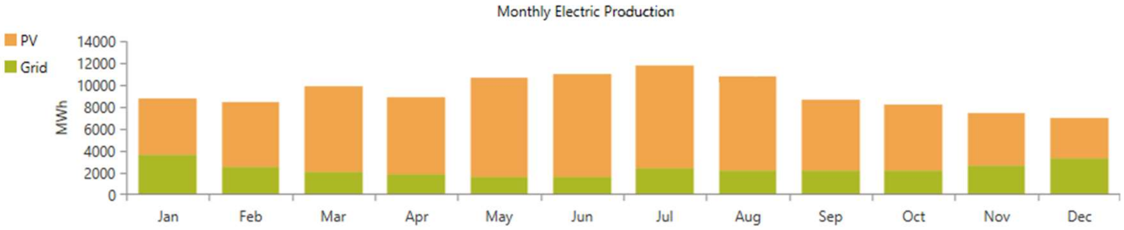


Figure 6.7 Monthly electric production after implementation of all measures by energy generation method: Simulation results

Table 6.5 summarizes the annual energy savings achieved through the implementation of various measures to meet the electricity demand of the neighborhood. Consistent with the results observed in the residential building of the neighborhood, the Heat Pump demonstrates the highest energy savings, followed closely by PV generation with batteries storage. On the other hand, the Induction stove shows a relatively lower energy savings compared to the other two measures.

Table 6.5 Summarized results of annual savings with the implementation of measures

Measure	Annual energy savings (MWh)	Total emissions savings (tCO_2e)
Heat Pump	-36,730.18	-7,386.61
Induction stove	-1,636.05	-407.45
PV generation with batteries storage	-34,482.70	-5,931.02

The Heat Pump stands out as the most effective measure for achieving energy savings and reducing emissions. Although this measure is specifically targeted for the residential sector, it yields the highest savings. This is because it replaces less efficient and more polluting technologies, resulting in significant overall energy savings and emissions reduction. If the comparison of emissions emission unit savings is made, the most effective measure would be the heat pumps because fossil fuels with a higher emission factor are replaced by electricity with a lower emission factor.

PV generation with battery storage achieves significant energy savings and emissions reductions by directly utilizing the generated energy. The incorporation of batteries enables the storage of excess energy, primarily in the residential sector, which can be utilized during periods of low production or high demand. This optimizes self-consumption and reduces reliance on grid electricity, leading to efficient energy utilization and decreased emissions. However, it's important to note that the reduction in emissions occurs on a one-to-one basis, as there is no change in the energy source, resulting in comparatively lower savings compared to the heat pump technology.

As mentioned earlier, if the savings from the electricity sold back to the grid were considered, it would be the measure with the highest savings. However, it is not reasonable to compare it directly because this electricity is not utilized to meet the neighborhood's demand. Instead, it would be used to offset electricity generation in other parts of the national grid, contributing to national savings but not to local savings within the neighborhood, which is the primary focus of this study.

Finally, the Induction Stove, despite being an efficient cooking technology, achieves relatively smaller energy savings compared to the other measures. This is mainly because its application is limited to the cooking subsector, which represents a smaller portion of the overall energy consumption in the residential sector. However, it continues to make a significant contribution to electrifying and improving efficiency.

The table provides an overview of the environmental savings achieved in various areas, based on the classification of emissions as defined in the previous state of the art.

Table 6.6 Summarized results of CO2 savings classified by scope

	SCOPE 1 (tCO_2e)	**SCOPE 2 (tCO_2e)**
Heat Pump	-6,366.19	-1,020.42
Induction stove	-407.45	
PV generation with batteries storage		-5,931.02

The final comparison between the evolution of the measures over the time of the project will be made in the following section.

7 ENERGY AND CO_2 ASSESSMENT: INITIAL VS FINAL STATE

The initial data have been expressed in point 5.1; therefore, these data have been used as year 0 or starting year. From this year onwards, the measures explained above have been developed from 2024 onwards, with the following implementation schedule:

Table 7.1 Timeline of the implementation of the measures

	Residential measures	PV	BATTERIES
2024	5%	40%	40%
2025	20%	50%	50%
2026	30%	60%	60%
2027	40%	70%	70%
2028	60%	80%	80%
2029	80%	90%	90%
2030	100%	100%	100%

This distribution suggests a gradual and progressive plan for implementing measures over several years. The ascending progression in the percentage of implemented measures reflects a strategic approach that allows for a smoother transition and gradual adaptation for both homeowners and the responsible authorities implementing these measures. As the years progress, there is an observed gradual increase in the implementation of measures. This can be attributed to a heightened awareness of the importance of these actions, as well as the experience gained during their initial implementation. As knowledge is acquired and challenges are overcome, it becomes increasingly feasible and efficient to implement a higher percentage of residential measures.

The goal is to achieve complete implementation of all planned measures by 2030, which implies that 100% of the actions will have been carried out by that year. This objective indicates a firm commitment and a determined approach to addressing challenges and opportunities in the residential sector within a defined timeframe.

The main concept is to leverage the existing photovoltaic installation and battery system's inertia in the initial years of implementing residential measures, allowing them to fulfill the electricity demand they require. This approach involves maintaining the previously proposed installation plan. Subsequently, residential measures will be gradually introduced to ensure that the PV and battery system can adequately meet the associated electricity demand. During these initial years, the implementation rate of residential measures is intentionally low, as the transition is expected to be progressive, allowing citizens sufficient time to replace conventional equipment. In contrast, the photovoltaic and storage system typically remains in place without replacement by other electricity generation equipment, and thus, its transition is distinct from household equipment.

Following the previous timeline, an energy and CO_2 analysis will be made at this point to account for the different data during these years, until full implementation in 2030.

7.1 Energy assessment

The progressive substitution of residential equipment has resulted in a decline in electricity and fossil fuel consumption. The electricity consumption trend exhibits a nearly linear distribution, whereas the decline in fossil fuel consumption has been more pronounced, particularly in recent years due to the increased replacement of fossil fuel-based equipment. The inherent inefficiency of these equipment compared to their electric counterparts has contributed to this decline.

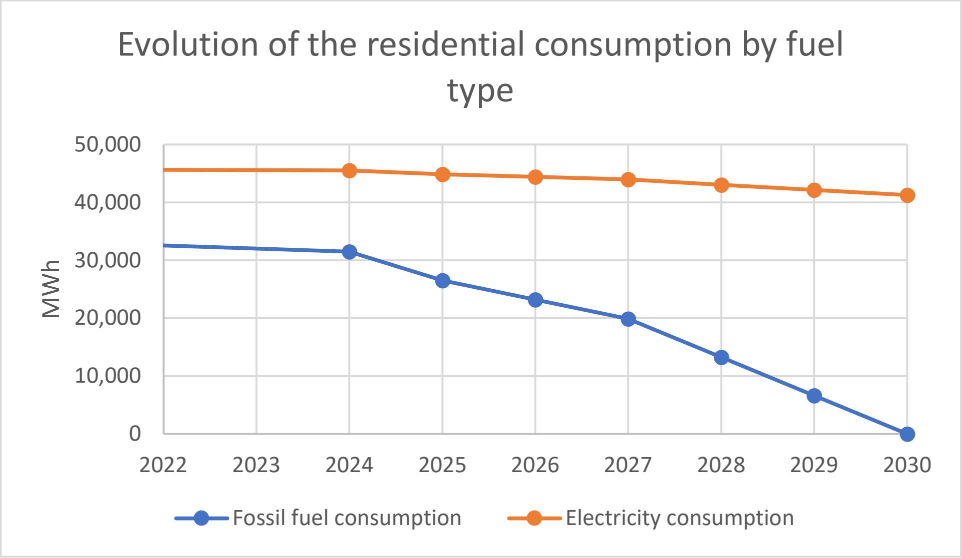


Figure 7.1 Evolution of new residential consumption by fuel type

The evolution of the trends in electricity and fossil fuels up to the total extinction of fossil fuel consumption in the residential sector can be extracted from the previous figure. These variations over time can be seen in Table 7.2, where in recent years the trend of switching from fossil fuel consumption to electricity has grown the most.

Table 7.2 Variation in consumption with respect to the initial situation

	Fossil fuel	Electricity
2025	-20.00%	-1.94%
2028	-60.00%	-5.83%
2030	-100.00%	-9.72%

The final consumption of the residential sector over the years can be seen in the following graph, showing a reduction in final consumption over the years, as fossil fuels have been replaced in their entirety by electricity. This is due to the installation of heat pumps and induction stoves that are more efficient than equipment that consumes fossil fuels, resulting in a reduction in final consumption.

Total consumption is reduced year after year, reaching a reduction of up to 48.2% in 2030 compared to the initial situation. As shown in Figure 7.2, the consumption in lighting and household appliances remains constant as no measures have been taken to reduce consumption in this area. Based on the analysis, it can be inferred that there is a consistent overall trend of energy consumption reduction across all categories, except for the one mentioned earlier.

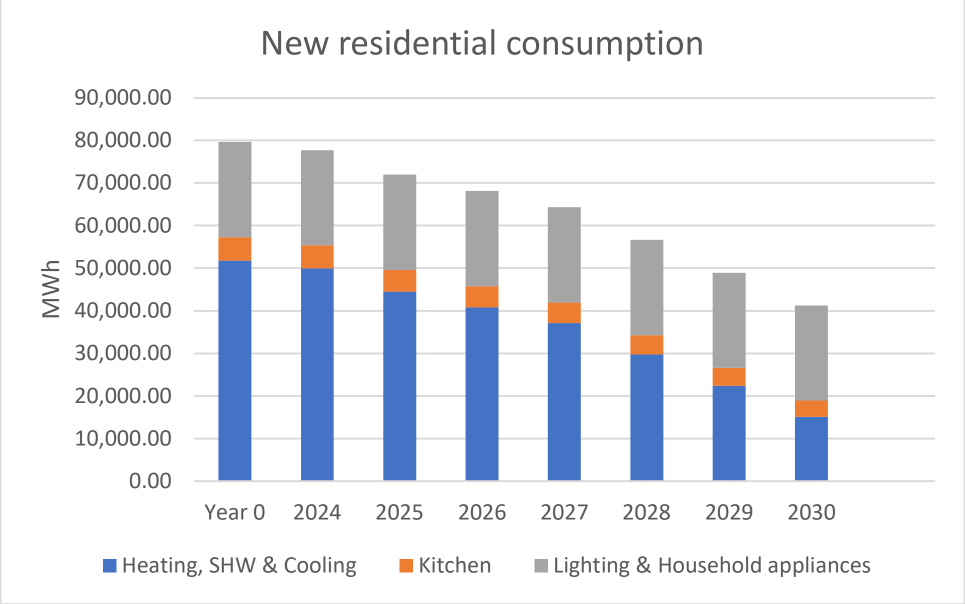


Figure 7.2 Comparison of the evolution of new residential final consumption by subsectors considering initial situation

The successful implementation of energy efficiency measures, as shown in Figure 7.3, has resulted in a reduction of total electricity consumption throughout the neighborhood. Despite being focused on electrification, these measures have managed to decrease the demand due to improved efficiency. Strategically designed, these measures aim to enhance energy efficiency and minimize waste across various sectors. The figure serves as evidence of this positive trend, clearly demonstrating a decline in electricity consumption. This decrease can be attributed to the effective implementation of energy efficiency measures, which have successfully curbed unnecessary energy usage and promoted sustainable practices throughout the neighborhood.

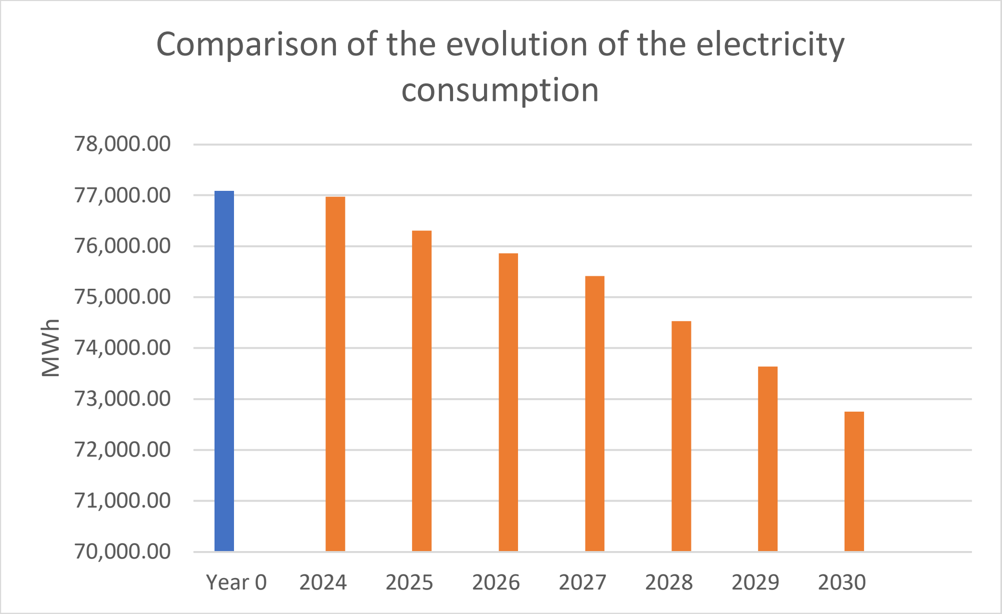


Figure 7.3 Comparison of the evolution of new final consumption considering initial situation

According to Table 7.3, which depicts the consumption changes leading up to the complete implementation of measures by 2030, it is clear that the heat pump yields the greatest savings, followed by the PV & Storage system. The table illustrates how energy savings are achieved through the adoption of more efficient technologies like heat pumps and induction stoves, as well as the generation of renewable energy using solar panels and storage. The increasing total savings over time reflect a growing emphasis on energy efficiency and renewable energy generation.

It is worth mentioning that the savings trend of the photovoltaic and battery system does not grow exponentially. This is because once a specific installed capacity is achieved, the trend stabilizes by meeting the overall electricity demand of the neighborhood and generating a higher volume of surplus energy, which is then sold. While this would result in a reduction at the national level, its impact at the local level would be relatively lower. However, this demonstrates that the photovoltaic system is capable of meeting future increases in electricity demand, showcasing its scalability for future needs.

Table 7.3 Variation in consumption savings by measure

Measure	**2025 (MWh)**	**2028 (MWh)**	**2030 (MWh)**
Heat Pump	-7,346.04	-22,038.11	-36,730.18
Induction stove	-327.21	-981.63	-1,636.05
PV & storage	-29,746.79	-33,295.97	-34,482.70
TOTAL	***-37,420.04***	***-56,315.71***	***-72,848.93***

For practical purposes, the best way to observe the impact of each measure over time is to perform an energy balance considering the initial situation.

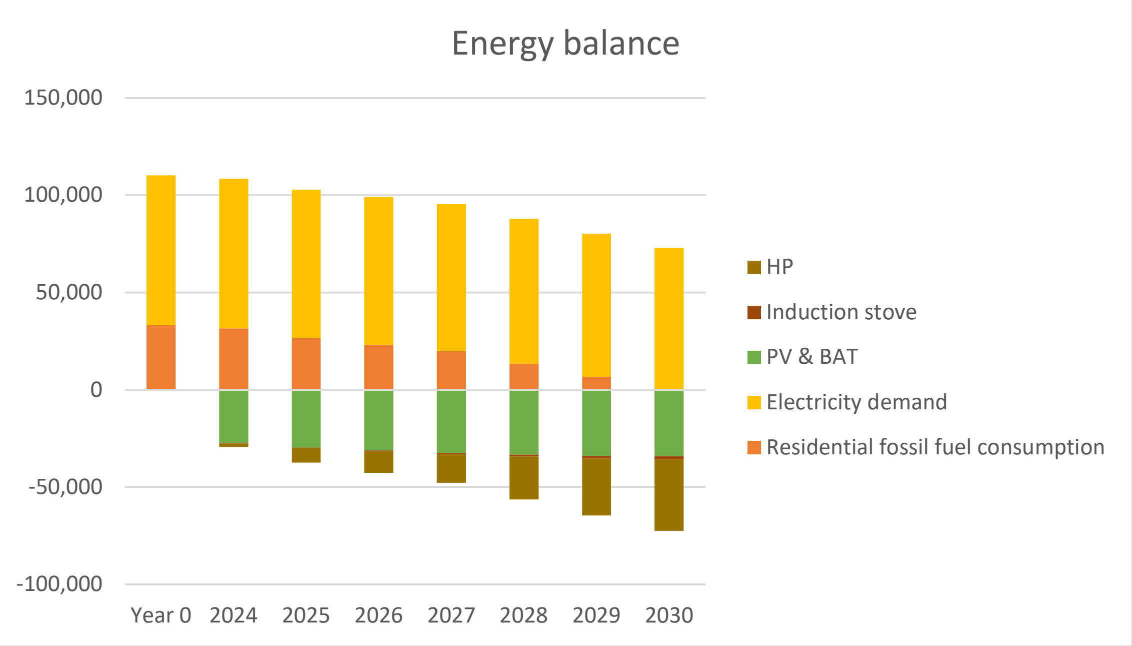


Figure 7.4 Energy balance considering initial situation and measures savings

The comparison between the heat pump, induction stove, and batteries is not direct because they are not electricity generating systems. However, the savings achieved through the implementation of these systems result in energy that does not need to be generated by the PV system or consumed directly from the grid. Additionally, it is important to consider the electrical decrement involved in the installation of heat pumps and induction stoves. Therefore, it is sensible to evaluate the savings obtained and the energy required for operating this equipment in order to establish a relationship and facilitate a quick and effective comparison.

The combination of heat pumps and induction stoves has enabled the complete elimination of fossil fuel consumption in the residential sector by 2030. This achievement not only has a positive impact on reducing carbon emissions and other pollutants but also enhances energy security by eliminating dependence on fossil fuel sources.

In terms of percentage savings over the years, the most effective measure in terms of energy savings is the PV & BAT technology (solar panels and storage). This technology consistently achieves increasing savings. The heat pump also demonstrates high energy savings over the years, surpassing the savings of the photovoltaic system with batteries in 2030. However, the induction stove exhibits relatively lower savings compared to the other two technologies, mainly due to its limited scope. It is important to consider that the effectiveness of the photovoltaic measure has decreased over time due to the implementation of other energy-saving measures. As a result, electricity consumption has been reduced, which means that generating the same amount of electricity through photovoltaic systems leads to lower savings.

It is important to note that the electricity generation from the photovoltaic system, combined with the savings achieved through various measures, results in a positive energy balance, even when considering the chosen meteorological data. However, this analysis assumes that 100% of the measures are installed.

Overall, the contribution of these measures is consistently positive and aligns with the achievement of Sustainable Development Goals (SDGs) and other government plans.

Finally, a study will be carried out in section 8 of this project on the synergy of the complementary measures [6] carried out for the Benicalap neighborhood and how they can jointly help to achieve energy neutrality.

7.2 CO_2 assessment

As with the evolution of consumption, the representative evolution of CO2 emissions from electricity consumption is similar to a straight line, while CO2 emissions from fossil fuels are even more exaggerated than in the case of consumption, showing a drastic reduction in emissions when incorporating measures in the residential sector.

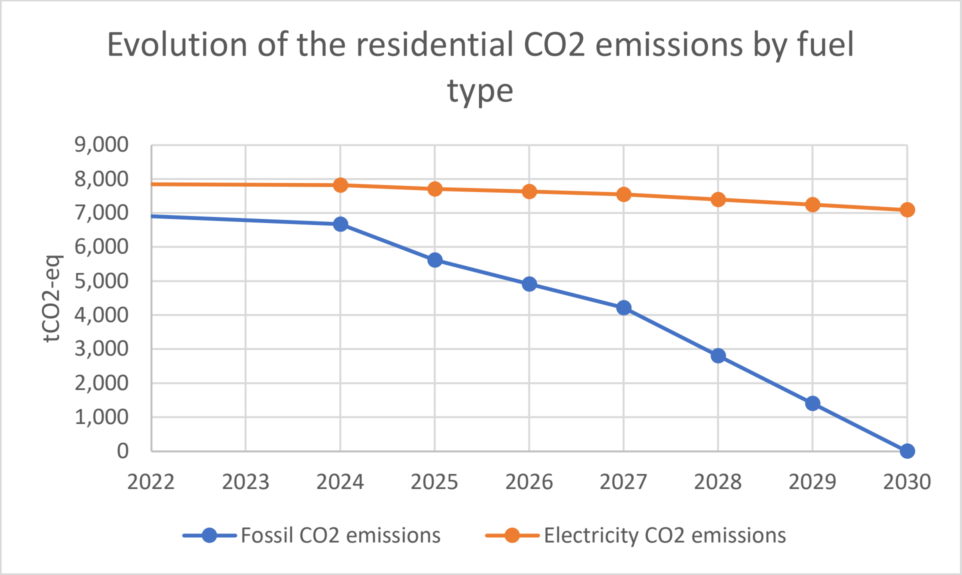


Figure 7.5 Comparison of the evolution of new residential final CO_2 by fuel type

From the perspective of the variation compared to the initial situation, the reduction trend in fossil CO2 emissions is significantly greater than the increase in electric CO2 emissions. The overall summary is that the table demonstrates a progressive decrease in fossil fuel consumption and a reduction in electricity consumption over the years 2025, 2028, and 2030. These changes reflect a transition towards cleaner and renewable energy sources, as well as a focus on energy efficiency. By 2030, complete elimination of fossil fuel consumption and total electrification of the sector is achieved, thanks to the implementation of technologies such as heat pumps and induction stoves.

Table 7.4 Variation in CO2 emissions with respect to the initial situation

	Fossil fuel	Electricity
2025	-20.0%	-2.05%
2028	-60.00%	-5.93%
2030	-100.0%	-9.82%

Residential CO_2 emissions have been reduced considerably after the implementation of the measures; a drastic reduction in the heating, DHW and cooling sectors can be seen in figure 7.6 due to the strong penetration of heat pumps and their high efficiency. In addition, in the cooking sector, a progressive reduction is also observed, although not as noticeable as the aforementioned sector, because the cooking sector is smaller in terms of emissions and induction stoves are not as efficient as heat pumps. The initial reduction with respect to the final situation is 52.36% for the residential sector, which represents a considerable saving in emissions to help achieve carbon neutrality.

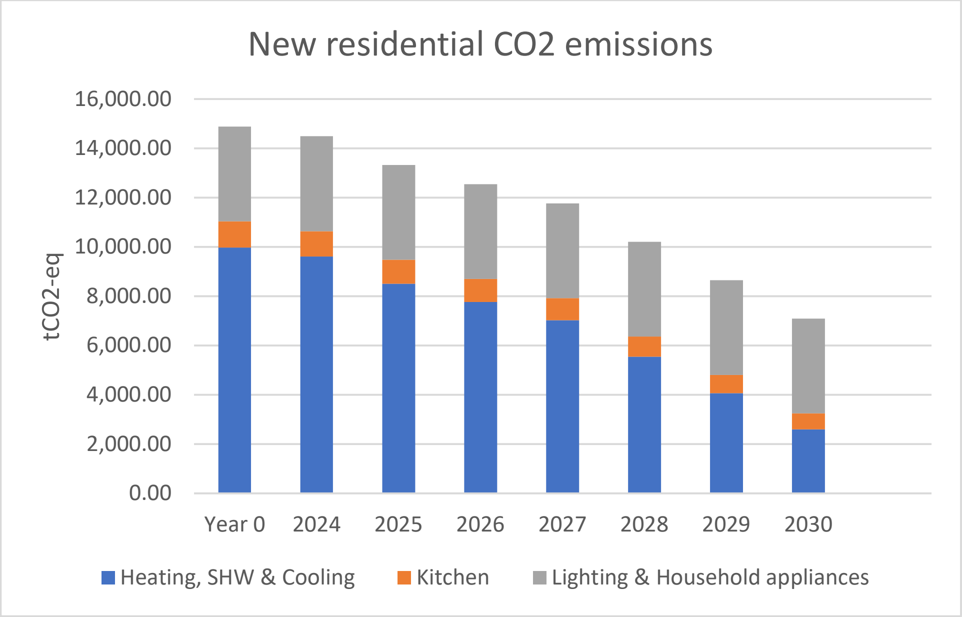


Figure 7.6 Comparison of the evolution of new residential final CO_2 by subsectors considering initial situation

Adding the photovoltaic electricity generation and energy storage measures to the residential sector measures, the following savings in tCO2 have been obtained for the years indicated:

Table 7.5 tCO2e emissions savings per measures

	2025	2028	2030
HP (tCO_2e)	-1,477.33	-4,431.98	-7,386.63
INDUCCTION STOVE (tCO_2e)	-88.09	-244.47	-407.45
PV & STORAGE (tCO_2e)	-5,116.45	-5,726.91	-5,931.02
TOTAL (tCO_2e)	***-6,681.87***	***-10,403.36***	***-13,725.10***

The heat pump consistently demonstrates the most significant impact in reducing greenhouse gas emissions across all three years, while the induction stove and PV & storage technologies also contribute to emissions reductions. However, similar to the consumption savings, the emissions reductions from the photovoltaic and battery system reach a saturation point once a specific installed capacity is achieved. As the system covers the neighborhood's overall electricity demand and generates surplus energy, the emissions reduction potential becomes limited. While this has a relatively lower impact at the local level, it still signifies the ability of the photovoltaic system to accommodate future increases in electricity demand while maintaining emissions reductions.

In table 7.6, when the measures are categorized by scope, it can be observed that the measures focused on the substitution of fossil fuels, such as heat pumps and induction stoves, would fall under scope 1. These measures directly impact the emissions associated with the consumption of fossil fuels by replacing them with more efficient and cleaner alternatives. On the other hand, the electrical savings generated by the PV system and batteries would fall under scope 2. However, to a lesser extent, the heat pump also helps to reduce emissions associated with this scope as it replaces more polluting electrical equipment, indicating a reduction in emissions. These measures contribute to reducing the demand for electricity from the grid, leading to lower indirect emissions associated with electricity generation.

Due to the implementation of other energy-saving measures, the photovoltaic measure is experiencing a decrease in its potential for achieving significant savings. While it can still generate the same amount of electricity, the overall savings have diminished due to the reduced electricity consumption resulting from the other measures. Therefore, the relative impact of the photovoltaic measure on environmental savings has become less pronounced.

The table indicates that both Scope 1 and Scope 2 measures contribute to reducing greenhouse gas emissions, with Scope 1 measures showing a smaller reduction compared to Scope 2 measures in each year. These savings will contribute to Valencia's goal of becoming a carbon-neutral city by 2030 and achieving the SDGs. Regarding Scope 3, no measures have been implemented that impact it.

Table 7.6 tCO2e savings classified by scope

	SCOPE 1 (tCO_2e)	**SCOPE 2 (tCO_2e)**
2025	-1,314.95	-5,368.31
2028	-3,930.99	-6,491.91
2030	-6,774.64	-6,951.42

In terms of the overall balance of the project parameters, the reduction in electricity demand plays a significant role in minimizing the increase in emissions. By replacing equipment that relies on fossil fuels with more efficient electric alternatives, the project achieves a positive final balance. This is because electricity has a lower emission factor compared to any fossil fuel. The reduced electricity demand not only contributes to emissions reduction but also promotes a more sustainable and environmentally friendly energy system.

According to the provided graph, the highest savings are achieved with the PV & BAT measure as it already has a higher percentage implemented in the early years compared to the heat pump and induction stove.

While the photovoltaic measure with battery storage may have limitations in terms of savings, it is essential to view it as part of a comprehensive approach to achieving overall energy savings. The main objective of this analysis is to study how all the measures, including the photovoltaic system, work together to achieve significant savings within the neighborhood.

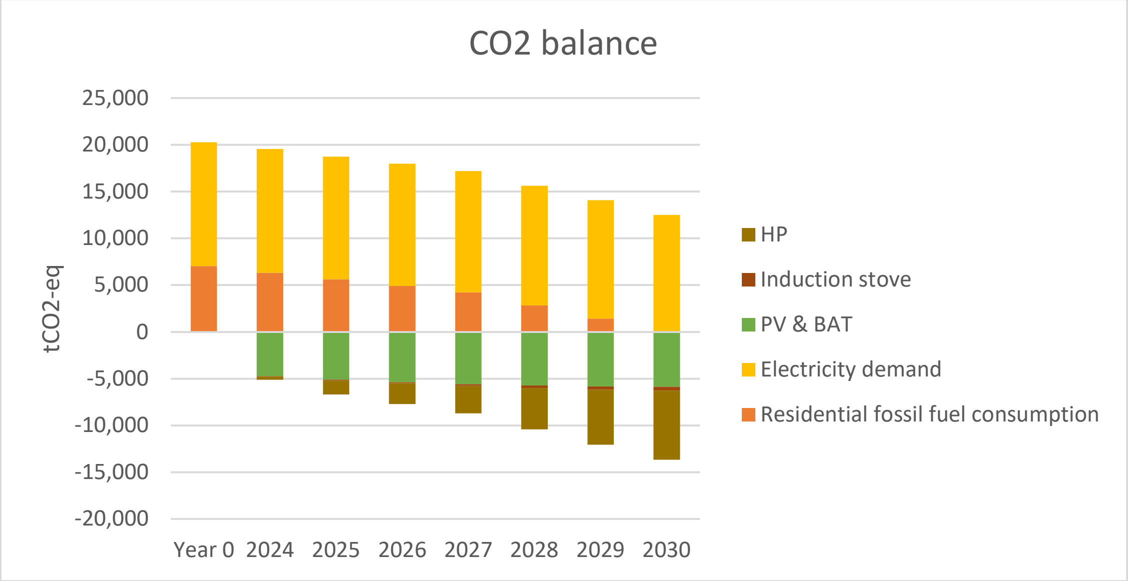


Figure 7.7 CO_2 emissions balance considering initial situation and measures savings

Overall, this result reflects a successful transition towards cleaner and more energy-efficient technologies. The adoption of photovoltaic systems, induction stoves, and heat pumps has led to a significant reduction in residential fossil fuel consumption and an increase in renewable energy utilization. These trends align with the goals of sustainability and energy efficiency.

As with the energy study, a study on the synergy of the complementary CO_2 saving measures carried out for the Benicalap neighborhood will be carried out in section 9 of this study.

8 ECONOMIC ANALYSIS

The economic analysis is a determining factor, especially when investments are made. At this point we have tried to expose the economic results of the measures, differentiating the system in two, with battery or without batteries.

Two analyses have been carried out from the budget, the first without considering the market interest rate and inflation. In the second one, these two parameters will be considered to see these influences on the project. Considering the costs explained below:

<u>Electricity cost</u>

To estimate the price of electricity based on current electricity billing, we have used hourly data provided by REE [41]. The price followed has been the "Precio voluntario para el pequeño consumidor (PVPC)", applying the 2.0 TD tariff, which came into effect in June 2021. The main problem of following these prices is that during these years these prices have undergone very drastic changes due to the Ukraine war crisis or COVID-19; therefore, it has been decided to use older data whose prices are more stable over time and allow us to perform a more consistent analysis in the future.

Therefore, the old 2DHA tariff prices have been adapted to the current 2.0 TD tariff. For this purpose, the data from 2016 have been adapted, so that they are as current as possible and we have a large volume of data for less error in the estimation, to the current data distributed in three current hourly periods. Table 7.1 shows the data of the old tariff adapted to the current tariff and the historical prices of the new tariff.

Table 8.1 Average of prices according to different tariffs

	Old tariff 2.0 DHA (January 2016 - May 2021)	**New tariff 2.0 TD (June 2021 - December 2022)**	**Deviation**
	€/kWh	€/kWh	
P1 Peak	0.11062	0.34767	0.02809
P2 Flat	0.10088	0.28405	0.01677
P3 Valley	0.05869	0.25053	0.01840

The calculated deviation has been used as a criterion for reducing the purchase and sale data of the 2.0 TD tariff, as these are influenced by the crisis periods. The results can be seen in table 7.2.

Regarding the sale of electricity, it has been assumed that the population of Benicalap will be able to sell the surplus energy using the simplified compensation mechanism since the measures have been designed to self-consume the energy generated, whether it is individual or collective self-consumption. The restrictions of this simplified compensation mechanism that have been considered as not applicable to the project are as follows [42]:

- Are associated with production facilities whose power does not exceed 100 kW.
- The generation is of renewable origin.
- The production plants have not been granted an additional or specific remuneration regime.

This type of sale is usually the most common option among consumers because it is the most advantageous among this type of applications, achieving greater economic savings. However, it should be noted that the maximum value of the energy term in the electricity bill will be 0 € since the marketers cannot pay benefits of surplus energy. [43]. This has been considered when calculating the savings that the sale of electricity to the grid can bring. The sale of self-consumption surpluses is new, coming into force in Royal Decree 244/2019, of April 5, which regulates the administrative, technical, and economic conditions for the self-consumption of electrical energy [44]. This means that the selling prices selected for the study have been chosen from April 2019 to December 31, 2022. The final purchase and sale price used for the economic calculation with their respective taxes, which can be seen in Annex F, is shown in the following table:

Table 8.2 Final purchase and sell electricity price

	Purchase Price (€/kWh)	Sell Price (€/kWh)
P1 Peak	0.178451	0.097978
P2 Flat	0.154515	
P3 Off peak	0.149028	

Remaining costs

The cost of fossil fuels for calculating average annual savings has been obtained from various national information pages. As well as the induction stoves and heat pumps cost, since these devices vary according to the supplier, place of purchase, model, etc.

To establish the cost for the photovoltaic system, it has been decided to use the same cost as in the previous study, as well as its operation and maintenance cost. Finally, it should be noted that the costs associated with the battery system have been established by the HOMER software using the prices in the catalogs available in the same program.

All these costs can be seen in table 12.15 of the annex G, as well as the sources from which each of them has been obtained.

8.1 Project Budget

The budget of the measures is a way to observe the total investment to be made and to know the things that suppose a higher cost. This budget is divided between what the owner of the installation has to pay, and the subsidies offered.

In Table 8.3, the investment costs associated with implementing measures at the neighborhood level are shown. It can be observed that the photovoltaic system incurs the highest cost, as this measure is intended to cover the overall electricity demand of the neighborhood, while the other measures are specifically targeted towards the residential sector.

Table 8.3 General budget for the entire neighborhood of Benicalap

Measure	Total investment (M€)
PV SYSTEM	56.70
STORAGE SYSTEM	12.24
HEAT PUMP	35.70
INDUCTION STOVE	6.74
TOTAL	***111.38***

On the other hand, the budget has been calculated for the proposed building in the project. In this case, the heat pump system is the most expensive among the proposed measures, followed by the photovoltaic system. These results can be observed in Table 8.4.

Table 8.4 General budget for the proposed building

Measure	Total investment
PV SYSTEM	*€ 15,894*
STORAGE SYSTEM	*€ 12,000*
HEAT PUMP SYSTEM	*€ 30,831*
INDUCTION STOVE	*€ 8,740*
TOTAL	**€ 67,465**

As an additional case, to save money on the investment of these measures, one can also opt for subsidies promoted by regional governments and the Spanish government. It is worth noting that accessing these subsidies is a personal decision, and the granting of aid may be influenced by socio-economic parameters that are beyond the scope of this project. However, an example will be provided to demonstrate how the budget would be reduced in a proposed scenario for the studied building.

The calculation of the subsidies has been based on the proposals in the "programa 4: autoconsumo y almacenamiento con energía renovable, Comunidad Valenciana" [45] and in the "plan Renove de Calderas y Aerotermia domesticas" [46] where, based on the number of residential properties for the Benicalap neighborhood, the following amounts have been chosen:

- For installations Photovoltaic installations for self-consumption (10 kWp < P ≤ 100 kWp): 450€/kWp.

- Incorporating storage in the renewable energy installation project for self-consumption in the residential sector, public administrations and the third sector (10 kWp < P ≤ 100 kWp): 350€/kWh.
- Replacement of a heating + DHW installation with a heating + DHW aerothermal system and the contribution of the installation company adhering to the Renove Plan: 950/installation and up to 5% on ducts and/or piping.

Considering the aforementioned subsidies, the following modified budget is obtained:

Table 8.5 New budget considering grants for the proposed building

Measure	Subsidies	New Total investment
PV SYSTEM	*-€ 6,300*	*€ 9,594*
STORAGE SYSTEM	*-€ 4,200*	*€ 7,800*
HEAT PUMP SYSTEM	*-€ 4,750*	*€ 26,081*
INDUCTION STOVE	--	*€ 8,740*
TOTAL	**-€ 15,250**	**€ 52,215**

This savings in the form of subsidies would result in a reduction of €15,250 from the investor's total investment, which translates to a savings of 22.6% of the total investment.

It is worth mentioning another scenario in which the entire neighborhood chooses to avail themselves of these subsidies. In this case, the government expenditure might be too substantial to be fully covered by the subsidies, and only a percentage of the cost would be assumed. Consequently, the study has been conducted solely for the standard building.

8.2 Simple analysis

In the simple analysis, the NPV, IIR, COE & PB will be used as economic indicators to know the viability of the project. The following graphs show the evolution of the NPV, as well as when the initial investment is recovered in the different

Figure 8.1 illustrates the cash flow evolution over the life of the proposed building project. It displays the year in which the progressive investment takes place, considering the investment costs as well as the annual expenses.

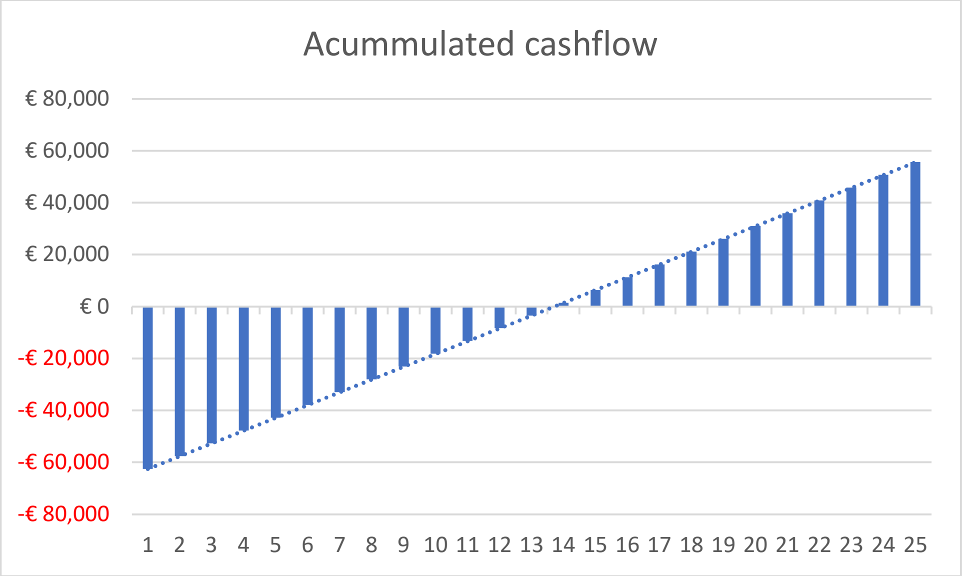


Figure 8.1 Cumulative cash flow from simple study on proposed building

The cash flow can be observed to turn positive starting from year 13, indicating that around this year is when the project begins to generate profits.

The results obtained from the simple analysis are presented in the following table. It can be observed that the economic results are similar, although the economic indicators position the battery system above the system without batteries.

Table 8.6 Economic results of the simple analysis of the proposed building

NPV (M€)	55.631
IRR (%)	*5.07*
LCOE (€/kWh)	*0.081*
PB (years)	*13.70*

Taking into consideration the subsidies, the payback period can be reduced to 10.60 years, showcasing the helpfulness of these subsidies.

The battery system demonstrates the lowest cost-saving ratio. Without its implementation, the payback period would be shortened to 13.40 years. It is evident that, from an economic viability perspective, it may not be worthwhile. However, when considering the objectives of reducing global emissions and dependence on the grid, the system can be a viable option. Hence, the selection of the battery system is contingent upon the individual's personal decision.

8.3 Inflation and interest rate analysis

Once it is confirmed that the battery system is more economically viable, the analysis will proceed with two scenarios: a 2% and a 4% inflation rate; but maintaining an interest rate of 1.74%. The equations applied to perform this analysis can be found in section B of the annexes.

The same as in the simple analysis has also been used as a comparative or reference scenario. The difference is that this scenario is also affected by inflation and market interest parameters.

The 2% interest rate scenario has been chosen because the European central bank's objective is to achieve an interest rate of 2% in the medium term through monetary policy [47]. The other scenario has been chosen to depict a more "aggressive" scenario for the future and demonstrate the project's effectiveness in difficult periods.

Furthermore, the choice of an interest rate has been made based on historical averages provided by the European Central Bank in Spain on long-term interest rate for convergence purposes [48].

Table 8.7 Economic study considering inflation and interest rates

	4% Inflation rate	**2% Inflation rate**
NPV_PROJECT (€)	110,043	58,142
IRR (%)	8.01	5.39
LCOE (€/kWh)	0.088	0.081
PB (years)	11.04	13.62

The analysis of the table reveals that the NPV, IRR, and payback period are more favorable in scenarios with higher inflation. This trend is attributed to the increased savings achieved during periods of high inflation, as they are not dependent on the rising prices of fuels and electricity.

On the other hand, the LCOE increases as inflation rises. This is because, regardless of inflation, the same amount of electricity is consumed, but its price is higher during inflationary periods. However, this price increase is offset by the savings generated from not relying on fossil fuels and the significant portion of electricity that would be consumed without the implementation of the proposed technologies.

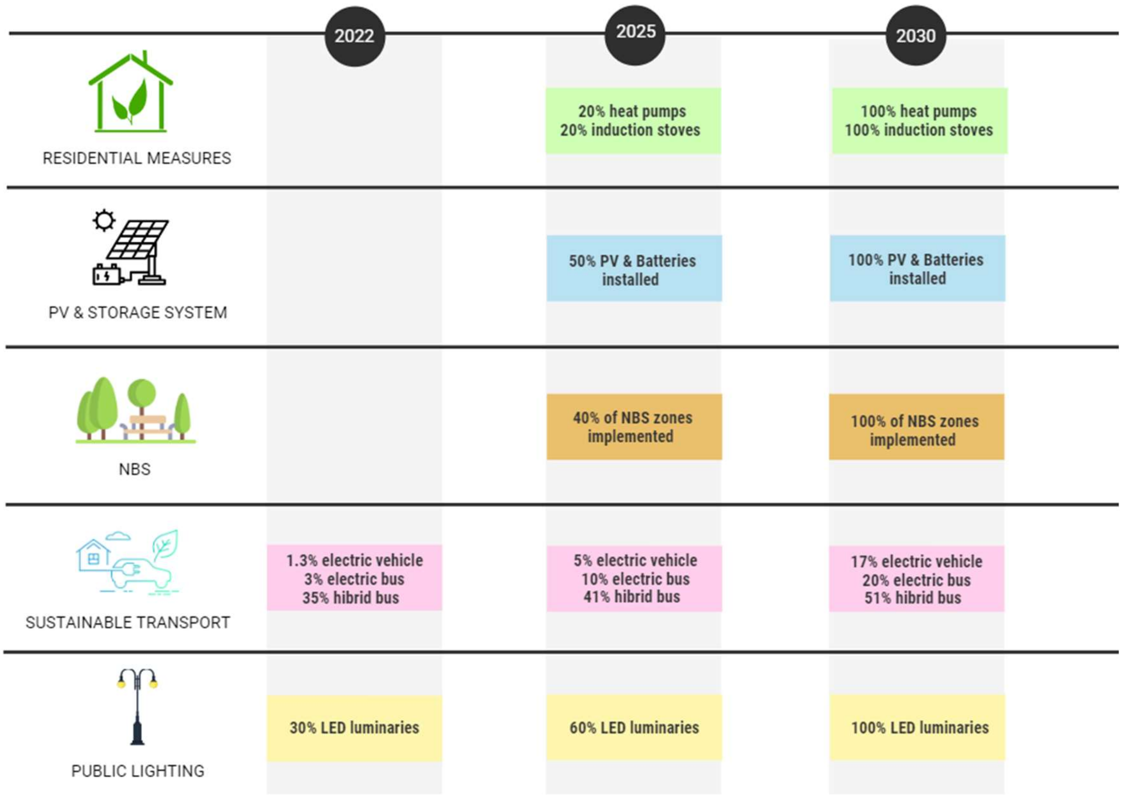
In summary, the project demonstrates more favorable financial outcomes during periods of higher inflation prior to investment in these technologies. These results showcase how the proposed measures help mitigate price increases by achieving energy independence through the non-use of fossil fuels and primarily harnessing electricity generation through the photovoltaic system, while enhancing savings with battery storage systems.

9 FINAL STATUS AND PROPOSED IMPROVEMENTS

The main objective of this section is to incorporate the measures developed in previous study [6] with those implemented in this project to know the final state of the neighborhood. Likewise, this final analysis will allow us to include future proposals for the improvement of the neighborhood and the achievement of the governmental results.

9.1 Final roadmap

The following figure shows the roadmap including the implementation schedule for the complementary measures of the previous study conducted on Benicalap [6].



	2022	2025	2030
RESIDENTIAL MEASURES		20% heat pumps 20% induction stoves	100% heat pumps 100% induction stoves
PV & STORAGE SYSTEM		50% PV & Batteries installed	100% PV & Batteries installed
NBS		40% of NBS zones implemented	100% of NBS zones implemented
SUSTAINABLE TRANSPORT	1.3% electric vehicle 3% electric bus 35% hibrid bus	5% electric vehicle 10% electric bus 41% hibrid bus	17% electric vehicle 20% electric bus 51% hibrid bus
PUBLIC LIGHTING	30% LED luminaries	60% LED luminaries	100% LED luminaries

Figure 9.1 Final roadmap for Benicalap neighborhood

9.2 Final CO_2 reduction

The purpose of this section is to show the environmental savings of CO2 by complementing the measures discussed in this study with those already carried out for the neighborhood.

Regarding the previous environmental study, it is important to highlight that the photovoltaic and battery system's savings potential has diminished due to the reduced demand resulting from the residential measures implemented. As mentioned earlier, the energy consumption within the neighborhood has decreased as a result of these measures, which ultimately leads to lower net savings achievable by the photovoltaic and battery system.

Table 9.1 provides an overview of the proposed savings outlined in the current study, as well as the savings proposed in previous studies [6]. This analysis enables a comprehensive understanding of the proposed strategies' effectiveness in achieving energy efficiency and sustainability targets in Benicalap neighborhood.

Table 9.1 Final tCO_2e savings, including complementary measures

	2022 (tCO_2e)	**2025 (tCO_2e)**	**2030 (tCO_2e)**
HP		-1,477	-7,386
INDICTION STOVE		-88.09	-407.45
PV & STORAGE SYSTEM		-5,116	-5,931
NBS	-22.37	-33.3	-59.54
PUBLIC LIGHTING		-59.66	-110.03
SUSTAINABLE TRANSPORT		-5,170.	-9,961
TOTAL	***-22.37***	***-11,945***	***-23,855***

From the presented measures, the one that would generate the highest savings in the final year would be the substitution of conventional vehicles with sustainable vehicles, followed by the heat pump and photovoltaic generation and storage. The table demonstrates how all the measures contribute to reducing GHG emissions in a complementary manner. It is possible to install all these measures simultaneously, showcasing their synergistic effect and the potential for maximizing emission reductions.

If the savings for 2030 were to be divided according to the previously defined scopes, the following results would be obtained:

Table 9.2 Final $tCO2$ savings by scope, including complementary measures

	SCOPE 1 (tCO_2e)	**SCOPE 2 (tCO_2e)**
HP	-6,366.19	-1,020.42
INDUCTION STOVE	-407.45	
PV & STORAGE SYSTEM		-5,931
NBS	-59.54	
PUBLIC LIGHTING		-110.03
SUSTAINABLE TRANSPORT	-9,961	
TOTAL	***-16,794***	***-7,061***

As can be seen, most of the savings achieved have been in scope 1, a positive point because the emissions corresponding to this scope are greater and these measures would mean a greater reduction of CO_2 emissions to achieve carbon neutrality; the savings concerning the initial situation for this scope is 62.01%. Likewise, within scope 2, a saving of 43.61% has been achieved with respect to the initial situation, which shows the importance of the photovoltaic system and electricity storage.

9.3 Budget

Table 8.4 shows the final budget, including the measures already created for the Benicalap neighborhood [6].

Table 9.3 Final budget, including complementary measures

Measure	Total investment (M€)	Investment porcentaje
PV SYSTEM	56.70	22.53%
STORAGE SYSTEM	12.24	4.86%
HEAT PUMP	35.7	14.19%
INDUCTION STOVE	6.74	2.68%
NBS	5.83	2.32%
PUBLIC LIGHTING	0.05	0.02%
SUSTAINABLE TRANSPORT	146.64	58.27%
TOTAL	***251.66***	***100.00%***

A significant portion of the investment is allocated towards the deployment of electric vehicle charging infrastructure and the installation of a photovoltaic system in the Benicalap neighborhood. With a population of 41,483 inhabitants, the investment per capita amounts to approximately €6,066. This translates to an annual cost of €606.6 per capita over a duration of 10 years.

It should also be noted that subsidies can help reduce this total investment. However, as mentioned before, this is beyond the scope of the project and requires socio-political-economic parameters that have not been considered.

9.4 Proposal for future measures and improvements

The effectiveness of the measures is reflected in the results shown during the development of the study; however, this does not imply that they cannot be improved or even developed as totally complementary measures, as long as they follow the objectives set.

If audits or interviews are conducted in the service or industrial sectors to ascertain the precise information regarding the installed equipment and their respective energy consumption, a similar approach as proposed in this project could be implemented for these sectors. The significance of having more accurate or new data and methods available in the future cannot be overstated, as they are vital for continuing to make contributions to the climate emergency. In this regard, future scientific and technological advancements will play a pivotal role in furthering our understanding and developing effective measures in this area.

If the implementation of such a measure is extended to electrify as many services as possible, the photovoltaic system would be capable of meeting this demand by generating ample surplus energy, covering all rooftops with panels. However, due to the limitations of increasing the photovoltaic capacity on the roofs of buildings in the Benicalap neighborhood, alternative locations within or nearby the neighborhood must be considered for photovoltaic installations. Even, to support this expansion, increasing the photovoltaic capacity can be accompanied by an expansion in storage capacity. This synergistic approach not only ensures a balanced energy supply but also offers the advantages of savings. By strategically combining increased photovoltaic capacity with adequate storage, the neighborhood can optimize energy generation, storage, and consumption, leading to greater efficiency benefits.

The ongoing commitment to sustainable transportation for future years is also regarded positively. However, it is important to note that this will result in an increase in electricity consumption if electricity is used as a fuel. Nevertheless, with the proper management and optimization of renewable energy sources, this increase in electricity consumption can be mitigated and the overall benefits of sustainable displacement can still be realized.

Another determining factor would be the intelligent and efficient use of shared equipment or energy. This efficient use can come from collective self-consumption and local energy communities. Today it has been demonstrated that collective self-consumption and the use of Local Energy Communities bring environmental and social benefits; and although the Energy Communities currently have a series of barriers that hinder the development of this new energy model, they are becoming more and more visible, which implies self-management and generation of their own energy, as well as in the development of energy efficiency and sustainable mobility measures [49].

Finally, it should be noted that the correct maintenance of the equipment is as important as its correct recycling replacement. In addition, if an intelligent replacement is made, covering the energy demand according to the typology of each building with new and therefore more efficient equipment, significant savings will be achieved.

10 CONCLUSIONS

Throughout the project, the implementation of an efficient electrification road powered by renewable energies has enabled the creation of a sustainable neighborhood environment, resulting in reduced total energy consumption and CO_2 greenhouse gas emissions. Despite limited data availability on consumption and installed equipment in the residential sector, a methodology was developed to estimate these factors. This methodology facilitated the implementation of measures focused on efficient electrification in the residential sector, utilizing heat pumps for heating, domestic hot water, and refrigeration, as well as induction stoves for the kitchen subsector. However, challenges were faced in electrifying other sectors due to the scarcity of data on installed equipment and consumption patterns, as the variation in building typologies in these sectors posed a risk for realistic estimations. Nevertheless, the mentioned methodology successfully achieved electrification of the entire residential sector.

The measures implemented in the residential sector are based on energy efficiency. The use of heat pumps has achieved savings of 36,830 MWh, while the adoption of induction stoves has resulted in savings of 1,636 MWh. These savings translate into environmental reductions of 7,386 tCO_2e and 407 tCO2e, respectively.

On the other hand, the incorporation of photovoltaic technology and battery-based electric energy storage systems enabled electrification from renewable sources. Surplus energy generated by the photovoltaic system is stored in the energy storage system, optimizing the process by reducing reliance on grid electricity. This system covers 54.3% of the neighborhood's total electricity demand, including the decreased demand resulting from the implementation of measures in the residential sector.

All actions were developed as a percentage over time, with annual assessments conducted to evaluate the obtained results. By 2030, the full implementation of all proposed measures applied to the neighborhood is projected to result in savings of 72,848.93 MWh and 13,725.10 tCO_2e for that year.

A specific case study was conducted for a typical building in the Benicalap neighborhood, where all measures were implemented, leading to annual savings of 51.34 MWh and 10 tCO2e. This corresponds to a reduction in consumption of 67.93% and emissions of 71.02%.

The implementation of these measures required an overall investment of 111.38 million euros (M€) for the neighborhood. Additionally, for the measures applied to the specific building, an investment of 67,465€ is necessary, which is expected to be recovered in 13.70 years, without considering factors such as inflation. Considering inflationary effects could potentially shorten the amortization period, leading to greater economic savings by mitigating price increases.

The measures developed complement previous efforts, resulting in increased energy and environmental savings for the Benicalap neighborhood. However, it is important to note that these measures also incur higher economic costs. The results of this project contribute positively to the achievement of targets set to make Valencia a carbon-neutral city by 2030, align with the Spanish National Energy and Climate Plan (NECP), and contribute to the global Sustainable Development Goals (SDGs). Furthermore, these positive effects can be further enhanced through future improvements to the proposed measures or by introducing new complementary measures.

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12 ANNEXES

A. Factors considered

Downscaling factor

These factors have been used to extrapolate data at different scales. In the absence of data at the neighborhood level, it has been necessary to resort to data at different scales, at the city and district levels.

Specifically, a reduction factor has been used to determine consumption at the neighborhood level based on real estate in the city of Valencia and the neighborhood. A factor of 1 has also been used for the assumption that the Benicalap neighborhood has the same percentage of installed equipment regarding heating equipment as in the Benicalap neighborhood.

Table 12.1 Downscaling factors considered for Benicalap.

	Factor	**%**
Properties based on municipal data	0.046	4.6
Heat installation equipment based on district data	1	1

Emission factors

Part of the appendix presents the different emission factors used in the development of the study. These data have been obtained from the Energy Data report for the Valencian Community for 2019 [31].

Table 12.2 Emission factors for energetic resources

Electricity (tCO_2/MWh)	0.172
Natural gas (tCO_2/MWh)	0.201
Butane & Propane (tCO_2/MWh)	0.225
Coal (tCO_2/MWh)	0.348
Gasoil C (tCO_2/MWh)	0.265
R.290 HP refrigerant ($kgCO_2e$)	1.18

It is worth mentioning that the emission factor of diesel oil C has been chosen because it is mainly used for heating and heat generation equipment.

B. Equations

This section shows some of the equations used for the development of the work. The rest of the equations have not been shown because it has not been considered that they need any explanation and they cannot lead to confusion, since they have been calculated using basic simple mathematical operations.

Table 12.3 Equations used for project development

#	Term	Equation	Definition	Variables
1	Hourly electricity consumption (HC)	$HC = DV * \frac{\sum Daily\ profile}{Hourly\ profile}$	Equation used to calculate the hourly electricity consumption of the Benicalap neighborhood using the REE profiles and the daily consumption of the neighborhood.	DV = Daily Value (kWh)
2	Annual consumption (AC)	$AC = AC_{Vlc} * \frac{properties_{Vlc}}{properties_{benicalap}}$	Equation used to estimate the annual consumption of Benicalap by extrapolating the data for the city of Valencia.	AC_{Vlc}= Annual consumption of the Valencia city (MWh) $propierties_{Vlc}$= Number of properties in Valencia city $propierties_{Benicalap}$= Number of properties in Benicalap neighborhood
3	Seasonal Coefficient Of Performance (SCOP)	$\mathrm{SCOP} = COP_{nom} * WF * CF$	Performance factor that considers the operating conditions for this type of technology, varying depending on the hot and cold source conditions.	COP_{nom}= Nominal coefficient of perfomance WF= Weighting factor CF= Correction factor

4	Levelized Cost Of Energy (LCOE)	$LCOE = \frac{C_{ann,tot}}{E_{served}}$	Average cost per kWh of useful electrical energy produced by the system in each year.	$C_{ann,tot}$ = Total annualized cost of the system (€/year) E_{served} = Total electric demand served (kWh/year)
5	Renewable fraction (f_{ren})	$f_{ren} = 1 - \frac{E_{non\ ,ren}}{E_{served}}$	The renewable fraction is the fraction of the energy supplied among the load from renewable energy sources.	$C_{ann,tot}$ = Total annualized cost of the system (€/year) E_{served} = Total electric demand served (KWh/year)
6	Payback (PB)	$PB = \frac{IC}{CF}$	The payback is the number of years it takes for the cumulative income to equal the value of the initial investment.	IC = Investment cost (€) CF = Net annual cash flow (€)
7	Net Present Value (NPV)	$NPV = AS_n - (AC_n * \frac{\left(1 + i_{inf}\right)^{n-1}}{(1 + i_{mrk})^n})$	The Net Present Value is the present value of all project components over the life of the project.	AS_n = Annual savings (€) AC_n = Annual cost (€) n = Project year i_{inf} = Inflation rate i_{mrk} = Market interest rate
8	Internal Rate of Return (IRR)	$IRR = NPV = \sum_{n=1}^{n} \frac{AC_n}{(1 + IRR)^n} - IC = 0$	The IRR is an indicator of investment returns, so that the higher the IRR, the higher the profitability.	AC_n = Annual cost (€) IC = Investment cost (€) n = Project year

C. Heat pump parameters

In this section we will try to expand the information about the heat pump, such as the justification for the choice of the heat pump model, its most relevant features and how the heat losses of the building's heating system have been calculated.

Heat pump model justification

To choose the appropriate power output for a residential heat pump, it is necessary to consider the size and distribution of the dwelling, thermal insulation, climate zone and efficiency of the heat pump. A professional installer should perform a thermal load calculation to determine the appropriate power output for the heat pump and ensure optimal system performance.

Unfortunately, it is not possible to carry out an individual study of each building in the neighborhood considering their unique characteristics. Therefore, the nominal power of the heat pump has been chosen based on the general operating hours for a heat pump of this type. The operating hours data provided by IDAE for the average operating hours of an air-to-air heat pump for the residential sector has been used as a reference since there are no specific data available for an air-to-water reversible heat pump in this sector.

According to IDEA, the average operating hours for an air-to-air reversible heat pump for the residential sector nationwide are 182.33 annual operating hours [50]. Using a similar study for a building in Lugo [51] , it has been calculated that each heat pump will operate an average of 256.9 hours per year to meet the demand for heating and domestic hot water, which is not too different from the national data provided by IDEA despite being focused on another climatic zone.

Based on the data presented, it has been determined that the annual demand for heating and domestic hot water in a generic building in the Benicalap neighborhood is 45,177 MWh and 21,134 MWh, respectively. Notably, these values exceed the cooling demand. Therefore, these higher thermal demands will be used as the reference for the sizing of the installation. Using the heat loss values presented in the third section of Annex C, an estimated power requirement of 60 kW has been calculated.

In order to meet the required power demand of 60 kW, a total of 5 units of the Valliant-manufactured aroTHERM plus commercial model 12 heat pump, each with a nominal power of 12 kW, will be used. Heating and domestic hot water demands will be met by individually operating each heat pump for 252.57 annual hours. For single-family homes, only one unit of the same commercial model will be needed to meet the heating demand of 2.38 MWh and 1.11 MWh for DHW demand. However, the operating hours for the single unit will increase to 339.42 hours.

Although a higher model providing the same power output with one less unit could have been selected, the aroTHERM plus commercial model 12 was chosen due to its highest seasonal annual performance in both heating and cooling mode in the entire catalog [37]. By using this model, the project can achieve greater energy savings and achieve the emissions savings targets.

Heat losses calculation

As previously mentioned, a scientific study has been used to calculate the heat transfer losses where the annual thermal losses are determined depending on the annual thermal varieties at district level using as example a few buildings of the district [35]. In this, thermal losses are established depending on cold, moderate, and hot days; therefore, the following classification has been made for the Benicalap neighborhood:

- Cold months: Corresponds to months whose average temperature is less than 15ºC.
- Moderate months: Corresponds to months with an average temperature between 15 and 20ºC.
- Warm months: Corresponds to months with an average temperature of more than 20ºC.

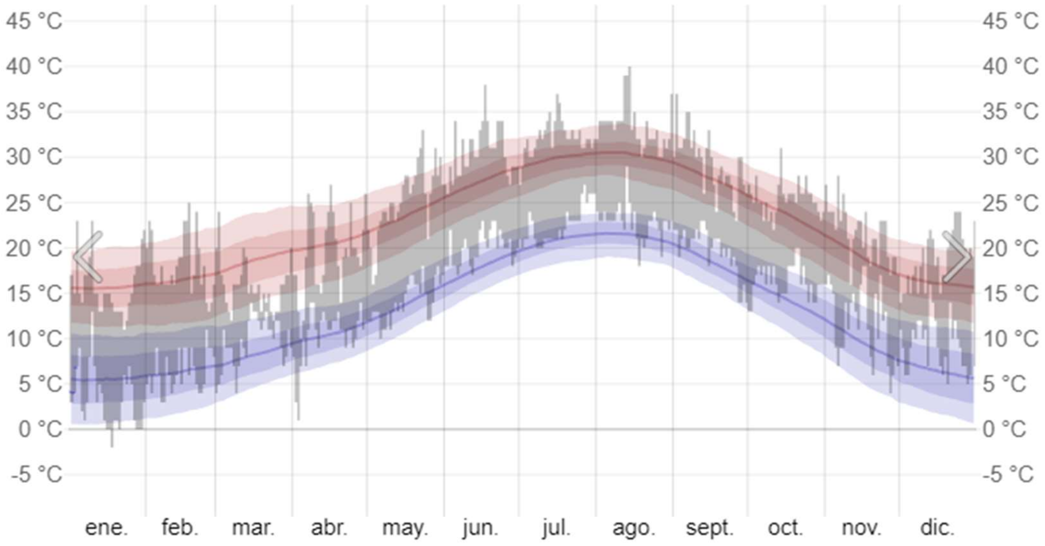


Figure 12.1. Valencia temperature data in 2022 **[74]**

The months considered as cold correspond to January, February, March, November, and December, which is 41.7% of the year. On the other hand, the warm months are April, May, and October, corresponding to 25% of the year. And the hot months would be June, July, August, and September, that is, 33.3% of the year.

Applying the following percentages following the above distribution, we obtain that the heat transfer loss percentage for heating is 14.2%, which makes a SCOP of 4.96 for the chosen heat pump.

- Cold months: 5.6%
- Moderate months: 14%
- Warm months: 28.8%

D. Energy performance factors

This section includes the performances of the equipment that have been considered during the study. These performances have been considered directly from different sources, with the exception of the heat pump, for which it has been necessary to rely on historical data to estimate its performance.

Table 12.4 shows the efficiencies of the equipment used except for the efficiency of the heat pump and portable air conditioning which will be explained after the table.

Table 12.4 Equipment performance factors

Equipment	Performance	Information source
Induction stove	76.3%	Average between the data obtained in the different experiments for different vessel sizes [52].
Conventional gas stove	35.7%	Average between the data obtained in the different experiments for different vessel sizes [52].
Standard NG boiler	82.4%	Maximum net efficiency values of a non-condensing boiler (table 5.32) applying the efficiency conversion factor for the NG (table 5.33) [53].
Standard LPG boiler	85%	Maximum net efficiency values of a non-condensing boiler (table 5.32) applying the efficiency conversion factor for the LPG (table 5.33) [53].
NG condensing boiler	93.7%	Maximum net efficiency values of a condensing boiler (table 5.32) applying the efficiency conversion factor for the NG (table 5.33) [53].
Gas fireplace	89.5%	Average performance of a commercial gas fireplace [54].
General radiator	88.8%	Efficiency of a radiator for free heating surfaces and a zone height less than 4 meters (table 5.4) [53].
Electric heating	86.9%	Electric heating performance for a zone height of less than 4 meters (table 5.9) [53].
NG water heater	85%	NG water heater performance (real case) [55].

Electric water heater	92.5%	Average between a standard electric tank and a high-efficiency electric tank according to commercial information [56].
Commercial biomass boiler	94.95%	Performance of Eco-PK 70 pellet boiler for residential use [57].
Commercial Coal-fired boiler	92.8%	Performance of H8-A brown coal boilerfor residential use [58].

For the heat pump, performances based on the seasonality of this machine have been used, for this purpose, the efficiency in heating mode and DHW production have been calculated as follows:

The COP has been calculated from the trend on the evolution of this performance of the Spanish heat pump fleet [59]. To calculate this trend, the evolution of the COP from 1990 to 2014 was studied.

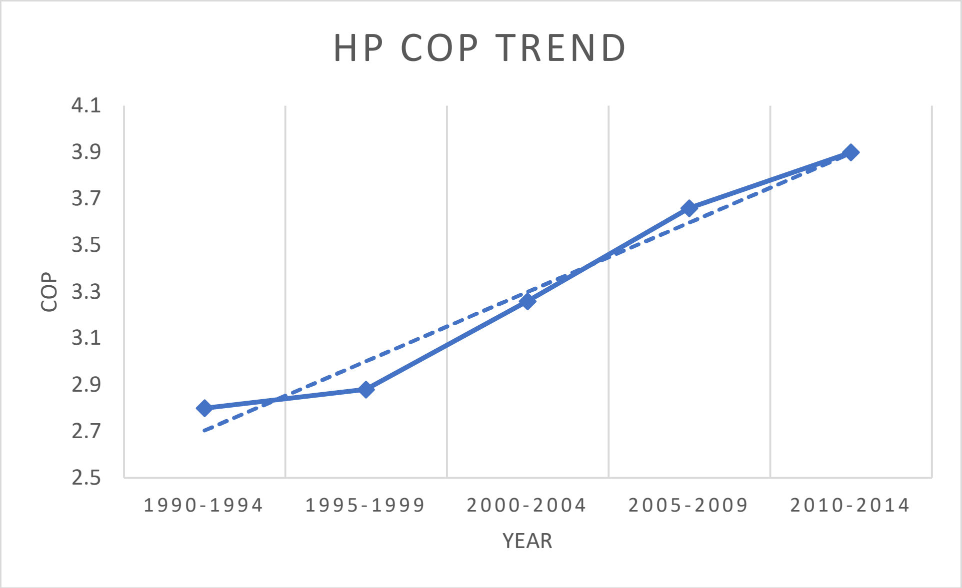


Figure 12.2. Evolution of the COP Of the HP installed in Spain

From this trend we observe that for the range of years 2019-2023 the heat pumps to be installed will have an approximate nominal COP of 4.49. However, this performance factor does not consider seasonality or the activity to be performed by the HP, so the SCOP must be determined. The SCOP is calculated from the COP, Weighting Factor and Correction Factor, as shown in the equation 3 shown in the annex B.

Regarding the weighting factor, it has been decided to make an average for zone B corresponding to the municipality of Valencia [60] between, depending on the energy source of the HP, in centralized and individualized split-type equipment. The same correction factor is used for heating and for DHW production because it has been considered that there is no difference between these temperatures, therefore the correction factor is 1. The table below shows the final factors used for the SPF calculation.

Table 12.5 SCOP calculation parameters

Mode	**COP**	FP	**FC**
Heating and DHW	4.5	0.74	1

The SCOP considered for both operation modes has been 3.3, which shows that all heat pumps to be considered for this study will be considered as renewable.

When evaluating the energy efficiency of air conditioning systems, it is important to consider the performance known as SEER, which is used in cooling mode. For reference, a SEER of 3.2 has been established based on historical data provided by the IDEA [50]. However, portable air conditioners have limitations in design and size that result in lower energy efficiency compared to wall mounted or central units and are typically rated with a SEER value of 2.7, which is just the limit to avoid being considered inefficient according to IDAE.

E. Residential consumption by energetic resource

As mentioned above, for heating, has been considered the data from the Benicalap district, where 88% of the people in the neighborhood have some kind of heating appliance.

Table 12.6 Residential consumption by energy resource

Energy resource	**Heating**	**DHW**	**Cooling**	**Cooking**	**Lighting**	**Household appliances**	***TOTAL (MWh)***
Oil products	5,602	766	-	814	-	-	***7,181***
Natural gas	10,104	13,041	-	2,262	-	-	***25,408***
Renewable resource	561	187	-	48	-	-	***796***
Coal	536	-	-	-	-	-	***536***
Electricity	12,773	3,592	4,637	2,349	4,073	18,291	***45,715***
TOTAL (MWh)	***29,576***	***17,586***	***4,637***	***5,473***	***4,073***	***18,291***	***79,636***

F. Simulation elements

This part of the appendix is intended to show the whole study carried out behind the simulation performed with the HOMER software.

As far as alternating current is concerned, the installation is mainly composed of the electrical grid and the photovoltaic system. These can directly cover the electricity demand of the neighborhood or, the photovoltaic system can charge the battery system through the converter. The converter acts as an AC to DC transformer element. The storage system can be discharged when pre-set requirements are met, meeting the electricity demand at times when the PV system cannot, thus reducing purchases from the grid.

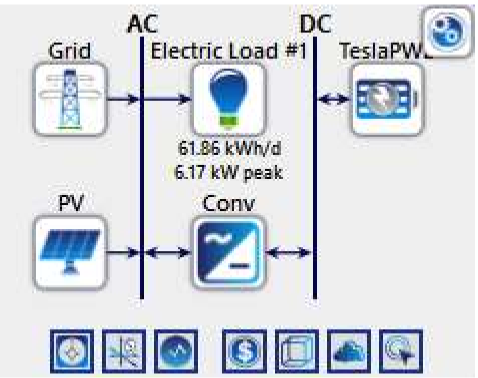


Figure 12.3 Scheme from Homer for the simulation of the project

The pattern chosen for the simulation has been to use the cyclical charging strategy. This strategy uses a generator element running every time the system requires it and the excess energy charges the battery bank.

<u>Simulation input data</u>

- **Solar resource:** from the hourly data obtained from PVGIS, HOMER calculates the daily radiation and a clearness index. This index varies according to sky conditions, having a high value in clear and sunny sky conditions, and a low value in cloudy sky conditions. The values and the graph representing these data can be seen in figure 12.4.

Choose Data Source: ○ Enter monthly averages ● Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.640	2.767
February	0.683	3.901
March	0.668	5.131
April	0.546	5.278
May	0.631	6.958
June	0.671	7.772
July	0.665	7.502
August	0.648	6.578
September	0.575	4.799
October	0.609	3.825
November	0.616	2.848
December	0.514	2.007

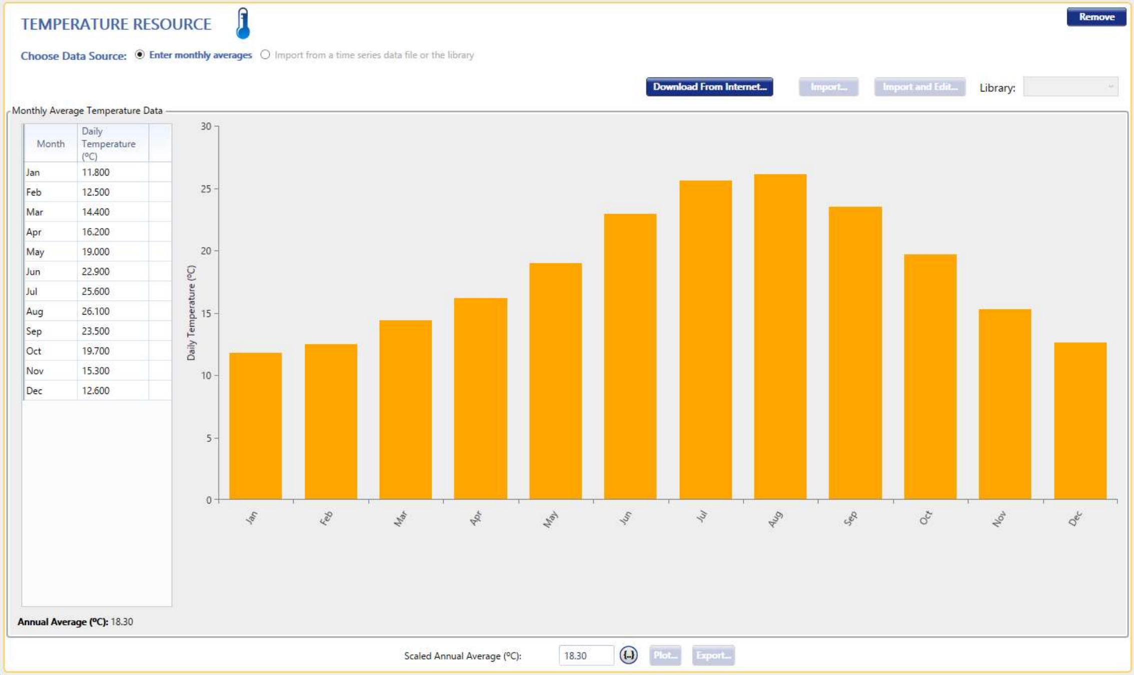
File: C:\Users\Sergi\Desktop\TFM\SIMULACIONES\Radiación_Beni.csv
Time step: 60 min
Imported on: Tue, 22 Nov 2022 13:28:56 GMT

Annual Average (kWh/m²/day): 4.95

Scaled Annual Average (kWh/m²/da 4.49

Figure 12.4 Solar Resource Inputs from the HOMER simulations

- **Temperature resource:** based on the normal monthly climatological values for Valencia provided by AEMET, a temperature profile has been established in HOMER for each month. Figure 11.3 shows how HOMER has read this file and displays it on the screen.



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Temperature Data

Month	Daily Temperature (ºC)
Jan	11.800
Feb	12.500
Mar	14.400
Apr	16.200
May	19.000
Jun	22.900
Jul	25.600
Aug	26.100
Sep	23.500
Oct	19.700
Nov	15.300
Dec	12.600

Annual Average (ºC): 18.30

Scaled Annual Average (ºC): 18.30

Figure 12.5 Temperature Resource Inputs from the HOMER simulation

- **Hourly energy demand of the neighborhood:** this data is obtained from the process explained from the data of Datadis. From this platform, 8760 hourly values have been entered into the system. The parameters required for the simulation, as well as the different profiles created by HOMER can be seen in figure 11.4.

Name: Electric Load #1

January Profile

Hour	Load (kW)
0	3.18
1	2.61
2	2.28
3	2.1
4	2.04
5	2.09
6	2.34
7	2.91
8	3.25
9	3.48
10	3.78
11	3.84
12	3.79
13	3.96

Time Step Size: **60** minutes

Random Variability
Day-to-day (%): **9.314**
Timestep (%): **4.388**

Peak Month: **January**

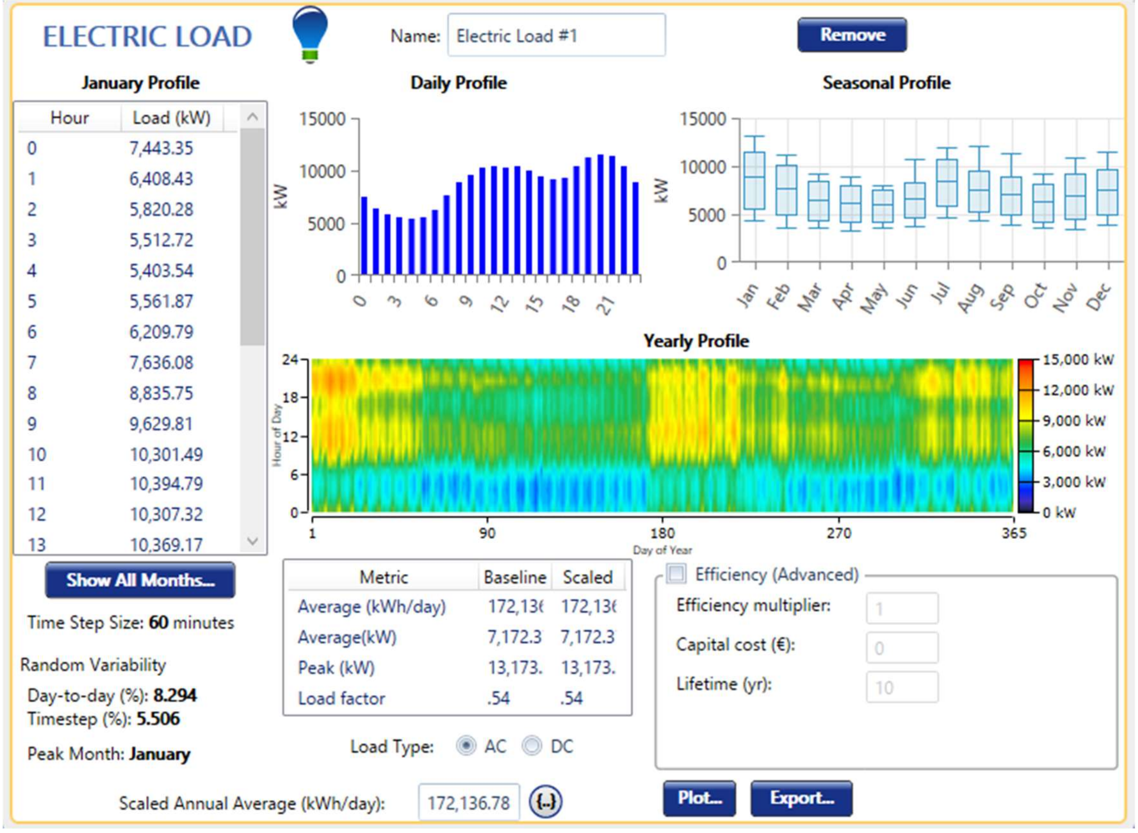
Metric	Baseline	Scaled
Average (kWh/day)	61.86	61.86
Average(kW)	2.58	2.58
Peak (kW)	6.17	6.17
Load factor	.42	.42

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)
Efficiency multiplier: 1
Capital cost (€): 0
Lifetime (yr): 10

Scaled Annual Average (kWh/day): 61.86

Figure 12.6 Data presented in Homer with the introduction of the electricity demand of the typical building.



Name: Electric Load #1

January Profile

Hour	Load (kW)
0	7,443.35
1	6,408.43
2	5,820.28
3	5,512.72
4	5,403.54
5	5,561.87
6	6,209.79
7	7,636.08
8	8,835.75
9	9,629.81
10	10,301.49
11	10,394.79
12	10,307.32
13	10,369.17

Time Step Size: **60** minutes

Random Variability
Day-to-day (%): **8.294**
Timestep (%): **5.506**

Peak Month: **January**

Metric	Baseline	Scaled
Average (kWh/day)	172,13	172,13
Average(kW)	7,172.3	7,172.3
Peak (kW)	13,173.	13,173.
Load factor	.54	.54

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)
Efficiency multiplier: 1
Capital cost (€): 0
Lifetime (yr): 10

Scaled Annual Average (kWh/day): 172,136.78

Figure 12.7 Data presented in Homer with the introduction of neighborhood electricity demand.

- **Hourly distribution in the different electricity pricing periods:** the new "Precio voluntario para el pequeño consumidor (PVPC)" in its tariff 2.0 TD, has an hourly discrimination in three periods in which the application of tolls and regulatory rates will vary depending on the period that acts in each hour of the day. The off-peak period (purple color represented in figure 12.8) will be the period when these tolls and charges will be lowest, the flat period (blue color represented in the figure) with an intermediate impact of these regulated costs, while the peak period (red color represented in the figure) will be when these regulated tolls and charges will be highest.

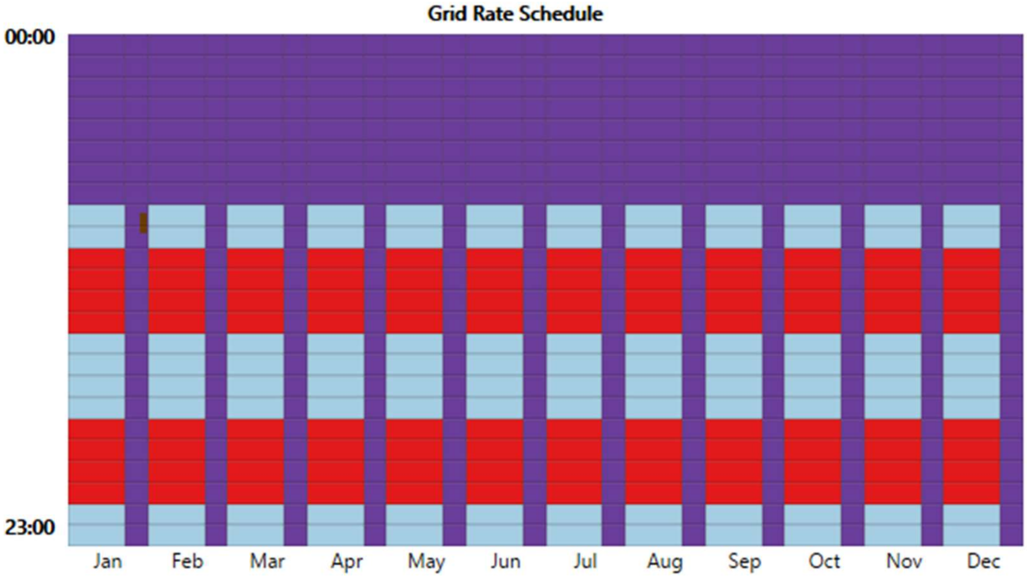


Figure 12.8 Rate schedule with the identification of the three period tariffs

- **Electricity prices:** in HOMER, electricity purchase and sale prices were introduced for the economic study. These prices can be seen in table 8.2 of section 8 of the "Economic Analysis".

- **Taxes and fees on electricity and energy:** The tariffs for the power and energy terms for the different periods have been obtained directly from the "Comisión Nacional de los Mercados y la Competencia" [61].

Table 12.7 Power and energy term fees for the different periods.

Regulated prices	**Period 1**	**Period 2**	**Period 3**
Power term fees (€/kW year)	30.672		1.4243
Energy term fees (€/kWh)	0.1331	0.0418	0.0060

The two taxes considered for marketing were as follows:

- "Impuesto sobre la electricidad (IE)": 5.113%
- "Impuesto sobre el Valor Añadido (IVA)": 21%

These taxes must be considered for the cost of energy, as well as for the distribution and commercialization values shown in the table above. The latter have been entered directly into HOMER.

Table 12.8 Power and energy term fees for the different periods including taxes.

Regulated prices	Period 1	Period 2	Period 3
Power term fees (€/kW year)	39,011		1.8116
Energy term fees (€/kWh)	0.1331	0.0531	0.0076

- **PV system:** Considering the optimum value of installed capacity as a function of the percentage of useful surface area, power, and economic parameters such as investment capital, replacement cost and O&M cost previously considered [6]. Further in this section, a detailed explanation is provided regarding the precise method for calculating the photovoltaic capacity that is installed on a roof surface.

  In summary, the parameters considered were as follows:

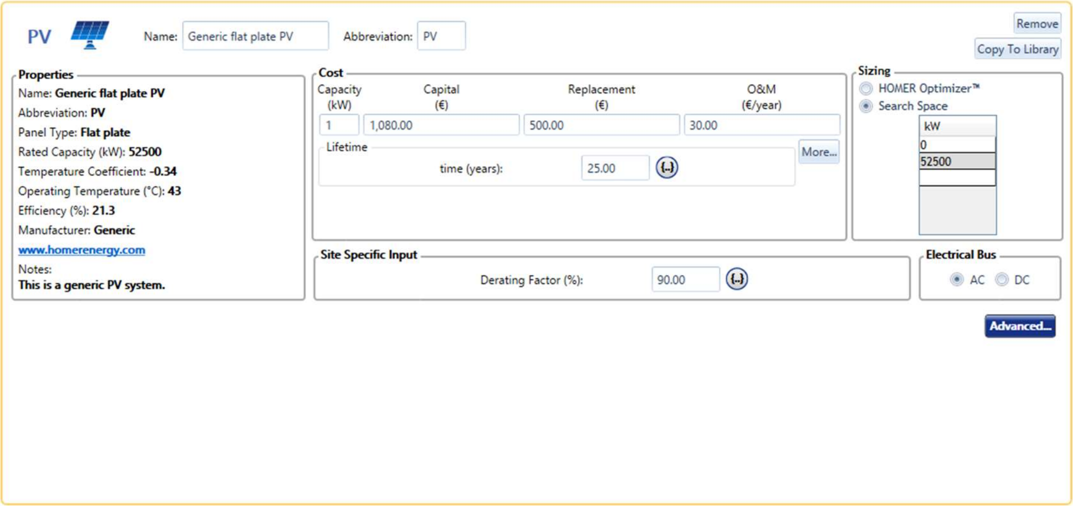
  - Installed capacity: 52,500 kW
  - Capital cost: 1,080 €/kW
  - Replacement cost: 500€/kW
  - O&M cost: 30 €/year per kW
  - Lifetime: 25 years

  The photovoltaic installation will be done progressively according to table 7.1 of section 7, this progressive installation will be introduced to HOMER as follows:

Table 12.9 Timeline of the PV system

	PV installed (kW)
Year 0	-
2024	21,000
2025	26,250
2026	31,500
2027	36,750
2028	42,000
2029	47,250
2030	52,500

Figure 12.9 shows the photovoltaic system represented in HOMER for the year 2030:



Name: Generic flat plate PV
Abbreviation: PV

Properties
Name: **Generic flat plate PV**
Abbreviation: **PV**
Panel Type: **Flat plate**
Rated Capacity (kW): **52500**
Temperature Coefficient: **-0.34**
Operating Temperature (°C): **43**
Efficiency (%): **21.3**
Manufacturer: **Generic**
www.homerenergy.com
Notes:
This is a generic PV system.

Cost

Capacity (kW)	Capital (€)	Replacement (€)	O&M (€/year)
1	1,080.00	500.00	30.00

Lifetime
time (years): 25.00

Sizing
○ HOMER Optimizer™
● Search Space

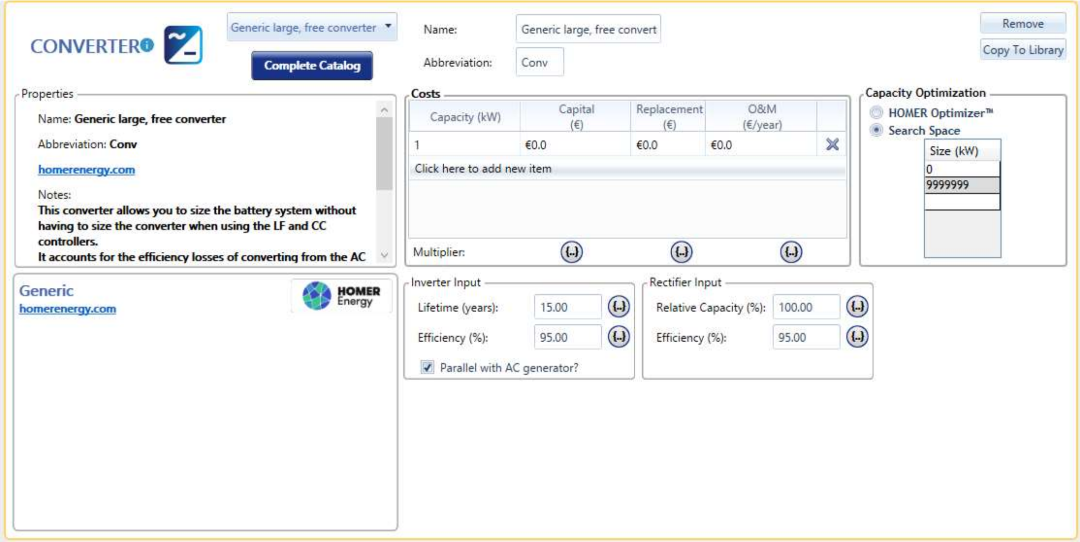
kW
0
52500

Site Specific Input
Derating Factor (%): 90.00

Electrical Bus
● AC ○ DC

Figure 12.9 PV inputs consideration in HOMER simulations.

- **Converter:** a generic converter has been included from the program's catalog; it has an efficiency of 95% and a lifetime of 15 years. It will not have any technical limitation in energy conversion. On the other hand, all the economic costs are included in the battery system itself, which will be shown later.



Name: Generic large, free convert
Abbreviation: Conv

Properties
Name: **Generic large, free converter**
Abbreviation: **Conv**
homerenergy.com
Notes:
This converter allows you to size the battery system without having to size the converter when using the LF and CC controllers.
It accounts for the efficiency losses of converting from the AC

Costs

Capacity (kW)	Capital (€)	Replacement (€)	O&M (€/year)
1	€0.0	€0.0	€0.0

Multiplier:

Capacity Optimization
○ HOMER Optimizer™
● Search Space

Size (kW)
0
9999999

Inverter Input
Lifetime (years): 15.00
Efficiency (%): 95.00
☑ Parallel with AC generator?

Rectifier Input
Relative Capacity (%): 100.00
Efficiency (%): 95.00

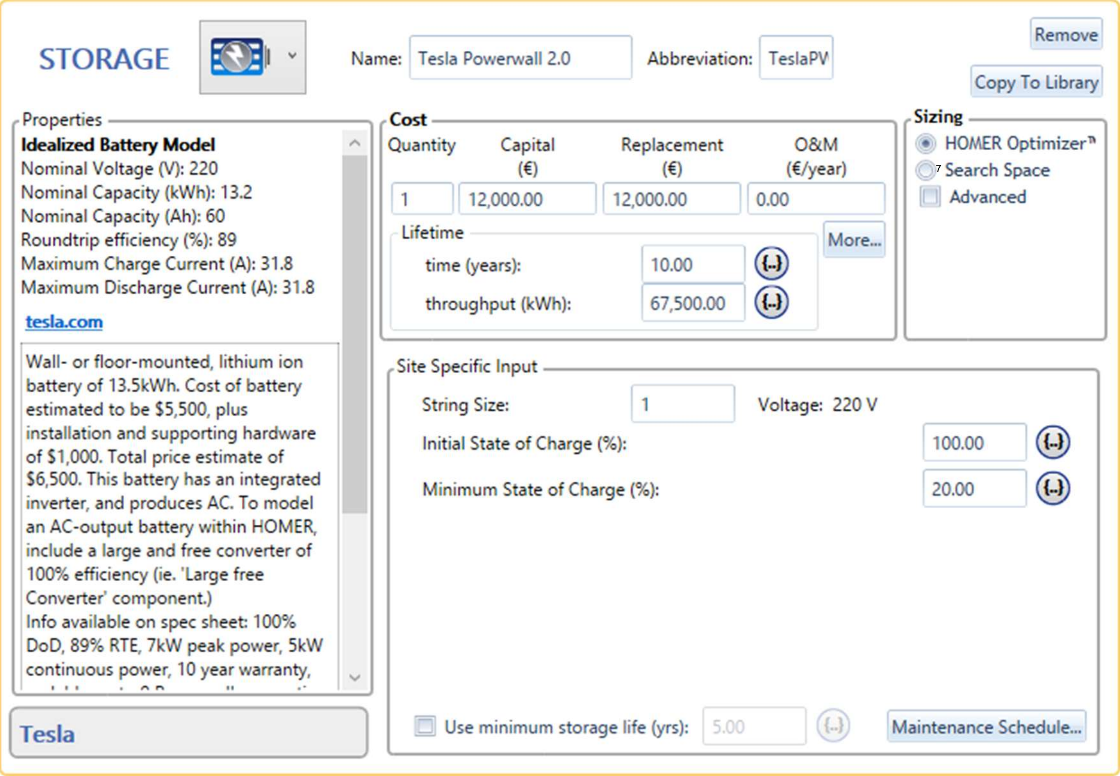
Figure 12.10 Converter consideration in HOMER simulations.

- **Battery system:** the chosen battery has been extracted from HOMER own lithium-ion battery catalog. This type of battery, based on the Idealized storage model, allows users to size the energy and power independently of each other. The idealized storage model reproduces a simple storage model that assumes a flat discharge curve because the supply voltage remains constant during the discharge cycle using this as the actual storage capacity. Some high-performance lithium-ion batteries, for example, can be modeled well with an idealized storage model.

The chosen commercial model is the 13.2 kWh Tesla Powerwall battery. The justification for selecting this model is explained further in this same section.The main parameters considered were as follows:

- Total nominal capacity: 13,464 kWh
- Capital cost: 12,000 €/u
- Replacement cost: 12,000 €/u
- O&M cost: 0 €/year
- Lifetime: 10-12 years

The rest of the characteristics and those previously mentioned can be seen in figure 11.8.



STORAGE

Name: Tesla Powerwall 2.0

Abbreviation: TeslaPV

Properties

Idealized Battery Model
Nominal Voltage (V): 220
Nominal Capacity (kWh): 13.2
Nominal Capacity (Ah): 60
Roundtrip efficiency (%): 89
Maximum Charge Current (A): 31.8
Maximum Discharge Current (A): 31.8

tesla.com

Wall- or floor-mounted, lithium ion battery of 13.5kWh. Cost of battery estimated to be $5,500, plus installation and supporting hardware of $1,000. Total price estimate of $6,500. This battery has an integrated inverter, and produces AC. To model an AC-output battery within HOMER, include a large and free converter of 100% efficiency (ie. 'Large free Converter' component.)
Info available on spec sheet: 100% DoD, 89% RTE, 7kW peak power, 5kW continuous power, 10 year warranty,

Tesla

Cost

Quantity	Capital (€)	Replacement (€)	O&M (€/year)
1	12,000.00	12,000.00	0.00

Lifetime
time (years): 10.00
throughput (kWh): 67,500.00

Sizing
● HOMER Optimizer™
○ Search Space
☐ Advanced

Site Specific Input
String Size: 1
Voltage: 220 V
Initial State of Charge (%): 100.00
Minimum State of Charge (%): 20.00
☐ Use minimum storage life (yrs): 5.00

Figure 12.11 Storage system consideration in HOMER simulations

As with the photovoltaic system, the installation of the battery system will also be done progressively following the schedule shown in table 7.1 of section 7.

Table 12.10 Timeline of implementation of the battery system

	Batteries nominal Capacity (kWh)
Year 0	-
2024	5,386
2025	6,732
2026	8,079
2027	9,425
2028	10,772
2029	12,118
2030	13,464

- **Progressive decrease in demand**: As previously mentioned, the implementation of electrification measures in the residential sector leads to a gradual reduction in electricity demand within the neighborhood. However, it is worth noting that HOMER has an option to incorporate this increase. The specific details regarding this increase can be observed in the following table:

Table 12.11 Progressive decrease in electricity demand during the application of the measures

Year	New demand decrease (MWh)	Data to HOMER	Variation
2023	77,085	100.00	0%
2024	76,973	99.8538309	-0.146%
2025	76,306	98.9889020	-1.011%
2026	75,862	98.4122828	-1.588%
2027	75,417	97.8356635	-2.164%
2028	74,528	96.6824250	-3.318%
2029	73,639	95.5291865	-4.471%
2030	72,750	94.3759479	-5.624%

Rooftop photovoltaic installed capacity

The selection of the installed capacity on the rooftops of the Benicalap neighborhood was based on a comprehensive preliminary study. It was determined that only 38% of the rooftop area was suitable for photovoltaic installation, taking into account shade avoidance. Subsequently, it was identified that the highest photovoltaic production could be achieved with a tilt angle of 15 degrees, resulting in a capacity of 142 W/m2 at this inclination [6]. This analysis utilized the dimensions of the Trina Solar TSM-DE09.08 panel as a reference, ensuring precise calculations and compliance with technical specifications.

These parameters were meticulously evaluated to optimize the utilization of rooftop surfaces in Benicalap and maximize solar energy generation potential. Unsuitable and unavailable areas for photovoltaic panel installation, such as chimney areas, zones near the rooftop limits, and areas affected by shadows from other elements, were eliminated. Therefore, only areas with a surface area greater than 20 m2 were considered as a filtering criterion to avoid the previously mentioned areas.

For the calculation of the photovoltaic capacity to be installed on a building's rooftop, the aforementioned criteria were taken into account. According to Datadis data, it was determined that the average number of dwellings per floor is 6, and the municipality of Valencia established that the average surface area per dwelling is 103.3 m2, resulting in an average rooftop surface area of 619.8 m2. However, considering the previously established criteria to maximize the gains from the photovoltaic installation, the usable surface area for installation was determined to be 486.1 m2. Despite the filters considered above, it has been decided to leave an additional 20% of the roof for residential use in case it would be necessary to place the heat pump and related equipment in this area, as well as the batteries.

Table 12.12 shows the main characteristics used for the performance of the photovoltaic installation in the building blocks.

Table 12.12 General characteristics of the proposed photovoltaic installation on the roof of a building in the Benicalap neighborhood

Panel inclination $(°)$	15
Power (kW/m^2)	0.142
Average area allocated for photovoltaic (m^2)	388.88
Power considered per rooftop (kW)	14.8

Determination of installed PV power on the proposed building

Through a series of simulations, the installed photovoltaic power capacity in each building has been determined, considering various capacities starting from a peak power of 6.17 kW. The chosen option, which prioritizes the optimization of the system for self-consumption, involves installing 14.8 kW of photovoltaic capacity on the available surface area of each building. This decision aims to minimize wasted energy and maximize the utilization of solar power generated within the system.

Table 12.13 Results of the iterations to estimate the installed photovoltaic power in the proposed building.

Installed capacity (kW)	PV/Energy Production (kWh/y)	Electricity from the grid (kWh)	Electricity sales to the grid (kWh)
6.7	10,555	12,585	117
8.4	13,233	10,935	886
12.4	19,535	9,314	5,348
14.8	23,315	8,854	8,621

16.8	26,466	8,615	11,517
20.4	32,137	8,328	16,884

Determination of the battery capacity on the proposed building

The choice of a 13.2 kWh battery capacity was made through iterations using the different batteries available in HOMER's catalog. The main idea was to use a commercial battery within the software's catalog, as it provides detailed battery specifications and allows for a more precise analysis.

Figure 12.12 shows that around the 13-14 kWh range, the curve becomes more moderate. Since it is the only battery within this range and offers good technical performance, without considering the economic aspect, the decision has been made to use the Tesla Powerwall model with a capacity of 13.2 kWh.

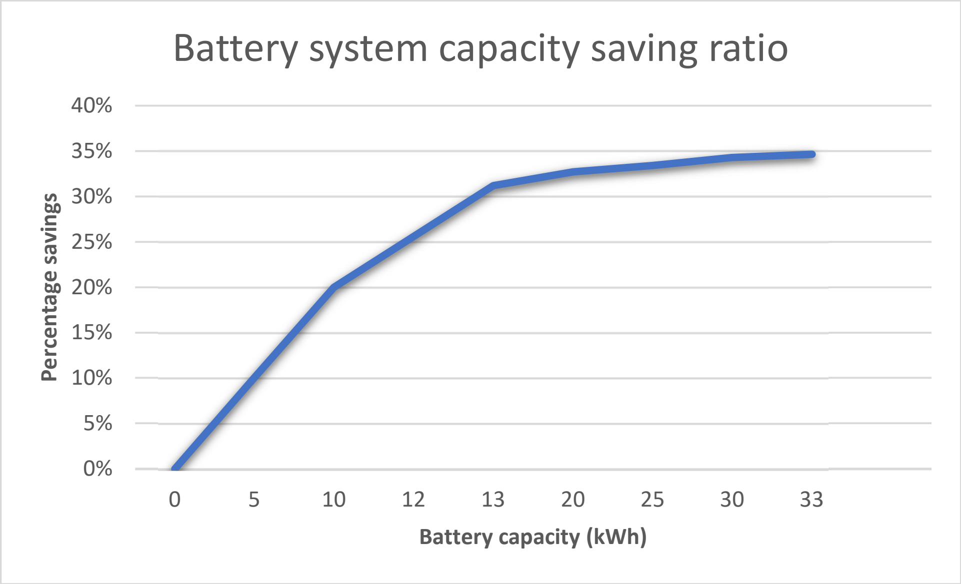


Figure 12.12 Curve for battery capacity estimation for proposed building

Simulation results

Table 12.14 intended to show the results of the simulations, showing the evolution of the system in the neighborhood. It is worth mentioning that some of the economic aspects have been modified following what was mentioned in section 8 on the sale of electricity associated with the simplified compensation mechanism.

Table 12.14 Simulation results in HOMER with the implementation of the measures in the neighborhood

Year	AC Primary Load Served (MWh/year)	Renewable fraction (%)	PV capacity factor (%)	PV operation time (hours)	PV nominal capacity (kW)	PV total production (MWh/year)	Battery Annual throughput (MWh/year)	Battery nominal capacity (kWh)	Annual net energy purchases (MWh)	Annual net energy sold (MWh)
2024	76,973	43.8%	17.98	4,079	21,000	33,082.6	1,580.7	5,386	41,984.9	5,235.3
2025	76,306	51.1%	17.98	4,079	26,250	41,353.3	2,230.5	6,732	39,142,4	11,124.3
2026	75,862	56.9%	17.98	4,079	31,500	49,623.9	2,801.9	8,079	37,206.9	17,737.1
2027	75,417	61.6%	17.98	4,079	36,750	57,894.6	3,321.2	9,425	35,622.7	24,712.1
2028	74,528	65.8%	17.98	4,079	42,000	66,165.2	3,846.1	10,772	33,987.6	32,036.8
2029	73,639	69.3%	17.98	4,079	47,250	74,435.9	4,369.5	12,118	32,531.7	39,540.5
2030	72,750	72.4%	17.98	4,079	52,500	82,706.5	4,876.6	13,464	31,196.1	47,167.7

G. Economic parameters and results

This section will show all the parameters considered for the economic study.

Starting with the investment costs of some of the equipment and fossil fuels, as well as the source from which this data was obtained.

Table 12.15 Cost of some equipment and fossil fuels

Equipment/fossil fuels	Cost	Information source
Heat pump with hydraulic system	7,000.01 €/u	Data obtained from the CYPE price generator for a reversible air-to-water heat pump with hydraulic power unit and inertia accumulator [62].
Heat pump unit	5,610.21 €/u	Data obtained from the CYPE price generator for a reversible air-to-water heat pump without hydraulic system [62].
Heat pump with hydraulic system O&M cost	448.00 €/year	Data obtained from the CYPE price generator for a reversible air-to-water heat pump with hydraulic power unit and inertia accumulator [62].
Heat pump unit O&M cost	359.05 €/year	Data obtained from the CYPE price generator for a reversible air-to-water heat pump without hydraulic system [62].
Storage system	12,000 €/u	Commercial price comparison website, in this case for the Tesla Powerwall model in Spain [63].
Induction stove	355 €/u	Data obtained from the CYPE price generator for a generic induction stove [62]
Induction stove O&M cost	24 €/year	Data obtained from the CYPE price generator for a generic induction stove [62]
Mean Butane & Propane cylinder	0.093 €/kWh	Average price of butane and propane cylinder from 2016 to 2022 based on historical and commercial data in Spain [64] [65] [66].
NG	0.043 €/kWh	Average natural gas price from 2022 to 2016 according to “Mercado Ibérico del Gas “ [67] and considering the tax on NG hydrocarbons [68].
Coal	0.049 €/kWh	Commercial coal price in 2022 [69].

The results of the simple economic analysis are shown in table 12.9. On the other hand, the results of the composite economic analysis are reflected in the last two tables: the first with an inflation rate of 2% and the other with an inflation rate of 4%.

For better visibility, costs have been represented as negative values in red color, including cases where the Net Present Value (NPV) is negative. On the other hand, savings are represented as positive values in dark green color, and cases where the NPV achieves positive values are also displayed in this color.

Table 12.16 Economic results of the simple study for the proposed building

Year	Elec cost (€)	CF savings (€)	Elec savings (€)	O&M cost (€)	Annual cost (€)	Annual savings (€)	NPV_project (€)	LCOE (€/kWh)
2024	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 62,541**	0.081
2025	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 57,617**	0.081
2026	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 52,693**	0.081
2027	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 47,769**	0.081
2028	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 42,846**	0.081
2029	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 37,922**	0.081
2030	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 32,998**	0.081
2031	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 28,074**	0.081
2032	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 23,150**	0.081
2033	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 18,226**	0.081
2034	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 13,303**	0.081
2035	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 8,379**	0.081
2036	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**-€ 3,455**	0.081
2037	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 1,469**	0.081
2038	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 6,393**	0.081
2039	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 11,316**	0.081
2040	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 16,240**	0.081
2041	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 21,164**	0.081
2042	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 26,088**	0.081
2043	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 31,012**	0.081
2044	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 35,936**	0.081
2045	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 40,859**	0.081
2046	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 45,783**	0.081

2047	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 50,707**	0.081
2048	-€ 906	€ 1,683	€ 6,588	-€ 2,441	-€ 3,347	€ 8,271	**€ 55,631**	0.081

Table 12.17 Economic results of the composite study for the proposed building (inflation at 2%)

Year	Elec cost (€)	CF savings (€)	Elec savings (€)	O&M cost (€)	Annual cost (€)	Annual savings (€)	NPV_project (€)	LCOE (€/kWh)
2024	-€ 890	€ 1,654	€ 6,476	-€ 2,441	-€ 3,332	€ 8,129	**-€ 62,667**	0.081
2025	-€ 893	€ 1,658	€ 6,492	-€ 2,441	-€ 3,334	€ 8,150	**-€ 57,850**	0.081
2026	-€ 895	€ 1,662	€ 6,509	-€ 2,441	-€ 3,336	€ 8,171	**-€ 53,016**	0.081
2027	-€ 897	€ 1,667	€ 6,525	-€ 2,441	-€ 3,338	€ 8,192	**-€ 48,162**	0.081
2028	-€ 900	€ 1,671	€ 6,542	-€ 2,441	-€ 3,341	€ 8,213	**-€ 43,290**	0.081
2029	-€ 902	€ 1,675	€ 6,559	-€ 2,441	-€ 3,343	€ 8,234	**-€ 38,399**	0.081
2030	-€ 904	€ 1,679	€ 6,576	-€ 2,441	-€ 3,345	€ 8,255	**-€ 33,489**	0.081
2031	-€ 906	€ 1,684	€ 6,592	-€ 2,441	-€ 3,348	€ 8,276	**-€ 28,561**	0.081
2032	-€ 909	€ 1,688	€ 6,609	-€ 2,441	-€ 3,350	€ 8,297	**-€ 23,614**	0.081
2033	-€ 911	€ 1,692	€ 6,626	-€ 2,441	-€ 3,352	€ 8,318	**-€ 18,648**	0.081
2034	-€ 913	€ 1,697	€ 6,643	-€ 2,441	-€ 3,355	€ 8,340	**-€ 13,663**	0.081
2035	-€ 916	€ 1,701	€ 6,660	-€ 2,441	-€ 3,357	€ 8,361	**-€ 8,659**	0.081
2036	-€ 918	€ 1,705	€ 6,677	-€ 2,441	-€ 3,359	€ 8,382	**-€ 3,636**	0.081
2037	-€ 920	€ 1,710	€ 6,694	-€ 2,441	-€ 3,362	€ 8,404	**€ 1,406**	0.081
2038	-€ 923	€ 1,714	€ 6,711	-€ 2,441	-€ 3,364	€ 8,425	**€ 6,467**	0.082
2039	-€ 925	€ 1,718	€ 6,728	-€ 2,441	-€ 3,366	€ 8,447	**€ 11,548**	0.082
2040	-€ 928	€ 1,723	€ 6,745	-€ 2,441	-€ 3,369	€ 8,468	**€ 16,647**	0.082

2041	-€ 930	€ 1,727	€ 6,763	-€ 2,441	-€ 3,371	€ 8,490	**€ 21,766**	0.082
2042	-€ 932	€ 1,732	€ 6,780	-€ 2,441	-€ 3,373	€ 8,512	**€ 26,904**	0.082
2043	-€ 935	€ 1,736	€ 6,797	-€ 2,441	-€ 3,376	€ 8,533	**€ 32,062**	0.082
2044	-€ 937	€ 1,740	€ 6,815	-€ 2,441	-€ 3,378	€ 8,555	**€ 37,239**	0.082
2045	-€ 939	€ 1,745	€ 6,832	-€ 2,441	-€ 3,381	€ 8,577	**€ 42,435**	0.082
2046	-€ 942	€ 1,749	€ 6,850	-€ 2,441	-€ 3,383	€ 8,599	**€ 47,651**	0.082
2047	-€ 944	€ 1,754	€ 6,867	-€ 2,441	-€ 3,385	€ 8,621	**€ 52,887**	0.082
2048	-€ 947	€ 1,758	€ 6,885	-€ 2,441	-€ 3,388	€ 8,643	**€ 58,142**	0.082

Table 12.18 Economic results of the composite study for the proposed building (inflation at 4%)

Year	Elec cost (€)	CF savings (€)	Elec savings (€)	O&M cost (€)	Annual cost (€)	Annual savings (€)	NPV_project (€)	LCOE (€/kWh)
2024	-€ 890	€ 1,654	€ 6,476	-€ 2,441	-€ 3,332	€ 8,129	**-€ 62,667**	0.081
2025	-€ 910	€ 1,691	€ 6,619	-€ 2,441	-€ 3,351	€ 8,310	**-€ 57,708**	0.081
2026	-€ 930	€ 1,728	€ 6,766	-€ 2,441	-€ 3,372	€ 8,495	**-€ 52,585**	0.082
2027	-€ 951	€ 1,766	€ 6,917	-€ 2,441	-€ 3,392	€ 8,683	**-€ 47,294**	0.082
2028	-€ 972	€ 1,806	€ 7,070	-€ 2,441	-€ 3,413	€ 8,876	**-€ 41,831**	0.083
2029	-€ 994	€ 1,846	€ 7,227	-€ 2,441	-€ 3,435	€ 9,073	**-€ 36,193**	0.083
2030	-€ 1,016	€ 1,887	€ 7,388	-€ 2,441	-€ 3,457	€ 9,275	**-€ 30,375**	0.084
2031	-€ 1,038	€ 1,929	€ 7,552	-€ 2,441	-€ 3,480	€ 9,481	**-€ 24,374**	0.084
2032	-€ 1,061	€ 1,972	€ 7,720	-€ 2,441	-€ 3,503	€ 9,692	**-€ 18,185**	0.085
2033	-€ 1,085	€ 2,015	€ 7,891	-€ 2,441	-€ 3,526	€ 9,907	**-€ 11,804**	0.085
2034	-€ 1,109	€ 2,060	€ 8,067	-€ 2,441	-€ 3,550	€ 10,127	**-€ 5,228**	0.086
2035	-€ 1,134	€ 2,106	€ 8,246	-€ 2,441	-€ 3,575	€ 10,352	**€ 1,549**	0.087

2036	-€ 1,159	€ 2,153	€ 8,429	-€ 2,441	-€ 3,600	€ 10,582	**€ 8,531**	0.087
2037	-€ 1,185	€ 2,201	€ 8,616	-€ 2,441	-€ 3,626	€ 10,817	**€ 15,722**	0.088
2038	-€ 1,211	€ 2,249	€ 8,808	-€ 2,441	-€ 3,652	€ 11,057	**€ 23,127**	0.088
2039	-€ 1,238	€ 2,299	€ 9,003	-€ 2,441	-€ 3,679	€ 11,303	**€ 30,750**	0.089
2040	-€ 1,265	€ 2,350	€ 9,203	-€ 2,441	-€ 3,707	€ 11,554	**€ 38,597**	0.090
2041	-€ 1,294	€ 2,403	€ 9,408	-€ 2,441	-€ 3,735	€ 11,810	**€ 46,673**	0.090
2042	-€ 1,322	€ 2,456	€ 9,617	-€ 2,441	-€ 3,763	€ 12,073	**€ 54,983**	0.091
2043	-€ 1,352	€ 2,511	€ 9,830	-€ 2,441	-€ 3,793	€ 12,341	**€ 63,531**	0.092
2044	-€ 1,382	€ 2,566	€ 10,049	-€ 2,441	-€ 3,823	€ 12,615	**€ 72,323**	0.093
2045	-€ 1,412	€ 2,623	€ 10,272	-€ 2,441	-€ 3,854	€ 12,895	**€ 81,365**	0.093
2046	-€ 1,444	€ 2,682	€ 10,500	-€ 2,441	-€ 3,885	€ 13,182	**€ 90,662**	0.094
2047	-€ 1,476	€ 2,741	€ 10,733	-€ 2,441	-€ 3,917	€ 13,475	**€ 100,219**	0.095
2048	-€ 1,509	€ 2,802	€ 10,972	-€ 2,441	-€ 3,950	€ 13,774	**€ 110,043**	0.096