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Assessment of the potential to achieve carbon neutrality at a neighborhood level. Case study of La Carrasca in Valencia, Spain

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Final Master Thesis

ASSESSMENT OF THE POTENTIAL TO ACHIEVE CARBON NEUTRALITY AT A NEIGHBORHOOD LEVEL. CASE STUDY OF LA CARRASCA IN VALENCIA, SPAIN

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ABSTRACT

Cities are responsible for more than 70% of global greenhouse gas emissions. Therefore, assessing an area's potential to achieve carbon neutrality is required to calculate and measure its actual greenhouse gas reduction capacity in order to mitigate these emissions and the effects of climate change. Nevertheless, estimating decarbonization is difficult, mainly when an urban zone's big and complex area is analyzed.

Before evaluating the decarbonization potential, it is required to investigate the carbon footprint in the studied area. In this work, a methodology for estimating the decarbonization potential of a particular area is developed and applied to the neighborhood of La Carrasca in Valencia City, Spain. The idea of choosing a smaller area rather than an entire city is to focus efforts on such an area, process less information, and consider details that are not possible when a more extensive area is selected. This method could be extrapolated to other neighborhoods, obtaining information about the potential, estimating the emissions, and determining if it is possible to get a negative carbon emissions neighborhood. The method not only takes into account all likely emissions according to scopes 1, 2, and 3 (Direct emissions, primary indirect emissions, and other indirect emissions, respectively) but also all possible decarbonization reduction measures (The use of renewables for power generation, nature-based solutions, the use of electric vehicle, electrifying other consumptions such as natural gas, and improved waste management). The tools used to carry out the study are HOMER for estimating the energy production, QGIS for evaluating the functional areas for photovoltaic installations, DATADIS to calculate the electricity consumption in the different sectors (residential, service, and industrial), Google Earth for measuring areas and distances, and Excel to analyze all of the data.

As a result, it was obtained that for the neighborhood of La Carrasca, the potential of decarbonization is 6796 tons of CO_2, representing a bit more than 10.5% of its overall emissions. It can be concluded that to reach complete decarbonization of the area, the mitigation measures proposed need to be more aggressive, while also proposing new measures, like the refurbishment of buildings to reduce their energy consumption for climatization, and changes of habits in the population. From an economic analysis it was concluded that for projects of this magnitude, government incentives and promotions are necessary.

Keywords: carbon neutrality, positive energy district, neighborhood, GHG emissions, scopes, sectors, carbon footprint, decarbonization strategies, renewable energies, emission factors, carbon mitigation measures, emissions balance.

RESUMEN

Las ciudades son responsables de más del 70% de las emisiones globales de gases de efecto invernadero. Por lo tanto, es necesario evaluar el potencial de un área para lograr la neutralidad en carbono para calcular y medir su capacidad real de reducción de gases de efecto invernadero con el fin de mitigar estas emisiones y los efectos del cambio climático. Sin embargo, estimar la descarbonización es difícil, principalmente cuando se analiza el área grande y compleja de una zona urbana.

Antes de evaluar el potencial de descarbonización, se requiere investigar la huella de carbono en el área de estudio. En este trabajo, se desarrolla y aplica una metodología para estimar el potencial de descarbonización de un área particular, el barrio de La Carrasca en la ciudad de Valencia, España. La idea de elegir un área más pequeña en lugar de una ciudad entera es concentrar los esfuerzos en dicha área, procesar menos información y considerar detalles que no son posibles cuando se selecciona un área más extensa. Este método podría extrapolarse a otros barrios, obteniendo información sobre el potencial, estimando las emisiones y determinando si es posible obtener un barrio con emisiones negativas de carbono. El método no solo tiene en cuenta todas las emisiones probables según los alcances 1, 2 y 3 (emisiones directas, emisiones indirectas primarias y otras emisiones indirectas, respectivamente), sino también todas las posibles medidas de reducción de la descarbonización (el uso de energías renovables para la generación de energía, soluciones basadas en la naturaleza, el uso del vehículo eléctrico, la electrificación de otros consumos como el gas natural y la mejora en la gestión de residuos). Las herramientas utilizadas para realizar el estudio son HOMER para estimar la producción de energía, QGIS para evaluar las áreas funcionales de las instalaciones fotovoltaicas, DATADIS para calcular el consumo eléctrico en los diferentes sectores (residencial, servicios e industrial), Google Earth para medir áreas y distancias, y Excel para analizar todos los datos.

Como resultado, se obtuvo que para el barrio La Carrasca el potencial de descarbonización es de 6796 toneladas de CO_2, lo que representa un poco más del 10,5% de sus emisiones totales. Se puede concluir que, para alcanzar la descarbonización completa de la zona, las medidas de mitigación propuestas deben ser más agresivas, proponiendo también nuevas medidas, como la rehabilitación de edificios para reducir sus consumos energéticos para la climatización, y cambios de hábitos en la población. Del análisis económico se concluyó que para proyectos de esta magnitud son necesarios incentivos y promociones gubernamentales.

Palabras clave: neutralidad de carbono, distrito de energía positiva, barrio, emisiones de GEI, alcances, sectores, huella de carbono, estrategias de descarbonización, energías renovables, factores de emisión, medidas de mitigación de carbono, balance de emisiones.

RESUM

Les ciutats són responsables de més del 70% de les emissions globals de gasos d'efecte d'hivernacle. Per tant, és necessari avaluar el potencial d'una àrea per a aconseguir la neutralitat en carboni per a calcular i mesurar la seua capacitat real de reducció de gasos d'efecte d'hivernacle amb la finalitat de mitigar aquestes emissions i els efectes del canvi climàtic. No obstant això, estimar la descarbonització és difícil, principalment quan s'analitza l'àrea gran i complexa d'una zona urbana.

Abans d'avaluar el potencial de descarbonització, es requereix investigar la petjada de carboni en l'àrea d'estudi. En aquest treball, es desenvolupa i aplica una metodologia per a estimar el potencial de descarbonització d'una àrea particular, el barri de la Carrasca a la ciutat de València, Espanya. La idea de triar una àrea més xicoteta en lloc d'una ciutat sencera és concentrar els esforços en aquesta àrea, processar menys informació i considerar detalls que no són possibles quan se selecciona una àrea més extensa. Aquest mètode podria extrapolar-se a altres barris, obtenint informació sobre el potencial, estimant les emissions i determinant si és possible obtindre un barri amb emissions negatives de carboni. El mètode no sols té en compte totes les emissions probables segons els abastos 1, 2 i 3 (emissions directes, emissions indirectes primàries i altres emissions indirectes, respectivament), sinó també totes les possibles mesures de reducció de la descarbonització (l'ús d'energies renovables per a la generació d'energia, solucions basades en la naturalesa, l'ús del vehicle elèctric, l'electrificació d'altres consums com el gas natural i la millora en la gestió de residus). Les eines utilitzades per a realitzar l'estudi són HOMER per a estimar la producció d'energia, QGIS per a avaluar les àrees funcionals de les instal·lacions fotovoltaiques, DATADIS per a calcular el consum elèctric en els diferents sectors (residencial, serveis i industrial), Google Earth per a mesurar àrees i distàncies, i Excel per a analitzar totes les dades.

Com a resultat, es va obtindre que per al barri La Carrasca el potencial de descarbonització és de 6796 tones de CO_2, la qual cosa representa una mica més del 10,5% de les seues emissions totals. Es pot concloure que, per a aconseguir la descarbonització completa de la zona, les mesures de mitigació proposades han de ser més agressives, proposant també noves mesures, com la rehabilitació d'edificis per a reduir els seus consums energètics per a la climatització, i canvis d'hàbits en la població. De l'anàlisi econòmica es va concloure que per a projectes d'aquesta magnitud són necessaris incentius i promocions governamentals.

Paraules clau: neutralitat de carboni, districte d'energia positiva, barri, emissions de GEI, abastos, sectors, petjada de carboni, estratègies de descarbonització, energies renovables, factors d'emissió, mesures de mitigació de carboni, balanç d'emissions.

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ACRONYMS

GHG	Greenhouse gases
SDG	Sustainable Development Goals
UPV	Polytechnic University of Valencia
UV	University of Valencia
JPI	Joint Programming Initiative
PED	Positive Energy District
PV	Photovoltaic
HP	Heat Pump
NBS	Nature-based Solutions
EV	Electric Vehicle
CO_2	Carbon Dioxide
CNG	Compressed Natural Gas
LPG	Liquified Petroleum Gas
IMD	Average Daily Intensity
QGIS	Quantum Geographic Information System
UNEF	Spanish Photovoltaic Union
IDAE	Institute for Diversification and Saving of Energy
PVGIS	Photovoltaic Geographical Information System
HOMER	Hybrid Optimization of Multiple Energy Resources
MITECO	Ministry for the Ecological Transition and the Demographic Challenge
SHW	Sanitary Hot Water
EMT	Municipal Transport Company
EMTRE	Metropolitan Entity for the Treatment of Waste
CAPEX	Capital Expenditure
OPEX	Operating Expenses
NPV	Net Present Value

1 INTRODUCTION

1.1 Background

In an attempt to mitigate and control the effects of climate change, countries have agreed to reduce their emissions to maintain the global temperature rise to 1.5°C or below. Cities have a huge role to play in achieving those goals since they are responsible for most of the worldwide energy demand and more than 70% of global greenhouse gas (GHG) emissions. To reduce their carbon footprint, city governments need to implement policies and technologies to improve how its inhabitants consume energy and the sources that produce it (renewables), impulse more sustainable transport, change their habits of consumption, and increase the carbon capture in the area to create a net zero environment where all of the emissions produced are absorbed. In order to kickstart this urban transition, the city of Valencia has become part of the European project to drive 100 cities to become climate-neutral by 2030 [1] and use them as examples for future projects in order to ultimately fulfill the targets of the Paris Agreement of 2015 [2] to reach net zero by 2050.

To address these global challenges, the United Nations have provided a set of 17 goals for achieving a more sustainable future, labelled Sustainable Development Goals (SDG) [3]. The project that is being proposed in this document addresses many of these goals. Mainly SDG 7 affordable and clean energy, SDG 8 decent work and economic growth, SDG 11 sustainable cities and communities, SDG 12 responsible consumption and production, and SDG 13 climate action.

1.2 Motivation and Justification

The goals of the city serve as the first motivation for the research and development of this project. This work aims to develop a methodology to estimate the potential of reducing the total GHG emissions on a neighborhood scale. The reason for choosing a smaller urban area, compared to the whole city, is to concentrate efforts on specific details that otherwise would not be considered by selecting a more extensive size while utilizing less, but more precise, information as well as providing a framework that can be extrapolated to other neighborhoods, especially if they are similar in structure and climate. In other words, analyzing this smaller area should provide more realistic results for all direct and indirect emissions, and all the decarbonization measures that will be presented, including renewable energy system implementations, natural-based solutions (NBS), sustainable transport, improved waste management, among others.

The Valencia city neighborhood that will be analyzed in this work is La Carrasca, which is located in the Algirós district on the northern part of the city. It's very particular in comparison to others in the city because of the complexities that make up the area. Primarily, it includes two big universities, the Polytechnic University of Valencia Campus of Vera (UPV) and the University of Valencia Campus of Tarongers (UV), as well as several secondary education institutes. Also, there is a large agricultural area on the northern part of the neighborhood. The diversity of the area provides a complex challenge when analyzing methods for its decarbonization, which adds motivation to analyze how carbon mitigation measures that have been used in other areas perform in a more specific urban area infrastructure.

In a state-of-the-art review about zero emission neighborhoods and positive energy districts (PEDs) [4], it's mentioned that although there are quite a few studies tackling the field of decarbonization at a neighborhood or district level, and it has been growing in the las decade, there is still a lack of common definitions, keywords and indicators that has made it difficult for researchers to follow and compare projects. There is also a lack of commonness in the definition of the area, whether it's neighborhood, district, community, cluster of buildings, etc. Meaning that studies done on a specific scale are scarce. In a similar way, there is a lot of diversity on the location of case studies and the climate of the location greatly influences the potential that an area has for implementing different technologies and how these technologies perform. Most of the studies are performed in countries with colder climates that in Valencia, meaning that they need more heating, less cooling, and their potential for PV production is different. As well as other particularities that affect the performance of different technologies. Finally, there is little homogeneity in the methodologies used as a considerable amount of the reviewed studies present new methodologies, as well as how much they include in the scope of the study. Because of this, it can be concluded that another novelty of this decarbonization study is that it intends to address all three scopes of emissions, presenting different strategies, technologies and solutions to determine the complete potential of an area with a Mediterranean climate to transition into a carbon neutral neighborhood.

1.3 Objectives

As it was mentioned before, the goal of this study is to establish a methodology for estimating the decarbonization potential of an area and create a roadmap on how to achieve it in the neighborhood of La Carrasca in Valencia. It will be developed through the following specific goals:

- Establish a GHG emissions inventory of the area, considering the different sectors that it encompasses across all three scopes of emissions.
- Develop a methodology to estimate these emissions, creating a carbon footprint of the neighborhood, and analyze its potential for decarbonization.
- Propose carbon mitigation measures to analyze how they change the structures and habits of the neighborhood in order to decrease its overall emissions and estimate how close it is to achieving carbon neutrality.
- Develop a carbon balance, comparing the initial situation with the proposed future scenario considering the mitigation actions proposed.
- Analyze the results, draw conclusions and detail guidelines for future actions towards improving and expanding on the presented study.

1.4 Methodology and Structure

This document is organized in nine established chapters that detail the process and development of the presented study.

Starting with an introduction that includes a background of general information on the subject, the motivation for realizing this study and justifications on its novelty, the main objectives that the project will try to achieve, and the current section about the organization of the redacted document.

The second chapter is a state-of-the-art review. Focused on conceptualizing a carbon neutral neighborhood, categorizing the GHG emissions in cities, and defining different strategies for achieving carbon neutrality which are being used worldwide.

The main tools that were used in the development of this study are presented in chapter three. Summarizing how their purpose and how they were used.

The fourth chapter focuses on explaining the used methodology throughout the realization of the study with the main steps followed.

The next chapter presents the selected neighborhood of La Carrasca and the results of applying the methodology and carbon mitigation strategies. It also includes an economic analysis of the project to analyze its viability and determine how government incentives contribute to it.

In the sixth chapter, the carbon balance comparing the initial situation and the proposed future scenario is analyzed considering the overall CO_2 emissions across the three scopes and sectors.

Chapter seven presents the main conclusions of the study and future actions to consider. Meanwhile, chapter nine displays the bibliography of references used for the research and development of the work.

Finally, a section of annexes presents detailed information to clarify and expand on the calculations made in the realization of the study.

1.5 Scope of the Project

The work done in this project aims to make a complete carbon emissions inventory of the studied neighborhood, classifying them in the three scopes of emissions (direct, main indirect, and other indirect emissions), and provide well developed mitigation measures to reduce them. It's succesfull in accounting most emissions across the three scopes. The direct emissions of the area that are considered come from two sources: the natural gas consumption in buildings, and the fuel consumption of the transportation inside the neighborhood which includes the private vehicles owned by the inhabitants and the public transport that is assigned to the area. The main indirect emissions come from the electricity consumption of the area, which is completely accounted for since its consumed by the buildings, the public lighting and the electric transport. Scope 3 emissions, which are the other indirect emissions, are more dificult to consider and quantify. This study focuses on the consumption of goods like food, clothes, and manufactured products, and the production of waste that comes after, which is classified by type (solid, organic, paper, plastic, etc.) and into its end-of-life use. Furthermore, an analysis of the green ares in the neighborhood was done to determine the carbon capture capacity that the area has.

The carbon mitigation measures that are presented in this work are well developed. A PV installation for the neighborhood which mostly focuses on using the rooftops of buldings is well dimensioned using GIS software and its production is simulated using reliable software and data. Electric vehicle integration is well calculated thanks to reliable data on the vehicles in the city. The same could be said about the nature-based solutions integration, although further analysis could lead to the implementation of more green areas, and for the public lighting measure, which focuses on implementing higher efficiency light points. Energy consumption savings from integrating heat pumps is also proposed and calculated using various studies on the gas consumption and heating demand of residential buildings in the area.

There are some processes or consumptions that are not accounted for that should be considered in the future to have a more complete inventory. For example, natural gas is not the only fuel used for heating, hot water, or kitchen stoves, but it's the only one that is quantified in this work. Other fuels like propane and butane are also used, although much less than NG so their contribution to scope 1 emissions wouldn't be too significant. The total assessment of the neighborhoods decarbonization potential is not fully complete, since other carbon mititgation measures can be proposed to continue the reduction of emissions. For example, the rehabilitation of buildings to reduce energy consumption and changes in the consumption habits of the population are measures that would ultimately reduce CO_2 emissions in all three scopes. These limitations are mostly due to difficulties in findings specific data from relaiable sources, especially at the neighborhood level, which most of the raw data is not and therefore it needed to be downscaled to the boundaries of the area.

2 STATE OF THE ART

2.1 Carbon Neutral Neighborhood

Climate neutrality can be defined as the idea of reaching net zero GHG emissions by creating a balance between those emitted and the emissions that get removed through the planet's natural absorption. This applies to individuals and organizations, who should strive to bring their emissions down to zero through technological investments and change in habits. But since it is difficult to make these changes immediately, there are other options like investing in compensation units or carbon offsets, emission reductions outside of the organization [5].

In a neighborhood setting, reaching carbon neutrality means achieving a net zero environment in a specifically delimited area. In this study, this selected area is the neighborhood of La Carracsa because of the unique specifications and motivations described in the introduction.

The Joint Programming Initiative (JPI) Urban Europe, which addresses priorities and their key issues for urban transformation [6], presented through a strategic dialogue event that there are three key principles to drive urban transitions to a more sustainable environment. Starting with energy transitions which can be achieved through the development of PEDs, defined as urban areas that have annual net zero emissions, don't import energy and work toward generating a surplus of renewable energy. The next principle is mobility transitions, that is achieved by concentrating efforts on accessibility and connectivity. Increasing the attractiveness of public transport is an essential part of this principle, as well as the concept of sustainable urbanization which focuses on discouraging private car use and creating a shift in the urban living environment while maintaining connectivity to the core of the city [7], [8]. Finally, the third principle is circular economy, which focuses on creating a circular value chain for the consumption of resources, meaning re-use, trade, and recycling of resources.

2.2 Inventory of GHG Emissions

Before providing strategies for decarbonization, the carbon footprint of the area must be calculated. This emissions inventory is divided into three main scopes [9]. First are direct emissions (Scope 1), which come from sources located within the studied area's boundaries, meaning direct combustion and energy use produced inside the neighborhood. The second scope are the main indirect emissions (Scope 2), that are produced as a consequence of the energy consumption of the grid-supplied electricity, heating, and/or cooling. Other indirect GHG emissions occurring outside the area but are produced as a result of activities taking place inside its boundary fall into the third scope. Examples of this are the consumption of goods that are purchased from outside the boundary, the outside management of the waste that is produced inside, or the outside travels.

2.3 Strategies to achieve carbon neutrality

A study for optimal pathways for decarbonizing building energy services [10] mentions that strategies can be divided into three categories: shifting to less carbon-intensive fuels in the building energy supply mix, adopting more energy-efficient end-use appliances, and improving the thermal properties of buildings. The first solution that usually comes to mind for changes in the energy supply is the integration of photovoltaics to cover the electricity needs of the building. In the book *Holistic Approach for Decision Making Towards Designing Smart Cities* [11], it's mentioned and proven with examples that integrating photovoltaic systems in the urban infrastructure is a key parameter to drive cities, communities or districts towards zero or positive energy areas. In a similar way, solar heat panels can be used to satisfy heating demands in buildings or sanitary hot water (SHW). This technology has been studied in various countries with different climatic conditions like Italy [12] and the UK [13], resulting in very favorable reduction in emissions especially when the system is coupled with thermal energy storage.

Another strategy and technology that has been researched in places like Switzerland [14] is the implementation potential of domestic biomass resources. This sustainable bioenergy has potential applications for electricity and heating, as well as compensation for other fluctuant renewable energy resources, meaning that they work well in combination with other technologies. The study showed significant potential for energy generation from this technology, but its limitations come from regional availability of biomass resources.

A highly efficient solution for decarbonizing the heating supply of buildings is the use of heat pumps (HP). This technology uses work energy, generated with a small amount of electricity, to convert a low-grade heat source into a higher-grade heat source. Heat pumps are categorized depending on the source that provides the heat it needs, which can be from the ground (geothermal), the air, or water. The challenge of this technology comes from the fact that it needs electricity to function, meaning that the peak and overall demand from the grid would increase. So, to make this a viable solution for decarbonization the heat pump systems should be coupled with renewable energy technologies to satisfy its electricity demand. This strategy is being studied in different places like Germany [15] and Spain [16], where it's proven that implementing air source heat pumps in existing buildings could result in a reduction of more than 8% in total emissions.

To make all of these presented strategies more efficient and cost effective, reducing the consumption of energy in buildings, mostly from climatization, should be the first step. A very efficient strategy to do this addresses the third category specified above, improving the thermal properties of buildings. In other words, the rehabilitation of existing buildings with efficient materials results in lower heating and cooling demands which in turn reduces the thermal or electricity consumptions of the buildings, resulting in reductions in costs and emissions. Case studies done by the University of Zaragoza's Department of Architecture compare two renovation strategies and prove that applying efficient solutions, including external insulation for existing brick-facing walls, could result in high levels of comfort, reduction in CO_2 emissions of around 20%, and reduction in heating energy use of 30% or more [17]. Another work done by universities in Spain [18], which mentions the previous study, also shows the importance of renovating existing buildings, but also highlights the significance of incorporating the principles of decarbonization and circular economy at the early stages of designing and building.

Similar strategies, that are being widely considered and implemented to change the infrastructure of buildings with the purpose of increasing thermal comfort and enhance carbon sequestration capacity, are nature-based solutions, the implementation of green infrastructure. There is little doubt that having green infrastructure mitigates GHG emissions and the effects of climate change on human health, the challenges it faces are on how it can be leveraged as a complex nature-based intervention if it is strategically applied, meaning that policies that enable the implementation of green infrastructure are often not coordinated in a way that helps facilitate wide adaptation which is why studies have focused on single applications. A study done in the University of Toronto Scarborough, in Canada [19], addresses this issue using the developed Climate Change Local Adaptation Action Model (CCLAAM) that provides a decision support framework for deep resilience by facilitating the application of multiple green infrastructures. Many of the strategies and technologies presented in this section could, and should, be used in unison and applied strategically based on location, limitations and potential to ensure a complete and efficient decarbonization of the buildings sector of a district aiming for carbon neutrality.

The transportation sector is more often than not the biggest contributor to carbon emissions in cities and presents a different challenge than the buildings sector. In order to address it, there are two main paths: changing vehicles themselves from a technical standpoint, meaning the fuel they consume, and reducing their amount while changing how they move, meaning increasing public transport, changing traffic and streets to provide less traffic jams, and increase walkable areas or bicycle lanes. As mentioned before, concepts like the 15-minute city and the superblock model try to tackle this transportation problem from a structural point of view, reducing traffic and incentivizing walking. The problem for implementing these strategies in already well-established cities is that it would be too difficult and costly to change the structure of the city. This is why improving public transportation by increasing its frequency, incentivizing its use and making it more environmentally friendly by changing its fuel consumption is essential to decarbonize the transportation sector.

Probably the most popular solution, regarding alternatives to replacing fossil fuel consuming vehicles, that is currently being studied and implemented is the integration of electric vehicles (EVs). The initial challenge of this is the slow integration in terms of private transport since for many people it’s difficult, mainly economically, to change their current vehicle. Which is why the integration of efficient and low-emitting public transportation is so important. But going forward with this implementation will impact the electricity grid by increasing the peak demand in the studied area and the overall electricity consumption, as it is presented by a case study in New South Wales, Australia [20]. In a city scale and for private car use, EVs seem to be the most promising alternative as prices are becoming more competitive and there is a growing penetration of these vehicles into the consumer market because of increasing manufacturers, the development of batteries at different scales, and new mandates to reduce the sales of petroleum-only vehicles.

The limitations of EVs come for more upscale transportation sectors, such as air and water transport, which is where other types of carbon neutral fuels could be more viable options. As far as integrating battery electric vehicles into an urban district, the main problems are making sure that the electricity for charging vehicles comes from renewable resources and the logistics for charging stations. A study done for the city of Kyoto, in Japan, researches the techno-economic-social considerations on the potential for decarbonizing the regions power system through the integration of electric vehicles and rooftop photovoltaics [21]. It shows that its implementation, along with the consideration of using EVs for electricity storage, could reduce CO_2 emissions from vehicle and electricity usage up to approximately 70%. The main challenge of this is still its implementation, and for a city like Valencia which is quite different from Kyoto it will present different challenges from an infrastructure point of view. The study also explores how this could be realized through peer-to-peer power trading initially on a community scale as smart microgrids.

3 TOOLS

In the next subsections, the tools that have been used in the realization of this study are presented and explained in detail.

3.1 Excel

The powerful software Excel is the most used tool in this study, providing support in every step of its development. It was first used to organize all the data that was gathered from different sources to establish a benchmark and then calculated how the area of study consumes energy and produces carbon emissions in all scopes, establishing a carbon footprint of the neighborhood. The results of this GHG inventory were analyzed with different calculations and summarized through the creation of graphs.

After determining the carbon mitigation measures that will be proposed, Excel was used to make calculations towards their development. For example: calculating the total PV power of a system from surface data of buildings and solar panel specifications, or cataloging the inventory of vehicles in the area to calculate how changing to electric vehicles reduces their emissions. The results of implementing all of the measures were also analyzed using this tool and presented through graphs, combining the initial emissions with the saved emissions from the planned actions in each sector, or scope. Creating a final carbon balance of the different scenarios. The economic analysis was also done using this tool.

3.2 DATADIS

DATADIS [22] is an online tool provided by the companies that distribute electricity in Spain that, through the use of smart meters, offer different services including daily consumption values. This data is provided for every zip code divided by sector (residential, industrial, and services), while also providing the number of clients that the data is being calculated from. It was used to make an estimation of the electricity consumption in the neighborhood of La Carrasca, and therefore determine the carbon emissions produced.

To obtain hourly consumption values, needed for the PV analysis using HOMER, the daily data needs to be adapted to hourly consumption profiles provided by the "Red Electrica de España" (REE) [23]. First, the zip code 46022 was chosen as the most representative for the consumption since it makes up most of the surface area of the neighborhood, as seen in **Figure 3.1**. This consumption was then scaled for the number of clients for each sector in the neighborhood. Considering that the universities that reside in the area (UPV and UV) make up most of the total consumption and actual values for each of them exist, then their consumption was first subtracted from the total in the services sector before scaling down to the neighborhood and then they were added again. This was done to salvage this accurate data without estimating it. The total yearly consumption of each sector was then adapted to the REE profiles mentioned before, using the profile for less than 15 kW peak power for the residential sector and the profile from 15 to 50 kW for the industrial and services sectors. This methodology is summarized in **Figure 3.2**.

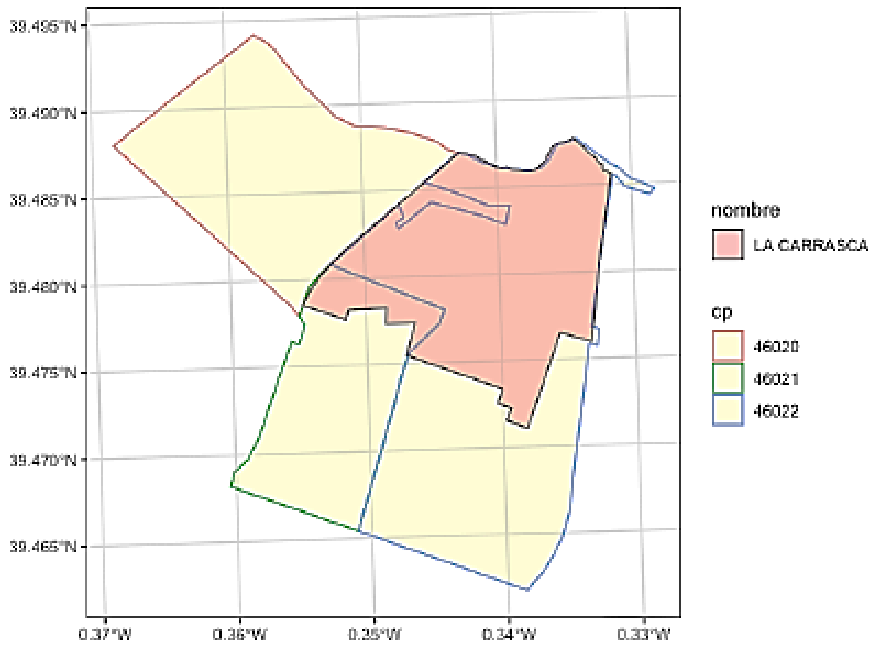

Figure 3.1 Zip codes that the La Carrasca neighborhood is located in [24].

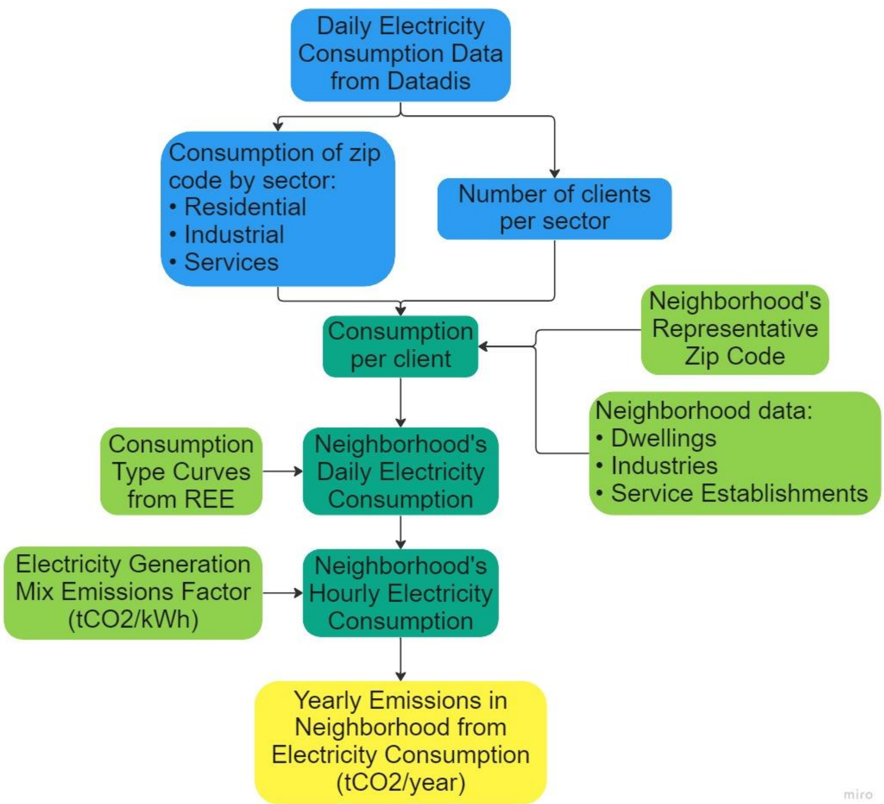

Figure 3.2 DATADIS tool methodology.

3.3 QGIS

QGIS (Quantum Geographic Information System) [25] is a free and open-source program that provides users the ability to compose, manage, and analyze data from maps. It was used in the development of the photovoltaic system measure, mainly with the purpose of estimating the amount of surface area available in rooftops to implement solar panels. The map layers used were taken from the Spanish Inspire Cadastral plugin that contains data of parcels, buildings and addresses in all of Spain. From there, only the data for the city of Valencia was downloaded using the city code. The two main layers used from this plugin were chosen because they have data on the number of floors and dwellings in each building, and their use (residential, industry or public services). The other layer used was found in the Spanish Government "Ministerio de Asuntos Económicos y Transformación Digital" open data page, which has data on the delimitation of the neighborhoods of Valencia [26]. It was used to make a cut in the city-wide layer to filter for the buildings inside La Carrasca.

The software's calculator tool was then used to determine the surface area of the remaining building polygons in order to have the complete area that will be considered. This was done after first removing many building polygons that were determined not useful for implementing PV panels based on visual examination using tools like Google Earth [27] and Huellasolar [28] in parallel, explained in detail in section **3.4**. After calculating the surface of the polygons, small areas with less than 20 m^2 were removed using a filtering tool. On the other hand, some polygons were added to the map for areas that are not rooftops but are being considered for implementing photovoltaic systems, like open lots for ground mounted systems and parking where roofs integrated with solar panels can be constructed.

In summary, the QGIS software helped in making a better analysis of the buildings in La Carrasca while providing data that was used to determine the total surface area to be considered for the implementation of a neighborhood wide PV system. This process is summarized in **Figure 3.3**, and the resulting map is shown in **Figure 3.4**, where the layer of Buildings removed from consideration are structures determined not useful or that already have a PV system installed.

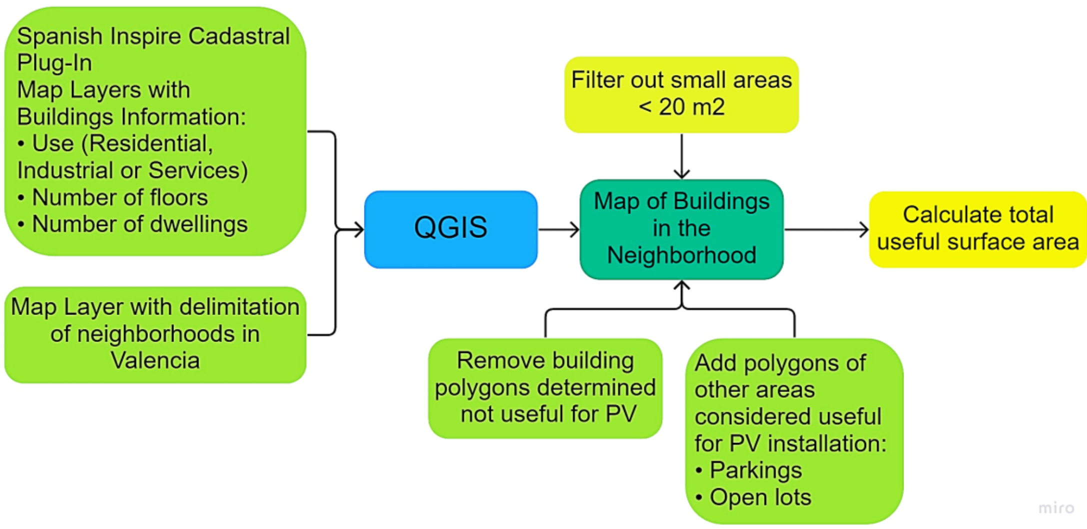

Figure 3.3 QGIS tool methodology.

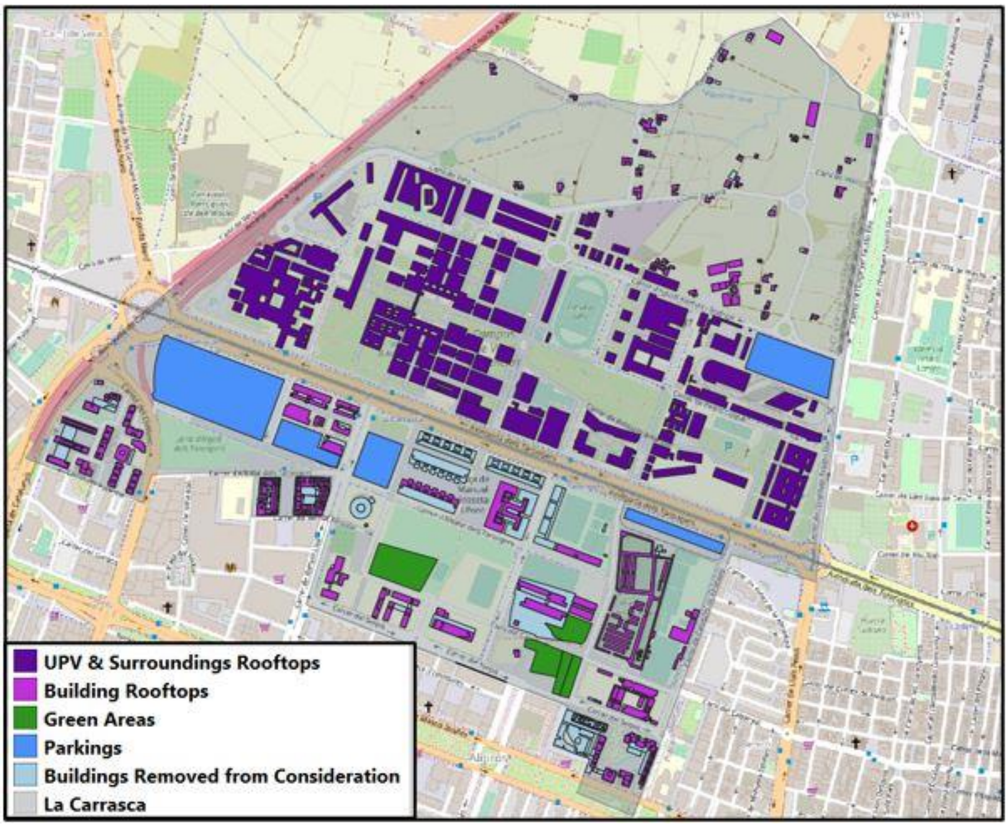

Figure 3.4 Map of areas considered for PV systems in La Carrasca using QGIS [25].

3.4 Google Earth and Valencia Geoportal

These two geospatial tools were used somewhat simultaneously for similar purposes in the development of the different measures. Mostly for measuring distances or areas, and to provide visual data on how the neighborhood is made up or structured. For the implementation of PV panels, Google Earth was used to analyze how much of the total rooftop area is available, in terms of space and sunlight hours. By taking a representative building block in the neighborhood, the total rooftop area was measured and compared to the sum of the smaller areas that were determined useful to install solar panels. These areas were selected through visual analysis to make sure that there are no obstacles, and with the HuellaSolar online tool to make sure these areas receive more than 75% of the annual sunlight hours (2167 hours). This analysis can be shown in **Figure 3.5** and **Figure 3.6**.

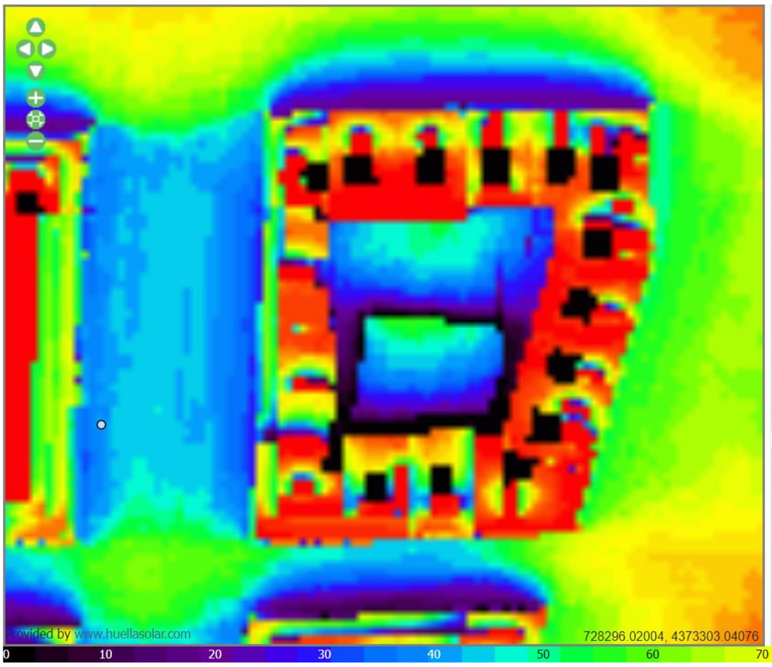

Figure 3.5 Sample building radiation analysis in Huellasolar (% of sunlight hours) [28].

Figure 3.6 Sample building rooftop analysis for PV installation [27].

The geoportal of the Valencia city hall [29] provides many useful information as to how the city is made up. In this study it was used for many purposes, as it is a visual representation of the data that the city collects yearly. For example, it shows how the city is divided into its districts, neighborhoods, green areas, agricultural areas, urban and rural cadastral parcels, the location of parking for vehicles and bicycles (including Valenbisi), bus stops, areas for recycling, among many more. Specifically, this tool was used for measuring the distances of the tram lines inside the neighborhood, shown in **Figure 3.7**, as well as for information on the green areas and agricultural land, including their surface area, which is all recorded in the "green spaces" and "rustic cadastral parcels" layers respectively. Also, some areas of particular interest like green zones that are not included in the layer mentioned before, and open areas that were considered in the PV system analysis were measured using this tool from the local government. For the bus lines, the geoportal of the "Empresa Municipal de Transportes" (EMT) was used since it was easier to visualize where the bus lines pass through the neighborhood [30], shown in **Figure 3.8** where the delimitations of the neighborhood were drawn on top.

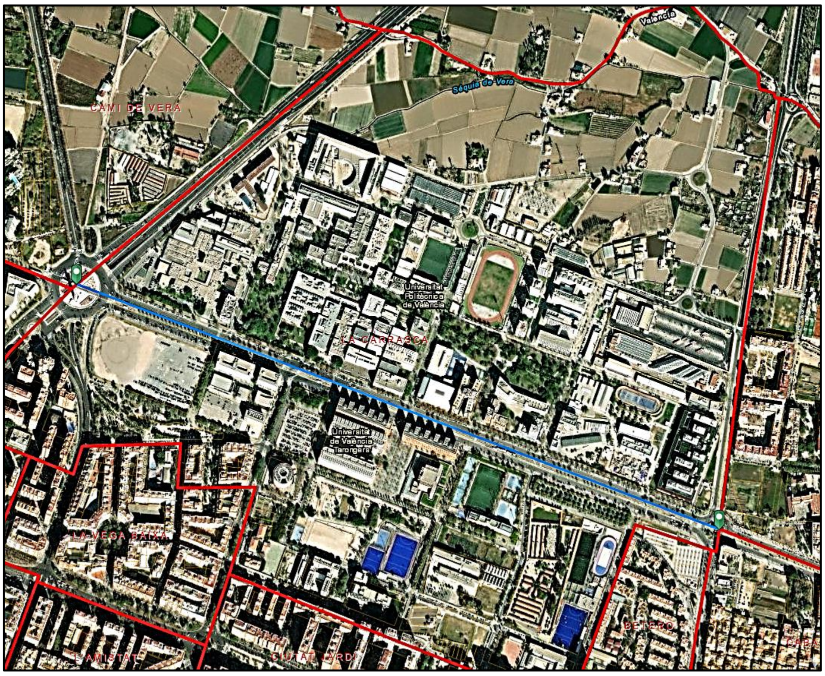

Figure 3.7 Measurement of tram lines 4 & 6 in La Carrasca [29].

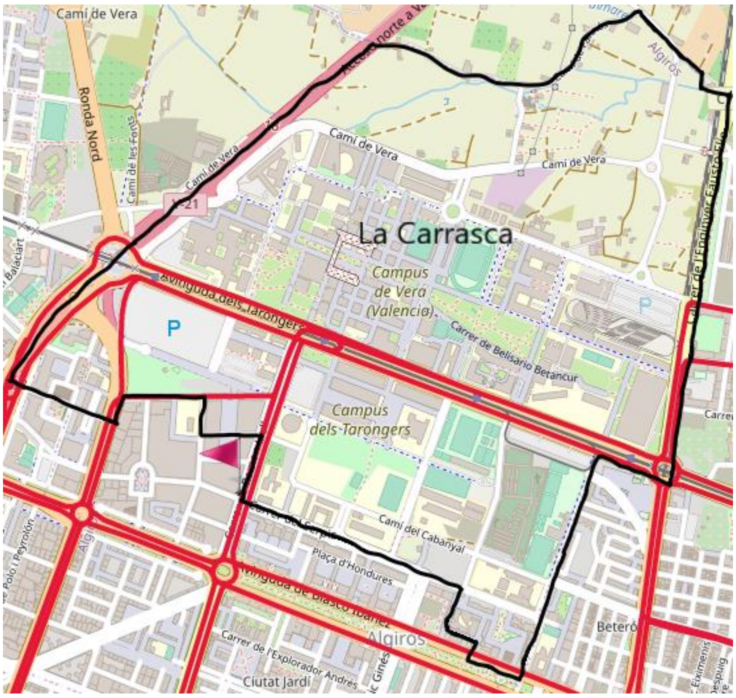

Figure 3.8 Measurement of EMT bus lines in La Carrasca [30].

3.5 HOMER

HOMER (Hybrid Optimization of Multiple Energy Resources) [31] is a simulation software for modeling hybrid energy systems, whether it's for a standalone microgrid or a distributed generation system, which is being analyzed in this study. Primarily, it was used for simulating the power generation of the PV installation that was dimensioned using the surface area calculated with QGIS, and reduced through the Google Earth analysis. For the software to carry out the simulation and make an accurate techno-economic analysis of the system, data needs to be provided in four main areas.

First, the primary load that the system will try to cover will be added. This is the electricity consumption of the neighborhood that was calculated from the data gathered from DATADIS and was processed to hourly values through the process described in section **3.2**. After introducing this demand, the aspects of the photovoltaic system were introduced. These include the sizing of the system, the costs associated to the system, the technical aspects of the panels and how they are oriented. Then, for the analysis of the production of the solar panels, solar resource data of the studied area must be introduced. Specifically, the global horizontal radiation during a year. This data was downloaded from the online tool PVGIS, which provides solar radiation data for any location in Europe.

Lastly, since the system will be considered as connected to the grid to analyze how much electricity needs to be bought to cover the demand and how much of the excess generation of the PV system will be sold back to the grid, then data for the prices of buying this energy and for selling it was introduced. Also, to account for the emissions produced and compare to a base case of no renewable energy generation to determine how much emissions are being saved by installing the system, an emission factor for the energy mix of the grid was provided. This complete process of data entry and simulation is summarized in **Figure 3.9**.

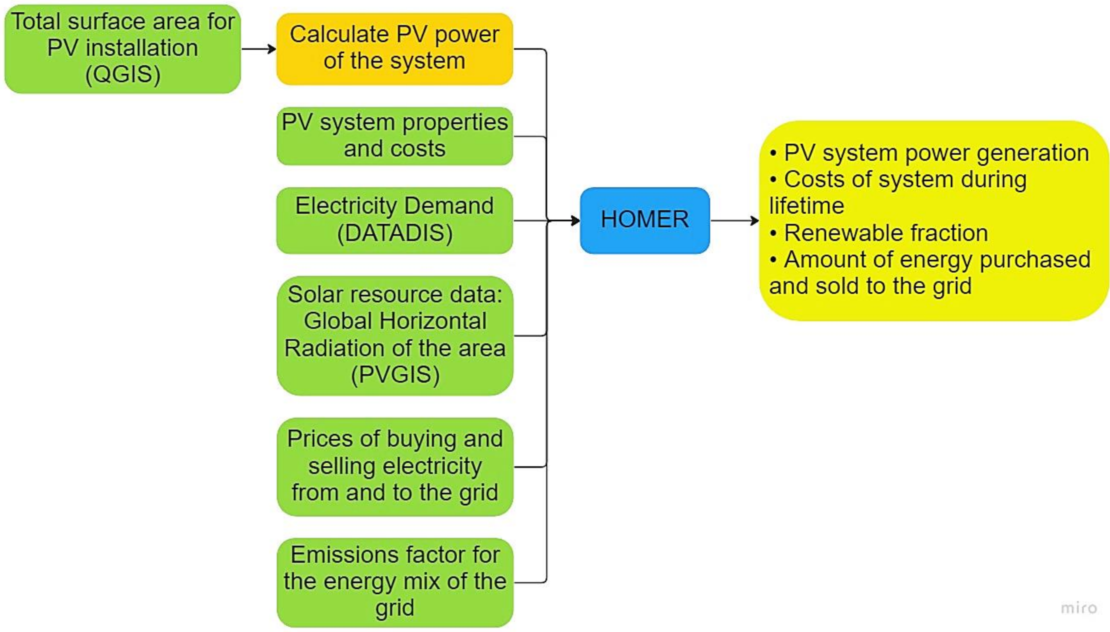

Figure 3.9 HOMER tool methodology

4 METHODOLOGY

The methodology that was followed to determine the potential of the neighborhood of La Carrasca to achieve carbon neutrality is detailed in this section.

4.1 General procedure

The methodology developed in this study can be divided into two main steps. Determining the carbon footprint of the area by analyzing how it consumes energy and produces or captures emissions. Then, providing different solutions and scenarios on how to reduce the global emissions of the area for all three scopes. The steps followed to achieve the results of this study are summarized in the scheme presented in **Figure 4.1**.

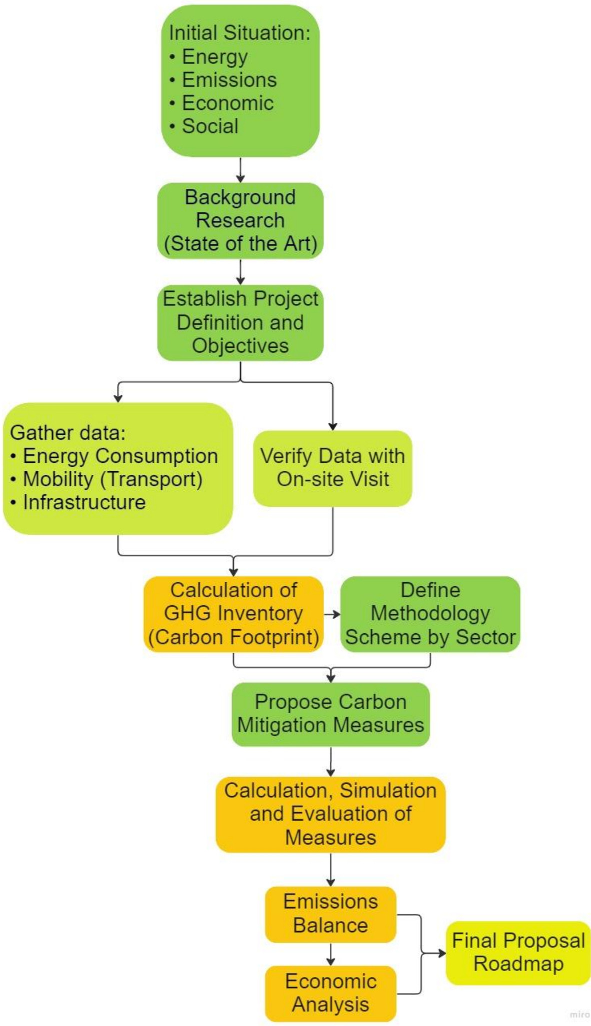

Figure 4.1 Scheme of General Methodology

This section will explain in detail the different steps included in the general methodology. Going through the process of gathering data, analyzing it, the decision-making process for the proposed solution, and how the results were obtained.

Background Research (State-of-the-Art):

Understanding the initial direction that the project will take; a state-of-the-art review was carried out to research studies and different topics related to carbon neutrality and sustainable development. Research articles, academic studies, government documents and proposed projects, statistics from the local Valencia City Hall or the Valencian Community, as well as European regulations and reports from different institutions, were used to establish an initial situation and understand the technologies used or scenarios considered for achieving carbon neutrality in urban areas. They included knowledge and data on sustainable cities, carbon neutral areas, nature-based solutions, renewable energy generation, energy efficiency measures for buildings, changes of habits for the population, sustainable mobility, and campaigns to impulse the development of the different carbon mitigation measure.

Project Definition and Objectives:

Having this baseline review and research, the project was defined and its main objectives were established. Since for this study the direction is to achieve carbon neutrality, two primary points were considered:

- The area of the city of Valencia selected to apply the defined methodology and the scale of this area. In this case, it will be the neighborhood of La Carrasca, which is a very particular area with well-defined structures and different areas not found in most of the other neighborhoods in the city. For example: it can be divided into a residential area, a large services area composed mostly of educational institutions, and an agricultural area.
- The carbon dioxide emissions that will be considered in relation to the three scopes mentioned in the state-of-the-art review. The focus of this study will be on the emissions produced by how the neighborhood operates at the present time (OPEX). For example, how its buildings consume energy or its vehicles produce emissions. The emissions that were produced for its construction are not being considered (CAPEX). Meaning that this study is not a full life cycle assessment of the area.

Initial Situation:

After defining the project's objectives, and using the information gathered in the state-of-the-art review, the initial situation of the area where the study will be applied was analyzed. Data was gathered and evaluated concerning the main characteristics of the neighborhood:

- Total surface area and use of the land.

- Population and its characteristics based on age, education, professions, poverty, etc.
- Transportation systems.
- Green areas, including the agricultural land.
- Energy consumption in each sector: residential, commercial, and industrial.
- Consumption of different goods: food, clothes, etc.
- Waste production and management

Whenever it was possible, on-site visits to the different neighborhood areas were done to have a better understanding of its characteristics and evaluate the data gathered to verify its veracity. Using all of the data confirmed, the carbon footprint of the area was calculated. This is the emissions produced by the neighborhood per type of sector, which were also classified in all three scopes, and furthermore, provide an inventory of the area's emissions.

Proposed Carbon Mitigation Measures:

Once established the initial situation of the neighborhood; the concepts learned from the state-of-the-art review, which provided possible measure to reduced carbon emissions, were used to develop a list of CO_2 mitigation measures in order to analyze the technical, economical, and environmental impact on the initial situation.

This list of carbon mitigation measures is:

- Implementation of nature-based solutions.
- Renewable energy generation though the use of PV systems.
- Introduction of sustainable transport for both the public and private transportation fleets.
- Energy efficiency measures in public lighting
- Energy efficiency measures in the NG consumption of the residential sector
- Reduction of waste production and improve its management

Calculation, Simulation, and Evaluation of Measures:

The proposed carbon mitigation measures were developed using the necessary calculations and simulations in order to measure and analyze the impact they produce on reducing the carbon footprint of the initial situation. The objective of this will be to verify which measures have the most impact considering their CO_2 reduction, economic repercussions, social ramifications, etc. Making them the most important to develop.

Emissions Balance:

A primary objective of this study is to evaluate the impact that the different mitigation measures have on the potential of cities to achieve carbon neutrality. A CO_2 emissions balance was developed to carry out this evaluation, considering the initial situation and the CO_2 reduction during the next years based on the proposed carbon mitigation measures. The emissions balance is presented in this document until the year 2030.

Economic Analysis:

In order to understand the economic repercussions that the development of these carbon mitigation measures will have on the city that will develop them, an economic analysis was carried out. It mainly considers the costs of the implementation and operation of the different technologies or policies proposed, as well as government incentives to reduce certain investment costs.

Final Proposal Roadmap:

After analyzing the initial situation, the proposed carbon mitigation measures and the impact that they have in reducing the carbon footprint of the neighborhood. A roadmap was planned in order to impulse the area to a carbon neutral zone.

Figure 4.2 shows the methodology scheme of **Figure 4.1** with more details on the different steps explained in this section.

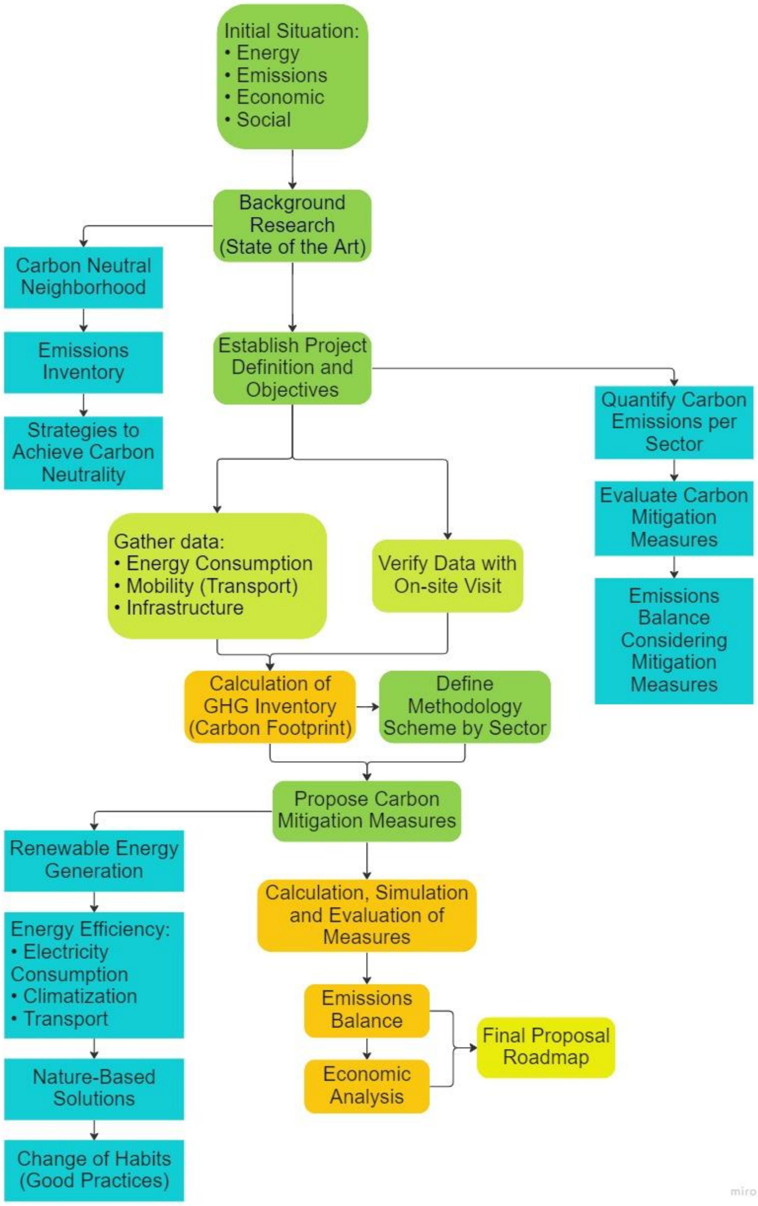

Figure 4.2 Detailed Scheme of General Methodology

4.2 Carbon Footprint

4.2.1 Buildings

The primary step to quantify the overall carbon emissions of the neighborhood is to gathered data on how the buildings in the area consume energy. Following the methodology described in section **3.2**, the electricity consumption of the neighborhood in each sector (residential, industrial, and services) was determined, shown in **Table 4.1**. As mentioned before, the universities in the area make up most of its electricity consumption. The UPV and UV consume 37,820 MWh [32] and 13,738 MWh [33] per year respectively, which add up to 85% of the total consumption of the neighborhood. The hourly distribution of the total consumption which resulted from the use of the consumption profiles from REE is shown in **Figure 4.3**, where the influence of the universities can be clearly seen by the reduction in August which is the month that they are closed. This resulting data was compared to the results found by the company ImpactE [34], which made an analysis to determine the electricity demand of the neighborhood using hourly data from DATADIS for the three zip codes that make-up La Carrasca (**Figure 3.1**) and a comparison of the constructed surface area for each sector. Their process is described in detail in **Annex C**, with a comparison of both curves. Ultimately, our curve was chosen since the results are somewhat similar and the data used is open to the public, while the data used by ImpactE needs company clearance to be accessed.

Table 4.1 Electricity consumption in zip code 46022 and La Carrasca by sector.

Sector	Electricity Consumption (MWh/year)		
	Zip Code 46022	La Carrasca	
Residential	60,779	4,597	7.6%
Services	89,198	55,838	91.9%
Industrial	2,317	326	0.5%
Total	**152,294**	**60,761**	

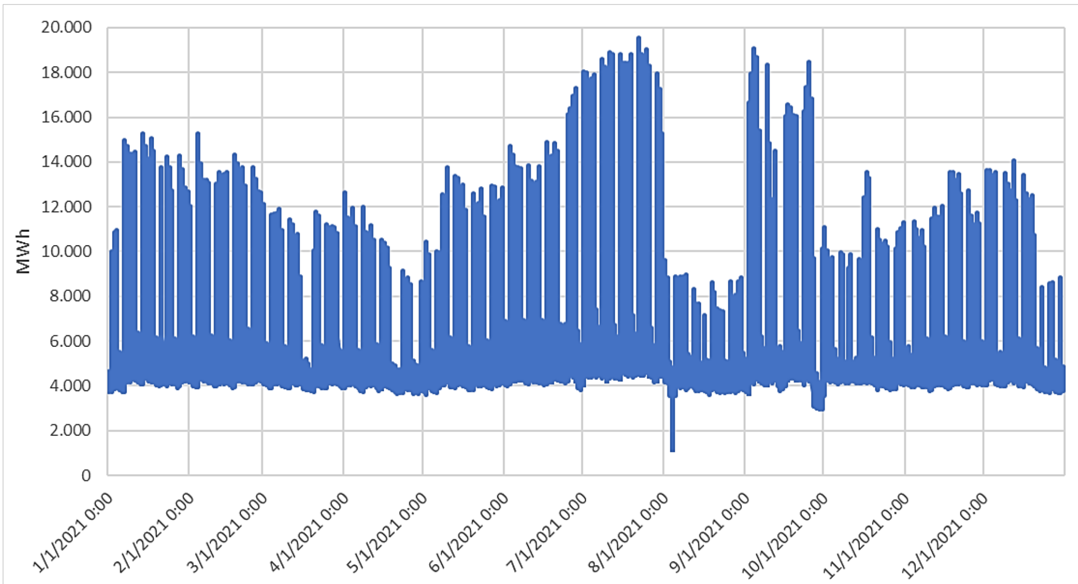

Figure 4.3 Electricity consumption in La Carrasca.

Knowing how the studied area is consuming electricity, the emission produced from its generation can be determined by knowing the mix of energy technologies that generate the electricity that the city consumes. A factor of CO_2 emissions for the mix of generation in the Valencia Province was used to calculate the total yearly carbon emissions that come from electricity consumption [35].

The neighborhood's gas consumption was estimated from data on the billed natural gas consumption of the city and the number of clients for each sector in 2019, found from the town hall yearly statistics [36]. This data is provided monthly and broken down into domestic (residential), industrial, and commercial (services) sectors. After estimating the amount of natural gas billed per customer in each sector, using the number of industries in the neighborhood the consumption for this sector was estimated. For the commercial sector, similarly to the services sector in the electricity consumption estimation, the universities needed to be specifically included because their consumption is significant and are found independently. To do this, their consumption was subtracted from the total consumption of the city's commercial sector, which was then ratioed by clients, and using the number of service establishments it was estimated for the neighborhood with the addition of the universities. The UPV and UV consume 9,007 MWh [32] and 17,888 MWh [37] of NG per year respectively. For the domestic sector, the yearly statistics also provide information on the number of main dwellings in the neighborhood and the percentage of these that have heating, which is what natural gas is mostly used for in inner-city buildings. With that number of dwellings, the gas consumption for the domestic sector was estimated. The results of these estimations are shown in **Table 4.2**.

Table 4.2 Natural gas consumption in Valencia and La Carrasca by sector.

Sector	NG Consumption (MWh/year)		
	Valencia	**La Carrasca**	
Domestic	580,798	2,420	7.9%
Commercial	143,120	27,442	89.6%
Industrial	215,091	775	2.5%
Total	**939,009**	**30,777**	

Using an emissions factor for NG consumption in the city provided in the "Plan de Acción para el Clima y la Energía Sostenible de la ciudad de Valencia" [38], the emissions produced from this consumption was estimated.

4.2.2 Transport

An important part of the total carbon footprint inventory of the neighborhood is the emissions produced by the transportation sector. There are many means of transport in the city of Valencia that will be divided into two main groups: public and private transport. For the former, the first step is to determine which services are available in the neighborhood. In La Carrasca there are two tram lines (4 & 6), eight bus lines, Valenbisi (public bicycle-sharing service), and taxis.

Public transport

For the tram trains, the total kilometers that they travel through the neighborhood were measured using the geoportal of the city. Both tram lines pass through the same 4 stops inside the neighborhood, meaning that even though they are different in total length, 17 km for line 4 and 3.57 km for line 6, the length that they have inside the neighborhood is the same. Then, by determining the number of trips that each line does for each type of day (Weekdays, Saturdays, and Sundays or holidays), through data from the Metrovalencia [39], and multiplying these values for a whole year, the number of kilometers traveled inside the studied area by the two tram lines in a year was determined. This data process is shown in **Table 4.3**. Since tram trains consume electricity, with a consumption factor of kilowatt per kilometer traveled the total yearly consumption was estimated. Using the emissions factor determined for the electricity generation mix of the city, the yearly CO_2 emissions produced from the use of the trams was then calculated.

Table 4.3 Distance traveled annually by tram trains in La Carrasca.

Tram Lines	Length Inside Neighborhood (km)	Number of Trips in a Year	Distance Traveled (km/year)
4	1.67	73,446	64,301
6	1.67	38,536	122,552
Total	**3.44**	**111,982**	**186,853**

Similarly, the process for calculating the emissions produced from the bus transportation system in the neighborhood is done by first measuring the total kilometers each bus line travels inside the neighborhood. Knowing the number of trips each line does during each type of day, through data from the EMT, and the number of days of each type during the year, the total kilometers traveled by all the bus lines inside the area during a year can be determined, as shown in the **Table 4.4**. The difference now comes when determining their consumption. The bus fleet in Valencia is composed of 485 buses, of which 52% are hybrid diesel buses [40], while the rest are considered conventional diesel consuming buses. Knowing how these buses consume diesel in liters per kilometer [40], and using an emissions factor for diesel consumption ($kgCO_2/l$), a direct emissions factor of $kgCO_2$ per kilometer traveled was calculated. Using this value, the total amount of carbon emissions produced by the buses inside the neighborhood was determined.

Table 4.4 Distance traveled annually by buses in La Carrasca.

Bus Lines	Length Inside Neighborhood (km)	Number of Trips in a Year	Distance Traveled (km/year)
18	3.610	17,047	61,540
31	0.156	21,373	3,334
40	1.210	22,161	26,815
71	1.210	30,133	36,461
81	0.156	34,865	5,439
93	4.220	38,337	161,782
98	4.220	52,560	221,803
99	0.891	31,427	28,010
Total	**15.673**	**247,903**	**545,184**

The number of taxis in the neighborhood was determined from data on the number that are assigned to the Algirós district. Using a downscaling factor of surface area between the neighborhood and the district, the number of taxis was estimated. Statistics were then found on how taxis travel, in terms of kilometers per day they in a city of Spain (208 km/day) [41]. Then, based on statistics provided in the “Plan de Impulso del Vehículo Eléctrico y Despliegue de la Infraestructura de Recarga en la Comunidad Valenciana” [42] where it mentions that the vehicle fleet in the province is 25% gas and 75% diesel and how much each of these vehicles consumes in liters per kilometer, the yearly consumption per taxi can be estimated. **Table 4.5** shows the taxis of each fuel type and the distance they travel per year. Finally, using emission factors (kgCO_2/l) for both fuels respectively, the number of yearly emissions produced by the movement of the taxis in the neighborhood was calculated.

Table 4.5 Distance traveled annually by taxis in La Carrasca.

Fuel type	Number of Taxis	Total Distance Traveled (km/year)
Gas	3	227,760
Diesel	10	759,200
Total	**13**	**986,960**

Private transport

The private transportation sector will be divided into two groups: the vehicles that are in the neighborhood and how much they travel in their own neighborhood, and the vehicles that come from outside and pass through it. To determine the vehicles that are established inside the area of study, data for the vehicle fleet in the city by type of vehicle (cars, small trucks, motorcycles) and type of fuel (petrol, diesel, electric, CNG, LPG) was found through the town hall statistics (**Table 9.9**) [36], and it was scaled down with a factor of population in the neighborhood compared to the city, shown in **Table 4.6**. Also, data on the car fleet in the city per year of registration (1971-2020) was used to determine a ratio of the number of vehicles registered per year, to then distribute the estimated vehicle fleet of the neighborhood. Resulting in the number of vehicles per type (car, small truck or motorcycle) and per year. The purpose of having this data is to then distribute the vehicle fleet per European regulation standards, because they provide emission factors for each type of vehicle by fuel type and regulation ([43], [44]). The resulting data is presented in **Table 4.7**. The only emission factors that will be calculated directly are the ones for electric cars and motorcycles, to take into consideration the electricity mix of the city. For cars and small trucks, an average value of kWh/km provided by the electric vehicle implementation plan of the Valencian Community [42] will be used. Meanwhile, for electric motorcycles, the consumption of the model Libélula from Greenmoto in city mode was considered [45].

Table 4.6 Vehicle fleet of population in La Carrasca per type of fuel.

Fuel	Cars	Small Trucks	Motorcycles	Total
Petrol	813	24	372	1209
Diesel	744	80	2	826
Electricity	2	1	3	6
CNG	1	0	0	1
LPG	3	0	0	3
Total	**1563**	**105**	**377**	**2046**

Table 4.7 Vehicle fleet of population in La Carrasca per European Regulation. Adapted from [43], [44].

Regulation	Years	Cars	Small Trucks	Years	Motorcycles
Pre Euro	<1992	57	4	<1999	31
Euro 1	1992-1995	29	2	1999-2002	41
Euro 2	1996-1999	74	5	2003-2005	59
Euro 3	2000-2004	289	19	2006-2015	155
Euro 4	2005-2009	421	28	2016-2019	78
Euro 5	2010-2014	248	17	>2020	12
Euro 6	>2015	445	30		
Total		**1563**	**105**		**377**

To have a common baseline for all vehicles, the distance that they travel yearly in the neighborhood will be considered the same. Based on the EV plan, vehicles travel 20,000 km per year. Considering that not all of the distance that the vehicles travel in a year is actually inside the neighborhood, an estimated 20% of that distance (4000 km) is considered as traveled inside the area [46]. Finally, using the number of vehicles, the kilometers they travel per year in the considered zone, and the emissions factors per type of fuel and regulation, the amount of yearly CO_2 emissions were calculated.

To account for the vehicles that travel through the neighborhood, but are not established in it, data for the average number of vehicles that travel during a day through many of the streets of Valencia, referred to as Average Daily Intensity, "Intensidad Media Diaria" (IMD), was used [47]. After identifying the streets that are inside the neighborhood, highlighted in **Figure 4.4**, and measuring their distance using Google Earth, the total distance traveled in a year inside the area by outside vehicles was estimated and main results are shown in **Table 4.8**. The total CO_2 emissions produced by these vehicles were calculated using an average emissions factor for cars since there is no data as to which types of vehicles they are. These emissions fall into scope 3 since they are indirectly produced inside the neighborhood from outside sources.

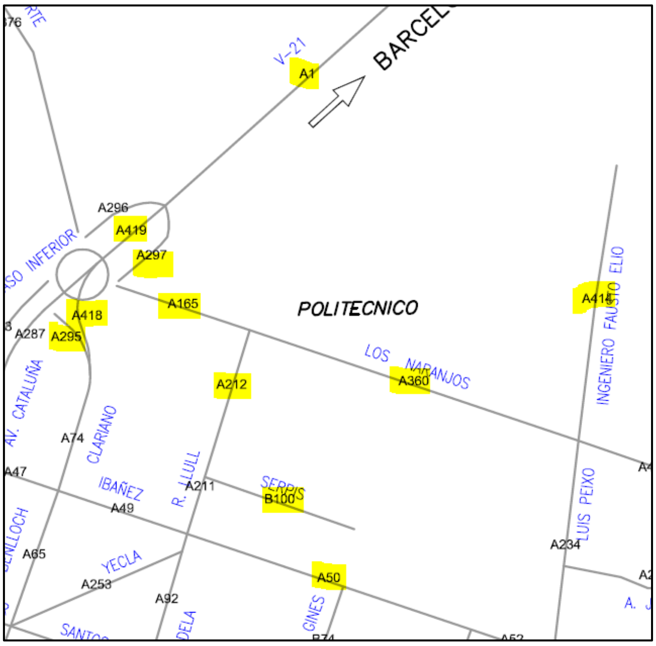

Figure 4.4 Streets considered inside La Carrasca (Highlighted) [47].

Table 4.8 Yearly distance traveled inside La Carrasca by outside vehicles. Adapted from [47].

Road	IMD	Length inside La Carrasca (km)	Distance Traveled per Day (km/day)	Distance Traveled per Year (km/year)
A1	75,250	0.396	29,806	10,879,309
A50	26,709	0.141	3,769	1,375,528
A74	26,804	0.126	3,364	1,227,801
A165	41,144	0.476	19,601	7,154,366
A212	15,277	0.475	7,261	2,650,236
A287	37,527	0.448	16,793	6,129,485
A295	16,275	0.153	2,493	910,065
A297	8,775	0.535	4,694	1,713,218
A360	34,062	1.064	36,255	13,233,097
A414	26,183	0.975	25,531	9,318,653
A418	11,052	0.263	2,908	1,061,292
A419	48,578	0.553	26,844	9,798,134
B100	4,948	0.867	4,289	1,565,661
	Total		**183,608**	**67,016,845**

4.2.3 Public Lighting

Another electricity consumption that is not being considered in the buildings analysis is the one that comes from the public lighting network in the neighborhood. To calculate this consumption, data about the number of light points, the type of light, the installed power of each type, and the yearly consumption at a district level was found in the yearly statistics reports compiled by the town hall mentioned before [36]. The number of light points was scaled down to a neighborhood level using a downscaling factor based on the ratio of total surface of La Carrasca inside its district, Algirós. The total power installed of each type of light in the neighborhood was calculated as the product of the number of light points in the neighborhood times the power of each type of light, which was calculated from the ratio of total power installed per number of light points at a district level. The public lighting network of La Carrasca as described before is presented in **Table 4.9**. Finally, the electricity consumption of the public lighting in the neighborhood was calculated from the total installed power times the number of hours they are on during the year, which was calculated from the ratio of consumption by the total installed power in the district. Using the factor of emissions for the electricity grid, the total CO_2 emissions from public lighting in the neighborhood was calculated.

Table 4.9 Public lighting network in La Carrasca.

Type of Light	Power per Light (kW)	Number of Light Points	Total Power Installed (kW)
Sodium Vapor	0.19	1573	456.99
Mercury Vapor	0.14	1	0.14
LED	0.04	515	23.14
Metal Halogen	0.09	888	82.96
Other	0.04	10	0.40
Total		**2987**	**409.80**

4.2.4 Consumption of goods

In this study, the sector of consumption of goods focuses on three categories: food, clothing, and manufactured products. Data on food consumption in Spain was found per capita (kg/cap) [48], shown in **Table 4.10**. Then, through the use of emission factors for each type of food that is being considered ([49], [50],[51], [52]), a factor of emissions from food consumption per capita was calculated. The total emissions for this category were estimated considering the population of the neighborhood and the number of students from both universities, to account for the consumption of these institutions. The UPV Campus of Vera has 28,450 students [53], while the UV Campus of Tarongers has 18.068 [54], [55]. Since students don't spend all of their time in the universities and don't consume all of their food there, a factor of 10.39% was used to reduce their consumption, which relates the number of hours students spend in the university during a year [56]. On the other hand, for clothing and other manufactured products, factors of emissions per capita were directly used [46], considering only the population of the neighborhood.

Table 4.10 Food consumption per capita in Spain. Adapted from [48].

Type of Food	Consumption per Capita (kg/cap)
Oil	10.13
Olives	2.68

Rice	4.02
Beverages	145.65
Wine	8.37
Cereals	1.65
Cookies	5.15
Coffee & infusions	1.94
Beef	4.75
Lamb	1.12
Other meat	44.74
Chocolate	3.63
Fresh fruit	91.80
Processed fruit & vegetables	12.99
Dried fruit	3.55
Fresh vegetables	57.94
Egg	8.74
Milk	72.54
Dairy products	35.20
Legumes	3.52
Bread & pastry	30.07
Flour	2.49
Pasta	4.22
Potato	29.22
Fish	22.72
Ready-to-eat	16.77
Rest	3.10

4.2.5 Waste

Waste emissions were calculated using data from the city's waste collection inventory [34], which is divided into municipal solid waste, organic waste, glass, paper, plastic or light packaging, vegetable oil, and batteries. Using a downscaling factor of the population in La Carrasca and the city of Valencia, this data was calculated at a neighborhood level, shown in **Table 4.11**. To consider both universities in this sector, average waste amounts for the UPV were calculated from data in their environmental declaration [32], and were then scaled down for the UV based on the difference in students, the UV Campus of Tarongers has 36.5% less students than the UPV Campus of Vera, shown in **Table 4.12**. Then, the total waste produced was categorized by how it is treated after. It's either thrown in a landfill, recycled for treatment, used for energy, or used for composting. The distribution to these uses were estimated by first knowing the amount of waste that enters the treatment plants of Los Hornillos and Manises [36] against the amount that enters the Dos Aguas plant of elimination [57], which will be the percentage that is throun in a landfill. Then, using guides from the Metropolitan Entity for the Treatment of Waste (EMTRE) [58], which runs the treatment plants, the percentage that is treated is divided into the other three uses, shown in **Table 4.13**. Excluding the amount used for energy, since these emissions are already accounted for in the electricity consumption of the neighborhood, the rest is calculated in waste emissions using average factors by weight for the other three uses [59]. The process to arrive at these average factors is described in **Annex G**.

Table 4.11 Waste in La Carrasca based on population. Adapted from [36].

Type of Waste	Waste in Valencia (tons)	Waste per Capita (kg/cap)	Waste in La Carrasca (tons)
Municipal solid waste	295,299	369.04	1270.97
Organic	12,020	15.02	51.74
Glass	13,149	16.43	56.59
Paper & cardboard	16,505	20.63	71.04
Plastic and light packaging	11,724	14.65	50.46
Vegetable oil	35.07	0.0438	0.15
Batteries	3.16	0.0039	0.01
Total	**348,736**	**435.82**	**1500.97**

Table 4.12 Waste in UPV and UV. Adapted from [32].

Type of Waste	UPV (tons)	UV (tons)	Total (tons)
Electronics	36.54	23.21	59.75
Paper & cardboard	206.32	131.03	337.35
Plastics	82.84	52.61	135.45
Total	**325.70**	**206.85**	**532.55**

Table 4.13 Waste management in La Carrasca. Adapted from [36], [57], [58].

Waste Management	Share	Total Waste (tons)
Landfill	57.72%	1174
Recycled (Treated)	20.57%	418
Energy	8.78%	179
Composting	12.93%	263
Total		**2034**

4.2.6 Green Areas

After determining the carbon emissions produced in the neighborhood, a correction is made by estimating the emissions that are sequestered by the urban green zones and agricultural land in the area. The total surface area of green zones was estimated by first finding specific information of the green areas that are managed by the city government through their open geodata [29]. More often than not, the data does not include every green surface in the neighborhood, which is why some needed to be measured through geospatial tools like Google Earth. Adding these areas, the total surface of urban green zones in La Carrasca is 20.03 ha. On the other hand, for the agricultural land the information on their surface area is well documented, but not what specific crops are being cultivated in them.

When determining how both these areas capture CO_2, they need to be treated quite differently. A factor for yearly emissions captured by urban green zones in the city of Valencia was found that the Generalitat Valenciana determined through a territorial mapping of the carbon stock [60]. That calculation gives a factor of tons of CO_2 equivalent fixed by hectare of green area. On the other hand, for the agricultural land in the neighborhood information was found on the types of crops in the city through the town hall yearly statistics, and the factors of carbon capture for these different types of crops from the territorial mapping document mentioned before. Assuming that the division of types of crops is the same throughout the city, it was estimated that the total area of agricultural land inside the neighborhood has the same percentage of crop types, as established in **Table 4.14**. Then, average factors for carbon capture by surface area (ha) were calculated for each crop type: herbaceous crops and woody crops. Fallow is not considered, since it’s land that is left without crops for various vegetation cycles with the objective of recovering its best conditions. Using these calculated factors of carbon capture by surface area the total yearly tons of CO_2 fixed by the land can be determined. Finally, these values of yearly CO_2 emissions sequestered by green and agricultural areas can be deducted from the total that is emitted in the neighborhood.

Table 4.14 Surface area of agricultural land (hectares). Adapted from [36].

Type of crops	Valencia city		La Carrasca
Total cultivated land	3231		35.12
Herbaceous Crops	2429	75%	26.40
Fallow	405	13%	4.40
Woody Crops	397	12%	4.32

5 CASE STUDY: LA CARRASCA

5.1 Presentation of Neighborhood

In this study, the methodology developed is applied to the La Carrasca neighborhood in the city of Valencia, located in the Mediterranean climatic zone of Spain. Inside the city, the neighborhood is located in the Algirós district, on the north-eastern part of the city. Its geographical location is shown in **Figure 5.1**. Meanwhile, its general data is presented in **Table 5.1**. Since the neighborhood has such a small residential area, it has one of the lowest population densities in the city. The average age of its inhabitants is just a bit over the average of the city, which is 44.7 years.

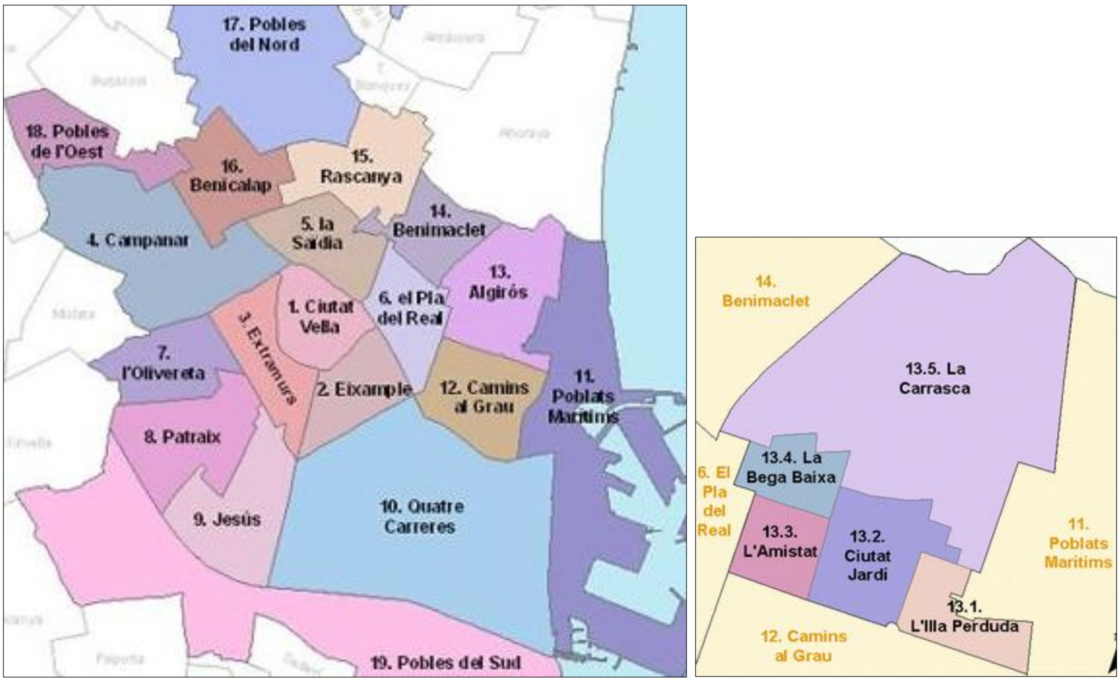

Figure 5.1 Location of Algirós district in Valencia, and La Carrasca neighborhood inside the district [61].

Table 5.1 General data of La Carrasca [62].

Population (number of inhabitants)	3444
Surface Area (km^2)	1.96
Population density (inhabitants/km^2)	1755
Average age	45.2

The initial situation of the neighborhood needs to be analyzed considering the demographics and aspects of La Carrasca when providing carbon mitigation measures in order to transform it into a carbon neutral neighborhood. These measures need to be adapted to the characteristics of the area, which is why the social, economic and energetic aspects of the neighborhood will be presented and analyzed in this section.

Social situation

The social situation in La Carrasca is based on population, age, and educational background. The neighborhood has a crude birth rate of 3.8 and a crude death rate of 6.7, meaning that its population is most likely decreasing, although immigration rates are higher than emigration rates. Considering the average age of the population in La Carrasca it is interesting to observe that people close to 45 years of age are not the highest percentage. Instead, the highest percentage of inhabitants are in the intervals of 20 to 30, and 55 to 65 years of age, as shown in **Figure 5.2**.

The population of La Carrasca can be considered well-educated. **Figure 5.3** shows that 81% of its inhabitants have at least graduated school or have an equivalent or superior title, while another 13% are aged under 18. This could be a result of the many educational institutions that are inside of the neighborhood.

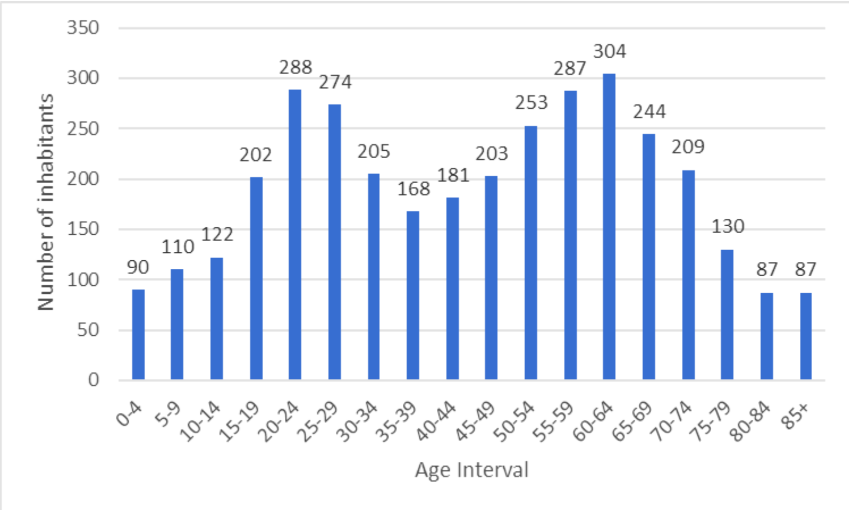

Figure 5.2 Age distribution of the inhabitants of La Carrasca [62].

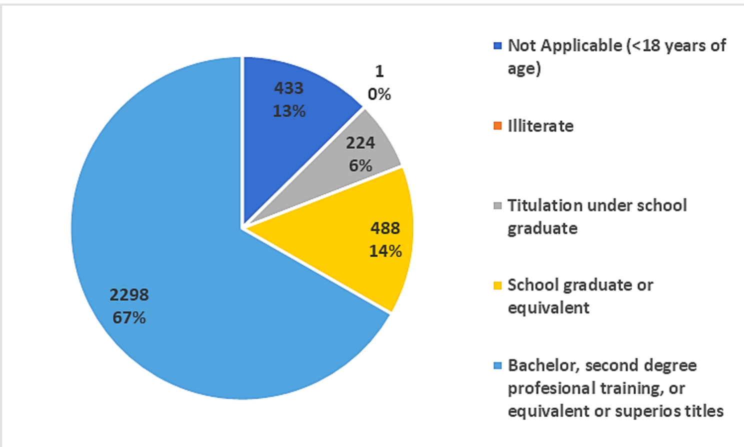

Figure 5.3 Educational background of the inhabitants of La Carrasca [62].

Economic situation

Observing the distribution of economic activities in the neighborhood, **Figure 5.4** shows that the economy of the area is highly dependent on business and services represent more than 70% of the activities. Followed by professionals at 20%. It can be concluded that this is very much due to educational institutions (mainly universities) in La Carrasca.

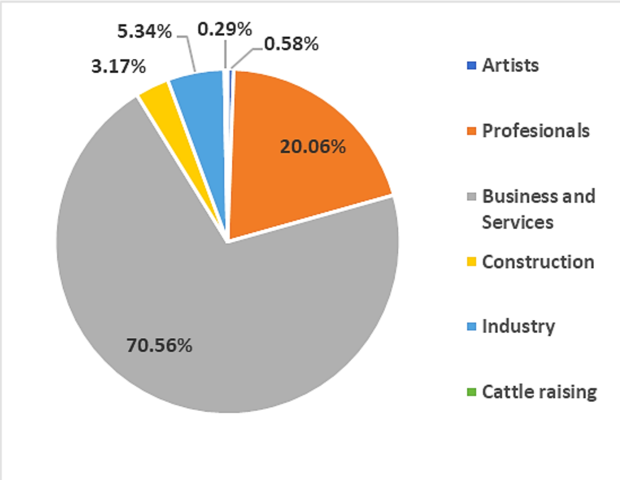

Figure 5.4 Economic activities in La Carrasca [62].

Energy situation

The energy situation in La Carrasca is presented in **Figure 5.5** and **Figure 5.6** below. They present the electricity and NG consumption of the neighborhood distributed by sectors. Clearly showing that the services sector is by far the most consuming, followed by the residential and finally the industrial. Once again, this is mainly due to universities in the neighborhood. Showing how dependent the area is of these institutions.

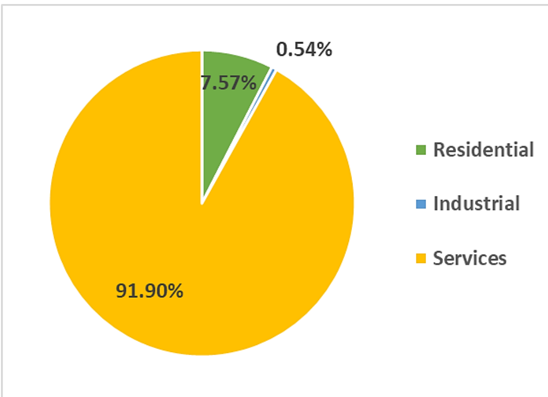

Figure 5.5 Distribution of electricity consumption in La Carrasca.

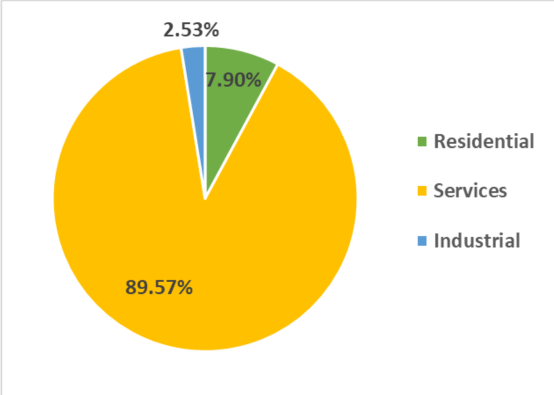

Figure 5.6 Distribution of gas consumption in La Carrasca.

5.2 Justification of the selection of this neighborhood

The decision of choosing the neighborhood of La Carrasca to assess its potential to achieve carbon neutrality was made through a multi-criteria analysis. Comparing it to other areas in the city of Valencia on technical, urban, social, economic, and environmental aspects, whose criteria are correlated with the strategic lines of the Valencia 2030 Urban Strategy [63] that aim to support the city into becoming carbon neutral. These lines are based on issues such as climate resilience of the city, inclusive energy transition, sustainable and efficient mobility, local food, accessible housing, well-being in all stages of life, inclusive and sustainable economic development, among others.

The multi-criteria analysis mentioned above was done in a study that analyzed the 19 districts of Valencia [64] to determine their potential for deploying a CND. Based on survey answers from a group of experts, the most important criteria were prioritized and selected to evaluate the different zones and obtain their results. These criteria are the following:

- Investment (E1)
- Grants and projects (E5)
- Interest or acceptance (S1)
- Community organization (S3)
- Cooperative projects (S2)
- Urban ecology and sustainable utilities (S5)
- Renewable energy resource potential (T3)
- Potential for improving the energy efficiency of buildings and activities in the neighborhood (T7)
- Renewable energy resources (T1)
- Annual thermal consumption of the neighborhood per capita (T5)
- Annual electricity consumption per capita in the neighborhood (T4)
- Surface of public buildings and plots (U5)
- Area per capita (U4)
- Total green areas (U6)

- Current developments in mobility (U7)
- GHG emissions (A1)
- Average air pollution in the neighborhood (A4)
- Fuel poverty (S7)
- Population (S10)

These criteria were also prioritized by the experts, with investment having the highest weighting, followed by the potential for improving the energy efficiency of buildings and activities, grants and projects, and interest or acceptance. This prioritization highlights the importance of economic aspects, although in this study, the technical and environmental aspects of the project are of higher importance.

The neighborhood of La Carrasca is located in the Algirós district. According to the criteria mentioned, the most significant in this neighborhood are the potential for improving the energy efficiency of buildings and activities, investment, and the current developments in mobility, as shown in **Figure 5.7**. In comparison to other districts, apart from the first two criteria just mentioned, shown in **Figure 5.8** and **Figure 5.9** respectively, it's also weighted high in renewable energy resource potential (**Figure 5.10**).

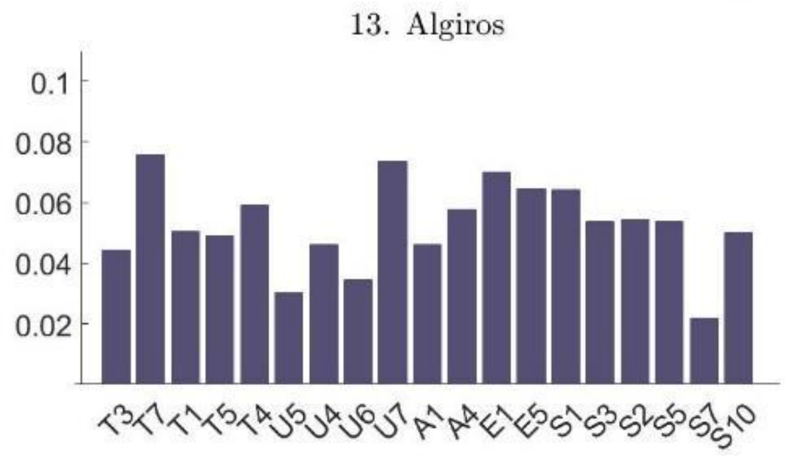

Figure 5.7 Criteria weighting in Algirós district [64].

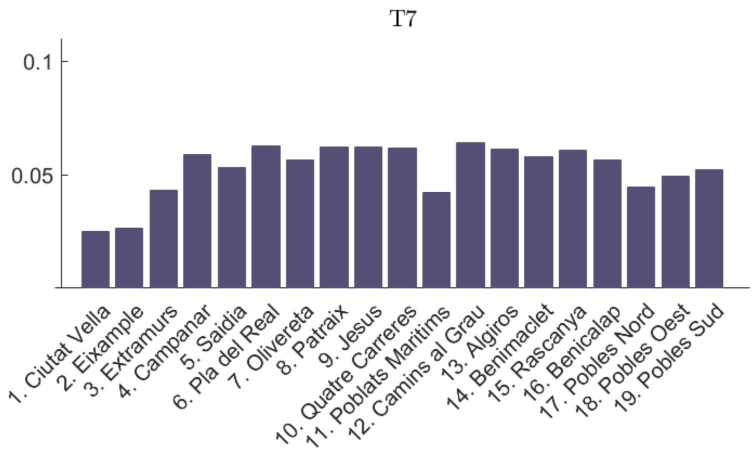

Figure 5.8 Weight of potential for improving the energy efficiency of buildings and activities in the districts of Valencia [64].

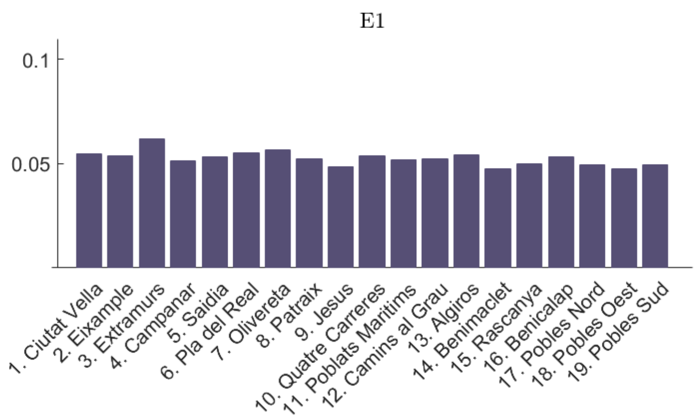

Figure 5.9 Weight of investment criteria in the districts of Valencia [64].

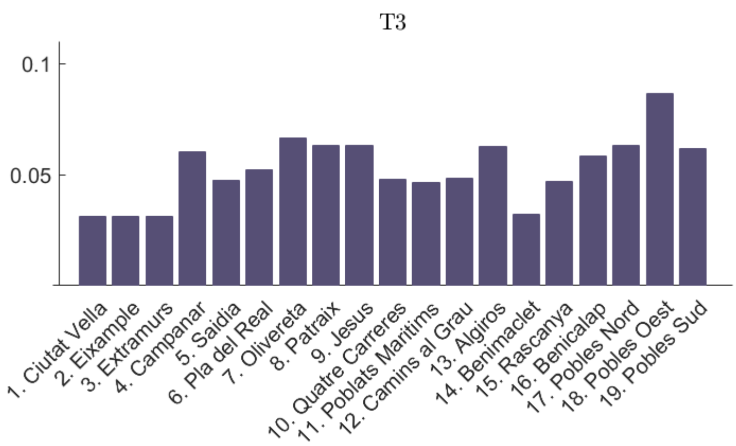

Figure 5.10 Weight of renewable energy resource potential in the districts of Valencia [64].

Summarizing the findings of the study for assessing the potential of the districts to become CNDs, **Figure 5.11** shows the normalized weighted potential of all 19 districts. It can be observed that Algiros is ranked around the middle, which raises the question. Why choose a neighborhood inside of this district if it's not weighted among the highest potentials? The three criteria shown above where the district does exceed give it a high potential to implement renewable energies and energy efficiency technologies and strategies which will help in achieving the objectives of this study to provide carbon mitigation measures in order to reduce its carbon footprint and determine the neighborhoods potential to achieve carbon neutrality. Other reasons, not included in the study mentioned, are the complexities that the neighborhood has. The fact that it has a large agricultural area and that its energy consumptions are highly influenced by the educational institutions in the area, making the services sector such a high contributor, set it apart from other neighborhoods. Making it that much more appealing to be studied.

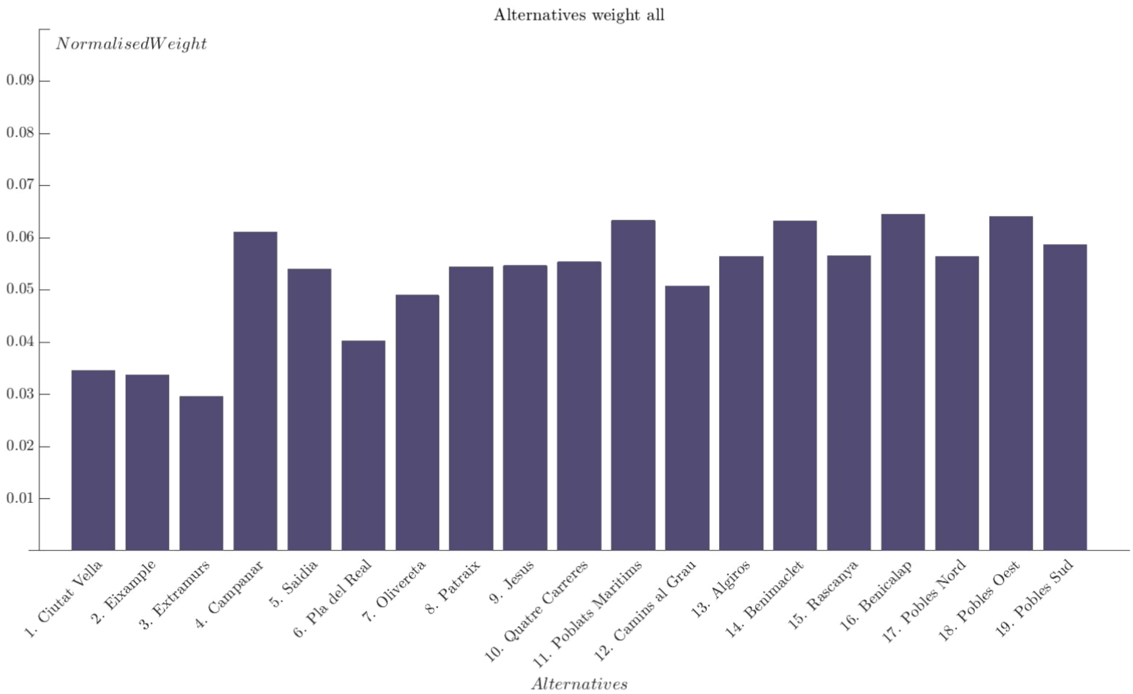

Figure 5.11 Normalized wighted potential of alternatives (districts) according to criteria [64].

5.3 Carbon Footprint

In this section, the results of emissions produced in the different sectors are presented, following the methodologies explained in section **4.2**.

Buildings

The carbon emissions produced by buildings are centered in their electricity and natural gas consumptions. Using the consumptions calculated in section **4.2.1** and the emission factors for these consumptions found in **Annex B**, **Table 9.4**, the resulting emissions produced in the residential, industrial, and services or commercial sectors are presented in **Table 5.2**. Based on these results, the total emissions produced by buildings in the neighborhood of La Carrasca amount to 16,803 tCO_2/year.

Table 5.2 Yearly carbon emission produced from electricity and NG consumption of buildings in La Carrasca.

Sector	Electricity Consumption (MWh/year)	Electricity Emissions (tCO_2/year)	Natural Gas Consumption (MWh/year)	Natural Gas Emissions (tCO_2/year)
Residential	4597	852	2560	486
Industrial	326	131	775	156
Services	55,838	9663	27,442	5516
Total	**60,761**	**10,645**	**30,777**	**6158**

Highlighting the universities in the area, the emissions they produced from their electricity and NG consumptions account for 85.47% of the total building emissions in the neighborhood, 49.83% the UPV and 35.64% the UV, shown in **Table 5.3**.

Table 5.3 Yearly carbon emission produced from electricity and NG consumption of the universities.

University	Electricity Emissions (tCO_2/year)	Natural Gas Emissions (tCO_2/year)	Total Emissions (tCO_2/year)
UPV	6,505	1,824	8,329
UV	2,363	3,595	5,958
Total	**8,868**	**5,420**	**14,288**

At this point it is worth noting that both of the universities already have PV systems. The UPV's produces 22.46 MWh/year [32], while the UV's produces 483.96 MWh/year [65]. These mean savings in emissions of 3.86 tCO_2/year and 83.24 tCO_2/year respectively (87.11 tCO_2/year in total) which reduces the overall emissions of the buildings sector to 16,716 tCO_2/year (0.52% reduction), and more specifically, it reduces the emissions produced by the electricity consumption of the services sector by 0.91%.

Public Transport

The tram lines that pass through the neighborhood are considered trains with a nominal tension of 750 Vcc and an electricity consumption of 4.52 kWh/km [66]. **Table 5.4** shows the yearly consumption and emissions produced by both tram lines, using a factor of emissions for the mix of electricity generation in the city presented in **Annex B**, **Table 9.4**. This electricity consumption represents 1.34% of the total consumption in La Carrasca (considering the buildings and public lighting).

Table 5.4 Yearly carbon emissions produced by tram lines in La Carrasca.

Tram Line	Electricity Consumption (kWh/year)	Emissions (tCO_2/year)
4	553,935	95.3
6	290,641	50.0
Total	**844,576**	**145.3**

The eight bus lines that pass through the neighborhood are traveled by 81 buses. 42 hybrid that consume 0.33 liters of gasoil per kilometer, and 39 conventional diesel that consume 0.49 l/km. Using an emissions factor for diesel consumption, shown in **Table 9.4** of **Annex B**, the amount of carbon emissions produced by the bus lines are presented in **Table 5.5**.

Table 5.5 Yearly carbon emissions produced by bus lines in La Carrasca.

Bus Lines	Diesel Consumption (l/year)	Emissions (tCO_2/year)
18	24,998	61.77
31	1,354	3.35
40	10,892	26.91
71	14,811	36.60
81	2,209	5.46
93	65,717	162.39
98	90,098	222.63
99	11,378	28.11
Total	**221,457**	**547.22**

Finally, the consumption of fuel and the emissions produced by the taxis assigned to the neighborhood are shown in **Table 5.6**.

Table 5.6 Yearly carbon emission produced by taxis in La Carrasca.

Fuel type	Vehicle Fuel Consumption (l/km)	Annual Fuel Consumption (l/year)	Emissions (tCO_2/year)
Gas	0.065	14,804	32.51
Diesel	0.050	37,960	93.80
Total		**52,960**	**126.31**

Private Transport

Using the factors for emissions based on vehicle type, fuel type, and european regulation, presented in **Annex E**, the carbon emissions produced yearly by the vehicles owned by the population of the neighborhood were estimated. As mentioned in section **4.2.2**, the emission factors for electric cars, considering that small trucks consume the same, and electric motorcycles were calculated independently, using consumption factors of 0.150 kWh/km [42] and 0.023 kWh/km [45] respectively, with the factor of emissions for electricity consumption mentioned in **Annex B**. The factor of emissions for both EV types are also presented in **Annex B, Table 9.5**. **Table 5.7** shows the amount of emissions produced by the vehicles of the population in La Carrasca per type of vehicle and european regulation.

Table 5.7 Yearly carbon emissions (tCO_2/year) produced by private vehicles of the population in La Carrasca

Regulation	Cars	Small Trucks	Motorcycles	Total
Pre Euro	89.48	5.75	15.19	110.42
Euro 1	43.89	2.83	20.19	66.90
Euro 2	108.00	6.96	29.13	144.09
Euro 3	407.15	26.31	76.45	509.90
Euro 4	568.98	36.84	38.45	644.27
Euro 5	325.49	21.17	6.11	352.77
Euro 6	565.10	37.02	-	602.12
Total	**2108.08**	**136.88**	**185.51**	**2430.48**

For the vehicles that pass through the neighborhood coming from outside its boundaries, it will be considered that 0.6% of them are electric, according to the EV implementation plan of the CV. Therefore, the calculated factor of emissions for electric cars (**Table 9.5**) was used for the estimated amount of distance traveled by EVs and the average factor of emissions for cars that use other fuels (petrol, diesel, CNG, LPG) calculated from **Table 9.13** in **Annex E**, and shown in **Table 9.5** of **Annex B**, was used for the rest. The results of carbon emissions produced by outside vehicles that pass through each road are shown in **Table 5.8**.

Table 5.8 Yearly carbon emissions produced by outside vehicles that pass through La Carrasca.

Road	Distance traveled by EVs (km/year)	Distance traveled by other vehicles (km/year)	Emissions produced by EVs (tCO_2/year)	Emissions produced by other vehicles (tCO_2/year)	Total emissions produced (tCO_2/year)
A1	65,276	10,814,033	1.68	3565	3567
A50	8,253	1,367,275	0.21	451	451
A74	7,367	1,220,435	0.19	402	403
A165	42,926	7,111,439	1.11	2345	2346
A212	15,901	2,634,335	0.41	869	869
A287	36,777	6,092,708	0.95	2009	2010

A295	5,460	904,605	0.14	298	298
A297	10,279	1,702,939	0.27	561	562
A360	79,399	13,153,699	2.05	4337	4339
A414	55,912	9,262,741	1.44	3054	3055
A418	6,368	1,054,924	0.16	348	348
A419	58,789	9,739,345	1.52	3211	3213
B100	9,394	1,556,267	0.24	513	513
Total	**402,101**	**66,614,744**	**10.37**	**21963**	**21973**

Public Lighting

In the Algirós district, where La Carrasca is located, the public lighting network has a total power installed of 617.8 kW and consumes 1912 MWh/year of electricity. From this data it was estimated that the public lighting network of the area is turned on for 3095 hours in a year. Using this calculation and the power installed of each type of light in the district, shown in **Table 4.9**, the total electricity consumption from each type of light in the neighborhood was calculated. Furthermore, with the factor of emissions from the electricity grid, the total emissions produced from this sector were calculated, shown in **Table 5.9**. This electricity consumption is only 2% of the total electricity consumption in the neighborhood.

Table 5.9 Yearly carbon emissions produced by the public lighting network in La Carrasca.

Type of Light	Electricity Consumption (kWh/year)	Emissions (tCO_2/year)
Sodium Vapor	938,280	161.38
Mercury Vapor	418	0.07
LED	71,635	12.32
Metal Halogen	256,791	44.17
Other	136	0.02
Total	**1,267,261**	**217.97**

Consumption of Goods

As mentioned in section **4.2.4**, factors of emissions per capita for each type of food consumed in the neighborhood were calculated. These were summed up to produce an emissions factor per capita for food consumption. Along with emission factors for clothes and manufactured products, and the population considered in each consumption, the total carbon emissions produced by this sector were calcuated. The results are shown in **Table 5.10**, where it can be observed that 75.6% of the emissions of this sector come from food consumption because of how much more population is considered. This being the students of the universities, whose estimated food consumption amounts to 58% of the emissions produced from this category, shown in **Table 5.11**.

Table 5.10 Yearly carbon emissions produced by the consumption of goods in La Carrasca [46].

Category	Emissions Per Capita (tCO_2/cap)	Emissions (tCO_2/year)
Food	2.07	17,107
Clothes	0.3	1,033
Manufactured Products	1.3	4,477
Total		**22,617**

Table 5.11 Yearly carbon emissions produced by the consumption of food in the universities.

Category	Emissions (tCO_2/year)
UV	3,880
UPV	6,109
Total	**9,988**

Waste

As mentioned in section **4.2.5**, factors of CO_2 emissions per weight of waste were calculated for each of the three uses considered: landfill, recycled (treated), and composting. This calculation is described in **Annex G**. Using the amount of waste that is managed through each use, the total carbon emissions produced from the waste generated by the population and universities in the neighborhood was calculated, shown in **Table 5.12**.

Table 5.12 Yearly carbon emissions produced by the waste generated in La Carrasca. Adapted from [59].

Waste Management	Emissions Factor (tCO_2/tons)	Emissions (tCO_2/year)
Landfill	0.270	316.49
Recycled (Treated)	0.096	40.06
Composting	0.164	43.19
Total		**399.75**

Once again focusing on the universities, they produce 26.19% of the total estimated waste of the neighborhood. Therefore, they produce the same percentage of the total emissions from this sector, 16.02% from the UPV and 10.17% from the UV, as shown in **Table 5.13**.

Table 5.13 Yearly carbon emissions produced by the waste generated in UPV and UV campuses.

Waste Management	Emissions from UPV (tCO_2/year)	Emissions from UV (tCO_2/year)	Total Emissions (tCO_2/year)
Landfill	50.69	32.19	82.88
Recycled (Treated)	6.42	4.08	10.49
Composting	6.92	4.39	11.31
Total	**64.03**	**40.66**	**104.69**

Green Areas

As it's described in section **4.2.6**, after measuring the surface area of urban green zones and the agricultural land in the neighborhood, carbon capture factors for both of these areas were determined. **Table 5.14** shows these factors and the resulting emissions captured during a year by each type of green area. The agricultural land amounts to 94.5% of the current carbon capture capacity of all green zones in La Carrasca.

Table 5.14 Carbon capture of green zones in La Carrasca. Adapted from [60].

Green Areas		Carbon Capture Factor (tCO_2/ha)	Emissions Captured (tCO_2/year)
Urban green zones		1.58	31.65
Agricultural land	Herbaceous crops	18.04	476.15
	Woody crops	15.22	65.69
Total			**573.49**

5.4 Development of defined lines to achieve carbon neutrality

In this section, the six different carbon reduction measures that were developed for this study are presented and explained. These measures pretend to reduce emissions across all three scopes. First, since a highlight of La Carrasca is the high energy consumption coming from its services sector, specifically the two big universities that reside in the area, then a PV system will be dimensioned to reduce the neighborhoods electricity consumption and reduce scope 2 emissions. The same can be said for the public lighting measure which intends to reduce the electricity consumption of this sector by changing to lower consuming lights (LED). The changing to electric vehicles and heat pumps for heating mainly reduce scope 1 emissions, the former also reduces scope 3 emissions, but in exchange they increase the overall electricity consumption of the neighborhood, and thus also increase scope 2 emissions. They will be considered beneficial if in turn the overall emissions are reduced. On the other hand, the improvement of how the waste of the area is managed should lead to reducing scope 3 emissions. Finally, nature-based solutions will be implemented, which will reduce the overall emission of the area by increasing its carbon sequestration potential through the implementation of more green areas.

5.4.1 Photovoltaic Generation System

To reduce carbon emissions from the neighborhoods electricity energy consumption, the most common and proven technology is the use of PV systems. Therefore, an objective of this work is to determine the potential areas to implement solar panels and simulate their performance in HOMER to determine how much energy they can produce to reduce the neighborhoods electricity consumption and CO_2 emissions. Mainly, the building rooftops will be considered. The amount of available rooftop area was determined using the program QGIS with the Spanish

Inspire Cadastral add-in, which has different layers of cadastral information that can be filtered for the city of Valencia. The functionality and use of this program was explained in detail in section **3.3**. The resulting surface areas estimated with QGIS are presented in **Table 5.15** based on the different building layers created.

Table 5.15 Surface areas considered for PV installation using QGIS

Layer	Surface (m^2)	
Neighborhood Rooftops	79,287	20.23%
UPV and surrounding rooftops	204,980	52.31%
Parking	84,011	21.44%
Open lots	23,611	6.02%
Total	**391,888**	

Through the rooftop analysis made with Google Earth, described in section **3.4**, it was determined that the useful rooftop area for PV installation is 32% of the total surface. Based on this result, the total surface area that will be considered to dimension the PV system that could be installed is 125,404 m^2. The system was also evaluated at 30% and 35% of rooftop availability to have points of comparison, whose results are shown in **Table 9.8**, but ultimately the percentage determined in the analysis was chosen as optimal. Then, based on the inclination angle chosen for installing PV panels and with the technical specifications of the type of panels to be installed, the area needed for each panel was calculated, and therefore the total power to be installed was determined. The chosen panels for this study are the SR-72M550HLPro from Sunrise [67]. A Mono-Crystalline Silicon panel with dimensions, efficiency, maximum power, nominal operating temperature and temperature coefficient of power shown in **Table 5.16**. They were considered to be placed at an inclination angle of 35°, considered optimal for the area, or 15°, considered based on space to place more panels and increase the total PV power installed. After evaluating the PV systems performance for both angles, the 15° angle of inclination was chosen. Using the panel specifications mentioned before, the power that can be installed for the area available was calculated at 0.144 kW/m^2, explained in **Annex D**. Resulting in total power for the PV system of 18,009 kW.

Table 5.16 PV panel specifications

Specification	Value
Length (mm)	2278
Width (mm)	1133
Efficiency (%)	21.31%
Maximum Power (W)	550
Nominal Operating Temperature (°C)	45±2
Temperature Coefficient of Power (%/°C)	-0.348

The prices for the photovoltaic system were determined from the predictions done by the UNEF in their annual report [68], and prices presented by IDAE in their renewable energy plan [69], shown in **Table 5.17**. On the other hand, the prices of electricity were determined from the historic data of REE using the platform Esios [70] and the new electricity bill tariffs from the National Commission of Markets and Competition [71]. The former was used to retrieve average values of the energy price for all three tariff periods and the selling price, while the latter was used to retrieve the power price values. **Table 5.18** presents these values, which include a value added tax of 21% and an electricity tax of 5.11%. Other inputs for the PV system include a lifetime of 25 years, a derating factor of 90% and a ground reflectance of 20%. Finally, the last input needed for simulating the system using HOMER is the solar resource. In other words, the global horizontal radiation in the area. It was determined using the platform PVGIS (Photovoltaic Geographical Information System) [72], which provides hourly radiation data for a year in a specific location. Choosing a latitude of 39.479° and a longitude of -0.343°, close to the center of the neighborhood, resulted in an annual average of 4.8 kWh/m^2 per day.

Table 5.17 Costs of PV system [68].

Capital (€/kW)	1320
Replacement (€/kW)	500
O&M (€/kW·year)	36.1

Table 5.18 Cost for the electric grid. Adapted from [70], [71].

<table>
<tr><th>Period</th><th>Energy Price (€/kWh)</th><th>Power Price (€/kW·month)</th><th>Selling Price (€/kWh)</th></tr>
<tr><td>P1</td><td>0.363</td><td rowspan="2">3.251</td><td rowspan="3">0.112</td></tr>
<tr><td>P2</td><td>0.288</td></tr>
<tr><td>P3</td><td>0.235</td><td>0.151</td></tr>
</table>

5.4.2 Nature-Based Solutions

Nature, or natural, based solutions (NBS) are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" [73]. In other words, they improve the overall environmental quality of an area. They do this by reducing the carbon footprint, since green areas serve to capture emissions.

As mentioned before when the carbon footprint of the neighborhood was being determined, the total surface of urban green areas and agricultural land was calculated. Green zones account for 9.8% of the total surface of the neighborhood, and by adding the total agricultural land of the neighborhood it can be concluded that 28% of the total surface of the neighborhood is covered by nature in some way. Having this base situation, the potential for increasing green zones in the studied area can be determined. First, the increase in CO_2 absorption by the urban green areas that are already established was calculated, because as trees grow older and bigger, they absorb more carbon dioxide. Then, potential areas that can be turned to green zones are identified and their absorption potential is estimated throughout the period of study, since it will increase each year.

To determine how the absorption factor for urban green areas will increase yearly, an average accunmulated absorption curve was estimated using CO_2 absorption values for some of the most common trees in Valencia (Platanus hispanica, celtis australis, pinus pinea, phoenix dectylifera, acer negundo) and considering each types contribution to the total surface area they occupy in the city, as shown in **Table 5.19** and **Figure 5.12**. This data was obtained from a study developed by the National Forest Inventory and the MITECO [74] and the carbon stock study mentioned in section **4.2.6**. Using an exponential tendential curve on the calculated average carbon absorption curve, an estimated tendency curve for the yearly increase in accumulatd CO_2 absorption for urban green zones in the city was determined, shown in **Figure 5.13**. A baseline of 15 years will be considered as the lifetime of these already established urban green areas.

Table 5.19 Contribution of most common trees in Valencia.

Type of Tree	Number of trees	%
Platanus hispanica	9,867	34%
Celtis australis	7,422	36%
Pinus pinea	3,059	11%
Phoenix dectylifera	3,446	12%
Acer negundo	5,265	18%
Total	**29,059**	

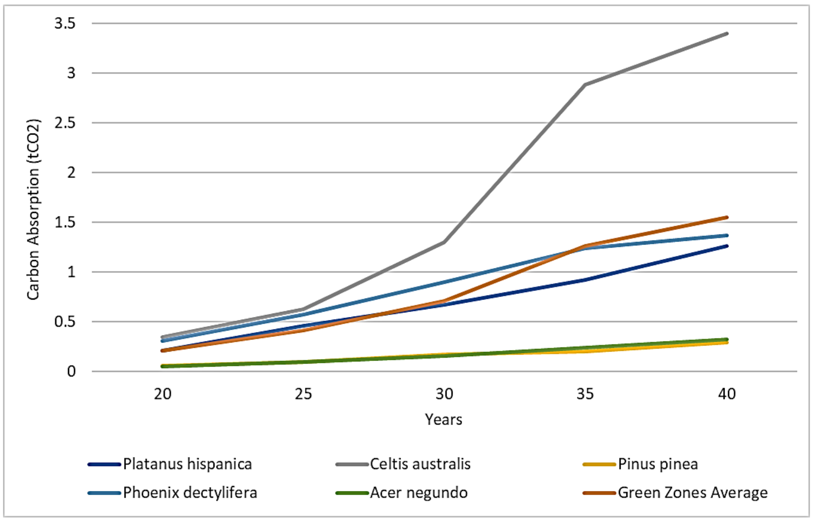

Figure 5.12 Accumulated absorption curves for common trees in Valencia and average. Adapted from [74].

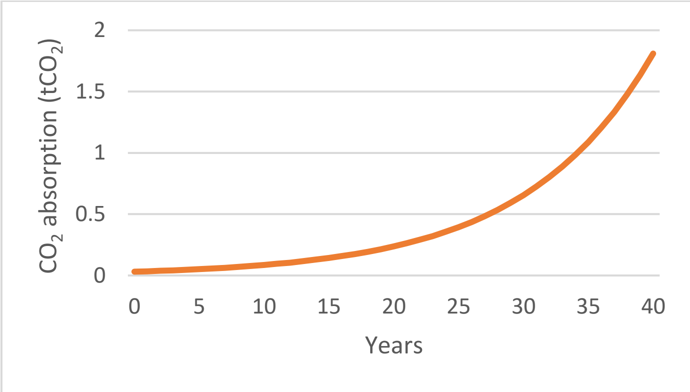

Figure 5.13 Estimated accumulated absorption curve for urban green zones in Valencia.

Potential new green areas were identified and measured using the geoportal of the "Ayuntamiento de Valencia". The neighborhood of La Carrasca does not have many areas without buildings or already established green zones. Specifically, there is only one area, which is open and used partly as parking, that will be considered for implementing an NBS, shown in **Figure 5.14**. Since part of this area is also being considered for implementing a PV system (32%). Then a conservative amount of space, 60%, is what will be used in this measure. Since these new green areas will have much younger vegetation, the baseline lifetime for this area will be considered at 3 years. The implementation of this measure will be done progressively, changing 10% of the total area considered yearly from 2022 to 2025, and then changing 20% yearly from 2026 to 2028, as shown in **Table 5.20**.

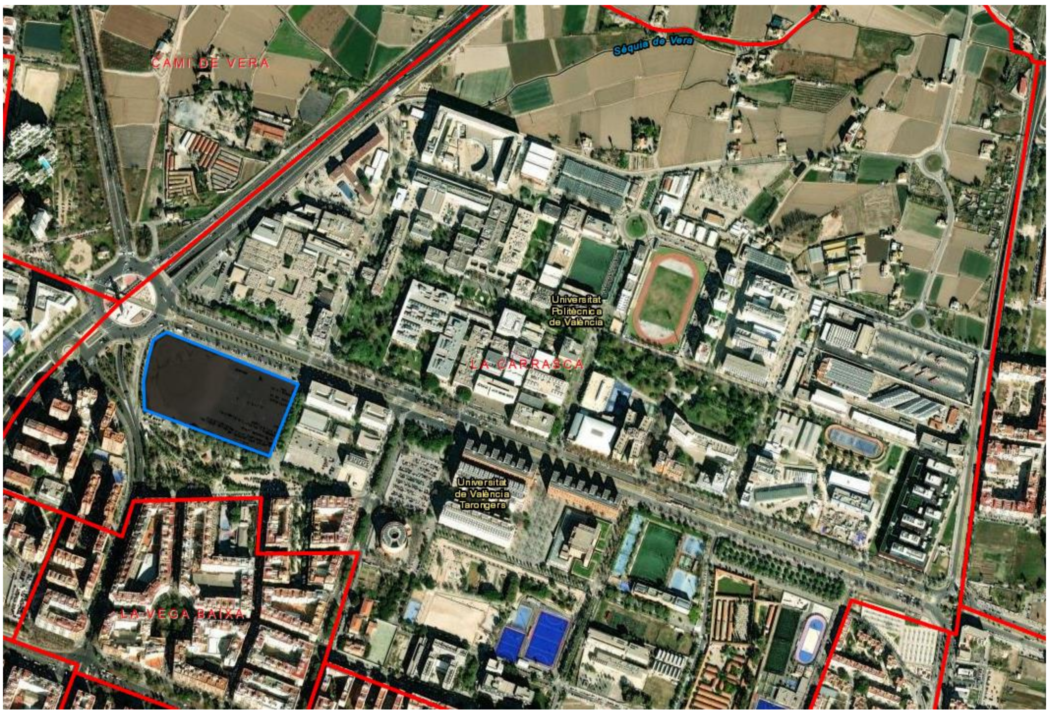

Figure 5.14 Location in neighborhood of area considered for NBS.

Table 5.20 Green area implementation plan.

Year	Surface (m^2)	
2022	2,601	10%
2023	5,202	20%
2024	7,802	30%
2025	10,403	40%
2026	15,605	60%
2027	20,806	80%
2028	26,008	100%

Considering this increment in green surface area and the natural increment in absorption based on the growth of the vegetation, the amount of CO_2 absorbed each year by this new green zone and the ones already established in the neighborhood was calculated. This analysis was done up to the year 2030 to consider how these areas carbon capture keeps increasing yearly and have a comparison as to how much more absorption comes from the new green zone after its complete implementation. Another consideration that should be included is implementing NBS in buildings or industries. For example: green roofs, green walls, urban gardens, green street furniture, etc. These areas will not only help with the absorption of carbon emissions, but also provide natural insulation and cooling to buildings.

5.4.3 Electric Vehicle

Since the transportation sector is the biggest contributor to GHG emissions in the neighborhood, one of the main mitigation measures of this study is to change this sector. The most effective technology at this time is to change existing fossil fuel consuming vehicles to EVs, which is why the Valencian Community has a proposed plan for this transition [53], mentioned in section **4.2.2**. This measure will first promote the electrification of public transport, buses and taxis, then tackle the private transportation sector.

Public Transport:

Starting with the buses that pass through the neighborhood, as mentioned in section **4.2.2**, they are hybrid and conventional diesel consuming, and their yearly carbon emissions produced were determined, shown in the public transport subsection of section **5.3**. To mitigate these emissions, electric buses will be implemented in exchange for the 39 conventional diesel ones progressively. The yearly savings that result from this change were calculated directly by first knowing how much an electric bus consumes in electricity per kilometer and consequently per year. Using as a reference the BYD K9G electric bus [75], that consumes 1.08 kWh/km, the electricity that these buses would consume travelling the same routes through the neighborhood was estimated. Then, with the emissions factor for the electricity grid of the province, the yearly emissions that they would produce were calculated. **Table 5.21** shows these results for the eight bus lines with the electricity consumption, the diesel consumption of the hybrid buses left, and the added emissions from both.

Table 5.21 Estimated yearly carbon emissions that electric buses would produce in La Carrasca.

Bus Lines	Diesel Consumption (l/year)	Electricity Consumption (kWh/year)	Emissions (tCO_2/year)
18	10,636	31,655	31.73
31	576	1,715	1.72
40	4,634	13,793	13.82
71	6,301	18,755	18.80
81	940	2,798	2.80
93	27,960	83,219	83.40
98	38,333	114,094	114.35
99	4,841	14,408	14.44
Total	**94,221**	**280,438**	**281.06**

For the taxis inside the neighborhood, the process is basically the same but using the statistics mentioned in section **4.2.2** for distances traveled by taxis, and an electricity consumption factor for common EVs of 0.15 kWh/km, mentioned in the private transport subsection of section **5.3**. With the estimated total distance traveled by the taxis assigned to La Carrasca, shown in **Table 4.5**, the total electricity consumption was calculated at 148,044 kWh/year. Therefore, using the emissions factor for the electric grid, the emissions that these electric taxis would produce are estimated at 25.46 tCO_2/year.

Private Transport:

For the private transport sector, this study will follow the proposed plan for EV implementation mentioned before. Its objectives are that the CV wants 2.2% of its vehicle fleet to be electric by 2025, and 7% by 2030. Currently (2020) in the neighborhood, as shown in **Table 4.6**, only 0.32% of all vehicles (6 of 2046) are electric. For each type of vehicle this is 0.14% of cars, 0.95% of small trucks, and 0.85% of motorcycles. The changing of vehicles will be done by removing the oldest, and most consuming, vehicles and adding new electric ones. Then, using the emissions factors for the different type of fuels determined before, the yearly emissions per type of vehicle was calculated. Finally, adding the values calculated for each year of study considered, the total emissions were calculated and then compared to determine the savings expected from this measure. **Table 5.22** shows the progression of the EV penetration in La Carrasca following the percentages mentioned before.

Table 5.22 Electric vehicle penetration in La Carrasca (Number of vehicles).

Year	Cars	Small Trucks	Motorcycles	Total
2020	2	1	3	6
2025	34	2	8	44
2030	109	7	26	142

From the open geodata of the city of Valencia, it was determined that there are no points of recharge for electric vehicles currently in La Carrasca. According to the plan mentioned before, it's expected that in the city of Valencia there will be an implementation of 184 semi-fast recharge points by 2025, and 406 by 2030. Using a downscaling factor based on the surface of the neighborhood in the city, it's estimated that in La Carrasca there will be at least 3 and then 6 respectively by year.

For the vehicles that pass through the neighborhood coming from outside its boundaries, the savings in emissions were estimated by changing the percentage of kilometers traveled by EVs against other vehicles using the same percentages of EV penetration applied above for their implementation inside the neighborhood. **Table 5.23** shows the increase in estimated yearly distance traveled by EVs compared to the decrease by vehicles that consume other fuels. Using the same factor of emissions applied in the private transport subsection of the carbon footprint, section **5.3**, the change in emissions produced was calculated.

Table 5.23 Estimated change in distance traveled (km/year) by EVs and other fuel consuming vehicles.

Type of vehicle	2020	2025	2030
Electric	402,101	1,474,371	4,691,179
Others	66,614,744	65,542,475	62,325,666

5.4.4 Public Lighting

The main objective of the energy efficiency measure on the public lighting network of La Carrasca is to decrease the electricity consumption of the network by changing all the points of light in the neighborhood to LED. Currently, around 17% of the light points in La Carrasca are LED, as shown in **Table 4.9**. The city of Valencia in its roadmap for the energy strategy [76] proposes this measure with an increase in LED incorporation of 60% by 2025, and 100% by 2030. This implementation strategy will be used on a neighborhood scale, shown in **Table 5.24**, excluding the 10 points of light categorized as "Others" since their power per light is the same as LEDs (**Table 4.9**). Using the power per type of light, **Table 5.25** shows the estimated amount of savings produced by changing each type of light to LED. Then, with the number of lights for each type that will be changed, the total energy savings per year for changing all of the lights to LED was calculated. Following the plan mentioned before, knowing how much savings the project would have in 2030 at 100%, then the savings that would be achieved by changing 60% of the lights by 2025 were estimated.

Table 5.24 Incorporation of LEDs in public lighting network.

Year	Number of LED		Installed Power
2020	515	17%	23.14
2025	1,792	60%	80.47
2030	2,977	100%	133.67

Table 5.25 Electricity consumption savings from changing each type of light to LED.

Type of Light	Power Savings per Light (kW)	Consumption Savings per Light (kWh/year)
Sodium Vapor	0.15	457.61
Mercury Vapor	0.09	2787.88
Metal Halogen	0.05	150.35

5.4.5 Heat Pumps

This carbon mitigation measure focuses on the residential sector, mainly changing its NG consumption used for heating and sanitary hot water (SHW) to electricity consumption by implementing heat pumps as an energy efficiency measure. Using studies about gas consumption in dwellings in the Mediterranean climatic zone of Spain, where the city of Valencia is, the calculated consumption of the residential sector was divided into its uses (heating, SHW, and kitchen), as shown in **Figure 5.15**, and the different devices that the population uses, specifically for heating and SHW [77]. These devices are primarily conventional NG boilers, condensation boilers, gas fireplaces, and thermos gas water heaters. Using average efficiency values for each type, the neighborhood's thermal demand for heating and SHW was calculated to 1862 MWh/year. This calculation process is presented in **Table 9.21** in **Annex F**.

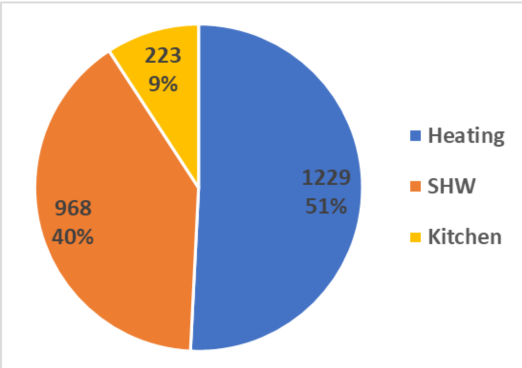

Figure 5.15 Natural gas consumption in the residential sector of La Carrasca [77].

Different types of HPs, with different nominal power and efficiency, were considered for covering such demand. Ultimately, the most efficient was chosen regarding the savings in energy of NG against the increase in electricity, the potential of savings in emissions, and costs. The LG Aerothermal model Therma V Monobloc S R32 HM051MR.U44 was chosen [78], with specifications presented in **Table 5.26**. Using these model specifications, the annual electricity consumption needed to produce the thermal demand of the neighborhood was estimated at 396.22 MWh/year. The GHG emissions saved per year were calculated comparing the amount of NG saved with the added electricity demand using emission factors for each consumption.

Table 5.26 Heat Pump model specifications [78].

Heating Capacity (kW)	5.5

Nominal Consumption (kW)	1.17
COP	4.70

Of the 1901 dwellings in the neighborhood, 89.3% have some type of heating system, based on the town hall statistics for the district of Algiros [36]. Of those, based on the types of fuels used for heating in the Mediterranean climatic zone of Spain [79], 24.8% use natural gas. Considering one HP for each home, this results in an investment of 397 devices. To reduce the number of decives and costs, higher capacity heat pumps that could be shared between several dwellings could be considered. But also the added conections and difficulties tham come with having a single device for several homes need to be taken into consideration and for this a much deeper analysis of how this affects specific buildings needs to be made.

5.4.6 Improve Waste Management

For the development of this measure, the guidelines created by the EMTRE for creating local plans for waste management [58] were used to create an objective scenario that follows many of their main objectives. The desired scenario will have the following objectives:

- Reduction of 10% of the total waste.
- Limit the amount of waste that is thrown in a landfill to 35%.
- Increase the recycling of waste products for treatment, energy and composting as close to 67% as possible, which currently stands at 42.28%.

Based on the distributions presented in **Table 4.13**, the new waste management distribution according to the total waste generated will be as shown in **Table 5.27**. This will be achieved through the development of a set of lines of strategy and actions based on the stages of waste generation, presented in the guidelines mentioned. This list is presented in **Table 5.28**, including the agents that should perform these actions.

Table 5.27 New waste management distribution scenario.

Landfill	35.00%
Recycled	31.62%
Energy	13.50%
Composting	19.87%

Table 5.28 Lines of strategy and actions to achieve improved waste management scenario [58].

Strategic Lines	Actions
Design & Production	**Prevention and minimization business plans**: Use of eco-design criteria Agent that performs it: Companies

Purchase	**Communication and environmental education plan**: Promote the use of durable products, Zero packaging (buy with your own packaging). Agent that performs it: EMTRE, Town Halls, Colleges and Institutes, Companies related to the consumption
Consumption	**Communication and environmental education plan**: Promotion of reusable products, Second-hand purchase, Favor the repairing of products, Citizen awareness, Implementation of Good Environmental Practices. Agent that performs it: EMTRE, Town Halls, Colleges and Institutes, Companies related to the consumption
Pickup	**Plan to promote selective collection for the five fractions**: greater endowment and access to containers and door-to-door collection of bulky waste. Agent that performs it: Public and private entities. Establishments of public or public-private and local management and private establishments (offices, shops, etc.). **Self-management plan for the organic fraction**: separation of the organic fraction and use of home composting. Agent that performs it: Public and private entities **Information Management Program**: Design of an information system on the data of waste generation, treatment, location of collection points, costs associated with the service and other information considered relevant. It must be available on the citizen's web portal and provide them with access to said information in order to have an understanding of the service and encourage its responsible use. Agent that performs it: Town Halls and other Public Administrations

	Recovery and valorization program: provide infrastructures for the recovery and valorization of waste, always applying the principle of waste hierarchy. Agent that performs it: Public and private entities that intervene in the final destination of the waste.
Destination	**Promotion of waste reuse**: promotion of the reuse of textbooks, collection of clothing and footwear, reuse of glass containers, etc. Collection points for these products will be provided, second-hand markets, etc. Agent that performs it: Town Hall
	Promotion of the repair of goods and products: promotion of the repair of goods and products through the creation of an advisory and self-repair service for products. Agent that performs it: Town Hall

5.5 Results and analysis

5.5.1 Carbon Footprint

The neighborhood's carbon footprint is shown in **Table 5.29**, where each sectors contribution to the overall amount of 65,173 tCO_2e/year is presented. The most significant sector is the private transportation, with 37.4%. Whose emissions contribute largely to scope 3 since 90% of the emissions private vehicles produce come from the ones that pass through the area (21,973 tCO_2/year), not the vehicles owned by the population of the neighborhood. On the other hand, the least constributing sector to the carbon footprint of the neighborhood, apart from the electricity or gas consumption of the industrial sector, is the electricity consumption of the public lighting network, with only 218 tCO_2/year for a 0.3% contribution.

The second most carbon emitting sector in La Carrasca is the consumption of goods, accounting for 34.7% of the total emissions, better shown in **Figure 5.16**. This percentage is less than usual in comparison to other neighborhoods in the city, as shown in a similar study performed in the neighborhoods of Benicalap and L'Illa Perduda [80]. This is due to a much higher contribution coming from the services sector of buildings consuming electricity and gas (23%). Based on the different characteristics of these three neighborhoods, this difference is mostly due to its high electricity consumption coming from the two universities that are in La Carrasca. Both of them consume more electricity individually than the rest of the neighborhood's buildings together. This helps in understanding better where the emissions of La Carrasca are being produced, which is why a buildings sector is considered that envelops most of the electricity consumption, except for public lighting and tram train travel, and all of the natural gas consumption. Buildings account for 16,716 tCO_2/year or 25.6% of the total emissions in the area. 90% of these building emissions, 15,092 tCO_2/year, come from the services sector. Once again highlighting the magnitude of the consumption of the universities, as stated in section **5.3** in the Buildings subsection. Considering the carbon sequestration from the urban green areas and agricultural land in the neighborhood, 573.5 tCO_2 the overall emissions in the baseline year descend to 64,600 tCO_2e/year, a 0.88% reduction.

Table 5.29. Carbon footprint by sectors in La Carrasca.

Sector		Carbon Emissions (tCO_2e/year)	Contribution
Electricity	Residential	852	1.3%
	Industrial	131	0.2%
	Services	9,576	14.7%
Natural Gas	Residential	486	0.7%
	Industrial	156	0.2%
	Services	5,516	8.5%
Private Transport		24,403	37.4%
Public Transport		819	1.3%
Public Lighting		218	0.3%
Waste Management		400	0.6%
Consumption of goods		22,617	34.7%
Total		**65,173**	

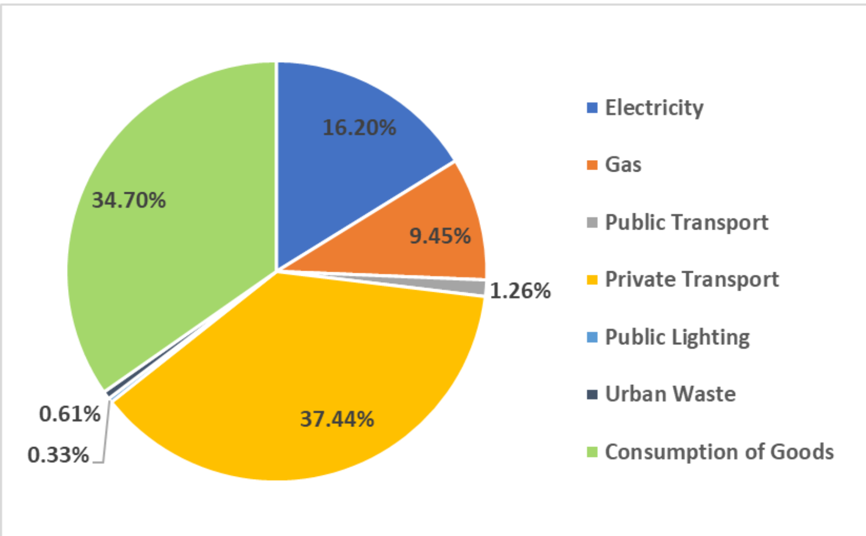

Figure 5.16 Contribution of each sector to the carbon footprint of La Carrasca.

Analyzing the emissions produced in the neighborhood divided into the three scopes, presented in **Table 5.30**, the results show that most of the emissions are indirect but result from activities inside the area's boundary (Scope 3), at 69%. Highlighted in **Figure 5.17**. These emissions come from the consumption of goods, the waste produced, and the vehicles that pass through the neighborhood but are not a part of it. Scope 2 emissions account for 16.8% of the total emissions of the area, which come from the electricity consumption of its buildings, tram train lines, and public lighting. This percentage is higher than other neighborhoods in the city [80]. It's also due to the high electricity consumption of the UPV and UV campuses, which is reflected in the services sector. Finally, scope 1 emissions comprise the gas consumption, public (except for the tram) and private transportation of vehicles inside the neighborhood, meaning the ones own by its population.

Table 5.30. Carbon footprint by scopes in La Carrasca.

Sector		Scope 1	Scope 2	Scope 3
Electricity	Residential		852	
	Industrial		131	
	Services		9,576	
Natural Gas	Residential	486		
	Industrial	156		
	Services	5,516		
Private Transport		2,430	0.4	21,973
Public Transport		674	145	
Public Lighting			218	
Waste Management				400
Consumption of goods				22,617
Total		**9,262**	**10,921**	**44,990**

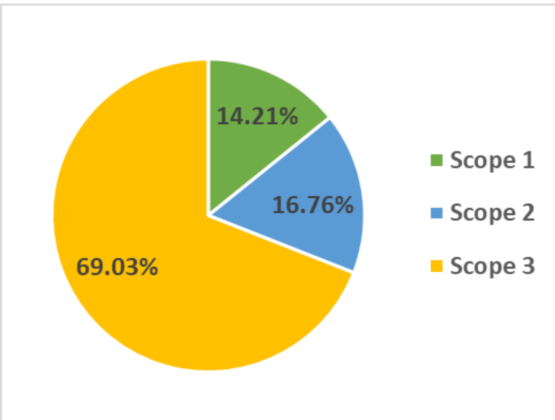

Figure 5.17. Contribution of scopes to carbon footprint.

5.5.2 Impact of Carbon Reduction Measures

Photovoltaic System

After introducing all of these parameters into HOMER, as described in subsection **5.4.1**, the simulation of the system resulted in the yearly production presented in **Table 5.31**. Along with the total electricity production of the complete system (PV and grid)percentage of solar fraction, which is the percentage of the demand that is being covered by the system, and the levelized cost of electricity, which measures the lifetime costs of the complete system divided by energy production.

Of the total electricity production from the PV system and grid conection, 53.8% is what needs to be bought from the grid. This is the opposite of the solar fraction (46.2%), which is the percentage that is being produced by the PV panels. Whenever the PV installation cant produce enough electricity for the demand, the system buys from the grid. On the other hand, whenever the PV system produces more than what is demanded at the moment, since there is no battery storage, the excess electricity is sold back to the grid, which is 9% of the total electricity produced.

Table 5.31 PV system production results from HOMER.

Total Electricity Production [PV + Grid] (MWh/year)	66,905
PV Production (MWh/year)	30,880
Grid Purchase (MWh/year)	36,025
Grid Sales (MWh/year)	6,148
Solar Fraction	46.2%
LCOE (€/kWh)	0.196

Figure 5.18 presents the system's monthly production compared to the electricity that is bought from the grid. It clearly shows that the PV system has a higher average production in the summer months, May to August, although is highest peak comes in April. This results in a mostly lower amount of electricity that needs to be bought from the grid, presented in **Figure 5.19**, except for the month of July because it's the highest electricity consuming month, as shown in **Figure 4.3**. It can also be observed how the month of august is where the least amount of electricity is bought, and consumed, due to the shutdown of the educational institutions in the area because of the summer break.

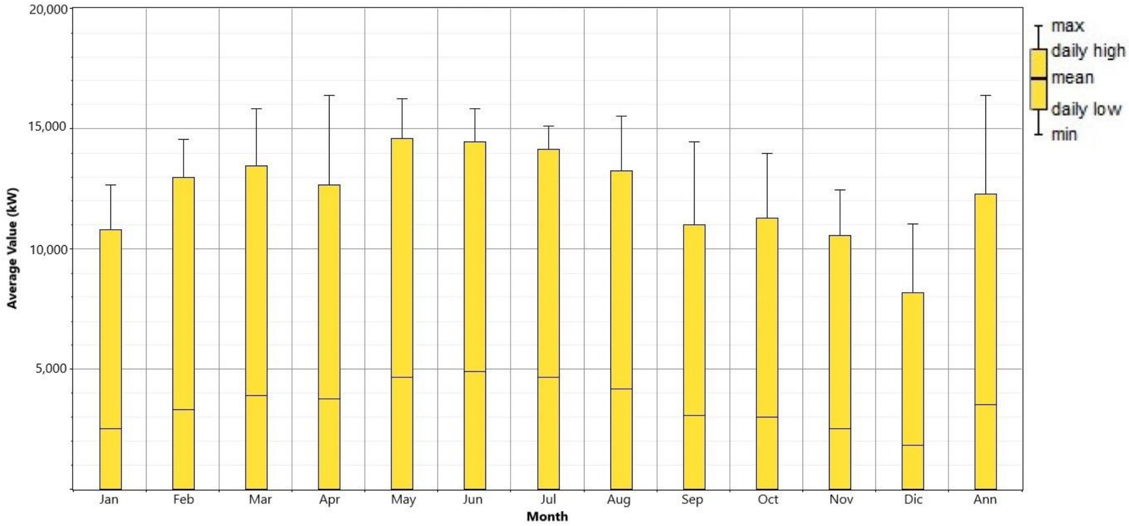

Figure 5.18 Monthly electricity production of PV system [31].

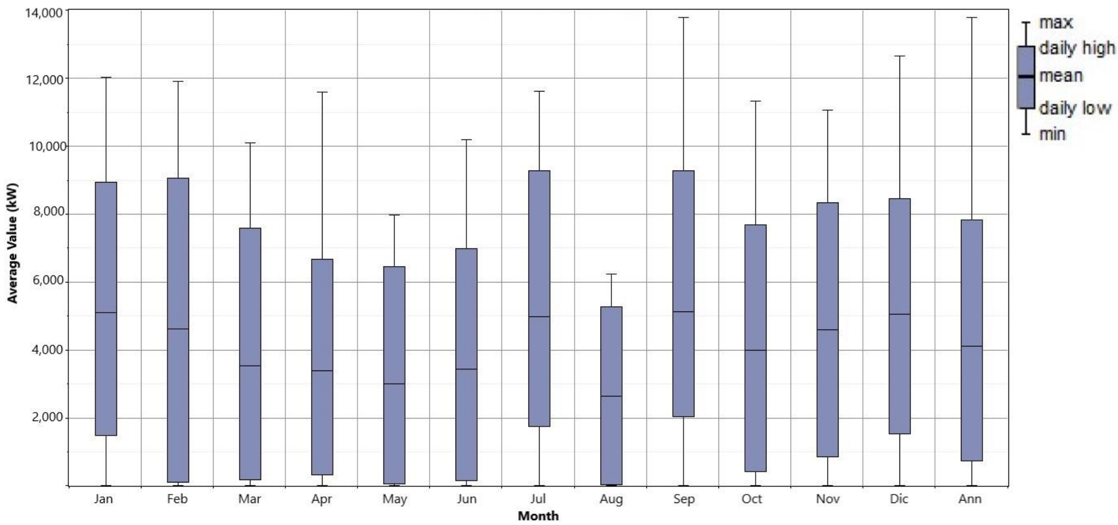

Figure 5.19 Monthly electricity that is bought from the grid [31].

In terms of savings in emissions, considering the increase in electricity consumption and the electricity produced by the PV system, the actual savings in electricity consumption are 24,732 MWh/year. Therefore, the amount of yearly emissions saved is 4254 tCO_2/year. This is 5.94% of the total emissions in the neighborhood and 40.29% of the total CO_2 emissions that come from the electricity consumption of buildings.

Nature-Based Solutions

As its described in section **5.4.2**, the first step was to calculate how much the urban green zones in the neighborhood are already capturing. Using the emissions factor for green zones and the total surface area of urban green zones in the neighborhood, it resulted in 31.65 tons of CO_2 captured per year. Considering the behaviour of the accumulated carbon absorption curve calculated, shown in **Figure 5.13**, this carbon capture value increases by 10.7% yearly. This behavior is presented in **Figure 5.20**.

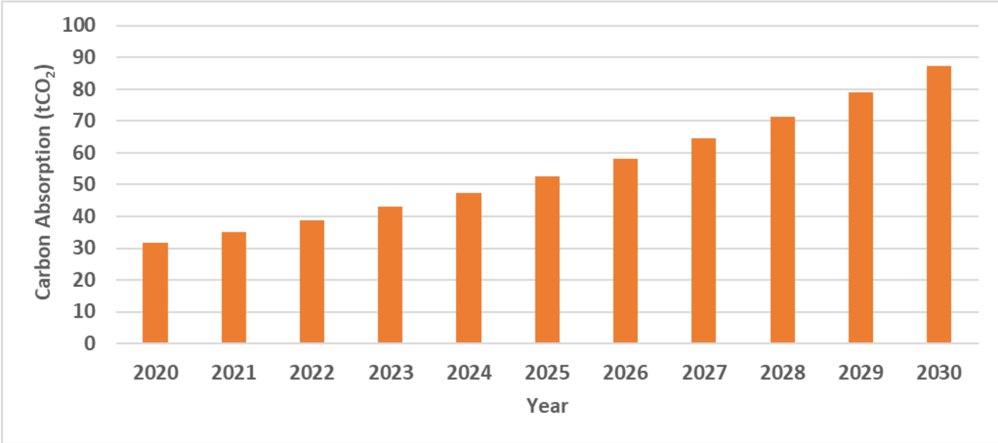

Figure 5.20 Carbon capture by current green zones in La Carrasca.

Considering the new green area that wants to be implemented, whose total surface area is 26,008 m^2, the implementation plan presented in **Table 5.20** is applied which is based on increasing the implemented surface until 2028 while also considering the absorption incrementation curve and calculating the results yearly until 2030. **Figure 5.21** presents how this new urban green area increases its yearly carbon capture as it begins implementation in 2022, where it captures 0.41 tCO_2, continues expanding in size until its completion in 2028, and grows in age. Which is why the graph shows a steadier increase in the last two years shown. By the year 2030 it ha captures 8.30 tCO_2. **Figure 5.22** presents both the current green areas and the new one as their carbon capture capacity increases yearly in comparison. By the year 2030, these areas capture 95.71 tCO_2/year, which means that the baseline year's carbon capture capacity by urban green areas in La Carrasca increased by 202%.

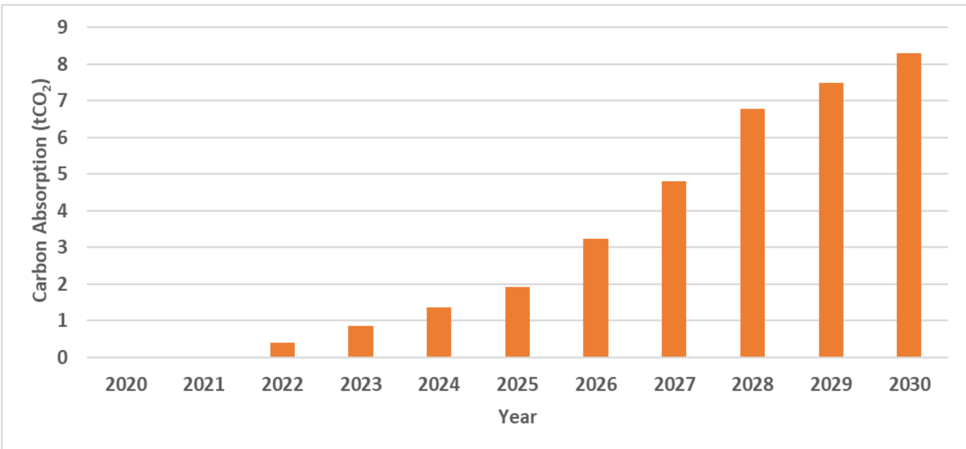

Figure 5.21 Carbon capture by the new green zone in La Carrasca.

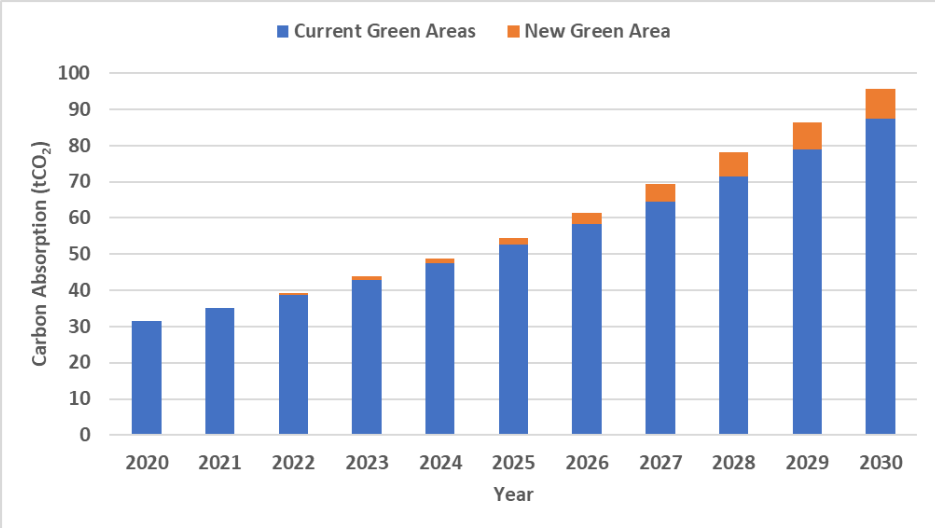

Figure 5.22 Carbon capture by current and new green zones in La Carrasca.

To have a complete quantification of how all green areas in the neighborhood capture carbon emissions, the carbon capture capacity of the agricultural land, considered stable yearly (541.84 tCO_2/year), was added to the scenario of **Figure 5.22**. Since the constant cultivation of the crops means that these plants don't keep growing, their carbon capture capacity is considered constant through the years. The results of the NBS measure are presented in **Figure 5.23**, where each type of green zone considered is specifically highlighted. Even though crops have a higher carbon capture capacity, and in this study their area is much larger, the results show that urban green areas should be aggressively implemented since their natural growth increases the neighborhoods capacity to capture CO_2 emissions. Finally, comparing the baseline year to the estimated scenario for 2030, the carbon absorption of the area increased by 64.06 tCO_2/year, an 11.17% increase which will reduce the carbon foot print of La Carrasca by 0.09%.

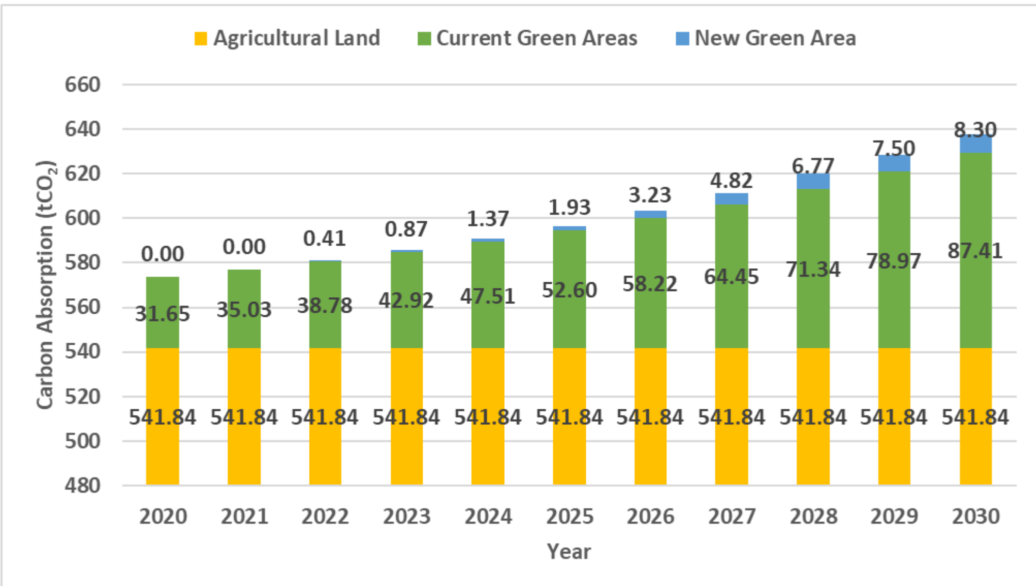

Figure 5.23 Results of NBS measure in La Carrasca.

Electric Vehicle

Based on the results of the carbon footprint by sectors, it was concluded that the electric vehicle implementation measure could be one of the most significant, since all of the transportation in the neighborhood amounts to 38.7% of the total CO_2 emissions produced. Starting with public transportation, the first change in vehicles will be for the taxis in the neighborhood. Each taxi travels an estimated 75,920 km/year in the city, which amounts to 10.84 tCO_2/year and 9.38 tCO_2/year produced by gas and diesel consuming cars respectively. Exchanging the 13 taxis in La Carrasca for EVs by 2030 will result in 100.85 tCO_2 saved per year, which is an 80% reduction from what the fossil fuel conuming vehicles produce currently.

For the bus fleet that travels through La Carrasca, based on the comparison of emissions produced by conventional and hybriddiesel consuming buses with electric buses, the emissions saved in each line are shown in **Table 5.32**. This can be interpreted as if by 2030, 39 of the buses that travel through the neighborhood are electric while the resting 42 are still hybrid, a 48.64% reduction of CO_2 emissions should be expected from the baseline scenario. Since electric buses are quite costly, this exchange of vehicles should be done progressively to segregate investment costs.

Table 5.32 Savings in emissions by implementing electric buses.

Bus Lines	**Emissions Saved (tCO_2/year)**
18	30.04
31	1.63
40	13.09
71	17.80
81	2.66
93	78.98
98	108.29
99	13.67
Total	**266.16**

In contrast to public transport, the private transportation sector is much more difficult to change, which is why the implementation is much slower. For the vehicles owned by the inhabitants of La Carrasca, following the implementation plan of the Valencian Community, 2.2% of all vehicles will be electric by 2025 and 7% by the year 2030. Adding EVs in exchange for the most emitting vehicles results in the estimated carbon emissions produced in 2025 and 2030 presented in **Table 5.33** and **Table 5.34** respectively. For 2025, all of the vehicles removed are Pre Euro in European Regulation. Meanwhile, for 2030 the vehicles removed range from Pre Euro to Euro 2. The vehicles added are always considered Euro 6 electric vehicles.

Table 5.33 Estimated carbon emissions (tCO_2/year) produced by private vehicles in La Carrasca in 2025.

Regulation	Cars	Small Trucks	Motorcycles	Total
Pre Euro	36.26	4.07	11.22	51.55
Euro 1	43.89	2.83	20.19	66.90
Euro 2	108.00	6.96	29.13	144.09
Euro 3	407.15	26.31	76.45	509.90
Euro 4	568.98	36.84	38.45	644.27
Euro 5	325.49	21.17	6.24	352.90
Euro 6	568.40	37.13	-	605.53
Total	**2058.16**	**135.31**	**181.67**	**2375.14**

Table 5.34 Estimated carbon emissions (tCO_2/year) produced by private vehicles in La Carrasca in 2030.

Regulation	Cars	Small Trucks	Motorcycles	Total
Pre Euro	0.00	0.00	3.78	3.78
Euro 1	0.00	1.40	20.19	21.59
Euro 2	75.49	5.42	29.13	110.03
Euro 3	407.15	26.31	76.45	509.90
Euro 4	568.98	36.84	38.45	644.27
Euro 5	325.49	21.17	6.48	353.14
Euro 6	576.14	37.64	-	613.78
Total	**1953.24**	**128.78**	**174.47**	**2256.49**

For the vehicles that travel through the neighborhood, but are not owned by its inhabitants, the percentages of EV penetration mentioned in section **5.3** and subsection **5.4.3** are considered to calculate the changes in distances traveled shown in **Table 5.23**. Applying the emission factors for cars in **Table 9.5**, provides the results of emissions produced per year observed in **Table 5.23**. It shows a reduction in carbon emissions of 1.48% (326 tCO_2/year) and 5.93% (1303 tCO_2/year) for the years 2025 and 2030 respectively. While EV emissions increase, the emissions produced by other fossil fuel consuming vehicles decrease much more to produce a positive impact on reducing emissions.

Table 5.35 Emission produced from private electric vehicle implementation on outside vehicles (Scope 3).

Emissions Produced (tCO_2/year)			
Type of vehicle	**2020**	**2025**	**2030**
Electric	10.37	38.04	121.03
Others	21,962.59	21,609.07	20,548.50
Total	**21,972.97**	**21,647.11**	**20,669.53**

To summarize the electric vehicle implementation strategy for this project, **Table 5.36** presents the estimated reduction in CO_2 emissions expected for the year 2030 in comparison to the baseline year's (2020) carbon footprint of the transportation sector, excluding the tram trains which already consume electricity. It can be observed that the public transport emissions are reduced more significantly according to the baseline year, 54.46%, in comparison to private transport emissions which are only reduced by 6.04%. It can be concluded that this is directly due to how much more aggressive the implementation of EVs is in public transport. This is why **Figure 5.24** is so important, because it presents the contributions that the reduction in carbon emissions of each type of vehicle has on the overall reduction of transport emission. It clearly shows that promoting the change to EVs for private transportation reduces the most emissions, specifically for vehicles that come from outside the neighborhood's boundaries. It can be concluded that this is due to high traffic volume roads inside La Carrasca. These roads connect to highways where people enter and leave the city, as well as, being the main entries for people commuting to the universities. Once again showing the importance of these educational institutions to the CO_2 emissions of the area.

Table 5.36 Electric vehicle implementation results.

Transport Type	Vehicle Type	Transport Emissions (tCO_2/year)			
		2020	2030	Reduction	
Public	Buses	547	281	266	48.64%
	Taxis	126	25	101	79.84%
Private	Cars	2108	1952	156	7.38%
	Motorcycles	182	174	7	3.96%
	Small Trucks	135	128	7	5.08%
	Outside Vehicles	21,973	20,670	1303	5.93%
	Total	**24,868**	**23,231**	**1840**	**7.34%**

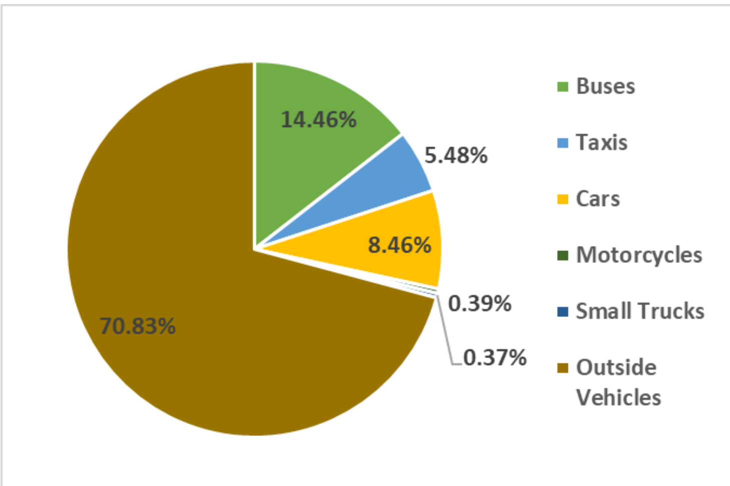

Figure 5.24 Contribution of EV implementation in each type of vehicle to overall transport emissions reduction.

In the end, private transport contributes to 80% of the total reduction in transport emissions. Another reason why this can be expected is because the number of vehicles changed is much higher in private than public transport. Nevertheless, from analyzing the results, the conclusion reached is that cities must promote and incentivize the implementation of electric vehicles and the necessary infrastructure for their recharge in order to reduce the significant impact that private vehicles have on their carbon footprint. Another strategy would be to highly promote public transport by increasing their efficiency and therefore reduce the use of private vehicles in the area, since it is easier to control the changing of these vehicles to higher.

Public Lightning

The public lighting system of the neighborhood is the least contributing to the total emissions produced (0.3%). But considering that every mitigation measure contributes to the overall goal of transitioning to a carbon neutral neighborhood, a change to LED for the light points in the area was analyzed.

Of the 2987 light points in La Carrasca, only 515 (17%) are currently LED. Following the implementation plan presented in **Table 5.24**, 1277 of the sodium vapor light points will be changed to LED for the year 2025 to reach 60% incorporation in the public lighting network. This amounts to a 46% reduction in electricity consumption and CO_2 emissions produced from this sector in comparison to current scenario. Furthermore, for 2030 when all of the light points will be LED, the total saving will be of 67%. Table 5.37 summarizes these results of the public lighting energy efficiency measure, showing the reductions in installed power of the network, its yearly electricity consumption, and the emissions produced from this consumption. Another consideration that could further reduce the emissions of the public lighting network would be implementing light points with small integrated solar panels.

Table 5.37 Reduction in carbon emissions from the public lighting energy efficiency measure.

Public Lighting Network	2020	2025	2030
Total Installed Power (kW)	410	221	134
Electricity Consumption (MWh/year)	1267	683	413
Carbon Emissions (tCO_2/year)	218	117	71

Heat Pumps

Following the process descried in section **5.4.5**, to cover the thermal demand of the neighborhood's residential sector for heating and SHW, which is currently being satisfied using natural gas, 397 heat pumps will implemented and placed throughout the area's 102 residential buildings based on necessity. These devices will increase the electricity consumption of the sector by 8.5%, which is also 0.64% of the total consumption of La Carrasca. This increases emissions from electricity consumption by 67.27 tCO_2/year. The replacement of the old NG consuming devices will decrease the residential gas consumption of the neighborhood by 90.8%, which is 7.17% of the total consumption, leaving only the 223 MWh/year of NG that will still be consumed in the area's residential sector by kitchens, and the resting 28,217 MWh/year from the services and industrial sectors. In terms of CO_2 emissions, the savings in gas consumption represent a decrease of 442 tCO_2/year. **Table 5.38** shows the results of this carbon mitigation measure, where the savings in CO_2 emissions are a result of the decrease from NG consumption and the increase from electricity consumption.

Table 5.38 Results from heat pump implementation strategy.

Heat Pump System	
Number of Heat Pumps	397
Electricity Consumption (MWh/year)	396.22
Savings in NG Consumption (MWh/year)	2197
Savings in CO_2 Emissions (tCO_2e/year)	374.40

Improve Waste Management

Through the implementation of the actions and strategies mentioned in subsection **5.4.6**, the new scenario shows a decrease of 10% in the total waste produced in the neighborhood. By reaching the desired scenario of waste distribution, the amount of waste thrown in a landfill is reduced by 45%, as it's presented in **Table 5.39**. Meanwhile, an increase of 28% is shown for waste that is recycled for treatment or used for composting. With this new waste management distribution, the carbon emissions generated from the waste produced in La Carrasca is reduced by 132.78 tCO2/year, a 28% reduction in emissions that come from waste and a 0.18% reduction of the carbon footprint of the neighborhood.

Table 5.39 Results of improved waste management scenario.

Waste Management	**2020**		**2030**	
	Waste (tons)	**Emissions (tCO_2e/year)**	**Waste (tons)**	**Emissions (tCO_2e/year)**
Landfill	1174	316.49	641	172.74
Recycled (Treated)	418	40.06	579	55.43
Composting	263	43.19	364	59.75
Total	**2034**	**399.75**	**1830**	**287.92**

Summary of Carbon Reduction Measures

Having calculated the savings in emissions resulting from each carbon mitigation measure, the impact they have on reducing the carbon footprint of the neighborhood of La Carrasca can be analyzed. **Table 5.40** presents the impact each measure has on decarbonizing the area. The most impactful strategy is the implementation of a neighborhood-wide photovoltaic system to reduce the electricity consumption, more clearly shown in **Figure 5.25**. The high importance of this measure can also be attributed to the scope that it affects, since apart from the public lighting energy efficiency measure, it is the only carbon reduction strategy that reduces scope 2 emissions.

The second most impactful carbon mitigation measure analyzed in this study is the implementation of electric vehicles, especially in the private transportation sector. As shown in the carbon footprint by sectors in section **5.5.1**, this sector is the most polluting in the neighborhood at 37.4%, highlighting the importance of this measure. It also contributes to reducing scope 1 and 3 emissions. The third most contributing mitigation measure is the implementation of heat pumps to cover the thermal demand for heating and SHW in residential buildings and removal of natural gas consuming devices, although it only reduced the carbon footprint by 0.58%. Its importance mostly comes from how it removes the consumption of a much more polluting energy, such as natural gas, and replaces it with electricity consumption, which is not only less polluting according to the energy mix that generates the electricity that is consumed by the city of Valencia, but with the continuing integration of renewable energies it has the potential to continue decreasing its factor of emissions.

Improving the energy efficiency of public lighting and the management of the waste generated in the neighborhood doesn't seem to have such a strong impact reducing its carbon footprint. This is mostly due to their low contribution of carbon emissions, because the public lighting network is not very high consuming in electricity and although waste is very high polluting, especially if left in a landfill, the city of Valencia has an already well-established waste management system with recycling strategies and campaigns to help reduce the waste generated and promote the reutilization of products. Finally, the least contributing of all mitigation measures are the nature-based solutions. This can be attributed to the fact that a large percentage of the land in the neighborhood of La Carrasca are already green zones, especially thanks to agricultural land as described in section **5.4.2**. Meaning that there was not much space for improvement. Nevertheless, this shouldn't minimize the importance of this measure, since it is a somewhat simple to implement measure that directly reduces the total carbon emissions produced in an area and in high density zones of a city where there are fewer green areas their inclusion should be more impactful. Especially since their implementation can also be considered not only for open lots, such as in this study, but also for building facades, rooftops, boardwalks, etc.

Table 5.40 Impact of carbon reduction measures.

Carbon Mitigation Measure	**Savings in emissions (tCO_2/year)**	
PV System	4254	6.58%
NBS	64	0.10%
Public Lighting	147	0.23%
Electric Vehicle - Private Transport	1479	2.29%
Electric Vehicle - Public Transport	367	0.57%
Heat Pumps	375	0.58%
Improve Waste Management	112	0.17%
Total	**6797**	**10.52%**

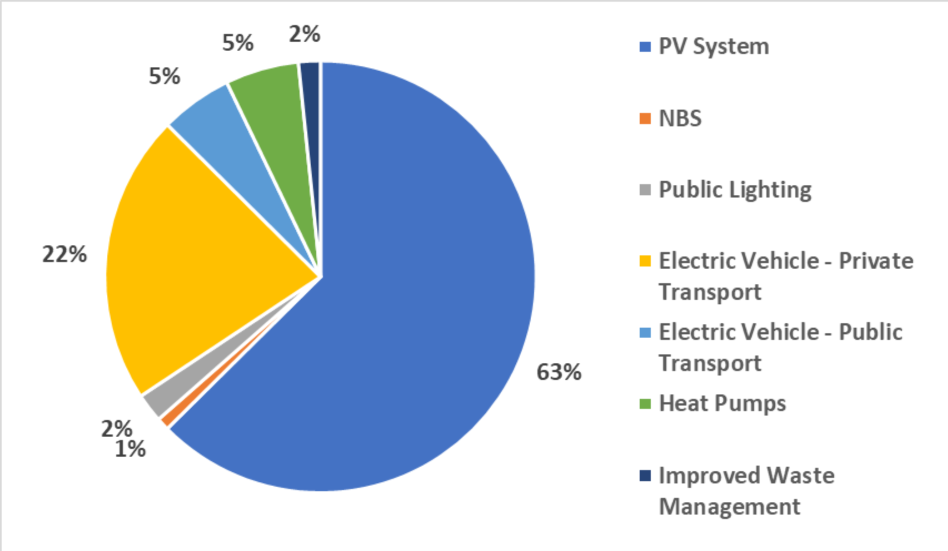

Figure 5.25 Contribution of each carbon reduction measures to overall reduction.

5.5.3 Economic Analysis

In this section, and extensive economic analysis of the project will be explained. It will try to include all of the costs, savings, benefits, and incentives that are related to the carbon reduction measures proposed in this study. The only measure whose costs aren't included is the improvement of waste management, since it is comprised of different promotion campaigns and plans to try and reach the desired goal of reducing the amount of waste and increase recycling. Therefore, there are no instantly tangible technologies that need to be applied which come at a determined cost. Also, the outside vehicles that travel through the neighborhood are not considered in this analysis since there is no specific quantification of them. It could be concluded that scope 3 emissions are not considered in this economic analysis. Meaning that the costs considered are for the society inside the neighborhood. This includes the government and population, since these measures represent costs and savings for both.

The carbon reduction measures will be considered as implemented in two stages, before 2025 and from 2025-2030, to segregate investment costs. Since the period before 2025 is shorter, the integration of the measures at this point will be less in this first stage, except for the public lighting measure which is 60% implemented at this point. This can be considered possible because of it's the easiest measure to implement.

Table 5.41 presents the investment actions considered in this project. Starting with the photovoltaic system, whose quantity and cost per unit of kWp installed are presented in section **5.4.1**. Before 2025, 30% of the total 18,009 kWp of the PV installation is considered to be implemented. For the public lighting action, the quantity of LED to be implemented in each stage was calculated from **Table 5.24**. While the cost per unit was determined from the model E27 40W LED lamp for public lighting from Ledkia [81]. For the NBS measure, the plantation of each tree was considered to calculate the costs of the measure. The quantity of trees needed was decided by determining the needed area for each tree, set at 36 m^2 [82], and calculating how many fit into the space available. The cost of planting each tree was calculated using a price generator for urban spaces in Spain [83] that includes the cost of materials, equipment, and manual labor for planting a tree in a transit area. Before 2025 the urban green area to be implemented is considered at 40% completion.

The quantity of electric vehicles to be implemented in each stage was determined in section **5.4.3** for private vehicles. For public vehicles (buses and taxis), it's considered that 30% would be changed before 2025 and the rest after. The costs however come from different sources. The cost of electric buses was determined from the study used to determine their consumption in comparison to hybrid buses [40]. For electric motorcycles, the same model from Greenmoto used to determine their consumption was used [59]. Finally, the same cost was used for electric cars, taxis, and small trucks since it is a somewhat average cost and these vehicles have been treated similarly throughout the study. It was taken from the EV implementation plan for the CV [42], which also provided the costs of the semi-fast recharge stations.

The last considered investment action is the implementation of heat pumps. Their quantity per stage was chosen as to have 30% of them installed before 2025. Their cost was determined from the catalog of the chosen LG model [78] mentioned in section **5.4.5**. The total investments of each measure are presented in **Table 5.42**, where 15% in contingency costs and another 5% in management costs were added to determine the CAPEX of the project in each period. Adding both of these investments results in a project budget of 50,693,617 €.

Table 5.41 Investment actions of project.

Actions	Units	€/unit	Quantity at 2025	Quantity at 2030
Energy Generation (PV)	kWp	1,320	5,403	12,606
Public Lighting	LED light point	63.83	1,277	1,185
NBS	Trees	27.86	289	433
Electric Buses	Vehicles	300,000	12	27
Electric Taxis	Vehicles	29,000	4	9
Electric Cars	Vehicles	29,000	32	75
Electric Small Trucks	Vehicles	29,000	1	5
Electric Motorcycles	Vehicles	3,895	5	18
Semi-fast Recharge Stations	Stations	3,429	3	6
Heat Pumps	HP	7,106	119	278

Table 5.42 CAPEX of project.

Actions	Initial Investment (2020-2025)	Second Investment (2025-2030)
Energy Generation (PV)	€ 7,131,564	€ 16,640,316
Public Lighting	€ 81,511	€ 75,639
NBS	€ 8,052	€ 12,075
Electric Buses	€ 3,600,000	€ 8,100,000
Electric Taxis	€ 116,000	€ 261,000
Electric Cars	€ 928,000	€ 2,175,000
Electric Small Trucks	€ 29,000	€ 145,000
Electric Motorcycles	€ 19,475	€ 70,110
Semi-fast Recharge Stations	€ 10,286	€ 20,571
Heat Pumps	€ 845,614	€ 1,975,468
Total	**€ 12,769,501**	**€ 29,475,179**
Contingency 15%	€ 1,915,425	€ 4,421,277
Management 5%	€ 638,475	€ 1,473,759
Project Budget	**€ 15,323,401**	**€ 35,370,215**

After the investment costs of the project have been determined, the annual costs of operation for each action are considered. **Table 5.43** presents the actions that are considered, their cost per quantity of units, and the units in each period. For the PV generation system, the annual costs of operation for the completely installed PV system (648,324 €) were determined from the results of HOMER, shown in **Table 5.44**, and with the quantity of electricity generated the cost per kWh was calculated. There is also the cost of purchasing the electricity from the grid needed to cover the rest of the demand of the neighborhood. The price per kWh purchased was estimated as an average value of the three rate periods from **Table 5.18**. This price was also used to determine the costs of electricity consumption from the electric vehicles added and the heat pumps installed in each stage.

For the maintenance of the green area that is being implemented, the price per hour of the manual labor was determined from the price generator for urban spaces in Spain mentioned above [83]. Assuming 4 hours per week of work, for a total of 209 hours a year, the total cost of maintenance per year was calculated. **Table 5.44** shows the total OPEX costs of the project.

Table 5.43 Operation actions of project.

Actions	Units	€/unit	Quantity in 2025	Quantity in 2030
Energy Generation (PV)	kWh	0.021	9,263,987	30,879,956
Energy Purchase (Grid)	kWh	0.295	10,807,591	36,025,304
Energy Consumption (EV)	kWh	0.295	118,877	383,020
Green Area Maintenance	h	20	209	209
Energy Consumption (HP)	kWh	0.295	118,767	396,222

Table 5.44 OPEX of project.

Actions	Costs in 2025 (€/year)	Costs in 2030 (€/year)
Energy Generation (PV)	€ 194,497	€ 648,324
Energy Purchase (Grid)	€ 3,188,239	€ 10,627,465
Energy Consumption (EV)	€ 35,069	€ 112,991
Green Area Maintenance	€ 4,171	€ 4,171
Energy Consumption (HP)	€ 35,036	€ 116,886
Total	**€ 3,457,013**	**€ 11,509,837**

Having determined all of the costs of the project, certain benefits, and even some government incentives, are considered. These actions and their costs are presented in **Table 5.45** and **Table 5.46** respectively. The latter presents the estimated yearly incomes of the project and the incentives to be considered in each period. From the PV system measure, the electricity that is sold back to the grid is quantified and given a cost according to the selling price in **Table 5.18**. Also, the estimated savings from the electricity that is not generated by the PV system which is not being bought anymore are considered, using the average electricity price mentioned before in the operation costs. This same price is also used to determine the amount of savings that comes from the energy saved by the installation of higher efficiency lamps (LED) in the public lighting network. The implementation of heat pumps also assumes energy savings but from natural gas. Using an average price for NG consumption of 0.07 €/kWh [84], which includes a hydrocarbon tax of 0.00234 €/kWh and a 21% IVA, the economic savings from this carbon mitigation measure were also determined.

For the electric vehicle implementation measure, estimating savings is somewhat more complicated. But knowing how much distance the different types of vehicles travel in a year, their consumption was estimated, and therefore, the savings expected from fuel consumption were calculated. For private vehicle, since the ones that are being replaced are all petrol or diesel consuming, an average consumption rate from these two fuels per vehicle (230 L/year) was used to estimate the consumption savings. A similar consideration was done for taxis, but for buses, since their all considered as hybrid diesel consuming vehicles, their consumption was more directly calculated. For the price of these fuels, a platform from the MITECO [85] that provides historical prices for different fuels was used to calculate an average of each during a year. The average price of diesel was used to calculate the savings from buses, while and average from both was used to calculate the savings from taxis and private vehicles. The incentives considered are all for the electric vehicle measure, and were determined from the EV implementation plan of the CV. Adding the incentives of both periods results in a total of 2,813,250 € in incentives for the project.

Table 5.45 Benefits and incentives considered in the project.

Actions	Units	€/unit	Quantity in 2025	Quantity in 2030
Energy Sales	kWh	0.112	1,844,522	6,148,406
Energy Savings from Generation	kWh	0.295	9,263,987	30,879,956
Energy Savings from LED	kWh	0.295	584,248	853,491
Energy Savings from Private Vehicles (Petrol & Diesel)	L	1.811	8,740	31,280
Energy Savings from Buses	L	1.810	39,576	128,623
Energy Savings from Taxis	L	1.811	4,365	11,350
Energy Savings from Natural Gas	kWh	0.070	699,517	2,333,682
Incentives Electric Bus	Bus	50,000	12	27
Incentives Electric Taxi, Car & Small Trucks	Vehicle	6,000	38	88
Incentives Electric Motorcycles	Motorcycle	750	5	18
Incentives Semi-Fast Recharge Stations	Recharge point	10,000	3	6

Table 5.46 Value of benefits and incentives in project.

Actions	Savings in 2025	Savings in 2030
Energy Sales	€ 206,586	€ 688,621
Energy Savings from Generation	€ 2,732,876	€ 9,109,587
Energy Savings from LED	€ 172,353	€ 251,780
Energy Savings from Private Vehicles (Petrol & Diesel)	€ 15,828	€ 56,649
Energy Savings from Buses	€ 71,630	€ 232,797
Energy Savings from Taxis	€ 7,906	€ 20,555
Energy Savings from Natural Gas	€ 48,698	€ 162,462
Incomes (€/year)	**€ 3,255,877**	**€ 10,522,451**
Actions	**Savings in investments (2020-2025)**	**Savings in investments (2025-2030)**
Incentives Electric Bus	€ 600,000	€ 1,350,000
Incentives Electric Taxi, Car & Small Trucks	€ 228,000	€ 528,000
Incentives Electric Motorcycles	€ 3,750	€ 13,500

Incentives Semi-Fast Recharge Stations	€ 30,000	€ 60,000
Incentives (€)	**€ 861,750**	**€ 1,951,500**

Considering that the lifespan of the implemented technologies is more than 10 years, the period of study of this analysis will be from 2020 to 2040 (20 years). For the initial financial analysis, no incentives were considered and a rate of return of 2% was used. This resulted in a negative Net Present Value (NPV) of -60,932,029 €, concluding that government incentives are necessary for the economic development of the project. Therefore, an economic analysis was made, that considered a higher rate of return of 6% and included incentives. Even with these new considerations, the analysis resulted in and NPV of -56,944,868 €. This is a 7% reduction from the financial analysis, which leads to the conclusion that government incentives are quite helpful, as well as necessary.

The implementation of the carbon reduction measures proposed in this study presents very high costs for the city that would apply them to the neighborhood. The highly negative resulting NPV leads to the conclusion that for the project to move forward it would need sufficient financial support for the national government and European Union. Nonetheless, it should also be considered that these mitigation measures, especially the implementation of electric vehicles, not only help the neighborhood of study reduce its carbon emissions, but also the whole city.

6 CARBON BALANCE: INITIAL SITUATION VS FINAL SITUATION

In this section, the total reduction in emissions in the neighborhood resulting from the proposed mitigation measures is summarized. After determining the number of emissions saved by each measure, they were categorized by the sector that each of them affects. **Table 6.1** shows the estimated expected reduction in CO_2 emissions for each sector considered in the neighborhood of La Carrasca. In total, the results from implementing the carbon reduction measures proposed suggest a decrease of 6,796 tons of CO_2 per year. Establishing the decarbonization potential of La Carrasca across al three scopes at 10.5%.

Table 6.1 Carbon balance by sector (tons of CO_2 per year).

Sector	2020	2030	Reduction
Electricity	10,558	6,372	39.65%
Gas	6,158	5,716	7.17%
Public Transport	819	452	44.82%
Private Transport	24,403	22,925	6.06%
Public Lighting	218	71	67.35%
Urban Waste	400	288	27.98%
Consumption of Goods	22,617	22,617	0.00%
Green Areas	-573	-638	11.17%
Total	**64,600**	**57,804**	**10.52%**

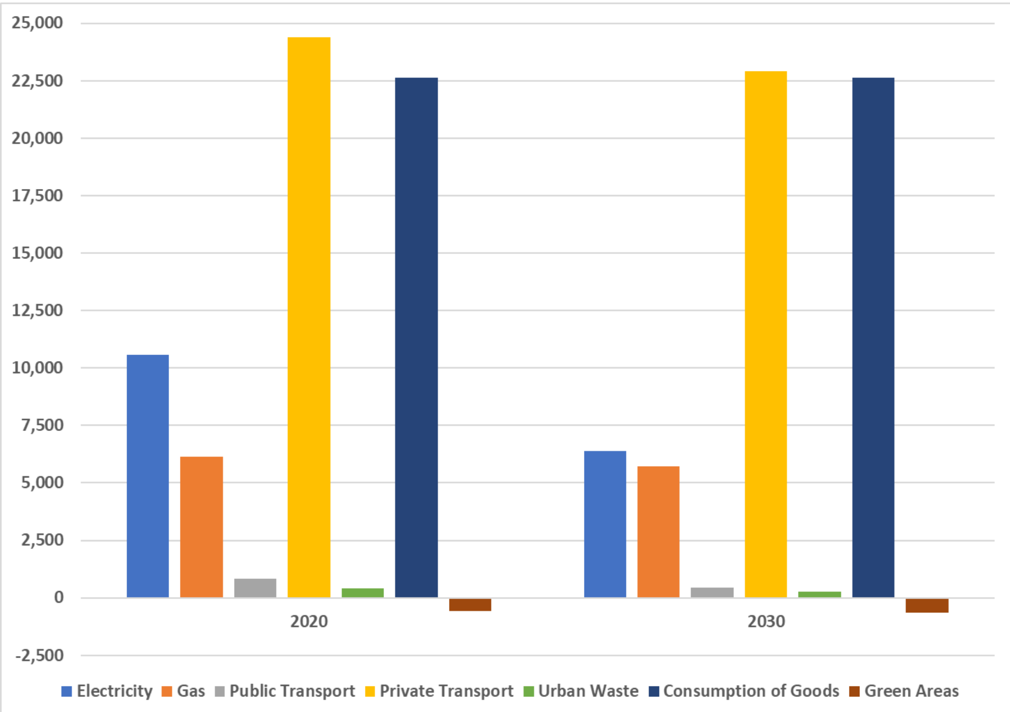

Figure 6.1 Carbon reduction in each sector considered in La Carrasca (tons of CO_2 per year).

One of the most noticeable factors is that the second most polluting sector, the consumption of goods (food, clothes, and manufactured products), is the only one that is not reduced, as presented in **Figure 6.1**. None of the carbon reduction measures directly affects this sector. The reason for this is that it's a difficult sector to control changes. It is directly dependent on the population's consumption, on human behaviors that can't be controlled. This does not mean that measures can't be proposed to try affect it. Governments can create campaigns to promote changes in the habits of their inhabitants and educate them on the harmful effects that the products their consuming have on the environment, as well as provide better and local options to help citizens make a change. Nevertheless, this highlights the importance of trying to reduce the carbon emissions of this sector, as well as the difficulty that comes with it.

The most reduced sector is the public lighting network, which is also the leats polluting, so its reduction doesn't greatly decrease the total carbon footprint of the neighborhood, as it's shown in **Table 5.40**. Reducing the electricity consumption of the public lighting network might be the least reducing measure, but it is also the easiest to implement which highlights its importance. The second most reduced sector is public transportation, which is affected by the electric vehicle implementation strategy, the second most impactful carbon reduction measure when it also considers private transport. Making it clearly one of the most important mitigation measures for decarbonization, even though it's one of the most difficult to implement in terms of logistics. Especially in private transport, where it depends on each citizen's initiative and economic situation to change their vehicles for EVs. Nonetheless, governments have the means to impulse this change by providing incentives to citizens, implementing public recharging infrastructures, and campaigning in favor of electric vehicles, like in the implementation plan of the CV. As well as implementing measures to reduce traffic from higher polluting vehicles and promoting the use of public transport to reduce the use of private vehicles.

The electricity consumption from buildings in La Carrasca is the third most impacted sector, calling attention to what is the most impactful carbon reduction measure in this study. The implementation of a PV generation system would reduce the most emissions at the present moment for what is the third most polluting sector in the area, primarily due to the service establishments, which include two big educational institutions (UPV and UV) that are high energy consuming. Generating clean electricity thorugh the use of photovoltaics not only helps reduce emissions from the electricity that is already being consumed, but it also provides help to other mitigation measures like the implementation of electric vehicles and heat pumps which decrease CO_2 emissions from consuming other more polluting fuels but increase the total electricity consumption in the neighborhood.

To consider the effects that the carbon reduction measures have on each of the three scopes of emissions, **Table 6.2** presents the estimated CO_2 emissions of each sector for the 2030 scenario broken down in the scopes that it affects. The impact of green areas was added in this case, in contrast to **Table 5.30**, to quantify their effect on the carbon footprint. Since they capture carbon emissions directly in the neighborhood, they're considered to directly decrease scope 1 emissions.

Table 6.2 Estimated carbon footprint of 2030 scenario by scopes in La Carrasca

Sector	Scope 1	Scope 2	Scope 3
Electricity		6,372	
Natural Gas	5,716		
Private Transport	2,243	12	20,670
Public Transport	307	145	
Public Lighting		71	
Waste Management			288
Consumption of goods			22,617
Green Areas	-638		
Total	**7,641**	**6,588**	**43,575**

Since all three scopes were affected by the carbon mitigation measures proposed, the contributions that they had on the carbon footprint have changed from the baseline year scenario presented in **Figure 5.17**. Comparing it to **Figure 6.2**, the most noticeable change is that scope 2 emissions are now the lowest contributors, when before it was scope 1. The results of this study have shown that this change is highly due to the large impact of the PV system implementation strategy which produced the biggest reduction in carbon emissions. On the other hand, the contribution of scope 3 emissions increased. Once again featuring the importance of quantifying these emissions and proposing mitigation measure to reduce its impact. These changes are more clearly shown in **Figure 6.3**, which presents the carbon balance by scopes of the project and how each one has been reduced. The biggest reduction came in scope 2 with a 39.57% decrease. Meanwhile, scope 1 was reduced by 17.64% and scope 3 by only 3.15%.

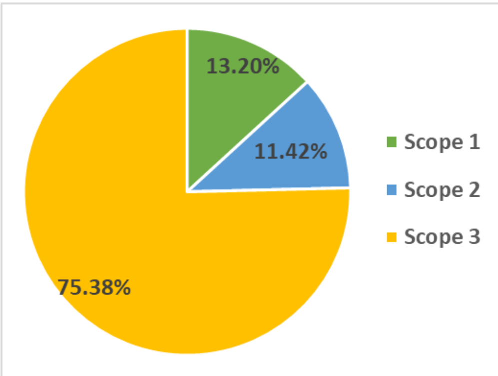

Figure 6.2 Contribution of scopes in 2030 scenario carbon footprint of La Carrasca

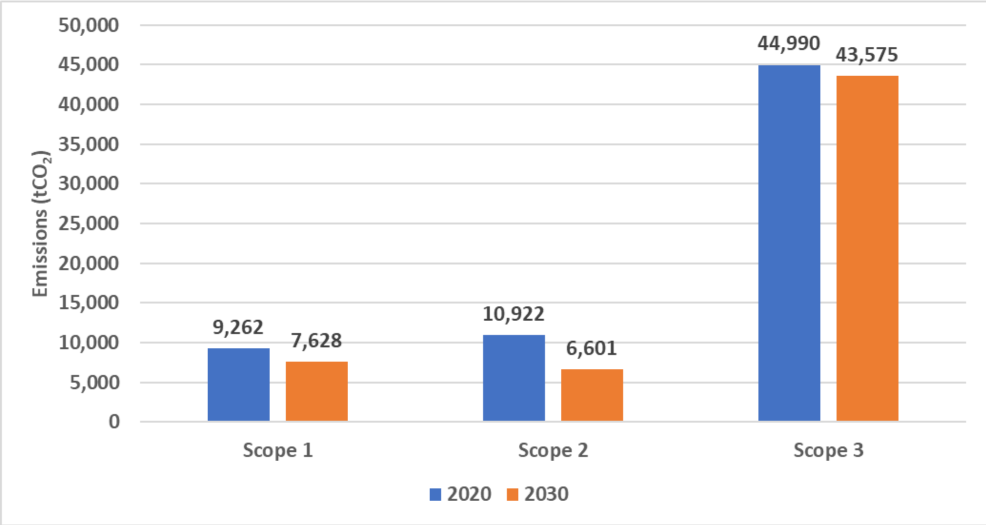

Figure 6.3 Carbon balance by scopes.

Its been mentioned before in this document that most of the research and projects on carbon neutrality measure decarbonization according to scope 1 and 2 emissions, leaving out scope 3. Based on the results obtained in this study, if only those two scopes of emissions are considered the neighborhoods potential for decarbonization would rise to 27.44%. **Figure 6.4** shows the reduction of 5955 tCO_2 comparing the emissions produced in the baseline year (2020) to the future scenario year (2030).

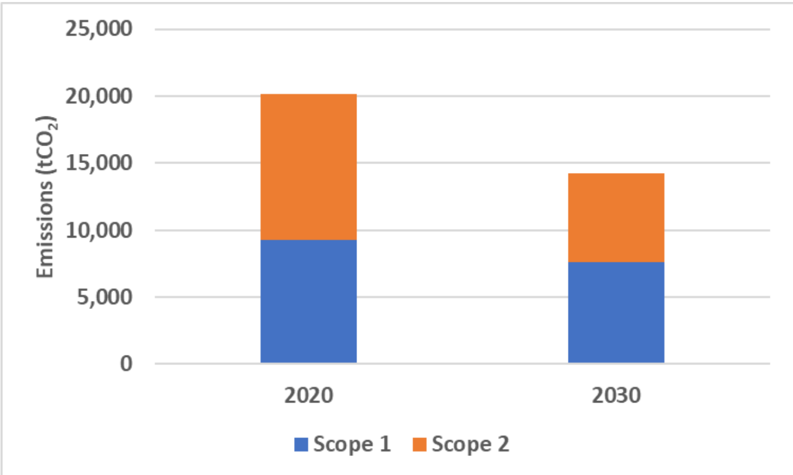

Figure 6.4 Carbon emissions reduction considering only scopes 1 & 2.

6.1 Roadmap

A final roadmap presenting the proposed progress of all the measures developed in this project is presented in **Figure 6.5**. Different considerations were made to establish these goals. For some, government plans or strategies from different entities were used. The progress of integration of electric vehicles in private transport was determined from the EV implementation plan of the CV [42]. The public lighting measure follows the the Valencia city's roadmap for energy strategy [76]. This plan was also used for the public transport measure, since it mentions goals of having 50% of public transport and 100% of municipal vehicles be electric by 2030, and for the heat pump measure, since it mentions limiting the functionality of natural gas consuming heating devices by 2030. The goals of these measures for 2025 were set considering the shortened period, since at the moment this study is published the year 2022 has already passed. Therefore, shorter goals were set in the first period to have a more realistic sense of where the implementation of these strategies could be at that time. This is the consideration that was also made for the PV installation and NBS measures. Since the goal is for them to be completely implemented by the year 2030, then for 2025 less than half could be considered as implemented, leaving the rest for the latter period which is longer in real time. Finally, the waste management improvement strategy wasn't considered to have a middle point goal, since its not as directly quantifiable as the other measures because it's composed of plans and campaigns to promote the reduction, classification and good management of waste. It is not restrained to the fisical implementation of a technology or product. Therefore the desired scenario for 2030 was established following the guidelines of the EMTRE [58].

	2020	2025	2030
PV Installation		30% PV power installed	100% PV power installed
NBS		40% of NBS area implemented	100% of NBS area implemented
Electric Vehicle	0.3% private electric vehicles 0% electric buses 0% electric taxis	2.2% private electric vehicles 15% electric buses 30% electric taxis	7% private electric vehicles 48% electric buses 100% electric taxis
Public Lighting	17% LED light points	60% LED light points	100% LED light points
Heat Pumps		30% of residential heat pumps installed	100% of residential heat pumps installed
Waste Management	57.7% landfill 20.6% recycled (treated) 8.8% energy use 12.9% composting		35.0% landfill 31.6% recycled (treated) 13.5% energy use 19.9% composting

Figure 6.5 Roadmap for the neighborhood of La Carrasca

7 CONCLUSIONS

In order to mitigate the effects of climate change, cities need to make changes through sustainability projects, policies and actions, since they are the biggest contributors to worldwide GHG emissions. The initiatives presented in this study can be great first steps in helping cities transition to carbon neutrality. The objective of this study was to determine the potential for achieving carbon neutrality in the neighborhood of La Carrasca in the Algirós district of the city of Valencia by estimating the carbon footprint of the area, and then providing carbon mitigation measures to reduce these emissions.

Through the development of the carbon footprint inventory of the neighborhood, it was found that scope 3 emissions are the biggest contributor, with 69% of the total emissions in La Carrasca. This is mostly due to the consumption of goods and private transport from outside sources. Many studies don't consider this scope, but based on these results it was concluded that its necessary to take it into consideration and provide measures to reduce its footprint. Comparing the emissions by sector, the biggest contributor is private transportation with 37.4% of th total carbon emissions.. Followed closely by the consumption of goods (34.7%), which include food, clothes and manufactured products, and after by building emissions (25.6%), which come from gas (scope 1) and electricity (scope 2) consumption.

Based on the carbon footprint estimation of the neighborhood considering all three scopes, six different measures were analyzed to determine the decarbonization potential: photovoltaic generation, nature-based solutions, electrification of public and private transport, efficiency of public lighting, electrification of heating and SHW supplied by natural gas, and improvement in the management of waste. From the results obtained, the biggest contributor to reducing CO_2 emissions is the integration of the PV system, decreasing total emissions by 6.58%. It's followed by the electrification of transport, which contributes a 2.86% reduction. While the rest of the measures contribute less than 1%. The total impact from these measures resulted in a 10.52% reduction. If only scopes 1 and 2 are considered, leaving out the improvement of waste emissions and the outside vehicles that travel through the neighborhood, the neighborhoods potential for decarbonization would rise to 27.44%

Analyzing these results, it can be concluded that to reach carbon neutrality in a neighborhood, many other measures should be implemented. More importantly ones that tackle scope 3 emissions. Specifically, the consumption of goods, which can be reduced through changes in the habits of the population through promotional campaigns and education plans. Not only that, some of the measures proposed need to be implemented more aggressively if cities wish to reach carbon neutral status in the near future. Most significantly the electrification of transport measure which needs to be more incentivized. Also, to reduce the total consumption of fossil fuels, better implementation of public transport and walkable areas should be a priority. Another important measure that should be implemented in future work is the reimbursement of buildings, which will help reduce the electricity and thermal demands, specifically for heating and cooling, providing higher levels of comfort for the citizens that live in the buildings. But it should also be considered that this is a very costly measure, which will further increase the costs of the project and will require economic support.

From the economic analysis it was concluded that for projects of this magnitude, and to help cities achieve carbon neutrality, financial support from national governments or the European Union is necessary. Also, local government incentives for each measure are quite helpful, especially when citizen involvement is necessary.

To summarize, the neighborhood of La Carrasca shows potential in the process of achieving carbon neutrality. Through the implementation of the measures proposed in this study it is still far from the goal, but they present lines of strategy that should be followed in order to mitigate emissions across the city and work in unison to help the city reach its goals of being carbon neutral by 2030.

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9 ANNEXES

A. Downscaling Factors

Most of the data used in this study is originally found at a city or administrative district level. Therefore, before it could be used it needed to be scaled down to a neighborhood level. For this purpose, downscaling factors based on population or surface area were calculated. **Table 9.1** compares this data between La Carrasca and Valencia city, while **Table 9.2** presents it for the administrative district of Algirós.

For the specific occasions of scaling energy consumptions (electricity and gas) to a neighborhood level, data on the buildings in the area was used. **Table 9.3** presents a comparison of the number of buildings for each use, or sector (residential, industrial, and services), between La Carrasca and Valencia city.

Table 9.1 Downscaling factors for La Carrasca based on city data

Category	Valencia	La Carrasca	Factor
Population	800,180	3,444	0.43%
Surface Area (ha)	13,835	196	1.42%

Table 9.2 Downscaling factors for La Carrasca based on district data.

Category	Algirós	La Carrasca	Factor
Population	36,390	3,444	9.46%
Surface Area (ha)	296	196	66.33%

Table 9.3 Downscaling factors for buildings in La Carrasca based on city data.

Building Use	Valencia	La Carrasca	Factor
Residential	411,452	1,901	0.46%
Industrial	8,747	18	0.35%
Services (Commercial, Offices, and others)	51,098	223	0.44%

B. Emissions Factors

To calculate the carbon emissions produced from different sources of consumption, factors of emissions are used that relate each type of consumption to the amount CO_2 emissions generated from consuming one unit of it. **Table 9.4** presents these factors the energy and fuel consumptions considered in this study. The electricity consumed from the grid that provides it to the city, whose emissions factor is based on the mix of different sources that generate the electricity consumed, the natural gas consumed in buildings, and the most common fuels consumed by vehicles, gasoline and diesel.

Table 9.4 Factors of emissions for different types of consumptions [35], [38], [42].

Consumption Type	Emissions Factor
Electricity (tCO_2/MWh)	0.172
Natural Gas (tCO_2/MWh)	0.201
Gasoline ($kgCO_2$/l)	2.196
Diesel ($kgCO_2$/l)	2.471

For the carbon emissions calculations of private vehicles, some factors of emissions based on the distance in kilometers these vehicles travel needed to be specifically calculated, presented in **Table 9.5**. For electric cars and motorcycles, factors for their consumption per kilometer mentioned in section **4.2.2** were used with the factor of emissions for the electricity consumption in the neighborhood (**Table 9.4**). For the category of "Other" in cars, the emissions factor was calculated as an average from the fuels considered, except electricity, and their European regulations in **Table 9.13**.

Table 9.5 Calculated vehicle emission factors for distance traveled

Type of vehicle	Type of Fuel Consumed	Emissions Factor (tCO_2/km)
Car	Electricity	0.0000258
	Other (Petrol, Diesel, CNG, LPG)	0.0003297
Motorcycle	Electricity	0.0000040

C. Energy Demand Calculations

Electricity Consumption

As described in section **3.2**, the platform DATADIS was used to retrieve daily electricity consumption data from the zip code in the city of Valencia (46022) which would most represent the consumption of the neighborhood in order to estimate its demand. The results of the process described are shown in subsection **4.2.1** of the methodology, where it also mentions that they were compared to results of the company ImpactE that made a similar process also using DATADIS. Thanks to them having a higher access to the data, they were able to retrieve hourly electricity consumption data from the platform. They did this for all three zip codes that the neighborhood of La Carrasca is a part of (46020, 46021, and 46022), as shown in **Figure 3.1**. This data was then normalized with the aggregate constructed area of each use for each zip code, and later scaled for the constructed area of the buildings in the neighborhood. **Figure 9.1** shows the resulting total electricity consumption of La Carrasca provided by ImpactE, 61,901 MWh/year, which can be compared to **Figure 4.3**. For further comparison, typical days of winter and of summer were chosen to compare daily curves for each sector from both methodologies. **Figure 9.2**, **Figure 9.3**, and **Figure 9.4** show this comparison for the January 15 and July 15 in the residential, services, and industrial sectors respectively. The results from ImpactE are shown in blue, while the results from the methodology of this study are shown in orange and referred to as CATENERG.

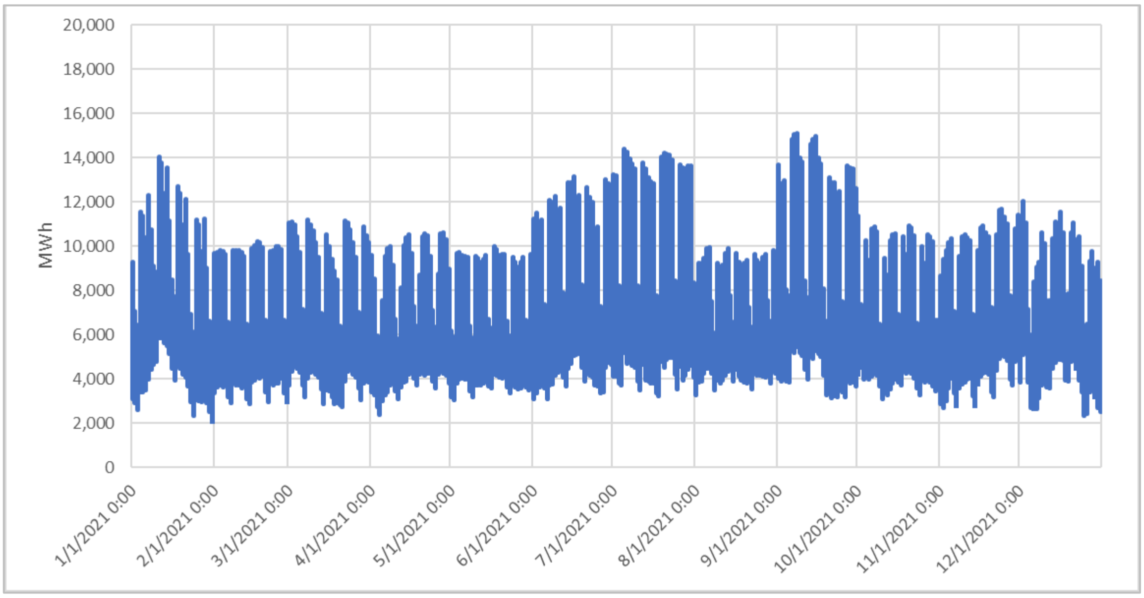


Figure 9.1 Electricity consumption in La Carrasca provided by ImpactE.

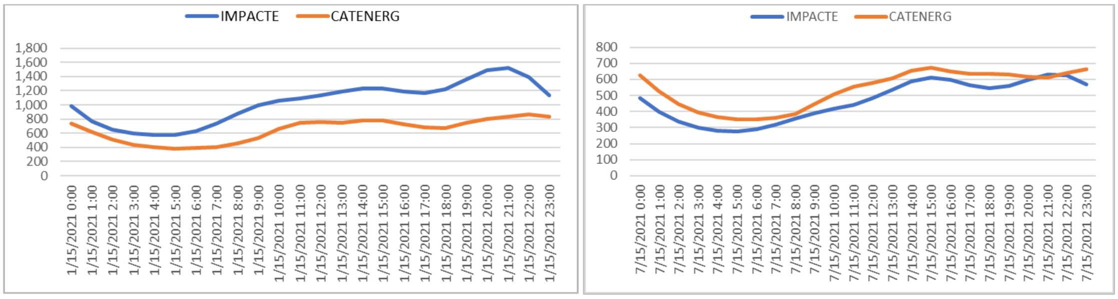


Figure 9.2 Daily curve comparison for a typical day in winter (left) and in summer (right) in the residential sector.

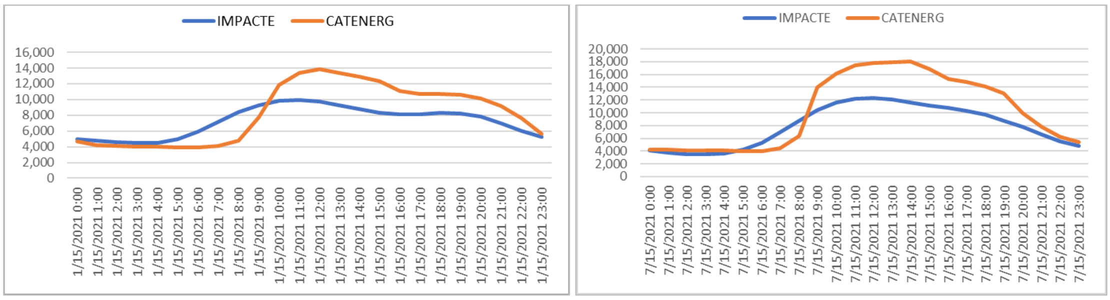


Figure 9.3 Daily curve comparison for a typical day in winter (left) and in summer (right) in the services sector.

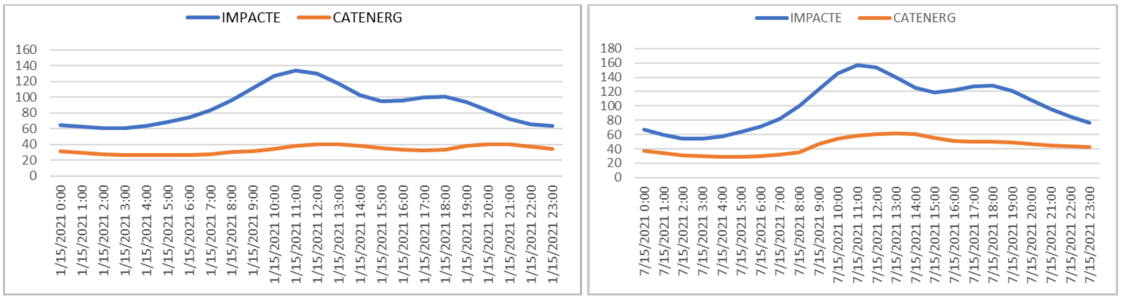


Figure 9.4 Daily curve comparison for a typical day in winter (left) and in summer (right) in the industrial sector.

D. Photovoltaic System Calculations

As described in section **3.5**, the program HOMER was used to simulate the photovoltaic system to be integrated in the neighborhood. After calculating the total surface that would be considered for the integration of PV panels, the system will be simulated with the different considerations of panel inclination angle and percentage of available surface to be used. The first step for setting up the simulation is to define the outlook of the system. **Figure 9.5** shows the equipment considered in this study, which is simply the electricity demand of the neighborhood or the primary load, the PV system, and the connection to the electricity grid.

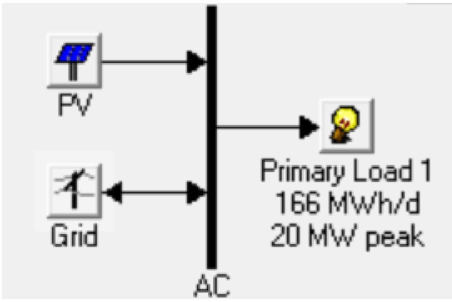


Figure 9.5 Equipment considered in PV system simulation in HOMER.

Focusing on the electricity demand of the neighborhood, **Figure 9.6** presents the primary load specifications as shown in HOMER. It shows a daily profile which highlights the peaks of demand from 10:00 to 12:00 in the morning, a data map (DMap) which highlights the same peaks in the day but mostly in the month of July, and a seasonal profile which also highlights the month of July as having the highest mean and peak demand. This behavior is also shown in **Figure 9.7**, where daily profiles of the primary load for each month.

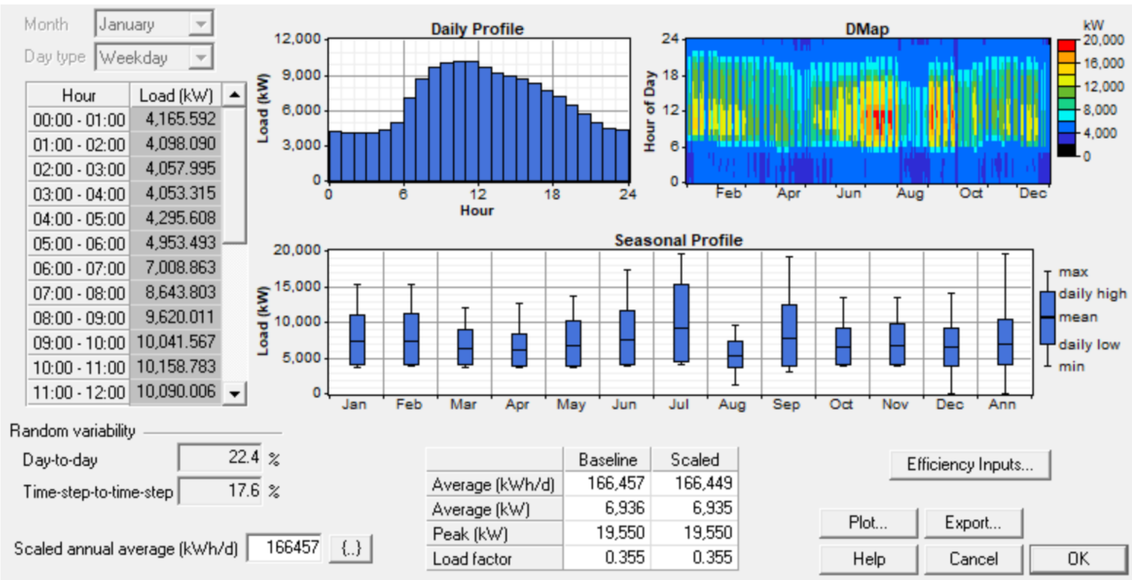


Figure 9.6 Primary load (electricity demand) specifications in HOMER.

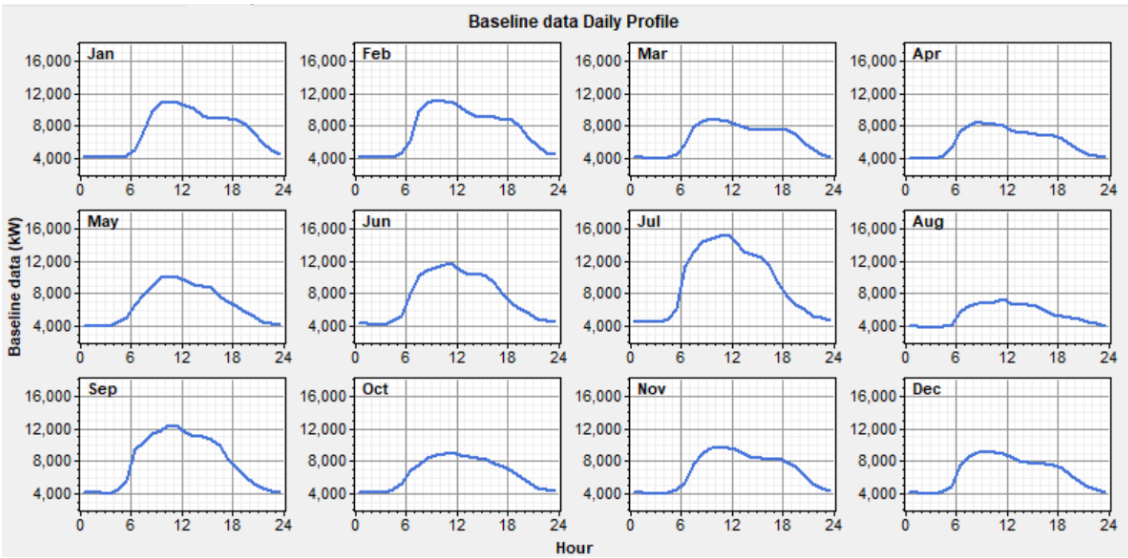
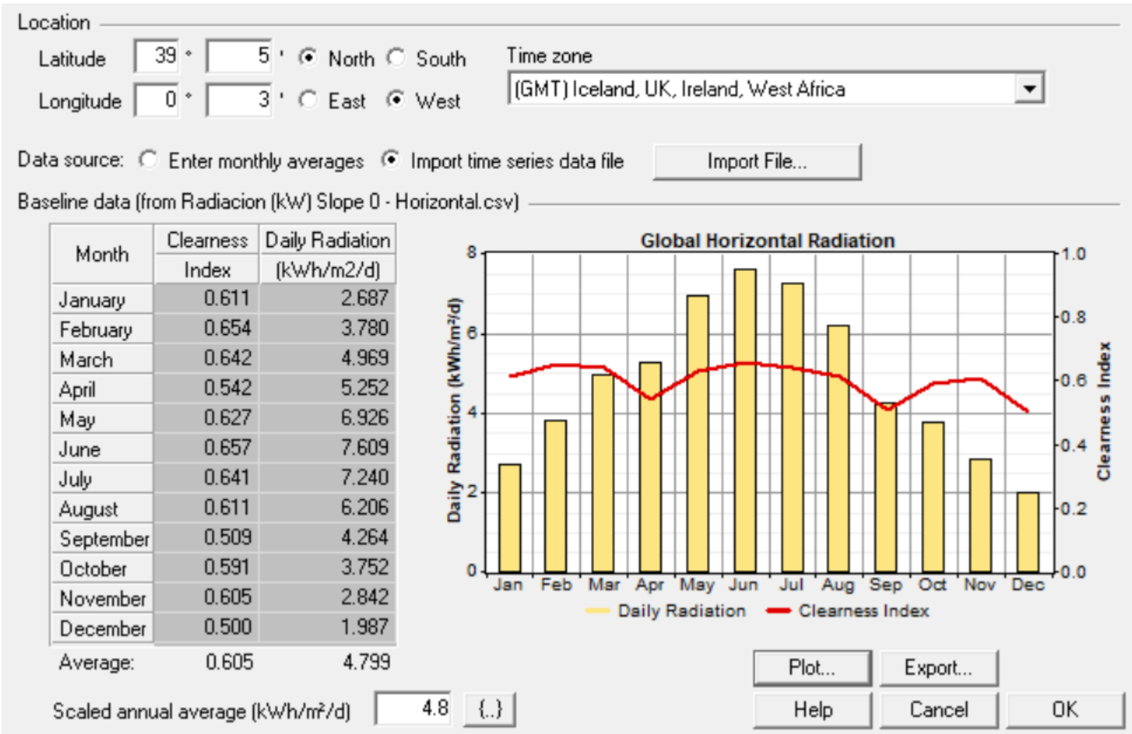


Figure 9.7 Primary load daily profiles for each month.

For the photovoltaic system to produce electricity, solar resource data needs to be included in the program. Global horizontal radiation hourly data was downloaded from the platform PVGIS [72] and introduced in the program to produce the specifications shown in **Figure 9.8**. It presents an average daily radiation of 4.8 kWh/m^2, with the highest averages coming in the summer months from May to July as expected since these months have the longest hours of sunlight in Valencia. This behavior is also shown in **Figure 9.9**, which presents daily profiles for each month. It also highlights the peaks of sunlight at midday.



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.611	2.687
February	0.654	3.780
March	0.642	4.969
April	0.542	5.252
May	0.627	6.926
June	0.657	7.609
July	0.641	7.240
August	0.611	6.206
September	0.509	4.264
October	0.591	3.752
November	0.605	2.842
December	0.500	1.987
Average:	0.605	4.799

Figure 9.8 Solar resource specifications in HOMER.

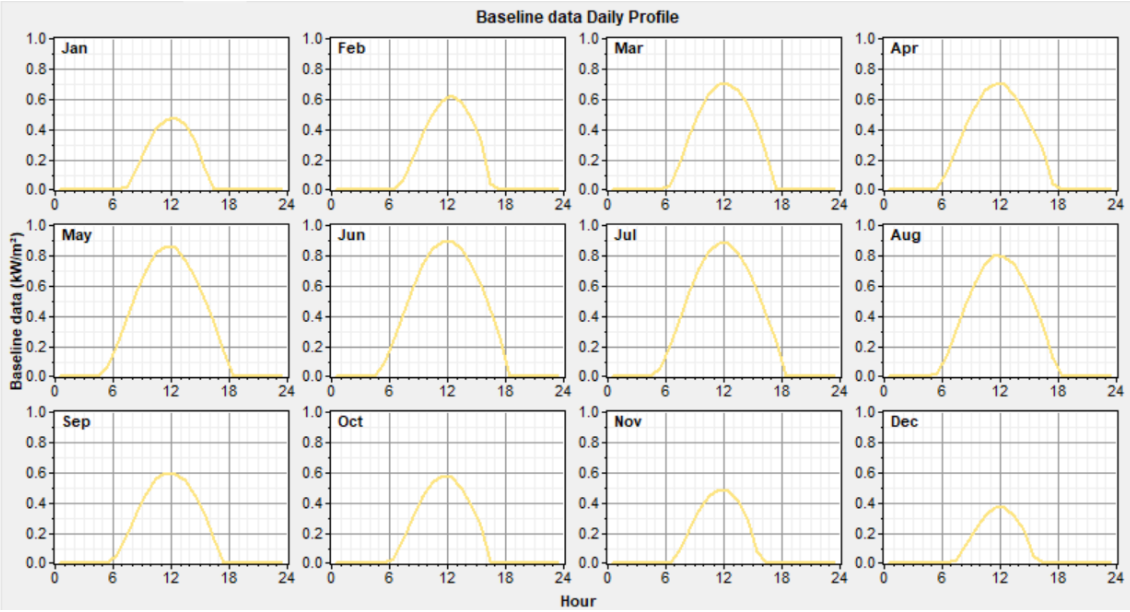


Figure 9.9 Solar resource daily profiles for each month.

As mentioned before, a sensitivity analysis was made to calculate the installed PV power in the neighborhood. It considers two different angles of inclination, 15° and 35°, and three percentages of useful area. Since through the rooftop analysis made the results showed a 32% useful area for PV installation, then 30% and 35% will also be considered. **Table 9.6** presents the calculated PV powers that were introduced in the HOMER software for simulation.

Table 9.6 PV powers introduced in HOMER for simulations

% Useful Area	Installed PV power with 15° panel inclination (kW)	Installed PV power with 35° panel inclination (kW)
30%	16,883	12,736
32%	18,009	13,586
35%	19,697	14,859

To arrive at the PV powers just presented, the value of power (kW/m2) for this specific location needed to be calculated considering the chosen panel specifications, as mentioned in section **5.4.1**. To arrive at the values needed, it’s necessary to make calculations about the distance of the panels. The distance to be considered is shown in **Figure 9.10**.

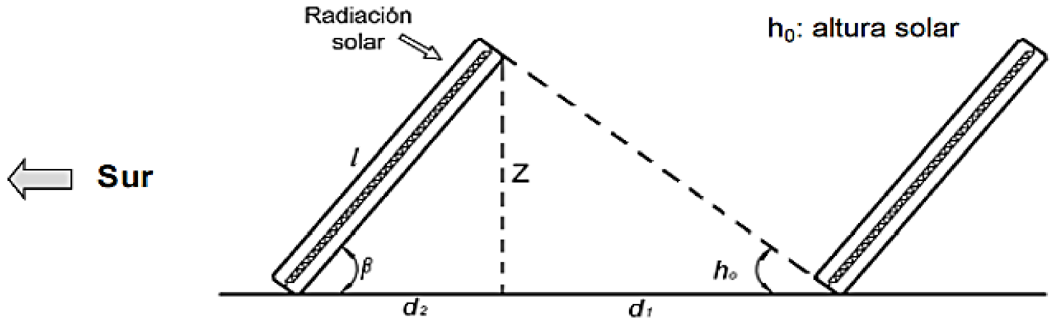


Figure 9.10 Scheme of PV panel distance between each row of panels.

Considering the distances shown in the scheme, the equations used are the following:

$$d = d_1 + d_2 = \frac{Z}{\tan h_0} + \frac{Z}{\tan \beta} = l\frac{\sin \beta}{\tan h_0} + l\frac{\sin \beta}{\tan \beta}$$

Since the installation will be working all year long, the calculations will be done considering the most unfavorable day. For this case it is the 21st of December, for which:

$$h_0 = 90 - latitude + \delta$$

The results obtained from applying these formulas, are presented in **Table 9.7**. Considering these values of kW/m^2 and the total surface available from the percentages considered, the resulting values presented in **Table 9.6** were obtained.

Table 9.7 Results of calculations to obtain value of power (kW/m^2) for the location of the neighborhood.

Latitude	40	40
Declination (δ)	-23.45	-23.45
h_0	26.55	26.55
Panel inclination (β)	15°	35°
Panel longitude, l (m)	2.278	2.278
Panel width (m)	1.133	1.133
d_1	0.59	1.30
d_2	1.09	0.93
D	1.68	2.23
Unitary rooftop area	3.83	5.08
Power (kW)	0.550	0.550
Power (kW/m^2)	0.144	0.108

Having calculated the PV powers to be considered, the final PV input are the costs of the system. Using the values mentioned in **Table 5.17**, the specifications of the system are presented in **Figure 9.11**.

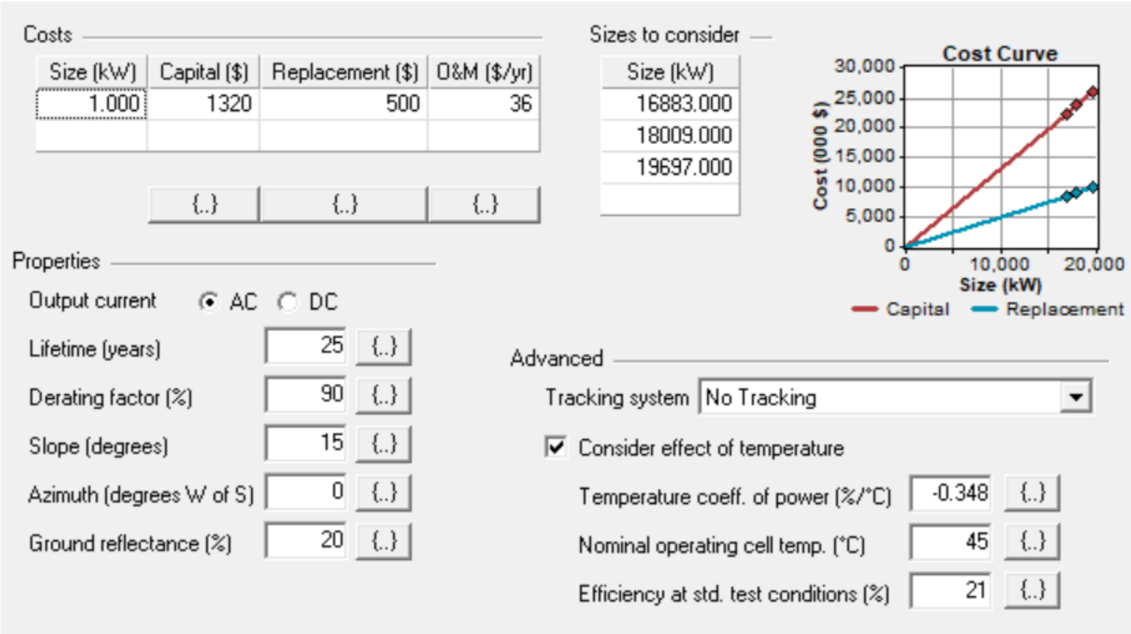


Figure 9.11 PV inputs considered in HOMER simulation.

Finally, for the connection to the grid, using the costs presented in **Table 5.18** the rate schedule for the three electricity tariff periods is shown in **Figure 9.12**. Where rate 1 is the peak period (period 1), rate 2 is the standard period (period 2), and rate 3 is the valley period (period 3).

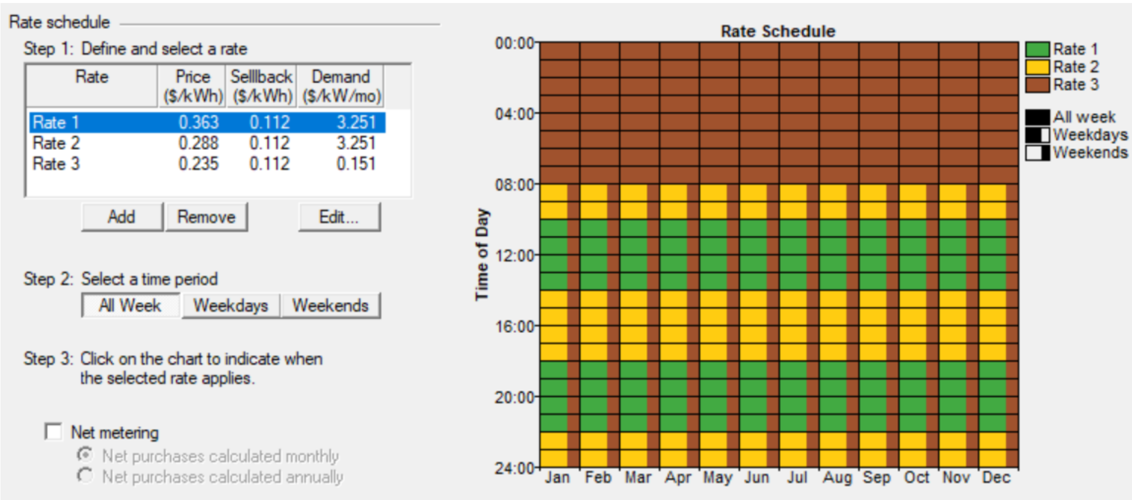


Figure 9.12 Rate schedule for the electricity grid connection considered in HOMER.

The results obtained from the HOMER simulations of the PV installations with the characteristics mentioned before are included in **Table 9.8**.

Table 9.8 Results of the PV installation simulations in HOMER for La Carrasca.

Percentage useful area (%)	Panel inclination (°)	PV Power Installed (MW)	Total Capital Cost (M€)	Operation Costs (M€/year)	LCOE (€/kWh)	PV Production (MWh/year)	Grid Purchases (MWh/year)	Grid Sales (MWh/year)	Total electricity production (MWh/year)	Primary load (MWh/year)	Renewable fraction
30	15	16.88	22.28	11.04	0.200	28,949	36,911	5103	65,860	60,754	0.44
32	15	18.01	23.77	10.69	0.196	30,880	36,025	6148	66,905	60,754	0.46
35	15	19.70	26.00	10.21	0.190	33,774	34,839	7856	68,613	60,754	0.49
30	35	12.74	16.81	12.22	0.215	22,980	40,397	2620	63,377	60,754	0.36
32	35	13.59	17.93	11.90	0.211	24,513	39,484	3241	63,998	60,754	0.38
35	35	14.86	19.61	11.44	0.205	26,810	38,229	4283	65,040	60,754	0.41

E. Transport Calculations

In this annex section, the calculations for the carbon footprint of the transportation sector and the EV implementation will be further explained. It will focus on the private system since the public system is well explained in the contents of the document.

Private Transport

Following the procedure described in section **4.2.2**, to calculate the emissions produced from the private vehicles of the population in La Carrasca, the vehicle fleet of Valencia city (**Table 9.9**) needed to be downscaled to neighborhood level and later categorized by type of fuel and European regulation. Using percentages for fuel type in each type of vehicle with the amount of each type of vehicle per European regulation, the vehicle fleet was segregated by fuel type and regulation. The results of this process are shown in **Table 9.10** for the car fleet, **Table 9.11** for the small truck fleet, and **Table 9.12** for the motorcycle fleet.

Table 9.9 Vehicle fleet of Valencia city. Adapted from [34].

Fuel	Cars	Small Trucks	Motorcycles	Total
Petrol	188,801	5661	86,495	280,957
Diesel	172,973	18,540	380	191,893
Electricity	521	80	746	1,347
CNG	133	15	0	148
LPG	778	49	0	827
Total	**363,206**	**24,345**	**87,621**	**475,172**

Table 9.10 Car fleet in La Carrasca per fuel type and European Regulation.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	30	27	0	0	0	57
Euro 1	15	14	0	0	0	29
Euro 2	38	35	0	0	0	74
Euro 3	150	138	0	1	0	289
Euro 4	219	201	1	1	0	421
Euro 5	129	118	0	0	1	248
Euro 6	231	212	1	1	0	445
Total	**813**	**744**	**2**	**3**	**1**	**1563**

Table 9.11 Small truck fleet in La Carrasca per fuel type and European Regulation

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	1	3	0	0	0	4
Euro 1	0	1	0	0	0	2
Euro 2	1	4	0	0	0	5

Euro 3	5	15	0	0	0	19
Euro 4	7	21	0	0	0	28
Euro 5	4	13	0	0	0	17
Euro 6	7	23	1	0	0	31
Total	**24**	**80**	**1**	**0**	**0**	**105**

Table 9.12 Motorcycle fleet in La Carrasca per fuel type and European Regulation

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	30	0	0	0	0	31
Euro 1	41	0	0	0	0	41
Euro 2	58	0	1	0	0	59
Euro 3	153	1	1	0	0	155
Euro 4	77	0	1	0	0	78
Euro 5	12	0	0	0	0	12
Total	**372**	**2**	**3**	**0**	**0**	**377**

To calculate the emissions produced from these vehicles, factors of emissions for each fuel type and European regulation need to be determined. **Table 9.13** presents the emission factors used for cars and small trucks, while **Table 9.14** presents the ones used for motorcyles.

Table 9.13 Emission factors for cars and small trucks (tCO_2/km) per fuel type and European Regulation. Adapted from [46].

Regulation	Type of fuel				
	Petrol	Diesel oil	Electricity	LPG	CNG
Pre Euro	0.000419	0.000368	0.0000258	0.000313	0.00035
Euro 1	0.000403	0.000356	0.0000258	0.000313	0.000366
Euro 2	0.000387	0.000344	0.0000258	0.000313	0.000322
Euro 3	0.000371	0.000332	0.0000258	0.000313	0.000308
Euro 4	0.000355	0.00032	0.0000258	0.000313	0.000294
Euro 5	0.000342	0.000313	0.0000258	0.000313	0.000285
Euro 6	0.000329	0.000306	0.0000258	0.000313	0.000276

Table 9.14 Emission factors for motorcycles (tCO_2/km) per fuel type and European Regulation. Adapted from [46].

Regulation	Type of fuel				
	Petrol	Diesel oil	Electricity	LPG	CNG
Pre Euro	0.000124	0.000124	0.0000040	0.000124	0.000124
Euro 1	0.000124	0.000124	0.0000040	0.000124	0.000124
Euro 2	0.000124	0.000124	0.0000040	0.000124	0.000124
Euro 3	0.000124	0.000124	0.0000040	0.000124	0.000124
Euro 4	0.000124	0.000124	0.0000040	0.000124	0.000124
Euro 5	0.000124	0.000124	0.0000040	0.000124	0.000124

For the electric vehicle implementation on the vehicle fleets presented above, the exchange of vehicles was made by removing the oldest most polluting vehicles in order to add new electric vehicles. This resulted in new distributions in the vehicles fleets for the two years considered, 2025 and 2030. The following tables presents these changes.

Vehicle fleet in 2025

Table 9.15 Car fleet in La Carrasca per fuel type and European Regulation in 2025.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	0	25	0	0	0	25
Euro 1	15	14	0	0	0	29
Euro 2	38	35	0	0	0	74
Euro 3	150	138	0	1	0	289
Euro 4	219	201	1	1	0	421
Euro 5	129	118	0	0	1	248
Euro 6	231	212	33	1	0	477
Total	**783**	**742**	**34**	**3**	**1**	**1563**

Table 9.16 Small truck fleet in La Carrasca per fuel type and European Regulation in 2025.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	0	3	0	0	0	3
Euro 1	0	1	0	0	0	2
Euro 2	1	4	0	0	0	5
Euro 3	5	15	0	0	0	19
Euro 4	7	21	0	0	0	28
Euro 5	4	13	0	0	0	17
Euro 6	7	23	2	0	0	32
Total	**23**	**80**	**2**	**0**	**0**	**105**

Table 9.17 Motorcycle fleet in La Carrasca per fuel type and European Regulation in 2025.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	22	0	0	0	0	23
Euro 1	41	0	0	0	0	41
Euro 2	58	0	1	0	0	59
Euro 3	153	1	1	0	0	155
Euro 4	77	0	1	0	0	78
Euro 5	12	0	8	0	0	20
Total	**364**	**2**	**11**	**0**	**0**	**377**

Vehicle fleet in 2030

Table 9.18 Car fleet in La Carrasca per fuel type and European Regulation in 2030.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	0	0	0	0	0	0
Euro 1	0	0	0	0	0	0
Euro 2	17	35	0	0	0	53
Euro 3	150	138	0	1	0	289
Euro 4	219	201	1	1	0	421
Euro 5	129	118	0	0	1	248
Euro 6	231	212	108	1	0	552
Total	**747**	**703**	**109**	**3**	**1**	**1563**

Table 9.19 Small truck fleet in La Carrasca per fuel type and European Regulation in 2030.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	0	0	0	0	0	0
Euro 1	0	0	0	0	0	1
Euro 2	0	4	0	0	0	4
Euro 3	5	15	0	0	0	19
Euro 4	7	21	0	0	0	28
Euro 5	4	13	0	0	0	17
Euro 6	7	23	7	0	0	37
Total	**22**	**76**	**7**	**0**	**0**	**105**

Table 9.20 Motorcycle fleet in La Carrasca per fuel type and European Regulation in 2030.

Regulation	Type of fuel					Total
	Petrol	Diesel	Electricity	LPG	CNG	
Pre Euro	7	0	0	0	0	8
Euro 1	41	0	0	0	0	41
Euro 2	58	0	1	0	0	59
Euro 3	153	1	1	0	0	155
Euro 4	77	0	1	0	0	78
Euro 5	12	0	23	0	0	35
Total	**349**	**2**	**26**	**0**	**0**	**377**

F. Heat Pump Calculations

Thermal Demand

As described in section **5.4.5**, to calculate the number of heat pumps to replace the natural gas consumption for heating and SHW of the neighborhood's residential sector, it's necessary to estimate the thermal demand that this consumption addresses. **Table 9.21** presents the NG consumption segregated by its use and the equipment that households use for each use. Knowing the efficiency of these components, the thermal demand was estimated.

Table 9.21 Estimated thermal demand of NG consumption in the residential sector of La Carrasca

Use	Equipment [79]	NG Consumption (MWh/year)		Efficiency [86] [87] [88]	Demand (MWh/year)	
Heating	Conventional Gas Boiler	66.19%	865	82.89%	717	1113
	Condensation Boiler	3.32%	43	91.00%	40	
	Gas Fireplace	30.49%	398	89.50%	356	
SHW	Conventional Gas Boiler	43.63%	448	82.89%	371	865
	Condensation Boiler	2.06%	21	91.00%	19	
	Thermos Gas Water Heater	54.32%	558	85.00%	474	
	Total	**2334**			**1978**	

Heat Pump Comparison

Having calculated the thermal demand that will be covered by heat pumps, a comparison of different aerothermal LG HP models was made to select the most suited for the application in terms of the number of devices necessary, costs, and the savings in emissions. **Table 9.22** presents the results of this comparison, where the savings in emissions are a product of the savings from natural gas consumption and the added electricity consumption.

Table 9.22 Heat pump comparison results [78].

Heat Pump Model	Capacity (kW)	COP	Nominal Consumption (kW)	Annual Electricity Consumption (MWh/year)	Cost of Equipment (€)	Number of Heat Pumps	Total Investment Cost (€)	Savings in emissions (tCO_2e/year)
THERMA V MONOBLOCK S R32 - HM051MR.U44	5.5	4.70	1.17	420.80	7,106	422	2,998,732	397.57
THERMA V MONOBLOCK S R32 - HM091MR.U44	9	4.60	1.96	429.95	7,441	258	1,919,778	394.49
THERMA V MONOBLOCK S R32 - HM141MR.U34	14	4.80	2.92	412.03	10,434	166	1,732,044	398.20

G. Consumption of Food and Waste Calculations

Food Consumption Emissions

To arrive at the factor of emissions per capita for the neighborhood presented in **Table 5.10**, emission factors for the different types of food consumed in Spain needed to be estimated. Using factors found in different articles and sources of data, the resulting factors of emissions per kilogram consumed of each type of food are presented below (**Table 9.23**).

Table 9.23 Food emission factors (tCO_2e/kg).

Oil	0.00182
Olives	0.00056
Rice	0.00356
Beverages	0.00093
Wine	0.00179
Cereals	0.00092
Cookies	0.00092
Coffee & infusions	0.02853
Beef	0.04486
Lamb	0.02013
Other meat	0.01252
Chocolate	0.04665
Fresh fruit	0.00050
Processed fruit & vegetables	0.00194
Dried fruit	0.00098
Fresh vegetables	0.00051
Egg	0.00289
Milk	0.00345
Dairy products	0.00678
Legumes	0.00061
Bread & pastry	0.00083
Flour	0.00083
Pasta	0.00181
Potato	0.00020
Fish	0.00741
Ready-to-eat	0.00133
Rest	0.00128

Using these emission factors and the food consumption values presented in **Table 4.10**, factors of emissions for food per capita were estimated. These resulting factors are presented in **Table 9.24**.

Table 9.24 Food emissions per capita (tCO_2e/cap).

Oil	0.01845
Olives	0.00150
Rice	0.01429
Beverages	0.13560
Wine	0.01498
Cereals	0.00152
Cookies	0.00475
Coffee & infusions	0.05535
Beef	0.21309
Lamb	0.02255
Other meat	0.56010
Chocolate	0.16934
Fresh fruit	0.04553
Processed fruit & vegetables	0.02520
Dried fruit	0.00348
Fresh vegetables	0.02958
Egg	0.02521
Milk	0.25026
Dairy products	0.23874
Legumes	0.00215
Bread & pastry	0.02496
Flour	0.00207
Pasta	0.00764
Potato	0.00584
Fish	0.16844
Ready-to-eat	0.02237
Rest	0.00396
Total	**2.07**

Waste Emission Factors

To arrive at the emission factors used for each type of waste management process presented in **Table 5.12**, and average was calculated from emissions factors of different treated materials in each process. This data is shown in **Table 9.25** below.

Table 9.25 Waste emission factors (tCO_2e/ton) based on waste management process [59].

Material	Recycled	Landfilled	Composted
Aluminum Cans	0.06	0.02	NA

Aluminum Ingot	0.04	0.02	NA
Steel Cans	0.32	0.02	NA
Copper Wire	0.18	0.02	NA
Glass	0.05	0.02	NA
HDPE	0.21	0.02	NA
LDPE	NA	0.02	NA
PET	0.23	0.02	NA
LLDPE	NA	0.02	NA
PP	NA	0.02	NA
PS	NA	0.02	NA
PVC	NA	0.02	NA
PLA	NA	0.02	0.17
Corrugated Containers	0.11	0.90	NA
Magazines/Third-class Mail	0.02	0.42	NA
Newspaper	0.02	0.35	NA
Office Paper	0.02	1.25	NA
Phonebooks	0.04	0.35	NA
Textbooks	0.04	1.25	NA
Dimensional Lumber	0.09	0.17	NA
Medium-density Fiberboard	0.15	0.07	NA
Food Waste (non-meat)	NA	0.58	0.15
Food Waste (meat only)	NA	0.58	NA
Beef	NA	0.58	0.15
Poultry	NA	0.58	0.15
Grains	NA	0.58	0.15
Bread	NA	0.58	0.15
Fruits and Vegetables	NA	0.58	0.15
Dairy Products	NA	0.58	0.15
Yard Trimmings	NA	0.33	0.19
Grass	NA	0.26	0.19
Leaves	NA	0.26	0.19
Branches	NA	0.53	0.19
Mixed Paper (general)	0.07	0.80	NA
Mixed Paper (primarily residential)	0.07	0.77	NA
Mixed Paper (primarily from offices)	0.03	0.75	NA
Mixed Metals	0.23	0.02	NA
Mixed Plastics	0.22	0.02	NA
Mixed Recyclables	0.09	0.68	NA
Food Waste	NA	0.58	0.15

Mixed Organics	NA	0.48	0.17
Mixed MSW	NA	0.52	NA
Carpet	NA	0.02	NA
Desktop CPUs	NA	0.02	NA
Portable Electronic Devices	NA	0.02	NA
Flat-panel Displays	NA	0.02	NA
CRT Displays	NA	0.02	NA
Electronic Peripherals	NA	0.02	NA
Hard-copy Devices	NA	0.02	NA
Mixed Electronics	NA	0.02	NA
Clay Bricks	NA	0.02	NA
Concrete	0.01	0.02	NA
Fly Ash	0.01	0.02	NA
Tires	0.10	0.02	NA
Asphalt Concrete	-	0.02	NA
Asphalt Shingles	0.03	0.02	NA
Drywall	NA	0.02	NA
Fiberglass Insulation	0.05	0.02	NA
Vinyl Flooring	NA	0.02	NA
Wood Flooring	NA	0.18	NA
Average	**0.0958**	**0.2697**	**0.1643**