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Methodology for estimating the decarbonization potential at the neighborhood level in an urban area: Application to La Carrasca in Valencia city - Spain

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ABSTRACT

Decarbonization potential estimation is critical to calculate and measure a specific area's actual greenhouse gas reduction capacity. However, it is often challenging to estimate decarbonization potential, especially when dealing with large and diverse urban areas. Therefore, it is necessary to study the carbon footprint in the study area before evaluating decarbonization potential. This study aimed to develop a methodology for estimating the decarbonization potential in a district and applying it to La Carrasca neighborhood in Valencia City, Spain. The concept behind selecting a smaller area encompassing multiple sectors, including residential and services, rather than an entire city was to concentrate on often overlooked details, streamline the information processing, and consider factors that are otherwise unfeasible when a larger area is chosen. The proposed method considers all potential emissions according to scopes 1, 2, and 3 (direct emissions, primary indirect emissions, and other indirect emissions, respectively) and all possible decarbonization measures, including renewables, nature-based solutions, electrification, and improved waste management. The study utilizes several tools to achieve these objectives, including HOMER, QGIS, DATADIS, Google Earth, and Excel. The results of this study showed that the decarbonization potential of La Carrasca neighborhood is 7488 tons of CO_2, representing a bit more than 11% of its overall emissions, and the total cost per emission saving during the lifetime of all the analyzed technologies is 200 €/tCO_2. However, achieving complete decarbonization of the area would require more aggressive mitigation measures, government incentives, policy changes, new measures, and changes in habits among the population. Overall, the numerical results demonstrate the importance of considering an area's carbon footprint and utilizing a comprehensive methodology to estimate the decarbonization potential for effective greenhouse gas reduction. The proposed methodology could be extrapolated to other areas to estimate decarbonization potential and emissions and to determine the feasibility of achieving negative carbon emissions.

1. Introduction

To mitigate and control climate change's effects, countries have agreed to reduce their emissions to maintain the global temperature rise to 1.5 °C or below. Cities have a huge role 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.

The Joint Programming Initiative (JPI) Urban Europe tackles priorities and critical issues related to urban transformation (Noll et al., 2020). These are effectively conveyed through strategic dialogue events, emphasizing the presence of three fundamental principles that propel urban transitions towards a more sustainable environment. One key aspect of this transition involves the development of positive energy districts (PEDs) and neighborhoods, which can be regarded as urban areas striving for annual net zero emissions, energy self-sufficiency, and the generation of surplus renewable energy. The following principle is mobility transitions, achieved by concentrating 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 (Graells-Garrido et al., 2021) (Mueller et al., 2020) Finally, the third principle is a circular economy, which focuses on creating a circular value chain for the consumption of resources, meaning reuse, trade, and recycling of resources.

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Nomenclature

GHG	Greenhouse gases
UPV	Polytechnic University of Valencia
UV	University of Valencia
CV	Valencian Community
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

Before providing decarbonization strategies, the area's carbon footprint must be calculated. This emissions inventory is divided into three main scopes (Wiedmann et al., 2021). First are direct emissions (Scope 1), which come from sources within city boundaries, direct combustion, and energy use produced inside the neighborhood. Indirect emissions from grid-supplied electricity, heating, or cooling energy consumption are considered scope two emissions. Other indirect GHG emissions occurring outside the area but are produced due to activities inside its boundary fall into the third scope.

A study for optimal pathways for decarbonizing building energy services, which fall into scope 2, 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 (Leibowicz et al., 2018). The book titled *Holistic Approach for Decision Making Towards Designing Smart Cities* (Cristian et al., 2021) mentions and proves with examples that photovoltaic (PV) systems in the urban infrastructure are a crucial parameter towards zero or positive energy areas. Similarly, solar thermal panels can be implemented to satisfy building heating demands (Ciampi et al., 2018), (Renaldi and Friedrich, 2019). Another strategy is the implementation of domestic biomass resources (Burg et al., 2018), which have potential applications for electricity and heating. A highly efficient solution for decarbonizing the building's heating demands is using heat pumps (HP) coupled with renewable energy technologies to satisfy its electricity demand (Popovski et al., 2019), (Borge-Diez et al., 2022).

These strategies could be made more efficient and cost-effective by reducing the energy consumption in buildings by improving their thermal properties. Adding insulation to existing brick-facing walls could result in high comfort levels while reducing heating demand and CO_2 emissions (López-Mesa et al., 2020). Similar strategies, which are being widely considered and implemented to change the infrastructure of buildings to increase thermal comfort and enhance carbon sequestration capacity, are nature-based solutions (NBS), like implementing green infrastructure (Anderson and Gough, 2020). Many of these strategies and technologies 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 neighborhood aiming for carbon neutrality.

On the other hand (Khatiwada et al., 2022), works study the decarbonization of natural gas systems in the EU, barriers, and constraints of hydrogen production with a case study in Portugal, Decarbonization of natural gas systems in the EU (Schulman et al., 2021), have analyzed the Supply chains of the Scope 3 for sustainable food systems, taking into account the greenhouse gas emissions due to de the food supply chain. Also, scope 3 is analyzed by (Radonjič and Tompa, 2018), where Carbon footprint calculation in telecommunications companies is analyzed, LCA is analyzed by (Bošković and Radivojević, 2023) due to concrete wall constructions in Serbia (Backe et al., 2023). explores the link between the EU emissions trading system and net-zero emission neighborhoods. Finally, a new fuzzy model of multi-criteria decision support based on Bayesian networks for urban areas' decarbonization planning was developed by (Mrówczyńska et al., 2022). The transportation sector is often the most significant contributor to city carbon emissions, presenting a different challenge than the buildings sector. The slow integration of fuel-efficient vehicles, especially in private transport, since for most people it's challenging to change their current car, is why integrating efficient and low-emitting public transportation is so important. A study done for the city of Kyoto researches the technical, economic, and social considerations of the potential for decarbonizing the region's power system through integrating electric vehicles (EV) and rooftop PVs (Kobashi et al., 2020). Also, increasing the role of public transport and bicycles would have a mixed effect on the emissions produced in the neighborhood. While it may increase the carbon footprint of the public transportation sector, it could reduce the carbon footprint of the private transportation sector by reducing the use of private owned motorized vehicles. This is supported by a comparison of carbon emissions produced per traveler, and km traveled for different types of motorized vehicles (IDAE, n.d.), which shows, for example, that using the metro or tram is approximately 75% less polluting than using a car. Nevertheless, at neighborhood levels, there isn't a methodology for analyzing the CO_2 emissions per scope and source and simultaneously providing measures to mitigate such CO_2 emissions.

In a state-of-the-art review about zero emission neighborhoods and positive energy districts (PEDs) (Brozovsky et al., 2021), it's mentioned that although quite a few studies are tackling the field of decarbonization at a neighborhood or district level, there is still a lack of commonness in the definition of the area (neighborhood, district, community, a cluster of buildings, etc.), meaning that studies done on a specific scale are scarce. This is coupled with the difficulty of finding data on a neighborhood level. Most of the available data, for example, on the energy consumption of buildings, vehicle fleets, and waste production, is found at a district, zip code, or city scale. This means that much of the data must be reworked or downscaled to the desired area. Finally, there's little homogeneity in the methodologies used since a considerable amount of the reviewed studies present new methods and how much they include in the scope of the study.

This project aims to establish a methodology for assessing the potential for decarbonization at the neighborhood level. By concentrating on a smaller urban area, the study aims to address specific details that would be overlooked in a larger area, using fewer but more precise data and providing a framework that can be applied to other neighborhoods with similar structures and climates. Specifically, the methodology can be transferred to each type of area, such as residential zones or large public establishments, like universities, to other neighborhoods that include these types of areas.

The city of Valencia has become part of the European project to drive 100 cities to become climate-neutral by 2030 (Krogh Andersen and

Jordan, 2020) and use them as examples for future projects to ultimately fulfill the targets of the Paris Agreement of 2015 (United Nations, 2015) to reach climate neutrality by 2050. In addition, the European Union has announced that Valencia will be the European Green Capital in 2024, a distinction awarded to leading cities in ecological and clean environmental policies. This study is made within the framework of the Urban Energy Transition Chair, funded by the City of Valencia, to seek measures to decarbonize the city. The study will focus on the La Carrasca neighborhood in the Algirós district of Valencia. Due to its intricate composition, La Carrasca is a particular neighborhood featuring two prominent universities, including the Polytechnic University of Valencia (UPV) and the University of Valencia Campus of Tarongers (UV) as several secondary educational institutes. Additionally, there is a vast agricultural region in the northern part of the neighborhood. This diversity poses a complex challenge when analyzing approaches to decarbonization, as there is no single solution, and various efforts and technologies will be necessary to achieve the project's objectives. Despite being a unique zone, the residential area of the neighborhood has very similar characteristics to other areas of the city, so the analysis of the residential area could be extrapolated to other residential Mediterranean areas.

The decarbonization potential estimation in large and diverse urban areas is challenging and requires an effective methodology considering all potential emissions and decarbonization measures. The study addresses this gap by proposing a methodology that estimates decarbonization potential in a neighborhood, considering all possible CO_2 emissions and decarbonization measures. The study also highlights that achieving complete decarbonization of an area requires a combination of mitigation measures, government incentives, policy changes, and changes in habits among the population. The proposed methodology provides a starting point for policymakers and stakeholders to identify the potential for reducing greenhouse gas emissions in urban areas and developing appropriate measures and policies to achieve a low-carbon future. The research also suggests that the proposed methodology can be extrapolated to other areas to estimate decarbonization potential and emissions and determine the feasibility of achieving negative carbon emissions. It must also be noted that decarbonization potential can change according to different future scenarios, technologies, and policies. The presented methodology has considered current technologies, near future (next 5–10 years) scenarios, and contemporary national/regional plans applicable to considered CO_2 savings strategies.

2. Methodology

The methodology to determine the CO_2 emissions inventory and the decarbonization potential of a particular area can be divided into two main steps. Determining the area's carbon footprint 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 scopes 1, 2, and 3. This section will go through the process of gathering data, analyzing it, the decision-making process for the proposed solution, and how the results were obtained, including which tools were used. This methodology is summarized in Fig. 1.

The decarbonization potential can be highly dependent on regional/national planning and policies, subsidies or taxes that can boost or slow down the implementation of specific measures as, for example, photovoltaic systems, electric vehicles, high efficiency heat pumps, etc. Then, as a limitation of the methodology, it must be acknowledged that obtained results are highly dependent on considered scenario.

2.1. Carbon footprint calculation

2.1.1. Buildings

The primary step to quantify the neighborhood's overall GHG emissions is to gather data on how the buildings in the area consume energy. Using the platform DATADIS (Asociación de Empresas Eléctricas et al., n.d.), daily electricity consumption value and the number of clients were extracted for each sector (residential, industrial, and services). Since this data is provided for every zip code in Spain, the 46022, which makes up most of the surface area of the neighborhood, was chosen. This consumption was then scaled for the number of clients for each sector in the neighborhood. The universities that reside in the area (UPV and UV) make up most of the total constructed surface area in the neighborhood, around 70%, as shown in Table 1. Since their electricity consumption represents almost 85% of the total, it was first subtracted from the total in the services sector in the zip code before scaling down to the neighborhood level. This was done to salvage the accurate data provided by each institution without estimating it. The total consumption of the area, 60,761 MWh/year divided by sector in Table 1, was adapted to an hourly profile using consumption profiles provided by "Red Electrica de

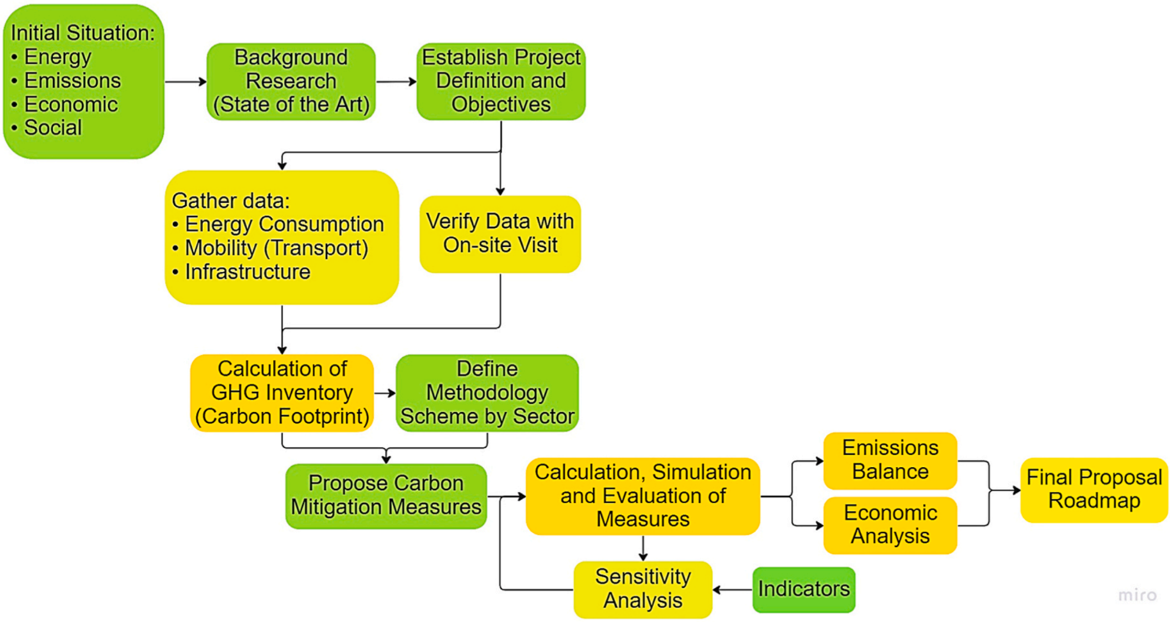

Fig. 1. Scheme of General Methodology [Own elaboration].

Table 1
Energy consumption of buildings in La Carrasca (Ayuntamiento de Valencia, 2019a).

Sector	Constructed Surface Area (m^2)	Electricity Consumption		NG Consumption	
		MWh/ year	kWh/ m^2/year	MWh/ year	kWh/ m^2/year
Residential	40,756	4,597	112.79	2,420	59.38
Services	51,289	4,280	83.46	477	9.31
Industrial	2,590	326	126.02	775	299.16
UPV	190,686	37,820	198.33	9,077	47.60
UV	45,985	13,738	298.74	17,888	388.99
Total	**331,307**	**60,761**	**183.40**	**30,637**	**92.47**

España" (REE) (Red Eléctrica de España, 2021). Knowing how the studied area is consuming electricity, a factor of CO_2 emissions for the mix of generation in the "Comunidad Valenciana" (CV), 0.172 tCO_2/MWh (IVACE-Energía, 2020), was used to calculate the total carbon emissions that come from electricity consumption.

The neighborhood's natural gas (NG) consumption was estimated from the amount that is billed monthly to the city in each sector, found in the town hall yearly statistics (Ajuntament de València, 2022), using downscaling factors comparing residences, industries, and service establishments between the city and the neighborhood. Similarly to the services sector in the electricity consumption estimation, the universities needed to be specifically included. The resulting gas consumption total for La Carrasca is 30,777 MWh/year, shown by sectors in Table 1. The neighborhood's emissions from this consumption were estimated using an emissions factor for NG consumption in the CV, 0,201 tCO_2/MWh (Ayuntamiento de Valencia, 2019a).

Comparing the energy consumption of the neighborhood to the city of Valencia, when the universities are included the total electricity and NG consumption of La Carrasca represents 15% and 3.3% of the city's consumption, respectively. Meanwhile, excluding the energy consumption of the universities and focusing on the three main sectors (residential, services, and industrial), they each represent between 0.39 and 0.45% of the city's electricity consumption in each sector and between 0.33 and 0.42% of the NG consumption.

2.1.2. Transportation

The transportation sector of the neighborhood is divided into two main groups: public and private transport. The former includes two tram lines (4 & 6), eight bus lines, Valenbisi (public bicycle-sharing service), and taxis. The distance that tram and bus lines travel inside the neighborhood was measured using the geoportals of the city. Then, knowing the number of trips each line travels during a year (Ferrocarrils de la Generalitat Valenciana, 2021), the distance traveled inside the area per year was determined, as shown in Table 2. Since tram trains consume electricity, with a factor of consumption per kilometer traveled (4.52 kWh/km) (García Álvarez and Martín Cañizares, 2012), the total yearly consumption was estimated. Using the emissions factor of the grid, the annual emissions they produce were calculated.

Table 2
Distance traveled (km/year) by tram, trains and buses in La Carrasca.

Tram Lines	
4	178,338
6	100,782
Total	**279,120**
Bus Lines	
18	61,540
31	3,334
40	26,815
71	36,461
81	5,439
93	161,782
98	221,803
99	28,010
Total	**545,184**

On the other hand, the bus fleet in Valencia is composed mostly of hybrid diesel buses (EMT Valencia, 2021). Through on-site visits, it was confirmed that the buses passing through La Carrasca are part of the hybridshe city has been introducing in the past years (EMT Valencia, 2022). Knowing how a typical hybrid bus consumes diesel per kilometer (0.33 l/km) (Grütter, 2015) and using an emissions factor for diesel consumption (2.47 $kgCO_2/l$), a direct emissions factor of 0.815 $kgCO_2/km$ was calculated for hybrid buses. With this value, the total carbon emissions produced by the buses inside the neighborhood were calculated.

The number of taxis in the neighborhood was determined from data on the number assigned to the Algirós district, using the ratio of surface area between them, 66% (13 taxis). In Spain, taxis travel around 208 km/day (UITP (Union Internationale des Transports Publics), 2020). Considering that 20% of that is traveled inside the neighborhood, each taxi's total yearly distance in La Carrasca is 15,184 km. Then, based on the CV plan to impulse the EV (IVACE-Energía, 2017), 25% of the vehicles consume gas (3 taxis), while the resting 75% (10 taxis) consume diesel. With this data, their yearly consumption was estimated. Using the emission factors for both fuels, the annual emissions produced by the movement of taxis in the neighborhood were determined.

The private transportation sector was divided into two groups: the vehicle fleet of the population in the neighborhood and other vehicles that come from outside and pass through it. Town hall statistics of the vehicle fleet of the city were used to distribute it by type of vehicle (cars, small trucks, and motorcycles), fuel type (petrol, diesel, electric, CNG, LPG), and year of registration (1971–2020). It was scaled down to the neighborhood using a population ratio between it and the city (0.43%). With this distribution, the vehicle fleet was classified per European regulation standards because they provide an emissions factor for each type of vehicle by fuel type and regulation (International Council on Clean Transportation and DieselNet, 2018a; 2018b), shown in Table 3. The emissions factors for EVs were calculated directly to consider the city's electricity mix. An average value of 0.15 kWh/km provided by the EV plan mentioned before was used for cars and small trucks. Meanwhile, the model Libélula from Greenmoto, with a consumption of 0.023 kWh/km was considered for motorcycles (Equipo Greenmoto, 2020). Based on the EV plan, vehicles travel 20,000 km a year. Estimating that 20% of that is inside the neighborhood (4000 km), then using the number of vehicles, the kilometers they travel per year, and the emission factors per type of fuel and regulation, the number of yearly CO_2 emissions produced 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" (IMD), was used (Ajuntament de Valencia Servici de Mobilitat Sostenible, 2021). After identifying the roads inside the neighborhood and measuring their distance, shown in Table 4, the

Table 3
The vehicle fleet in La Carrasca (International Council on Clean Transportation and DieselNet, 2018a; 2018b).

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**

Table 4
Outside vehicles traveled a yearly distance inside La Carrasca (Ajuntament de Valencia Servici de Mobilitat Sostenible, 2021).

Road	IMD	Length Inside La Carrasca (km)	Average 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**

total CO_2 emissions produced by these vehicles inside the neighborhood were calculated using an average emissions factor of 0.3297 $kgCO_2/km$. These emissions fall into scope three since they are indirectly produced inside the area from outside sources.

2.1.3. *Consumption of goods and waste management*

The two sectors, consumption of goods and waste management, produce scope three emissions. In this study, the former focuses on food and clothing, but other manufactured goods should be considered. Using the food consumption in Spain per capita (Ministerio de Agricultura, 2021) and emission factors for each type of food ((Clune et al., 2017), (Ritchie and Roser, 2020),(Cai et al., 2022; Cimini and Moresi, 2019)), an average emissions factor of food per capita was calculated. The total emissions for this category were calculated knowing the neighborhoods population, 3444 inhabitants, and the student body of both universities, 79,796 students. 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 to the number of hours students spend in the university during a year (Martinez-Perez et al., 2022). On the other hand, a factor of emissions per capita (Peters et al., 2021) was used to estimate clothing emissions. The emission factors for the consumption of goods can be seen in Table 5.

Meanwhile, waste emissions were calculated using data from the city's waste collection inventory, divided into municipal solid waste, organic waste, glass, paper, and plastic. This data was calculated at a neighborhood level using a downscaling factor of the population in La Carrasca and Valencia. To consider both universities in this sector, average waste amounts for the UPV were calculated from data in their environmental declaration (Unitat de Medi Ambient, 2020), which were then scaled up for the UV based on student differences. Then, the total waste produced, 2414 tons, was categorized by how it is treated after. It's either thrown in a landfill (57.72%), recycled (20.57%), used for energy (8.78%), or used for composting (12.39%). 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 factors by weight for the other three uses (Center for Corporate Climate Leadership, 2021), shown in Table 5.

Table 5
Emission factors for consumption of goods and waste management (Peters et al., 2021), (Center for Corporate Climate Leadership, 2021).

Emissions Per Capita (tCO_2/cap)	
Food	2.07
Clothes	0.30
Emissions by Weight ($tCO_2/tons$)	
Landfill	0.27
Recycling	0.10
Composting	0.16

2.1.4. *Green areas*

The total green surface area inside the neighborhood, including urban green areas and agricultural land, was determined through the city's open geodata (Esri Community Maps Contributors et al., n.d.) and by measuring the areas that are not included in those statistics. For urban green areas, the added surface area resulted in 20.3 ha in La Carrasca. The capacity of these zones to capture CO_2 emissions was determined using a factor for yearly emissions captured by green zones in Valencia calculated through a territorial mapping of the carbon stock (Conselleria de Política Territorial, 2021). For the agricultural land, their capacity was calculated using average emission factors for the types of crops in the city, herbaceous crops, and woody crops, assuming that the ratio of these throughout the city is the same inside the neighborhood, shown in Table 6. Fallow land is excluded since it's left without crops for various vegetation cycles. Using these calculated factors of carbon capture by surface area, shown in Table 7, the carbon emission fixed by the total of green areas was calculated.

After accounting for all the emissions the neighborhood produces for all three scopes, different measures are proposed and analyzed to try and reduce this carbon footprint. The following subsections will explain the methodology for the mitigation measures considered in this study.

2.2. *Carbon mitigation measures*

2.2.1. *Photovoltaic system*

The first climate mitigation strategy proposed for this project is the implementation of PV panels, mainly on the rooftops of the buildings in the neighborhood. QGIS (Quantum Geographic Information System) (Open Source Geospatial Foundation (OSGeo), n.d.) was used to estimate the available rooftop area for PV panel installation, resulting in 391,888 m^2, of which 54% (211,825 m^2) belongs to the universities. This process is explained in detail in section **2.3.2**. Then, through a rooftop analysis described in section **2.3.3**, the percentage of useful rooftop surface area was estimated to be 32%, as shown in Table 8 divided into the area that belongs to the universities and the other buildings, which are mostly collective residential buildings (95% of that zone's area). The chosen PV panels for this study are mono-crystalline silicon cells with a 21.3% module efficiency (Sunrise Energy Co., 2021), which will be placed at an inclination angle of 15°. These types of solar panels are currently some of the most efficient, 5% more than their polycrystalline counterpart, with the highest power capacity, although they are also more expensive than other types. PV technology is rapidly progressing every year, but since this study focuses on the time period until 2030, the evolution of efficiency in the technology wouldn't significantly affect energy consumption and cost savings.

With the panel dimensions and specifications, the ratio of installed power per unit area was calculated as 0.144 kW/m^2, resulting in total power for the PV system in each zone presented in Table 8. The prices for the photovoltaic system were determined from the predictions done by IDAE in their renewable energy plan (Instituto para la Diversificación y el Ahorro de la Energía, 2011), shown in Table 9. The electricity prices were determined from the historical data of REE using the platform Esios (Red Eléctrica de España, n.d.), shown in Table 10. The global horizontal

Table 6
Cultivated land distribution (hectares).

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

Table 7
CO2 capture factors for green zones (Conselleria de Política Territorial, 2021).

Green zones		Carbon capture factor (tCO_2/ha)
Urban green areas		1.58
Agricultural land	**Herbaceous crops**	18.04
	Woody crops	15.22

Table 8
Surface area for PV installation and installed power in each zone.

Zone	Surface (m^2)	PV Power (kW)
Universities (UPV and UV)	67,784	9,734
Residential and other buildings	57,620	8,275
Total	**125,404**	**18,009**

Table 9
Costs of PV system (Instituto para la Diversificación y el Ahorro de la Energía, 2011).

Investment	Cost
Capital (€/kW)	1320
Replacement (€/kW)	500
O&M (€/year·kW)	36

Table 10
Cost for the electricity grid (Red Eléctrica de España, n.d.).

Period	Energy Price (€/kWh)	Power Price (€/kW/month)	Selling Price (€/kWh)
P1	0.363	3.251	0.112
P2	0.288		
P3	0.235	0.151	

radiation data of the area was extracted from the PVGIS platform (Photovoltaic Geographical Information System) (Joint Research Centre, n.d.), which resulted in an annual average of 4.8 kWh/m^2 per day. Using all of this data as inputs, the system was simulated using the program HOMER (Hybrid Optimization of Multiple Energy Resources) (UL LLC, n.d.). This tool provides data about the system's potential for electricity generation, grid purchases to fully cover the electricity demand and the costs throughout its lifetime.

2.2.2. Nature-based solutions

The NBS measure is based on incrementing green areas in the neighborhood to increase its total carbon capture potential. As trees grow older, they absorb more CO_2. Considering this, carbon capture values in different years for some of the most common trees in Valencia were used to produce an average carbon capture curve for the green areas in the city, estimated using an exponential tangential curve of the average values calculated, shown in Fig. 2. Those values for the common trees were obtained from a study developed by the National Forest Inventory and the MITECO (Ministerio para la Transición Ecológica, 2019). With this curve, the increment in carbon capture potential from the green areas in the neighborhood was calculated. A baseline of 15 years will be considered for the lifetime of the already established green zones.

In La Carrasca, only one area will be considered for a new urban green area. Since part of this area is also being considered for implementing PV panels (32% of the site), a conservative amount of its space, 60% (26,008 m^2), 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 three years. The implementation of this measure will be done progressively, as shown in Table 11.

Considering this increment in green surface area and the natural increment in absorption factor 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.

Fig. 2. Estimated increase in carbon absorption potential for green areas in Valencia (Ministerio para la Transición Ecológica, 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 11
Green area implementation plan.

Year	Surface (m^2)	
2024	2,601	10%
2025	5,202	20%
2026	7,802	30%
2027	10,403	40%
2028	15,605	60%
2029	20,806	80%
2030	26,008	100%

2.2.3. Electric vehicles

Starting with the bus fleet in the city of Valencia, of which 81 pass through La Carrasca, electric buses will be implemented in exchange for half (40) of the older hybrid ones. The BYD K9G electric bus (BYD E-MOTORS ECUADOR, 2021) is used as a reference, which consumes 1.08 kWh/km (15% below an average current electric bus), has a lithium-iron-phosphate battery, and charge regeneration capabilities through braking and deceleration. With the emissions factor for the CV's electricity grid (0.172 tCO_2/MWh), the yearly emissions that an electric bus would produce were calculated and compared to the hybrid counterpart. The process for changing taxis to EVs is similar, considering that electric cars consume an average of 0.15 kWh/km, based on the EV implementation plan mentioned in section 2.1.2. The technology of electric vehicles is also rapidly progressing in recent years. Considering the state of the technology at the time this work is done, the result should provide a clear conclusion on the CO_2 savings that its implementation would produce. Nevertheless, the uncertainty in the evolution of efficiency and cost in the coming years could represent an underestimation of the obtained results.

For the private transport sector, 10% of each type of vehicle will be electric by 2030, as shown in.

Table 12. Currently, only 0.32% of all vehicles in the neighborhood (6 of 2046) are electric, and no recharge points are inside the area.

Table 12
Electric vehicle implementation.

Year	Cars	Small Trucks	Motorcycles
Current	2	1	3
2030	156	10	38

Changing vehicles will be done by removing the oldest and most consuming vehicles while adding new electric ones. The total savings in emissions were calculated with emission factors for the different types of vehicles and fuels mentioned in section **2.1.2**.

Currently, in La Carrasca there are no recharge points for EVs. According to the EV plan, it's expected that there will be 406 semi-fast recharge points in Valencia by 2030. Using a downscaling factor based on the neighborhood's surface inside the city, 1.42%, it's estimated that in La Carrasca, there will be at least 6 of those recharge points.

2.2.4. *Heat pumps*

This 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. Based on studies done by the IDAE (Departamento de Planificación y Estudios - IDAE, 2019) about gas consumption in dwellings in the Mediterranean climatic zone of Spain where the city of Valencia is located, the calculated consumption of the residential sector was divided into its uses (heating, SHW, and kitchen), as shown in Fig. 3, and the different devices that the population uses, specifically for heating and SHW. These devices are primarily conventional NG boilers, condensation boilers, gas fireplaces, and thermos gas water heaters (Asesor Revisión, 2017). The neighborhood's thermal demand for heating and SHW was calculated to 1975 MWh/year using average efficiency values for each type.

Different types of HPs, with different nominal power and efficiency, were considered for covering said demand. Ultimately, the most effective 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 HM141MR.U44 was chosen (LG Business Solutions, 2022), with a COP of 4.70 and a capacity of 5.5 kW. Using the model specifications, the annual electricity consumption needed to produce the thermal demand of the neighborhood was estimated. The GHG emissions saved per year were calculated by comparing the amount of NG saved with the added electricity demand using emission factors for each consumption.

2.2.5. *Improved waste management*

For the development of this measure, the guidelines created by the Metropolitan Entity for the Treatment of Waste (EMTRE) for creating local plans for waste management were used (EMTRE, 2020). The objective scenario will be a reduction of 10% of the total waste and an increase in the recycling of waste products for treatment, energy, and composting to 67%, which currently stands at 42.28%. Based on the same distributions presented in the GHG inventory, the new distribution for recycled products based on the total waste generated will be shown in.

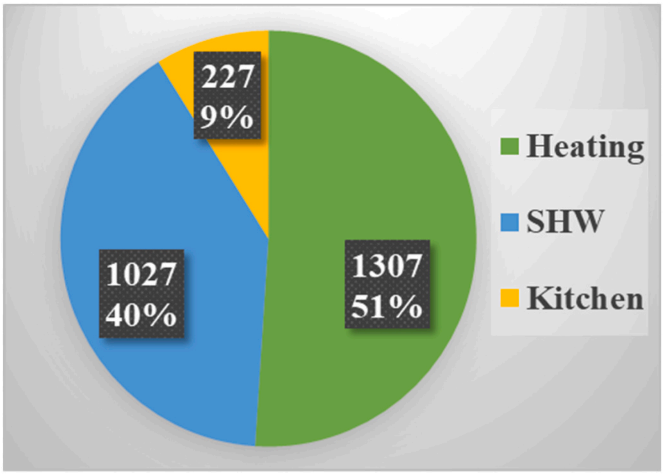

Fig. 3. NG consumption (MWh/year) in the residential sector (Departamento de Planificación y Estudios - IDAE, 2019).

Table 13. This will be achieved through the following set of actions: prevention and minimization plan for businesses (eco-design), environmental communication and education plans (good environmental practices), promotion plan for selective collection (greater provision and access to containers and waste collection), organic fraction self-management plan, information management program (facilitate access to the information to promote its use), recovery and valorization program (provide infrastructures), promote of waste reuse, and promotion of repairing goods and products.

2.3. *Tools*

2.3.1. *DATADIS*

DATADIS (Asociación de Empresas Eléctricas et al., n.d.) is an online tool provided by companies that distribute electricity in Spain that, through smart meters, offers different services, including daily consumption values. It was used to estimate the electricity consumption of the neighborhood and therefore determine the GHG emissions produced from the neighborhood's electricity consumption. The process of making these calculations is described in section **2.1.1** and summarized in Fig. 4.

2.3.2. *QGIS*

This program (Open Source Geospatial Foundation (OSGeo), n.d.) is a free and open-source program that allows users to compose, manage, and analyze data from maps. According to INSPIRE directive, the map layers used were taken from the Spanish Cadastral that contains data on parcels, buildings, and addresses in all of Spain. From there, only the data for the city of Valencia was downloaded using the city code and filtered for La Carrasca using an added layer with the delimitation of the neighborhoods in Valencia (Ayuntamiento de Valencia, 2019b). The main layers used from the plugin provided data on the number of floors and dwellings in each building and their use (residential, industrial, or services). Building polygons deemed useless for implementing PV panels through a visual examination using tools like Google Earth were removed. The software's calculator tool was then used to calculate the neighborhood's surface area of the building polygons. Small areas with less than 20 m^2 were removed using a filtering tool. Other areas of opportunity for installing PV panels were considered in the analysis and added to the map, including parking lots where roof structures with PV panels can be constructed to produce energy and provide shading for cars and open fields where ground-mounted systems can be placed. This process is summarized in Fig. 5, and the resulting map is shown in Fig. 6.

2.3.3. *Google Earth and Geoportal Valencia*

These two geospatial Google Earth ("Google Earth," n.d.) and Geoportal Valencia (Esri Community Maps Contributors et al., n.d.), tools were mainly used to measure distances or areas and provide visual data on how the neighborhood is structured. For implementing PV panels, Google Earth was used to analyze how much of the total rooftop area was useful in terms of space and sunlight hours. By taking a representative building block in the neighborhood, the entire rooftop area was measured and compared to the sum of the smaller areas that were determined useful to install PV. These areas were selected through visual analysis in Google Earth to make sure there are no obstacles, and with the HuellaSolar online tool (HUELLASOLAR, n.d.), to make sure these areas receive more than 75% of annual sunlight hours (2167 h). This

Table 13
New waste management distribution (EMTRE, 2020).

Waste Use	Distribution
Landfill	33.0%
Recycled	32.6%
Energy	13.9%
Composting	20.5%

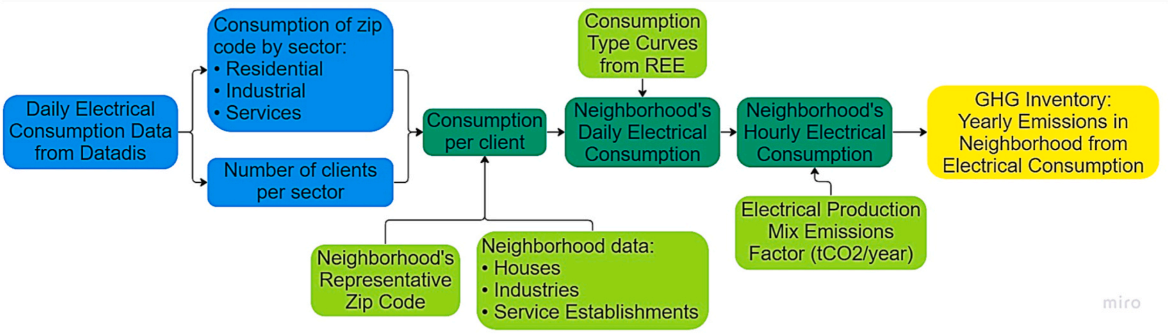

Fig. 4. DATADIS tool methodology [Own elaboration].

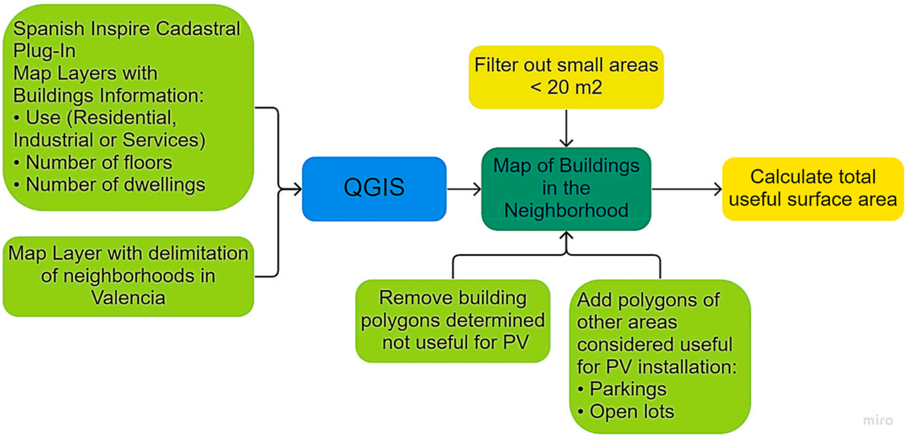

Fig. 5. QGIS tool methodology [Own elaboration].

analysis is shown in Fig. 7.

The geoportal of the Valencia city hall provides valuable information about how the city is made up, showing how the city is divided into its districts, neighborhoods, green areas, agricultural areas, and cadastral parcels, the location of parking for vehicles and Valenbisi, bus stops, and recycling, among many more. It was used for measuring the distances of the tram lines inside the neighborhood (Fig. 8) and for information on the green areas and agricultural land, including their surface area. The EMT company's own geoportal (EMT Valencia, n.d.) was used for measuring the bus lines since it was easier to visualize where they pass through the neighborhood, as shown in Fig. 8.

2.3.4. HOMER

HOMER (UL LLC, n.d.) is a simulation software for modeling hybrid energy systems, whether for a standalone microgrid or a distributed generation system, which is being analyzed in this study. Primarily, it was used for simulating the PV system's power generation. Six main data sources need to be provided for the techno-economic simulation of the system, as described in Fig. 9.

2.4. Economic analysis

This sub-section examines each carbon mitigation measure's capital investment costs, except waste management improvements. Such improvements consist of various promotion campaigns and plan to reduce waste and increase recycling, which does not require the immediate application of tangible technologies at a predetermined cost. Furthermore, this analysis excludes vehicles outside the neighborhood, as their specific quantification is unavailable. Therefore, this economic analysis only considers costs for the society within the neighborhood (scopes 1 and 2), including the government and population, as these measures represent costs and savings for both.

Table 14 outlines the investment actions (CAPEX), tCO_2 reduction, and lifetime considered by technology in this study. In absolute cost, the most expensive strategy is the PV system, whose costs were determined through simulation using the HOMER software and Table 9 cost data. The PV system cost is around 1320€/kWp being possible to install 18MWp in the neighborhood under study. Conversely, the NBS measure is the least expensive, costing 27.86 € for each of the 722 trees to be planted (36 m^2 per tree), including materials, equipment, and manual labor (CYPE Ingenieros, n.d.). Nevertheless, the available area to apply NBS is very limited. Therefore the CO_2 mitigation reduction by applying this measure is very low. The costs for EVs were determined to be 300, 000 € for each electric bus (Grütter, 2015), 29,000 for electric cars or small trucks (IVACE-Energía, 2017), and 3,900 for electric motorcycles (Equipo Greenmoto, 2020). Since buses are not assigned or owned by the neighborhood, their costs will be downscaled based on the percentage of distance that they travel inside the neighborhood. Of the total km that the 40 buses travel in a year, only 2.89% are inside La Carrasca, bringing their cost down to 8670 € per bus. Finally, heat pumps, which will replace gas boilers in 397 homes, cost 7106 € per unit. This information allows for estimating the cost per tCO_2 during the lifetime of the technologies to be implemented.

3. Results

3.1. Scopes

The neighborhood of La Carrasca produces 67,580 tCO_2/year, divided into three scopes, as seen in Fig. 10. The results show that most of the emissions (71%) are indirect but result from activities inside its boundary (scope 3). These emissions come from the consumption of

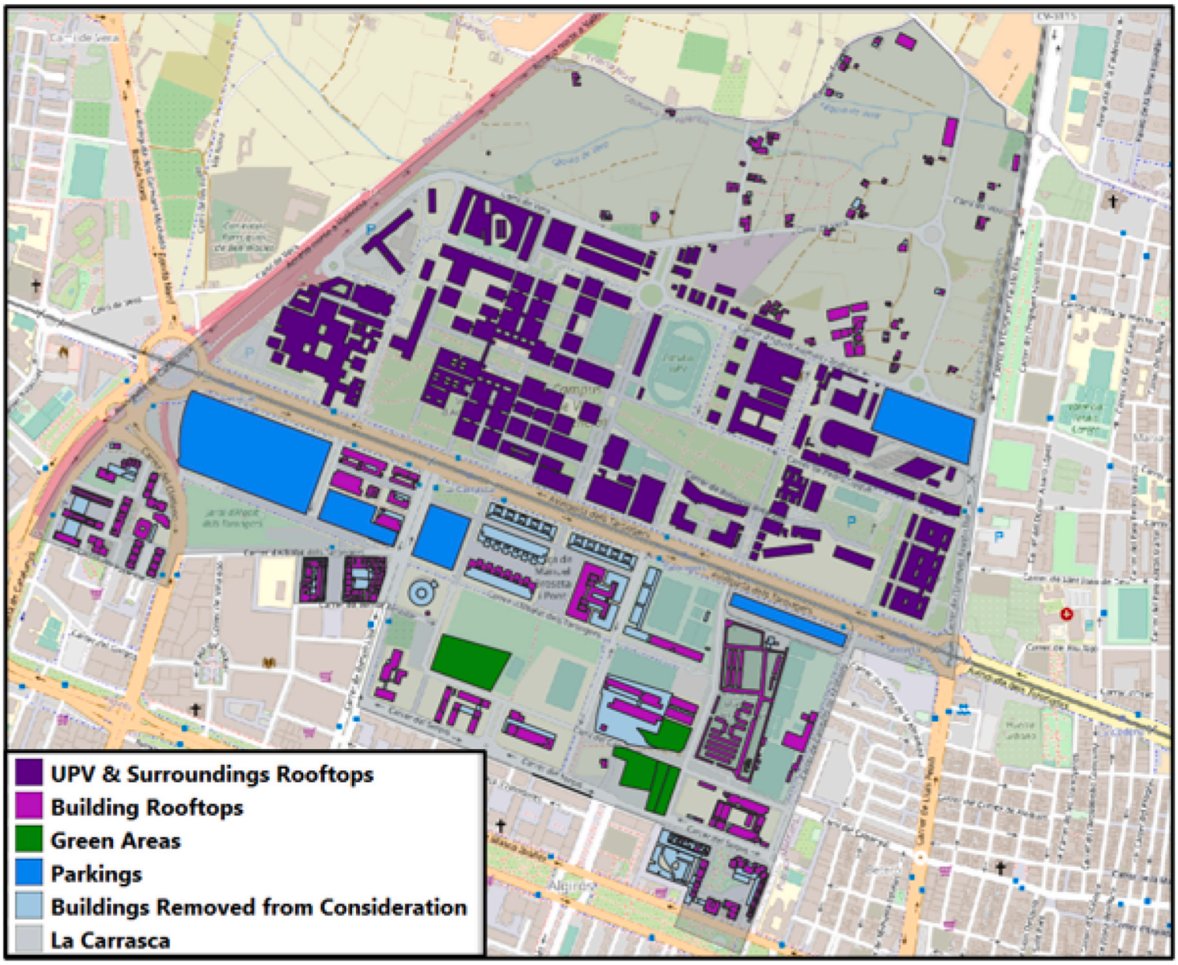

Fig. 6. Map of areas considered for PV systems in La Carrasca (Open Source Geospatial Foundation (OSGeo), n.d.).

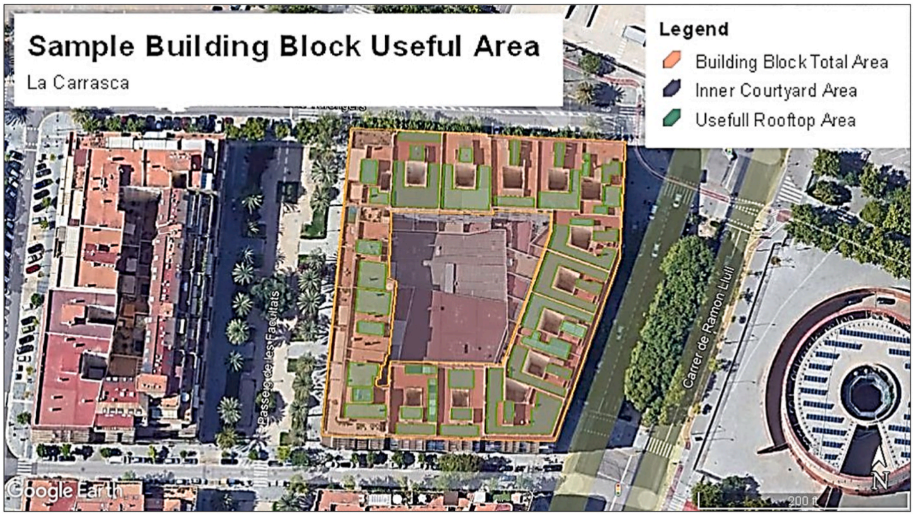

Fig. 7. Sample building used for PV analysis ("Google Earth," n.d.).

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% of the total emissions of the area, which come from its electricity consumption, especially from its universities. Finally, scope 1 emission comprises the neighborhood's gas consumption and transportation.

3.2. Sectors

Analyzing the neighborhood's carbon footprint by sectors, shown in Fig. 11, the most significant sector is the consumption of goods, accounting for 37% of the total emissions. The private transportation sector contributes mainly to Scope 3 since 90% of the sector's emissions

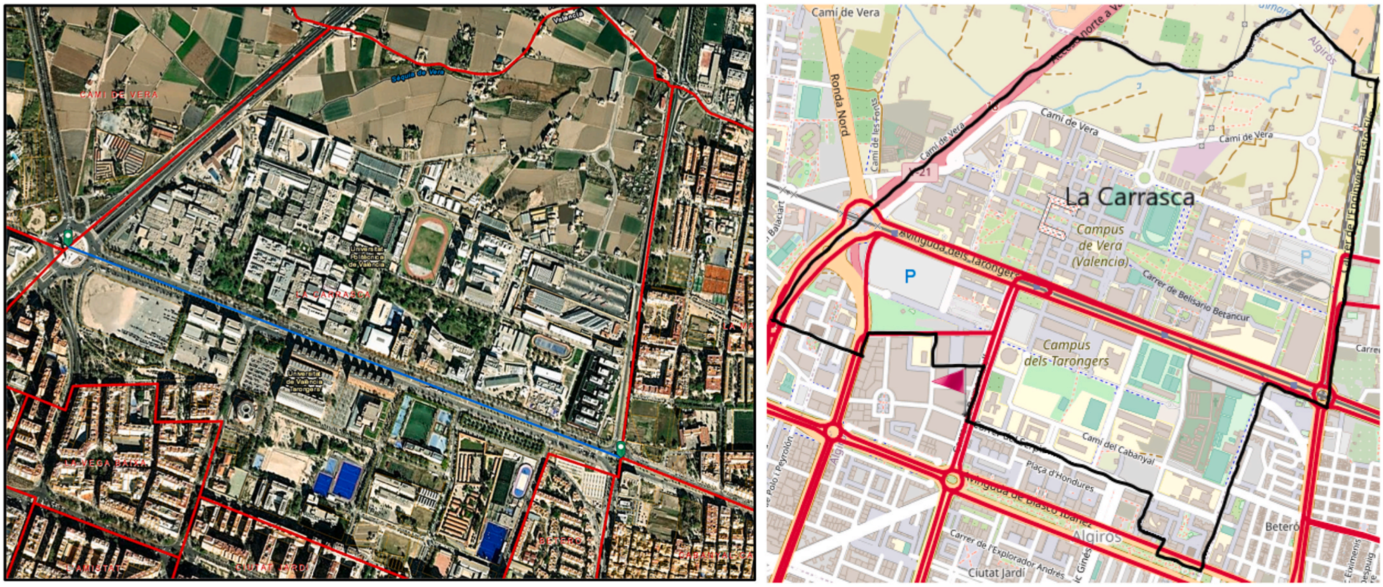

Fig. 8. Measurement of tram and bus lines in La Carrasca (Esri Community Maps Contributors et al., n.d.), (EMT Valencia, n.d.).

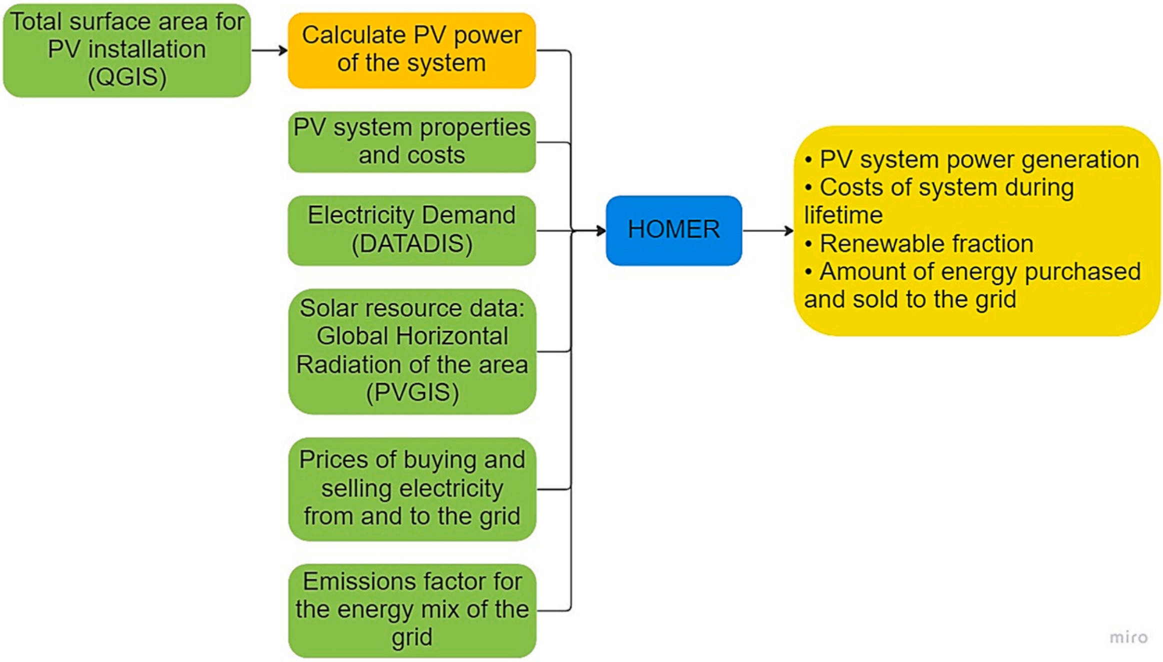

Fig. 9. HOMER tool methodology [Own elaboration].

Table 14
Investment costs, tCO_2 reduction, and lifetime technologies under study (Ager-Wick Ellingsen et al., 2022; Kastanaki and Giannis, 2022; Violante et al., 2022; Wei et al., 2022).

Mitigation Measure	Cost (€)	tCO_2 annual reduction	Lifetime (Years)
PV	23,771,880	4253.83	25
NBS	20,127	22.13	30
EV - Public	723,800	363.45	12
EV - Private	3,397,442	2183.06	15
HP	2,821,082	398.30	25
Total	**30,734,331**	7,221	

(22,031 tCO_2/year) come from the vehicles that pass through the area. To understand better where the emissions of La Carrasca are being produced, a buildings sector could be considered that would envelop all of the electricity and gas consumption. They account for 16,832 tCO_2/year, or 25% of the total emissions. Considering the carbon sequestration from the green areas and agricultural land established in the neighborhood and the PV systems currently in place in each university, the overall emissions descend to 67,008 tCO_2/year.

Based on the comprehensive carbon footprint analysis conducted across different sectors and considering the associated costs of each strategy, presented in section 2.4, it is recommended to prioritize carbon mitigation measures based on their effectiveness in addressing sector-specific emissions. It is important to acknowledge that the consumption of goods (included in Scope 3), which is identified as the most

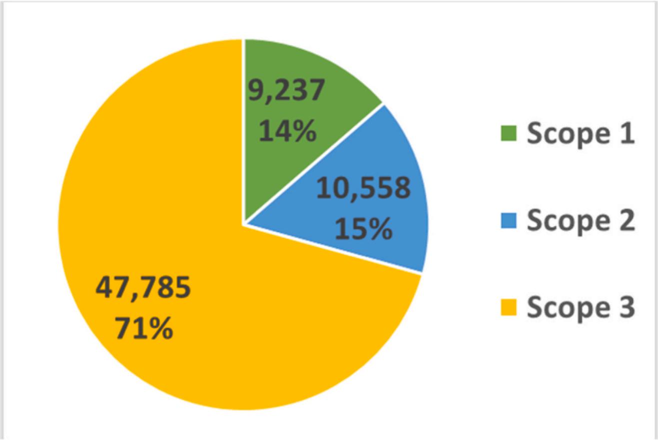

Fig. 10. Carbon Footprint (tCO_2/year) by scopes in La Carrasca.

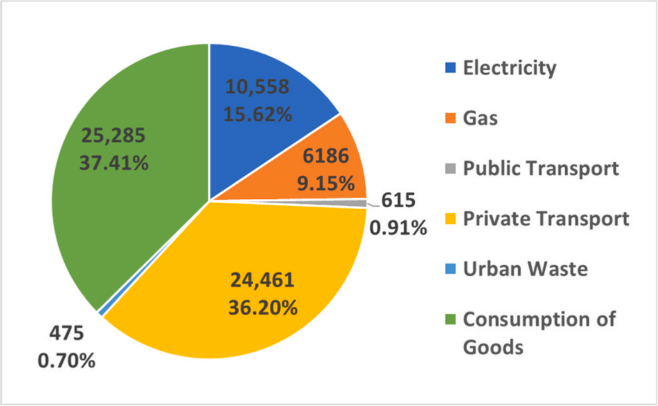

Fig. 11. Carbon Footprint (tCO_2/year) by sectors in La Carrasca.

polluting sector, does not have a dedicated measure in the proposed strategies. This is primarily due to the inherent challenges associated with controlling individual behaviors, cultural factors, and the involvement of numerous stakeholders. Additionally, the lack of extensive studies and comprehensive strategies addressing Scope 3 emissions further complicates the development of targeted measures for this sector. Consequently, the initial focus of the decarbonization efforts will be on addressing other highly polluting sectors. To begin with, a crucial step will involve the introduction of electric vehicles to mitigate carbon emissions from private transportation, which is identified as the second most polluting sector. By prioritizing this measure, we can effectively reduce the carbon footprint associated with transportation and encourage the adoption of cleaner and more sustainable modes of travel.

The subsequent strategy will involve the integration of photovoltaic (PV) systems to reduce CO_2 emissions stemming from electricity consumption, which is the third most polluting sector. This measure not only helps in minimizing carbon emissions but also supports the increased electricity demand resulting from the integration of electric vehicles and heat pumps.

3.3. Impact of carbon reduction measures

3.3.1. Photovoltaic system

The simulation of the entire system resulted in a PV production of 30,880 MWh/year. Meanwhile, 36,025 MWh/year needs to be bought from the grid to cover the increase in the total demand of the area due to the excess electricity sold back to the grid (6148 MWh/year). This is because, at times, the production of the PV system is higher than neighborhood demand, but in other moments where the PV production is not enough, electricity is purchased from the grid. These results mean a solar fraction of 46.2% for the system's performance. As for the system's costs, the resulting levelized cost of electricity (LCOE) is 0.196 €/kWh. Fig. 12 shows the system's monthly production compared to the electricity that is bought from the grid. In terms of savings in emissions, considering the increase in electricity consumption and the electricity produced by the PV system, the number of yearly emissions saved resulted in 4254 tCO_2/year. This is 6.35% of the total emissions in the neighborhood and 38.24% of the total CO_2 emissions that come from electricity consumption.

To consider each building zones separately, the PV system placed in each area was simulated independently. The one on the universities (UPV and UV) would produce 16,690 MWh/year, decreasing these establishments' electricity consumption and reducing their carbon footprint by 30%. Meanwhile, the solar system that would be placed on the rest of the buildings would produce 14,189 MWh/year, which is much more than the demand for those buildings (9162 MWh/year). Still, to cover the peak demands where the PV is not producing enough electricity since storage is not being considered, the system needs to purchase 5895 MWh/year from the grid. This means that 54% of the electricity produced by the PV array is sold back to the grid, and only 3267 MWh/year is reduced from the area's consumption (36%).

3.3.2. Electric vehicle

The change to EVs focuses on public transport (buses and taxis) and 10% of each type of private vehicle (cars, motorcycles, and small trucks). Resulting in a reduction of 2404 tCO_2/year, as shown in.

Table 15. This means a decrease of 60% (189.69 tCO_2/year) for public transport emissions and 9% (2214.37 tCO_2/year) for private transport. Outside vehicles fall into scope 3 emissions, while the rest are all scope 1.

3.3.3. Nature-based solutions

Urban green zones already established in the neighborhood capture 31.65 tCO_2/year. Considering the carbon absorption curve calculated in section 2.2.2, this carbon capture value increases by 10.7% yearly. Adding the new green area that is considered progressively results in a higher increase in absorption until 2030, for an added average of 22.13 tCO_2/year captured, as shown in Fig. 13. Agricultural land is not considered in this measure since the constant cultivation of the crops means that these plants don't keep growing. Their carbon capture can be considered stable at 541.84 tCO_2/year.

3.3.4. Heat pumps

To cover the thermal demand of the neighborhood's residential sector for heating and SHW, which is currently being covered using NG, the necessary HPs will be placed throughout the area's residential buildings based on necessity. The annual HPs electricity consumption to produce the required heating is 396.22 MWh/year, a 8.6% increase for the residential sector (0.65% of the total consumption). Compared with the 2334 MWh/year of NG being replaced, the CO_2 savings are 375.53 tCO_2/year. This strategy provides that only 227 MWh/year of NG that will still be consumed in the area by kitchens in the residential sector, and the resting 56,164 MWh/year for the services and industrial sectors.

3.3.5. Improve waste management

By implementing the actions mentioned in the methodology, waste thrown on a landfill could be reduced from 1394 to 717 tons (49% reduction). Meanwhile, the waste that is recycled for treatment, energy, or composting increased by 43%, from 1021 to 1456 tons. By reaching this desired scenario of waste distribution, the neighborhood's total generated is reduced to 2173 tons/year (10% reduction) and the carbon emissions were reduced to 178.27 tCO2/year, which is 38% of the originally produced emissions. Finally, this mitigation measure

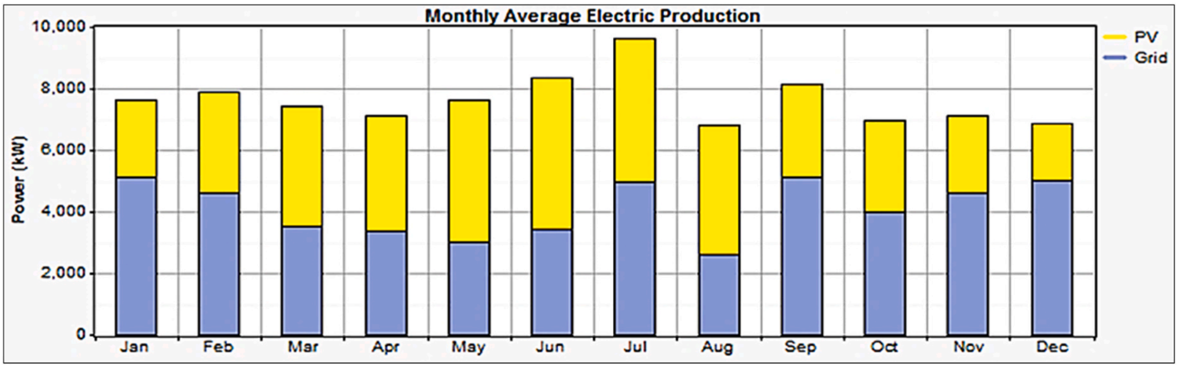

Fig. 12. Monthly electric production of PV system (UL LLC, n.d.).

Table 15
Electric vehicle implementation results.

Vehicle Type	Transport Emissions (tCO_2/year)		
	Current	2030	Reduction
Buses	444.56	275.04	38%
Taxis	25.26	5.09	80%
Cars	2108.08	1889.73	10%
Motorcycles	181.67	168.71	7%
Small Trucks	135.31	124.62	8%
Outside Vehicles	22,030.91	20,058.55	9%
Total	**24,925.80**	**22,521.74**	**10%**

represents a 0.44% (296.37 tCO_2) reduction of the total emissions of the neighborhood.

3.4. Balance of GHG emissions

The results of this work show a reduction in emissions of 7488 tCO_2/year, as shown in Table 16. The current emissions from the electricity sector appear reduced from section 3.1 due to the savings from the existing PV systems. Analyzing such results, it can be concluded that the most impactful mitigation measure is the implementation of photovoltaic panels in the neighborhood, reducing 6.35% of the total emissions. This was followed by the implementation of EVs in the private transportation sector, which decreased by 2.21%. Considering each scope, the most impacted is scope 2, which experiences a 38.15% reduction in its emissions. This is followed by scope 1 with 13.75% and scope 3 with 4.75%, as seen in Fig. 14.

3.5. Economic analysis

A cost-effectiveness analysis was conducted to compare the investment costs and annual emissions savings of each carbon mitigation measure in La Carrasca, as presented in Table 14. The objective was to identify the most cost-effective strategy for achieving decarbonization goals and to address political measures to mitigate CO_2 emissions. The results of this analysis, as shown in Table 17, indicate that the integration of heat pumps in exchange for gas boilers emerges as the least cost-effective strategy, primarily due to the high costs involved in installing these new technologies in each individual home and secondly because in Mediterranean areas as Valencia, the heating system is mainly used during some months and at particular hours in winter. However, one potential improvement is to explore the feasibility of deploying a few heat pumps with higher power capacity per building to provide heating for multiple homes, thereby optimizing cost efficiency. In contrast, NBS emerge as the most cost-effective strategy, although they offer the

Table 16
Emissions balance by sector (tCO_2/year).

Sector	Current	2030	Reduction
Electricity	10,558	6372	39.64%
Gas	6186	5717	7.58%
Public Transport	615	345	43.96%
Private Transport	24,461	22,242	9.07%
Urban Waste	475	178	62.53%
Consumption of Goods	25,285	25,285	0%
Green Areas	−573	−620	−8.20%
Total	**67,008**	**59,519**	**11.18%**

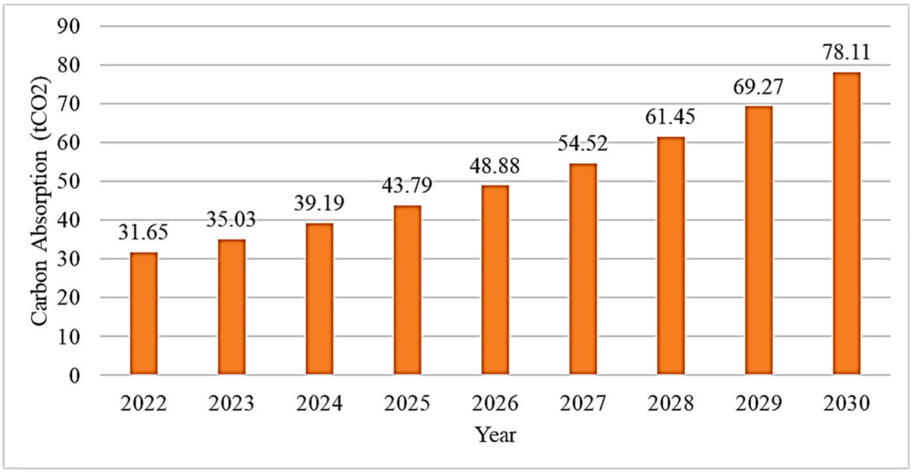

Fig. 13. Results of NBS measure in La Carrasca.

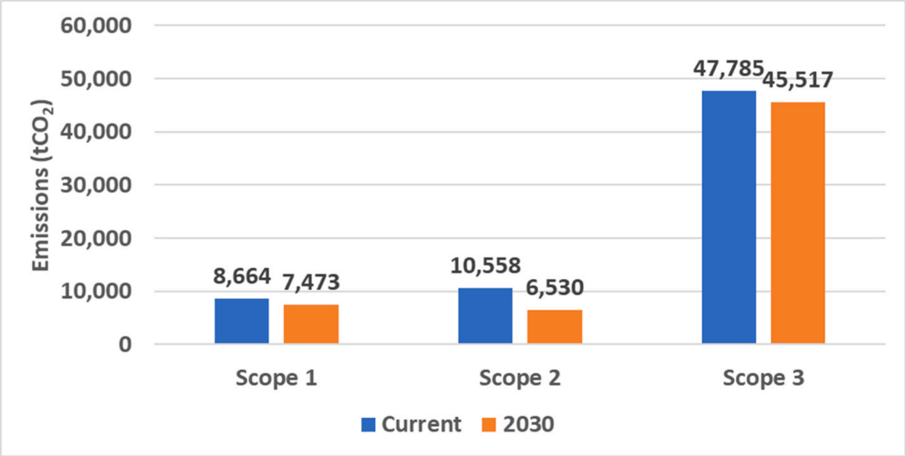

Fig. 14. Emissions balance by scopes.

Table 17
Costs of decarbonization.

Mitigation Measure	Lifetime cost per emissions savings (€/tCO2)
PV	223.5
NBS	30.3
EV - Public	166.0
EV - Private	103.8
HP	283.3
Total	199.5

lowest emissions savings. Nevertheless, the available area to apply this measure is very limited.

Although installing PV panels may not appear as cost-effective as the other strategies, they offer the most significant reduction in carbon emissions and play a critical role in supporting other decarbonization measures. This is particularly important considering that integrating electric vehicles and heat pumps leads to increased electricity consumption in the neighborhood, resulting in higher emissions from the electricity sector due to the energy mix not yet decarbonized. By ensuring cleaner energy production through PV panels, the reduction in emissions from these technologies can be effectively supported.

The government must exert concerted efforts in facilitating the adoption of these technologies and enhancing their effectiveness in reducing carbon emissions. This entails implementing incentives, providing the necessary infrastructure for EVs, formulating favorable policies and regulations for PV panel installations, and fostering public awareness and engagement in sustainable transportation practices. Additionally, anticipating advancements in technology efficiency and cost reductions for EVs and PV panels by 2030, further improvements in both effectiveness and affordability can be expected. Active government involvement and commitment are paramount in realizing significant reductions in carbon emissions in La Carrasca. Regarding lifetime cost, the emissions savings costs range from 30 to 284 €/tCO2. The cost during the lifetime of all technologies combined amounts to 200 €/tCO$_2$, highlighting the economic considerations of these decarbonization measures.

4. Conclusion

The paper highlights the importance of cities making changes to their sustainability projects, policies, and actions to mitigate the effects of climate change since they are the most significant contributors to global greenhouse gas emissions. The study focuses on a methodology to estimate the potential for decarbonization of a neighborhood. The objective is to assess, through the applied method, the area's carbon footprint and provide measures to reduce emissions. The methodology is applied to the neighborhood of La Carrasca in the Algiros district of the city of Valencia.

Applying the methodology, it was found that the third scope, which is often overlooked, is the most significant contributor to emissions in the neighborhood, with 71% of the total emissions in the area. This is due mainly to private transport that passes through the neighborhood and the consumption of goods. Many studies do not consider this scope, but based on these results, it was concluded that its necessary to consider it and provide measures to reduce its footprint. Comparing the emissions by sector, the most significant contributor is private transportation, followed by building emissions from gas (scope 1) and electricity (scope 2) consumption.

According to the available information, the study proposes four measures to determine the potential for decarbonization: NBS, PV generation, electrification of transport, and implementation of heat pumps to electrify the NG consumption. From the results obtained, the integration of the PV system is the most effective measure, reducing total emissions by 6.31%. Electrification of private transport follows closely with a 2.21% reduction. NBS, HPs, and waste management measures contribute a 0.93%, 0.59%, and 0.44% decrease, respectively. Together, these measures could reduce emissions by 11%, or 7488 tCO$_2$, in the La Carrasca neighborhood.

Finally, an economic analysis has been developed, obtaining; as a result, a lifetime cost per emissions savings of the proposed mitigation measures, getting an average saving cost of 200 €/tCO2, being the most and least profitable measures the NBS and the installation of Heat pump systems, whit a saving cost of 30 and 283 €/tCO$_2$ respectively. However, the paper suggests that more measures must be implemented to achieve carbon neutrality, particularly those that tackle waste management and the consumption of goods. Changes in population habits are essential to achieve this goal. The study also emphasizes the need for more aggressive implementation of some measures, especially those that incentivize electric transport and reduce the consumption of fuels through more efficient public transport and walkable areas.

It must be noted that decarbonization potential is highly dependent on technology characteristics, policies, and short or long-term approaches so that many scenarios can be analyzed. The presented methodology can be valid for short- or medium-term approaches based on present data about energy demand or technology features and also on national/regional plans and policies about evaluated strategies.

CRediT authorship contribution statement

Adrián Rivera-Marín: Data curation, Writing – original draft, Visualization, Investigation. **David Alfonso-Solar:** Conceptualization, Methodology, Visualization, Investigation, Supervision, Writing – review & editingWriting- Reviewing and Editing. **Carlos Vargas-Salgado:** Conceptualization, Methodology, Visualization, Investigation, Supervision, Writing – review & editingWriting- Reviewing and Editing. **Sileno Català-Mortes:** Data curation, Writing – original draft, Visualization, Investigation, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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