UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Industrial Engineering

# Development of an urban strategic planning tool for carbon neutrality from a district perspective. Case study: Valencia.

Master's Thesis

Master's Degree in Energy Technologies for Sustainable Development


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ACADEMIC YEAR: 2022/2023

## Acknowledgement

En primer lloc, vull agraïr a la Càtedra de Transició Energètica Urbana l'oportunitat de treballar amb ells. Ha estat un plaer aprendre dels meus tutors, Carla i Tomás. Gràcies per confiar en mí i aportar-me un troç del vostre coneixement. Gràcies a la resta de l'equip: Lucas, Álvaro, Isa, Iván i Davids. Gràcies per fer que em senta a casa entre quatre parets sense entrada de llum. Heu cultivat una llavor d'investigadora.
Un especial agraïment també a tots els companys que he conegut al màster i al IIE que m'han acompanyat en aquesta aventura. També agraïr als amics, que m'han escoltat contant-los històries de transició justa i ciutats i m'han ajudat a entendre altres perspectives.
Finalment, gràcies als pares i a Marina, per creure en mi i animar-me sempre a continuar fer camí.

# Abstract

This master's thesis provides a decision-making tool for planning the decarbonization of cities. The tool is based on the use of a methodology for calculating the Carbon Footprint of a city and Geographic Information Systems (GIS) to visualize carbon footprint data.

First, the development for calculating the emissions inventory is presented, following the previous work carried out in the framework of the Chair of Urban Energy Transition of the Polytechnical University of Valencia. In this work, the carbon footprint calculations have been completed for all districts and neighborhoods of the city, correcting and modifying, where necessary, the methodology.

Second, based on the detailed calculations of Greenhouse Gases (GHG), an analysis of emissions has been carried out using GIS tools. These have been used to visualize and better understand the main emission sources: transport, energy, construction, etc., at both district and neighborhood scales at a higher level of detail.

Third, the analysis has been completed with a study of strategies that could be implemented for the decarbonization of the city, such as renewable energy generation, electrification of thermal demand, or transport modal shift. Thus, the effect of the different strategies has been evaluated in reducing greenhouse gas emissions in the district with the highest emissions and their respective neighborhoods. In this sense, the tool presented in the current work has been generated to facilitate the strategic planning of the decarbonization of cities, particularizing by districts and neighborhoods.

To verify the tool's usefulness, it has been applied to the case study of the city of Valencia. Specifically to a total of 19 districts and 87 neighborhoods. The three scopes of the carbon footprint have been calculated based on statistics provided by the Valencia City Council. The data has been obtained by using a bottom-up approach. Nevertheless, in those cases where the information was unavailable, it was obtained by applying other calculation methods, such as inhabitant allocation and the adaptation of other city studies.

**Keywords:** Greenhouse gases (GHG); carbon footprint; Geographic Information Systems (GIS); decarbonization of cities; urban strategic planning; carbon neutral districts; urban energy transition; sustainable cities

## Resumen

Esta tesina de fin de máster proporciona una herramienta para la toma de decisiones para la planificación de la descarbonización de las ciudades. La herramienta está basada en el uso de una metodología de cálculo de la Huella de Carbono de una ciudad y de sistemas de Información Geográfica (SIG) para la visualización de los datos de huella de carbono.

Primero, se presenta el desarrollo para el cálculo del inventario de emisiones, siguiendo el trabajo previo realizado en el marco de la Cátedra de Transición Energética Urbana de la Universitat Politècnica de València. En este trabajo, los cálculos de huella de carbono han sido completados para todos los distritos y barrios de la ciudad, corrigiendo y modificando, en aquellos puntos que fuera preciso, la metodología.

Segundo, a partir de los cálculos detallados de los Gases de Efecto Invernadero (GEI), se ha llevado a cabo un análisis de las emisiones con el uso de herramientas SIG. Se han utilizado para visualizar y comprender mejor las principales fuentes de emisión: transporte, energía, construcción, etc. tanto a escala de distrito como de barrio con un nivel más elevado de detalle.

Tercero, el análisis ha sido completado con un estudio de estrategias que podrían ser implementadas para la descarbonización de la ciudad tales como generación con energías renovables, electrificación de la demanda térmica o cambio modal de transporte. Así pues, el efecto de las diferentes estrategias ha sido evaluado en la reducción de las emisiones de efecto invernadero en el distrito que presenta mayores emisiones así como en sus respectivos barrios. En este sentido, la herramienta presentada en el actual trabajo, ha sido generada para facilitar la planificación estratégica de la descarbonización de las ciudades, particularizando por distritos y barrios.

Con el fin de verificar la utilidad de la herramienta, se ha aplicado al caso de estudio de la ciudad de Valencia. Específicamente, a un total de 19 distritos y 87 barrios. Los tres alcances de la huella de carbono han sido calculados basados en estadísticas provistas por el ayuntamiento de Valencia. Los datos se han obtenido utilizando un procedimiento de abajo a arriba. En aquellos casos en que la información no estaba disponible, ha sido obtenida aplicando otros métodos de cálculo como la distribución por cápita así como la adaptación de otros estudios en ciudades.

**Palabras Clave:** Gases de efecto invernadero; huella de carbono, Sistemas de Información Geogràfica (SIG); descarbonización de las ciudades; planificación estratégica urbana, distritos neutros en carbono, transición energética urbana; ciudades sostenibles

## Resum

Aquesta tesina de fi de màster proporciona una eina per a la presa de decisions per a la planificació de la descarbonització de les ciutats. L'eina està basada en l'ús d'una metodologia de càlcul de la Petjada de Carboni d'una ciutat i de sistemes d'Informació Geogràfica (SIG) per a la visualització de les dades de petjada de carboni.

Primer, es presenta el desenvolupament per al càlcul de l'inventari d'emissions, seguint el treball previ realitzat en el marc de la Càtedra de Transició Energètica Urbana de la Universitat Politècnica de València. En aquest treball, els càlcul de petjada de carboni han sigut completats per a tots els districtes i barris de la ciutat, corregint i modificant, en aquells punts que calguera, la metodologia.

Segon, a partir dels càlculs detallats dels Gasos d'Efecte d'hivernacle (GEH), s'ha dut a terme una anàlisi de les emissions amb l'ús d'eines SIG. S'han utilitzat per a visualitzar i comprendre millor les principals fonts d'emissió: transport, energia, construcció, etc. tant a escala de districte com de barri amb un nivell més elevat de detall.

Tercer, l'anàlisi ha sigut completat amb un estudi d'estratègies que podrien ser implementades per a la descarbonització de la ciutat com ara generació amb energies renovables, electrificació de demanda tèrmica o canvi modal de transport. Així doncs, l'efecte de les diferents estratègies ha sigut avaluat en la reducció de les emissions d'efecte d'hivernacle en el districte que presenta majors emissions així com en els seus respectius barris. En aquest sentit, l'eina presentada en l'actual treball, ha sigut generada per a facilitar la planificació estratègica de la descarbonització de les ciutats, particularitzant per districtes i barris.

Amb la finalitat de verificar la utilitat de l'eina, s'ha aplicat al cas d'estudi de la ciutat de València. Específicament, a un total de 19 districtes i 87 barris. Els tres abastos de la petjada de carboni han sigut calculats basats en estadístiques proveïdes per l'ajuntament de València. Les dades han sigut obtingudes amb un procediment de baix a dalt. En aquells casos en què la informació no estava disponible, ha sigut obtinguda aplicant altres mètodes de càlcul com distribució per càpita, així com l'adaptació d'altres estudis en ciutats.

**Paraules clau:** Gasos d'Efecte Hivernacle; petjada de carboni; Sistemes d'Informació Geogràfica (SIG); descarbonització de les ciutats; Planificació estratègica urbana; districtes neutres en carboni; transició energètica urbana; ciutats sostenibles

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# List of Abbreviations

| | |
|---|---|
| $A_i$ | Activity data of i |
| AL | Agricultural Lands |
| B | Buildings |
| CEAP | Circular Economy Action Plan |
| CF | Carbon Footprint |
| CNG | Compressed Natural Gas |
| CoM | Covenant of Mayors |
| C | Clothing |
| E | Electricity |
| ES | Electric Scooters |
| F | Food |
| FE | Factor Emission |
| GHG | Greenhouse Gases |
| GIS | Geographic Information System |
| GWP | Global Warming Potential |
| INE | Statistical National Institute of Spain |
| IPCC | Intergovernmental Panel on Climate Change |
| ISO | International Organization of Standardization |
| LPG | Liquefied Petroleum Gas |
| NBS | Natural Based Solutions |
| NG | Natural Gas |
| MP | Manufactured Products |
| PB | Private Bicycles |
| PC | Private Cars |
| R | Roads |
| SECAP | Sustainable Energy and Climate Action Plan |
| TC | Waste Treatment Category |
| TW | Two-wheelers |
| TX | Taxi |
| UGA | Urban Green Areas |
| UNFCC | United Nations Framework Convention on Climate Change |

| | |
|---|---|
| VKT | Vehicle Kilometer Travelled |
| W | Waste |
| WRI | World Resources Institute |
| WBCSD | World Business Council for Sustainable Development |

# Part I
# MEMORY

# 1 Introduction and objectives

## 1.1 Background

"Human-induced climate change has caused widespread adverse impacts and related losses and damages to nature and people." That is the first conclusion of the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC): Impacts, Adaptation and Vulnerability [1]. Hence, experts report that the accelerated change we are witnessing becomes a problem that is impossible to avoid. We must focus on reducing their impacts and stopping the current trend. In this context, cities play a crucial role as they cause 70% emissions worldwide [2]. In addition, high population density in cities produces enormous social and economic impacts. Therefore, transforming cities and generating more sustainable urban ecosystems is both a challenge and an opportunity. It is necessary to develop strategies that reduce these impacts and consider the various factors involved in the sustainability of cities in order to achieve carbon-neutral cities. Given the importance of the current situation, numerous initiatives have been launched over the last decades. Some of the most relevant is the Covenant of Mayors (CoM) [3], Energy Cities [4], C40 Climate Action Plan [5], or the European Missions launched by the European Commission [6]. These initiatives aim to reduce emissions by 2030 through systemic research and innovation that integrates new governance approaches, public-private partnerships, and engaging citizens. Specifically, those cities engaged in the CoM commit to submitting a Sustainable Energy and Climate Action Plan (SECAP). As a fundamental part of this plan, municipalities must calculate a baseline emissions inventory (BEI). Hence, the calculation of emissions in cities is established as a basis for drawing up a plan to develop climate-neutral cities. The missions go a step further as they were established to provide concrete solutions to European challenges. Among the five European Missions, 100 cities are set to become a reference in the challenge of decarbonization, so-called 100 Climate-Neutral and Smart Cities by 2030. These cities must perform the City Climate Contract to start outlining the strategic framework they intend to implement. Due to the diversity of elements that influence the decarbonization of cities, there are many possible strategies. Hence, each city with its differentiated characteristics will have to seek the appropriate way to reduce its emissions and achieve climate neutrality.

Furthermore, although many initiatives focus on cities, not many consider their areas' diversity as a whole. Nevertheless, other European initiatives are considering the development of Zero-Emission Neighbourhoods (ZEN) and Positive Energy Districts (PED) to tackle decarbonization according to their particular characteristics. ZEN is a delimited urban area whose emissions balance over a year is equal to, or less than zero [7]. In contrast, PED is a district with annual net zero energy import, and net-zero $CO_2$ emissions [8]. With these initiatives, it is possible to dig deeper into a city's different social and economic problems. Thus, connecting them with indicators can help draw up an effective plan for implementing actions.

The plans and strategies that succeed in reducing emissions need to consider these two visions as a whole: the city and the grouping of districts and areas. In this way, it is possible to complete a study of actions implications and differences between the areas that comprise a city.

## 1.2 Objectives

This master's thesis aims to develop a tool to assess the decarbonization potential of different urban actions. For this purpose, the work is divided into two main blocks. First, a diagnosis of the carbon footprint is carried out, and then several actions will be evaluated for their GHG emissions reduction. For both stages, the differences between districts and areas of the city are studied.

## 1.3 Motivation

As the central focus of decarbonization initiatives, cities must create efficient strategies considering the diversity of the areas that compose them. To this end, this project focuses on the study of emissions and the proposed evaluation of different actions to achieve carbon-neutral cities. Thus, this project is intended as the first step in developing a decarbonization roadmap based on the $CO_2$ emissions of the districts on the first level and neighborhoods on a second, more detailed level. Also, this work is intended to show the differences in emissions of the districts to promote a clearer vision of where and how to focus efforts and priorities in cities and, at the same time, to assess the potential of actions to determine whether these are sufficient or the actions need to be rethought.

# 2 Literature Review

In order to obtain a clear view of the work carried out in the field of this master thesis, a literature review is done. On the one hand, a review of carbon footprint highlights the methods and the general results for cities, and on the other hand, a review of the leading carbon reduction strategies in cities and their connection with the different aspects of ecosystems in cities.

## 2.1 Carbon footprint inventories

The concept of the carbon footprint comes from the ecological footprint. Although the term ecological footprint is clear, the term carbon footprint has yet to be clearly defined. William Rees and Mathis Wackernagel first proposed the ecological footprint in 1996 [9] as a measure of the regenerative capacity of the environment that is calculated by summing the natural resources consumed by humans in terms of land area. However, the most widespread definition of *Carbon Footprint* is the measurement of harmful emissions caused by human sources in a given period and a given system [10]. Carbon footprint inventory is a widespread tool used to calculate emissions over the lifetime of a product, company, or country [11]. In addition, it is useful for monitoring and managing emissions and constructing strategic plans for their reduction [12]. Through its calculation, it is possible to identify the sources of major emissions and thus prioritize efforts to reduce them.

Given that there is no consensus on the carbon footprint definition, there is no single methodology for its calculation, and the international community accepts several methods. The first standards were developed to assess the environmental aspects produced by the life cycle of products and services, called Life Cycle Assessment (LCA). Over time, the standards have been covering different boundaries, such as organizations, countries, or cities. In addition, they have become more specific on air emissions because it is the major contributor to the environmental impact associated with climate change: Global Warming Potential (GWP). Thus, the current carbon footprint standards cover the leading greenhouse gases. As written in the last IPCC report [1], the primary GHG in the world are 4, being them $CO_2$ (75%), methane (18%), nitrous oxide (4%), and fluorinated gases (2%). As the significant part corresponds to $CO_2$ emissions, the carbon footprint inventories methods convert all emissions to a standard unit: the mass of $CO_2$ equivalent (see table 1) [13, 14, 15, 16]. The weight of each one of them, according to their GWP, is as follows:

| **Name** | **Formula** | **GWP** |
|---|---|---|
| Carbon dioxide | $CO_2$ | 1 |
| Methane | $CH_4$ | 28 |
| Nitrous oxide | $N_2O$ | 130 |
| Fluorinated gases | $F - gases$ | 1,300-23,400 |

**Table 1:** Weight GHG gases

Calculating greenhouse gases for a given activity is to make a weighted sum of all the gases with global warming potential involved in the process. Thus, 1 kilogram of $CH_4$ emissions is equivalent to 28 kilograms of $CO_2$ emissions, 1 kg of $N_2O$ to 130 kg of $CO_2$, and 1 kg of fluorinated gases, depending on the gas type, is equivalent to between 1,300 and 23,400 kilograms of $CO_2$ emissions.

The selection of the most appropriate standard for each case depends on several factors, including the objective and the level of study. The objective defines whether it is for internal or external use in an organization, whether it is voluntary, or to comply with legislative requirements. The level of the study refers to the limits within which the study will be established: product, organization, country, city, building, etc. In this sense, the following diagram presented in Figure 1 can be used for selecting the most appropriate standard.

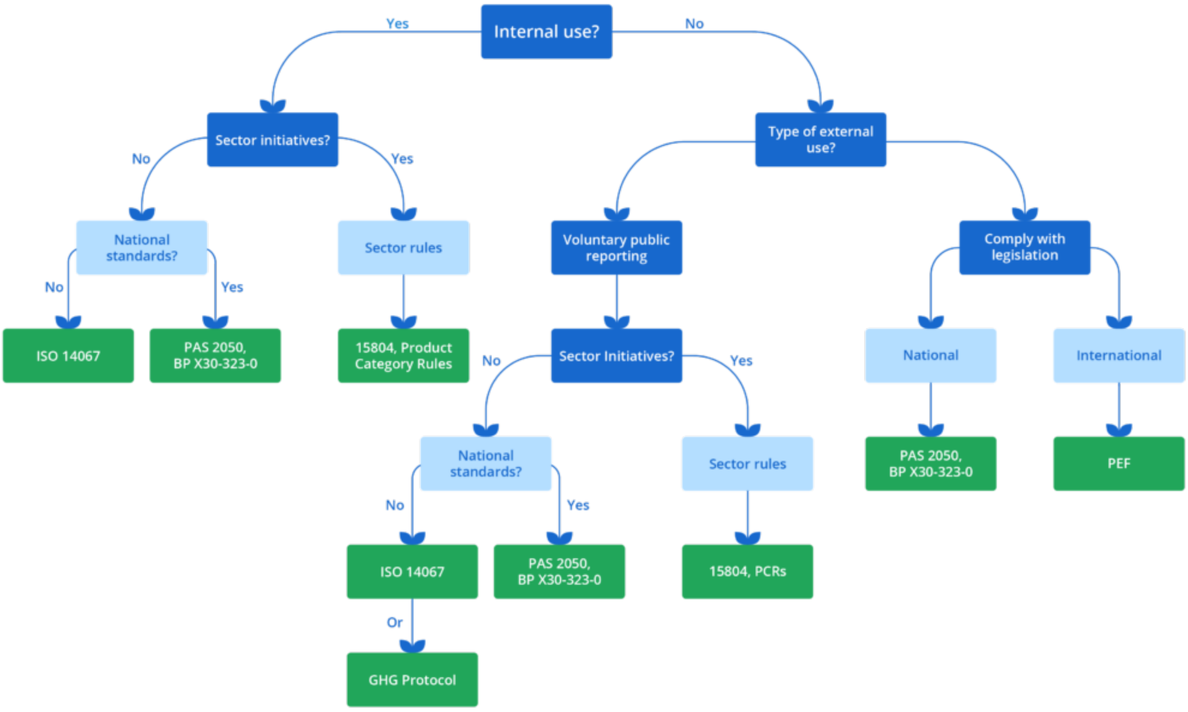



**Figure 1:** Footprinting project steps [17].

The standards shown in Figure 1 can be separated into two main groups: those that consider only the impact of climate change or a wider range of environmental impacts. In the case of the first group, i.e., those used to measure the carbon footprint, there is ISO 14067, the most widely used at present and developed by the International Organization for Standardization (ISO). In the case of nations, each country can develop its own method for organizations and public reports based on others standards. The most widely used national standard is PAS 2050, developed by the British Standards Institute (BSI). Furthermore, in more specific cases, the GHG Protocol Product Standard is developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). In the specific case of cities, there are various initiatives to develop standard methodologies [18, 19, 20]. The GHG protocol has created a guide for Community-Scale, and Greenhouse Gas Inventories [21]. Also, households, as the main drivers of the economy and consumption in a city, are responsible for a high share of worldwide emissions and resource use along global supply chains [22]. Thus, carbon footprint at the household level is being studied and offers an opportunity of applying efforts in a more localized way [23, 24, 25, 26]. Nevertheless, studies at district and neighborhood scales are less studied than household studies. They need further research to efficiently implement strategies in cities and conduct better management of carbon emissions.

In this project, the most widely used methodology for calculating the inventory of emissions in cities (GHG protocol for communities [21]) has been combined with the method of accounting for the life cycle of products and services. This approach has been used to generate a specific procedure that can be applied to districts and neighborhoods.

Although there are a wide variety of standards, they all follow a common set of steps that also contemplate four fundamental concepts: the life cycle of products and services, systems boundaries, and data collection methodology. The steps to be followed for the development of the carbon footprint calculation are as follows:

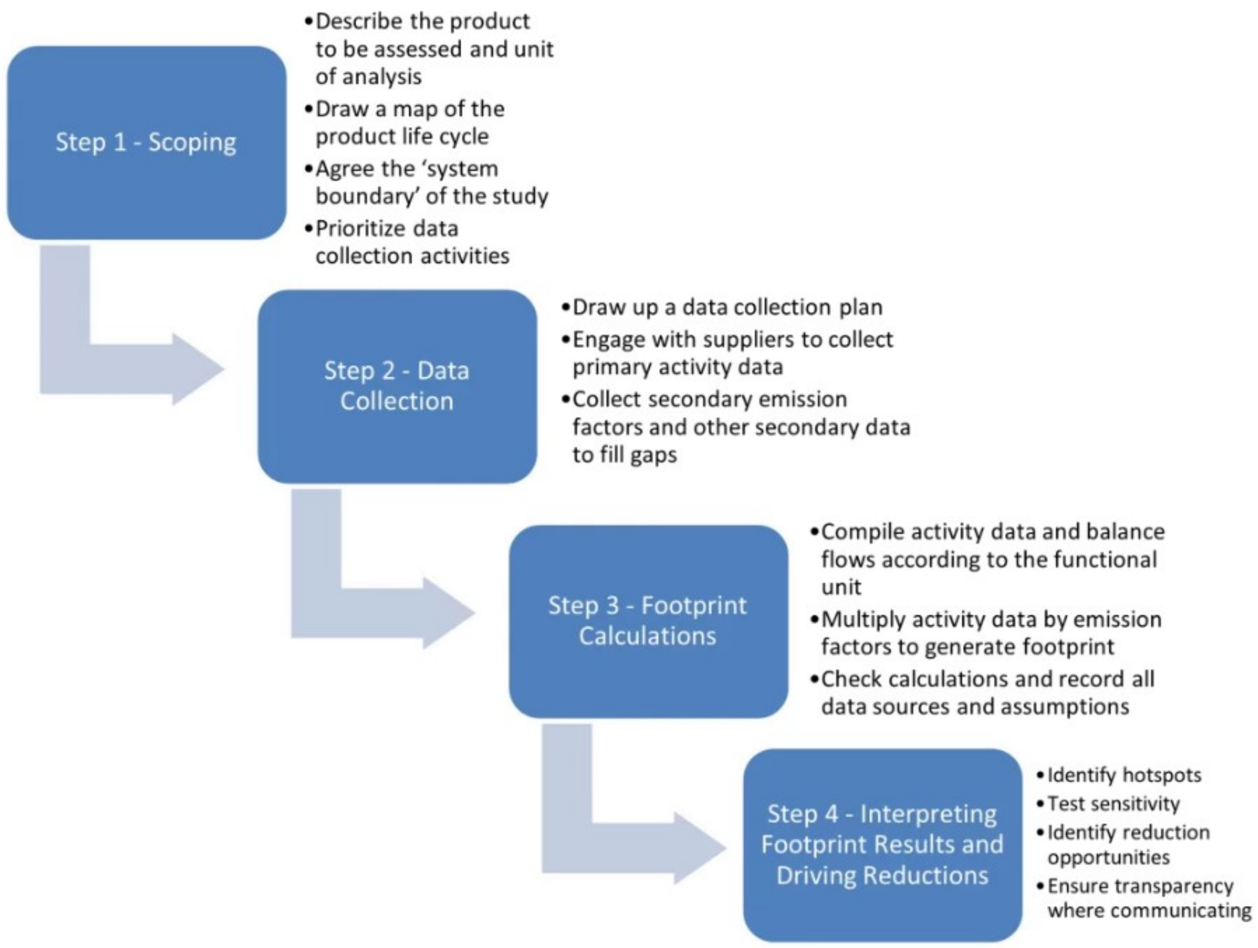



**Figure 2:** Footprinting project steps [27].

### 2.1.1 Step 1: scoping

The first step in developing any carbon footprint calculation is the definition of the scope. At this stage, the product to be analyzed, the boundaries, and the functional unit are clearly defined. Mapping and defining the product life cycle and deciding which stages to consider are essential for analyzing the activities. The life cycle of a product can be divided into three main phases: downstream activities, use phase, and upstream activities. Downstream activities are the extraction of raw materials, their processing, and transportation between these two stages and to the consumption site. In contrast, upstream activities are the activities that involve the end-of-life of a product where the treatment operations are considered once the product becomes a waste. For example, the figure below shows the life cycle of wind turbines.

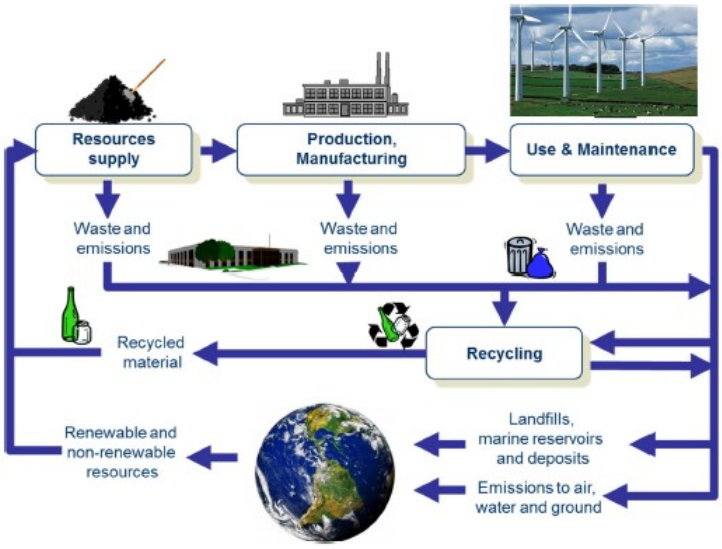



**Figure 3:** Life cycle of wind turbines [28].

Another thing to consider when preparing a carbon footprint assessment is whether to consider direct or indirect emissions. Direct emissions are those produced at the study site during the use phase of a product or service. In contrast, indirect emissions correspond to those produced in the downstream and upstream activities of the use phase. However, specific emissions occur at the use stage of some products that are not strictly direct. In order to identify system emissions, the GHG protocol [29] proposes three different, defined in Figure 4.

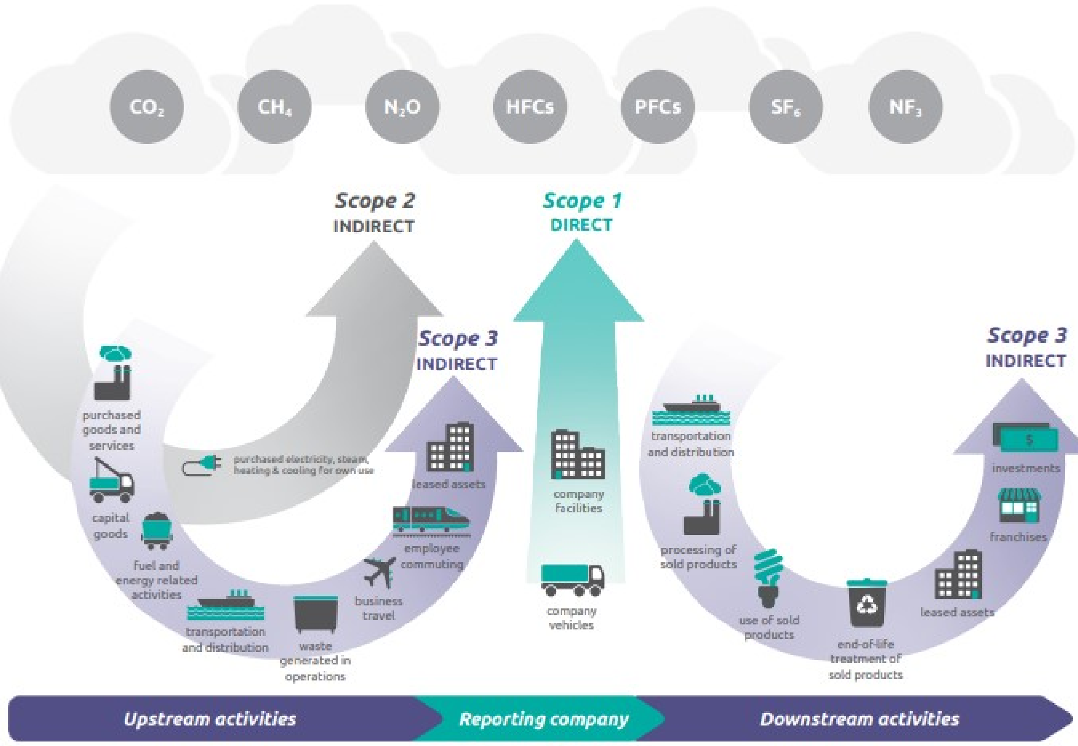



**Figure 4:** Definition of GHG emissions scopes [29].

Scope 1 emissions are direct emissions that occur at the study site. Are due to the use of the products, such as burning oil for an automobile in a city. Scope 2 emissions are indirect emissions referring to emissions caused outside the system but due to the present consumption of a product. An example would be the purchase of electricity from the national grid since the effect of emissions from electricity consumption in a city is conditioned by the energy mix, which can produce emissions from burning fuels in thermal power generation plants. Scope 3, on the other hand, is all those indirect emissions produced in other processes such as raw materials extraction, transportation, manufacturing, or recycling of a product.

Nowadays, as the third scope of emissions is the most difficult to calculate, it is optional to include scope 3 emissions in some cases. This case applies to cities, and the BEI that cities commit to CoM must upload every two years usually does not include it. Nevertheless, in recent studies, there is a growing concern about externalities in consumption patterns leading to an increasing number of studies that include this scope. This project, scope 3 has been considered since part of the indirect emissions are produced due to the activities carried out in the city and have been accounted for in the case study of Valencia.

### 2.1.2 Step 2: data collection

Calculating the carbon footprint requires collecting two types of data: activity data and emission factors. The inventory of activity data can be approached from two directions: bottom-up or top-down. The method used differs depending on the data and specificity required. While carbon footprinting at the national level uses the top-down methodology, the bottom-up methodology is often used in developing an inventory for a product. Although the bottom-up method is considered the most complete, mixed methodologies are becoming increasingly widespread. The lack of data at a small scale restricts the study and makes bottom-up approaches unfeasible. Hence, mixed methods are often the best way to combine both advantages [30]. Subsequently, the corresponding emission factors are collected once the activity data are obtained. One of the key aspects in calculating the carbon footprint is the emission factors, which are highly dependent on the time and place. Emission factors should be as reliable as possible. The IPCC has generated an Emission Factor Database (EFDB) where many factors for various activities and products can be found. In addition, other databases with reliable emission factors can be used, such as EcoInvent, European reference Life Cycle Database (ELCD), and Environmental Performance Indicators (EPD), among others.

### 2.1.3 Step 3: Footprint calculations

Once the activity data and emission factors are obtained, it is necessary to adapt the data for multiplication with the emission factors taking into account the functional unit of the study. Then, the carbon footprint is calculated by multiplying the sum of each one of the activities per its corresponding emission factors to give the total carbon footprint. The general expression is as follows:

$$CF = \sum A_i \cdot EF_i \tag{1}$$

Where $A_i$ represents the activity data, and $EF_i$ represents the Emission Factor.

### 2.1.4 Step 4: interpreting carbon footprint results and driving reductions

The last phase of any carbon footprint project is interpreting the results. In this phase, the key points, sectors, and causes that lead to emissions are identified. Depending on the study, a more focused analysis of the life cycle stages will be made. In this sense, it is possible to easily identify which stage of a product has a higher contribution of emissions and propose strategies to reduce the carbon footprint. At this point, product improvements emerge, different strategies are evaluated, and changes are made at one or more stages of the product to reduce the carbon footprint. For example, emission reduction strategies such as using recycled materials as raw materials or a shift from combustion vehicles to electric means of transportation could be evaluated to determine the impact they would have on reducing the carbon footprint. In addition, in this phase, the results are also being compared with other similar studies in order to determine the reliability and validate the results obtained.

In the case of cities, the interpretation of results leads to determining the areas and sectors with the highest emissions in the city and provides answers to the causes of these emissions. Once the main answers are obtained, it is necessary to proceed with the evaluation of actions. Also, it is necessary to select which will be implemented and follow their evolution to achieve GHG emission reduction. Monitoring results is necessary to draw up efficient strategies as, if the objectives are not met, it will be necessary to rethink the actions implemented or modify the strategy. An example methodology for monitoring progress in the decarbonization of cities is the study developed by Camille Reynaud [31]. The study includes the selection of indicators to verify if the annual objectives established are being met or if, on the contrary, it is necessary to put more effort into them.

## 2.2 Strategies and policies

Since the creation of the Covenant of Mayors in 2008 by the European Commission, many cities have been committed to developing plans to achieve carbon neutrality. Cities committed to the Covenant of Mayors agreed on reducing $CO_2$ emissions by at least 40% by 2030. To do so, they would use the carbon footprint baseline for the city and commit to a strategic plan that included the actions they would promote to reduce their emissions, the Sustainable Energy and Climate Action Plan (SECAP). Also, they had to carry out periodic evaluations and rewrite those strategies. Based on that, numerous research articles have emerged to guide city governments and propose strategies and policies that contribute to the goal. Thus, many scientific articles evaluate the commitment, the type of policies, and the effectiveness of these towards achieving the objective [32, 33, 34, 35, 36, 37].

For climate action, there are two main strategies: mitigation and adaptation. As defined by Stehr and Storch, mitigation actions refer to protecting nature from society, whereas adaptation comprises actions to protect society from nature [38]. Thus, mitigation measures comprise those strategies for reducing anthropogenic GHG emissions. In comparison, adaptation is intended to change the systems, not to notice (or notice less) the effects of climate change and climate disasters such as droughts and floods. Hence, many scientists have sought ways to observe which measures can be beneficial for both and, in this way, execute the actions effectively.

Moreover, since emissions are a consequence of human life, the way society is shaped, its consumption patterns, and needs must be considered. Therefore, a systemic change that considers environmental sustainability, social justice, and economic viability for all city members must be considered to develop and re-think new sustainable cities. That is why many authors define strategies implementation as multi-level and polycentric, as it concerns many decision-making levels and involves a series of public and private actors through various actions [39, 40]. According to, cities committed to being carbon neutral can re-think politics on what, how, and by whom. In this context, many aspects such as governance, incentives, market, and business have to be considered and distributed implications in the best possible way.

In order to address the changes that a city needs, it is necessary to study the implications of the strategies in a more local context. Subsequently, district-level initiatives such as PED emerged to carry out more localized measures, [41, 42], underlying the importance of each of the city's fundamental parts and considering all of their diversities. The implementation of PEDs has made significant breakthroughs in the interconnection of the different aspects involved in the sustainability of urban areas [43], pointing out actions of interest at multiple scales.

In this part of the literature review, two fundamental initiatives for the development of citizen climate change mitigation strategies in cities have been brought together. On the one hand, the review of SECAPs and, on the other hand, the measures proposed by organizations guiding the 100 neutral cities chosen by 2030 in the context of European Missions.

The study conducted by Croci et al. compares the calculated emissions and proposed strategies of 124 cities SECAPs with 5500 proposed strategies. In the 124 SECAP studies, the highest emissions sectors are buildings (49%) and transportation (26.6%), with residential buildings and private transportation being the most critical [44]. Emissions related to buildings are almost entirely due to emissions from energy consumption. Therefore, most of the proposed actions are linked to these sectors, with 58% of cities planning actions in the building sector, 66% developing plans for the transport sector, and 49% planning local electricity production. The following pie chart represents the results obtained from the analysis:

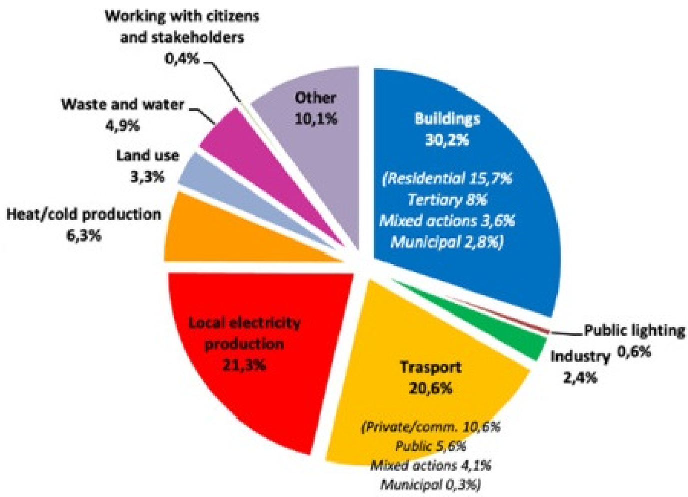



**Figure 5:** Sector distribution of intended emission reduction [44].

Furthermore, to guide cities selected in the European Mission 100 Climate-Neutral and smart cities by 2030, the Net Zero Cities platform has been created to support and assist the selected cities and the support through Climate-KIC. Nevertheless, based on a literature review, Climate-KIC proposes 15 key measures to decarbonize cities (Figure 6). These measures are focused on 6 action sectors and they are chosen based on the medium and long-term reduction potential and the possibility for cities to implement them.

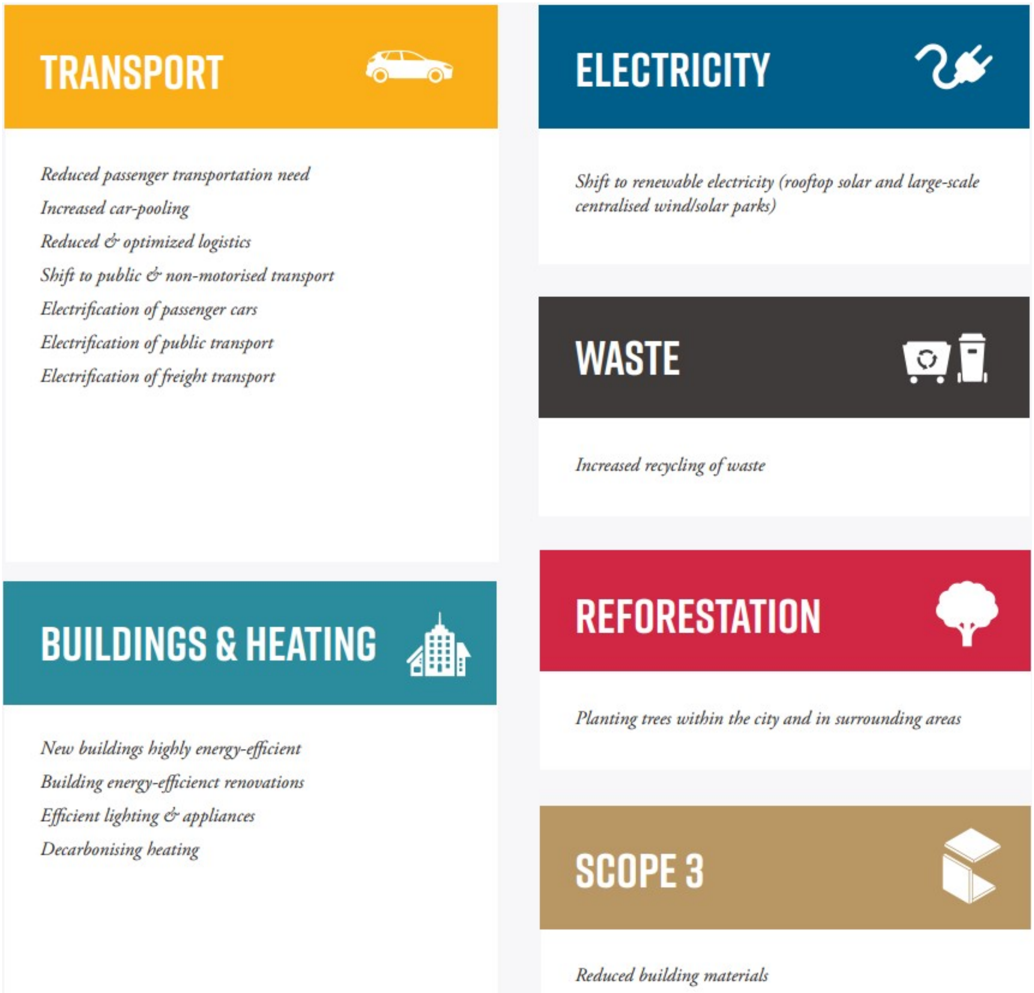



**Figure 6:** Key decarbonization measures according to Climate-KIC proposal [45].

### 2.2.1 Transportation

Transportation, due to a large amount of fossil fuel use, accounts for 37% of global emissions [46]. In cities, transportation patterns are often in line with this distribution, accounting for 26% of cities' emissions [44]. To reduce these emissions, two main strategies are proposed: reducing mobility needs and shifting to more sustainable means of transport.

The most ambitious strategy to reduce this source of emissions is reducing mobility needs. To achieve this, one of the crucial barriers to be tackled from the transition is the reduction of private car ownership in households. However, the reduction of car ownership is favored by the high fuel and vehicle maintenance costs compared to public services and bicycles [47, 48]. In this sense, compact and dense cities have many advantages in climate neutrality promotion. Denser settlements tend to lower GHG emissions from transportation [49, 50]. Also, compact cities allow the integration of the 15-minute city concept [51]. The 15-minute city is a concept defined for the first time by Carlos Moreno (see figure 7).

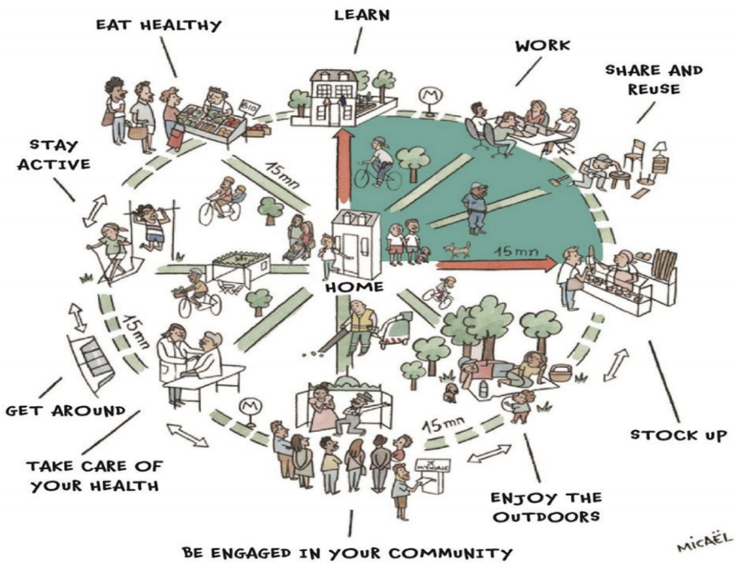



**Figure 7:** 15-minute city concept [52].

The ”15-minute city” is an urban planning concept where all the necessary amenities and services are covered within a 15-minute walk or bike from the resident’s home. The idea is to create more livable, sustainable, and equitable communities by reducing the need for long commutes and car ownership and by increasing access to a variety of amenities and services. This concept has gained attention in cities as a way to address issues such as traffic congestion, air pollution, and social isolation.

When mobility is necessary, another option is to share a private car or use a more sustainable means of transportation such as cycling or walking. Car-sharing programs have been proven effective in carbon emission reduction that reduces the number of cars on the road and, therefore, reducing traffic. In the case of cycling and walking, the existence of an adequate network and accessibility is closely related to the use of more sustainable modes of transportation [53, 54, 55]. Also, providing safe infrastructure for walking and biking can encourage people to use these means of transportation while reducing traffic congestion and improving city health in cities [56, 57, 58]. In addition, shifting to public transport is another of the key actions in cities. The study by Zahabi et al. [59] highlights that a 10% of increase in public services transport accessibility can reduce 5.8% travel-related GHGs. Furthermore, in these cases where walking or biking is not an option due to the large distances, using electric and low-emission vehicles can help reduce air pollution.

### 2.2.2 Buildings and energy

As said before, the building sector in cities is one of the largest contributing sectors to the carbon footprint, with 49% of emissions of the city [44]. Emissions produced in the building sector are largely related to a multitude of socioeconomic and technical aspects such as the age of the residents, educational level, income level, and gender as well as the location or size of the dwelling and year of construction [60]. Among the consumption vectors, the most relevant is income level, which is closely linked to higher energy and product consumption [61]. In a study developed by Pulselli et al. [62], different strategies concerning energy savings reduction actions have been evaluated for 10.000 average European households. The results of the study showed that the 51.33% of carbon footprint is based on energy consumption, 21.39% on electricity, and 29.94% on fuels (for heating and cooking).

From a technical point of view, the main component of reducing emissions in buildings is the adaptation of existing buildings. In many European cities, especially in the south and east of Europe, the building stock is old, and therefore the rehabilitation and adaptation of these buildings to achieve greater thermal comfort and, at the same time, reduce emissions is a key issue. In this field, many studies have been centered on passive strategies and retrofitting [63, 64, 65, 66]. Energy efficiency actions that include buildings as a whole, such as retrofitting and insulation are one of the key efforts proposed by Europe [67]. Insulation of walls, floors, and ceilings is effective due to the energy consumption reduction by keeping buildings warm in winter and cool in the summer. Retrofitting cooling and heating systems with more efficient and sustainable equipment is a key strategy in the energy transition. Especially in the case of thermal demand, as the average European home consumes large amounts of fossil fuels for heating, domestic hot water, and cooking. The electrification of thermal demand promises on the one hand the use of systems with lower emissions and, on the other hand, to increase the efficiency of the installations to reduce consumption.

### 2.2.3 Electricity

Another strategy with great advantages is the installation of renewable energy sources, highly dependent on climate conditions [68]. The efforts are especially focused on photovoltaic self-consumption as promotes resilience and energy independence of cities while leading to a significant reduction in greenhouse gas emissions, displacing the use of grid electricity that still involves electricity production from coal and natural gas. Furthermore, depending on the mode of installation used, citizen cooperation could be increased as well as in the case of energy cooperatives and communities, widely studied for their promising social, economic, and environmental improvement [69, 70, 71].

### 2.2.4 Reforestation and green infrastructure

Green infrastructure offers many benefits as a source of change in today's cities, where grey concrete dominates. In this sense, the European Union focuses on Natural Based Solutions (NBS) as a critical element of the transformative changes needed to achieve a sustainable future. This is represented in the strategic plans launched by the European Commission as "Biodiversity strategy for 2030" [72] and "EU Adaptation Strategy" [73]. On the one hand, green areas help cities adapt to the uncontrollable advance of climate change. They help in runoff and flooding to absorb part of the water that a built-up area cannot take up at normal levels. Also, implementing green areas greatly promotes biodiversity and helps in the survival of animal species, especially birds and small rodents [74, 75]. On the other hand, green infrastructure helps with climate change mitigation, as green areas are fundamental for lowering noise, and air pollution, as well as proper ventilation and the reduction of temperatures and the heat island effect in cities [76, 77, 78, 79, 80]. In addition, the shading effects of trees on buildings generate a considerable reduction in the energy consumption of buildings by reducing the heat they absorb. Therefore reducing the $CO_2$ emissions due to energy consumption [81, 82, 83, 84, 85]. In this field, several evaluation studies of the different strategies and implementation examples as forestation and green walls or rooftops have made important breakthroughs [86]. Furthermore, essential aspects for GHG emissions sequestration are the size of the area and the type of vegetation, as well as the age. Diverse studies have explored the effect of carbon sink urban parks worldwide, and they can offset within 2.3% and 3.6% of the GHG emissions annually [87, 88, 89]. NBS also offers many benefits related to well-being, improving physical and mental health with a longer life expectancy in cities [90, 91, 92].

### 2.2.5 Waste

Consumption of clothing, manufactured products, and food in cities produce a large amount of waste. These wastes must be separated and treated to recycle, incinerate, or taken to a disposal site. This process also consumes resources, energy, and chemical products that damage the environment and emit GHG emissions. The European Commission, aware of this, has made the Circular Economy Action Plan (CEAP) [93] one of the central blocks in the European sustainable development agenda. CEAP aims to keep resource consumption within planetary limits by following a regenerative economic model. Product design, consumer empowerment, and changing the current production model are essential. The following figure shows the basic principles of circular economy:


**Figure 8:** Circular economy concept [94].

The fundamental principle of the circular economy is to eliminate waste and promote the continual use of resources. Changing citizens' habits of consuming less and extending the useful life of products as much as possible would be needed. Eliminating the need to purchase new products is essential, followed by extending the useful life of existing products. Hence, improving the durability, reusability, upgradeability, and reparability of products at the design stage, limiting the use of single-use products, and planned obsolescence are key issues in this transition to sustainable consumption [95]. A circular economy potentiates benefits by reducing environmental impacts, increasing resource efficiency, and improving economic performance. In addition, transitioning to a circular economy can create new business opportunities and jobs, especially in resource recovery and recycling areas.

### 2.2.6 Urban design, land use planning, and urban consumption

Scope 3 emissions are those that are produced outside the city limits but are due to activities that occur in the city. Therefore, urban design, land-use planning, and consumption in urban centers are part of this scope. Urban design and the distribution of land use in urban centers interfere enormously with cities' consumption, being relevant in the construction of society and economy in dense areas [96]. Several studies have determined the relation of urban space with emissions [97, 98] and some relate it to socioeconomic characteristics [99]. Among the most relevant studies are the relationships with income level, as it has been shown that those with a higher income, who is a low proportion of the population, contribute much more to emissions in cities, while the middle and low income keep its emissions rate low [100, 101]. Other studies focus on household size, spatial location, lifestyles, and eating habits as determinant factors of household carbon footprint. Hence, inequality may play an essential role in the energy transition in cities [102], and the climate agreements should pay attention to it [103, 104, 16].

Some actions as the existence of green and pedestrian areas with traffic restrictions, can promote changes in the behavior of citizens towards a fairer and more sustainable model with a decrease in $CO_2$ emissions [105, 106, 107, 108]. Also, strategies related to consumption-based emissions, such as encouraging the purchase of local products in cities, could significantly reduce related emissions and generate local economies, as current consumption systems in cities are tied mainly to long-distance transportation. In addition, reducing the intake of foods with a high carbon footprint and increasing the consumption of seasonal and local products and their production enhances the food independence of cities [109]. Strategies that have demonstrated effectiveness in this line are the urban vegetable gardens self-managed or citizens' cooperatives on rooftops or public spaces provided by municipalities [110].

Furthermore, the expected increase of up to 68% in population in cities [111] makes the need for new housing construction and reduces as much as possible the current high emissions produced by this industrial sector [112]. This is why passive or near-Zero Emission Buildings (nZEBs) as well as sustainable construction are becoming relevant. New buildings have to be based on high-efficiency requirements, circular economy, and renewable energy. Thus, in the construction process of new buildings, it is necessary to focus on unconventional techniques involving using other building materials such as lumber, the quality and efficiency of envelopes, and the integration of energy systems powered by renewable [109]. In addition, it should be noted that although energy use stands out for its emissions, water and resource consumption are also key in the adaptation of cities. The installation of water management systems to reduce water consumption. Another interesting measure that combines both water and energy resources is green roofs, which, while insulating and absorbing water, help reduce energy consumption in buildings.

# 3 Methodology

The developed tool aims to evaluate the efficiency of specific measures in the decarbonization of the city. Thus, following European plans and initiatives, the carbon footprint is calculated at different scales. Subsequently, emissions reduction due to the implementation of specific actions is estimated. It is important to note that since the strategies for achieving carbon-neutral districts are large and multi-sectoral, this project only discusses the most commonly considered in cities context from an environmental and GHG reduction perspective. Then, once the tool's usability is proven, other indicators can be incorporated in the future and combined to perform more complex studies taking into account additional variables to help outline a decarbonization plan for a city.

The tool comprises the four phases of a carbon footprint study: scooping, data collection, calculation of the carbon footprint, and interpretation of the results. In addition, a proposal for evaluating different actions for a specific case study (the city of Valencia) is included.

First, the scooping phase defines the model, including boundaries, activities, and emissions. Second, the data collection is performed. Third, the carbon footprint calculation is based on previously collected data. Four, once the carbon footprint results are obtained, the following phase interprets results and driving reduction. In this phase, the mapping of results and the analysis is done. The fifth and last phase is the evaluation of the proposed actions.

Figure 9 shows the diagram of the general methodology for the development of the method and, therefore, the necessary steps proposed to start drawing up this decarbonization plan. In the next section, each of the steps shown in Figure 9 is explained.

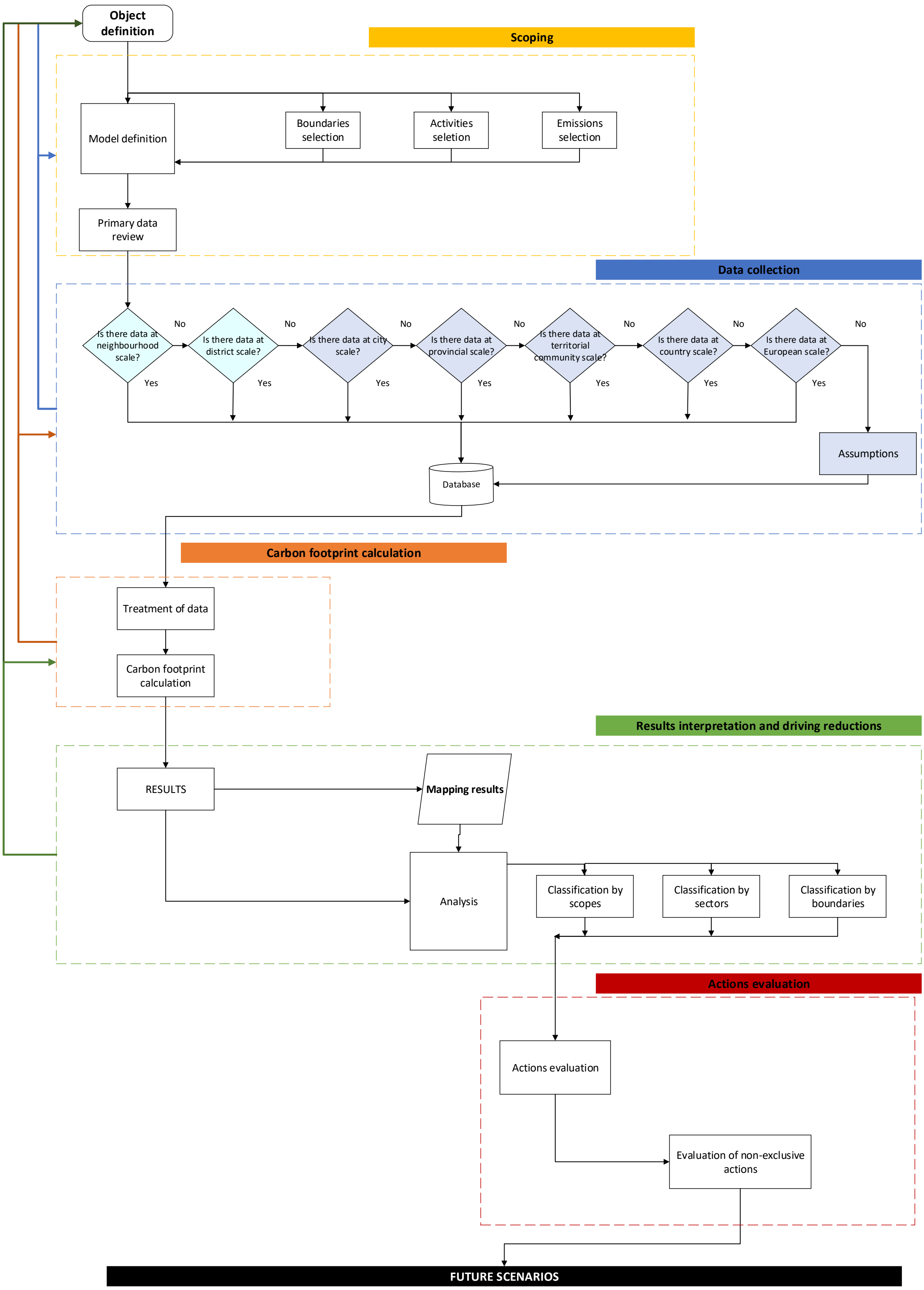



**Figure 9:** General methodology diagram (source: author's elaboration).

### 3.1 Scoping

The first step is to define the action limits to proceed with the carbon footprint calculation. To do so, it is necessary to select the boundaries of the areas and the emissions scopes and classify the activities to be considered. For the emission scopes, it has been considered the three emission scopes defined by the GHG protocol [29] where redefining for the case of districts and neighborhoods would be as

| | |
|---|---|
| **Scope 1** | Those emissions produced by sources located within district/neighborhood boundary. |
| **Scope 2** | Those emissions produced as a consequence of the electricity grid use. |
| **Scope 3** | Those emissions that occur outside district/neighborhood boundaries but are due to consumption and actions within them. |

Most city-level studies do not account for Scope 3 emissions because they do not occur directly at the study site. However, this project considers that the emissions and impacts produced to obtain a good consumed by the cities is one more part of the impacts caused by the cities and should be incorporated at least to identify the magnitude of these impacts.

On the activity side, cities can be considered systems that need resources to carry out activities and emit waste. Each sector is interrelated with another, so there is no fixed and defined boundary. However, activities can be grouped according to the GHG protocol that considers five main activity sectors: transportation, energy consumption, consumption of goods, built environment, and waste. Although each study differs in the boundaries and sub-activities under consideration, the activities considered in the method are further explained.

<u>Transport sector</u>

Generally, the transport sector can be divided between vehicles and the network used to operate them. Another distinction that can be used is between public and private transportation. Public means of transport include bus, metro, taxi, and bicycle-sharing services, while private vehicles include passenger cars, two-wheelers, electric scooters, and bicycles. Direct emissions from transport in the urban area are those produced in the use phase due to fuel consumption and the atmospheric pollution produced. Therefore, combustion vehicles used within urban areas belong to Scope 1, and vehicles that run on electricity belong to Scope 2 due to the use of electricity from the grid. On the other hand, all downstream and upstream vehicle use emissions are accounted for as Scope 3. Emissions from raw material extraction, manufacturing, and final disposal of vehicles are accounted for in scope 3. It should be noted that, in the case of bicycles, they are considered in this last scope as no emissions are produced during their use. In the case of the transportation network, it can highlighted the infrastructure required for the metro network, including stations and road construction. For the network, therefore, emissions produced during on-site construction are considered Scope 1, as is maintenance, while emissions from material extraction, production, and final disposal are placed in Scope 3.

Energy sector

The energy sector is concerned with supplying the energy needs of an urban area. It is intimately related to various factors that establish demand and consumption, but the main functions are to supply the demands for cooling, heating, and electrical devices and cooking. The drivers in the city are fuels, highlighting natural gas and butane, and electricity. Fuel consumption is considered in scope 1, electricity consumption in scope 2, and scope 3 is considered transmission and distribution losses due to electricity consumption occurring in the grid.

Built environment

The built environment sector refers to how the urban area is distributed and constructed. This sector includes buildings, green infrastructure and streets, and roads. The on-site construction and maintenance can be allocated in scope 1, whereas the production and transportation of the material are allocated in scope 3. Also, the sequestration of $CO_2$ emissions due to green areas is considered Scope 1.

Consumption

Consumption of goods can be classified into three main groups: clothing, food, and manufactured products. All the emissions are considered in scope 3. Goods transportation and production are the most relevant emissions in this sector.

Waste

Waste produced in a city can be differentiated by type according to whether it is organic waste, plastics, cardboard, metals, or others. These must then be treated. In this waste treatment stage, more emissions are generated; therefore, this project considers them separately. There are four main treatment categories: landfilling, recycling, incineration with energy production, and incineration without energy production. Scope allocation for waste is considered scope 3, as waste treatment is mostly done in cities outside its boundaries.

Since the grouping of each of the scopes can be a somewhat confusing task, the Figure 10 shows in general terms the emissions from each activity by scope.

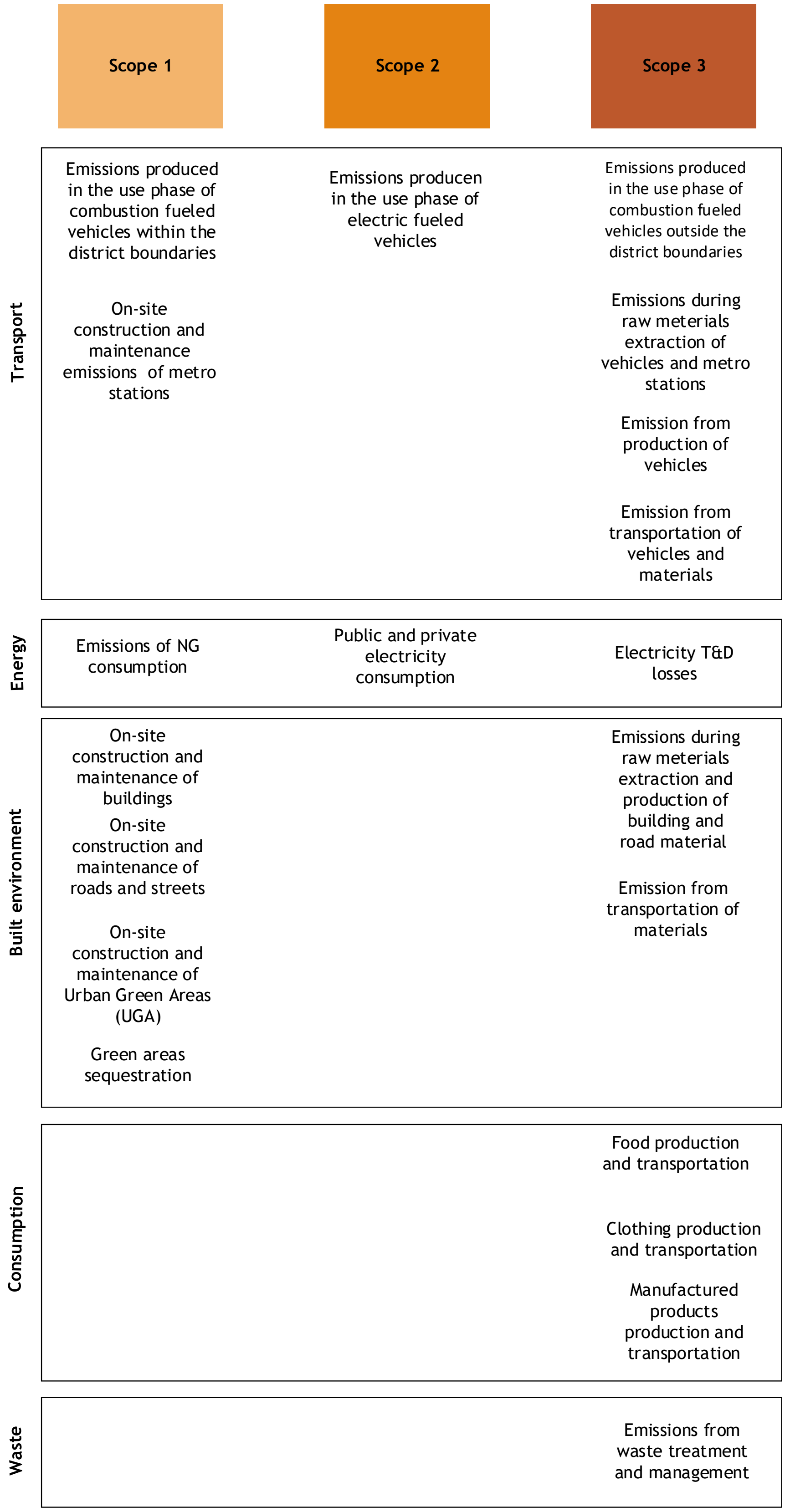



**Figure 10:** Scopes allocation of activities (source: author's elaboration).

## 3.2 Data collection

Most of the difficulty for carbon accounting in cities, urban districts, or neighborhoods is the need for activity data to be directly monitored. Usually, the activity data is available at the regional, provincial or municipal level. Most cities may have data at the city level, some activity data at the district level, and usually less at the neighborhood level. However, municipalities usually have a fairly large collection of statistical data that can be used to approximate much of the calculations made in this methodology.

A general method is proposed as data collection and availability may vary from city to city. A review of the available data is conducted for each activity to get a general idea. Then the necessary data is compiled and stored in a database. In order to obtain the data, an iterative process has been carried out, starting with available data at the neighborhood and district level, considered bottom-up data. However, for those data that are not available at this scale, data available at the city scale, metropolitan area, region, country, and European level is considered top-down data. In those cases where data is unavailable, assumptions are made using similar studies carried out in other cities, districts, or neighborhoods. The same procedure is followed to collect emission factors for activities. Since the emissions considered in this project are meant to reflect the three scopes, the emission factors for the activities include the whole life cycle, i.e., not only the use phase but also the upstream and downstream emissions. So, the production of materials, transportation, and disposal is considered in this work.

## 3.3 Carbon footprint calculation

Once the data collection is done, the next step of the methodology is the calculation of the carbon footprint. For calculating the carbon footprint for districts and neighborhoods, the project has been carried out based on previous work by Eric Wieselblad [113] done within the framework of the Energy Urban Transition Chair of UPV. The previous work followed the carbon footprint calculation guidance of GHG protocol for community-scale [21] and had been adapted for the carbon footprint inventory calculation for one district. The methodology and calculations for each district have been updated, considering each city district's particular characteristics and adapting them to be useful for other cities following the methodology.

The calculation method for the carbon footprint is performed based on Equation 1 of section 1.2.3, based on activity and emissions factors data; the sum of each one of the activities per its corresponding emission factors gives the total carbon footprint. Some examples of activity data and emission factors are shown in Table 2.

**Table 2:** Activity and emission factors example.

| $A_i$ | $EF_i$ |
|---|---|
| MWh of electricity consumed per year | $tCO_2e$ per MWh consumed |
| kg of rice consumed per year | $tCO_2e$ per kg of rice |
| Number of bicycles | $tCO_2e$ per bicycle |
| kg of organic waste generated per year | $tCO_2e$ per kg of organic waste generated |

As each one of the sectors has its differences, the calculation methodology could vary from one to another. In addition, the activities are also differentiated by the three scopes defined above. Therefore, calculating the carbon footprint considers each of these scopes separately to group them subsequently. To better explain the process followed, each activity calculation is explained.

### 3.3.1 Transportation

The functional unit of measurement of vehicle activity is its annual distance traveled, or in other words, Vehicle Kilometer Traveled (VKT). Therefore, it is sought to obtain this value for all vehicles in the district and multiply if corresponding emission factor, which refers to the equivalent tons of $CO_2$ emissions per kilometer traveled. For each type of vehicle, the considerations can be different. For this, private and public transport can be further divided to calculate their carbon footprint.

Private transport

The carbon footprint due to private transportation has been calculated through the sum of each scope emission for each vehicle type. Dividing the calculation between private cars, two-wheelers, electric scooters, and private bicycles. The diagram in Figure 11 shows the general methodology followed:

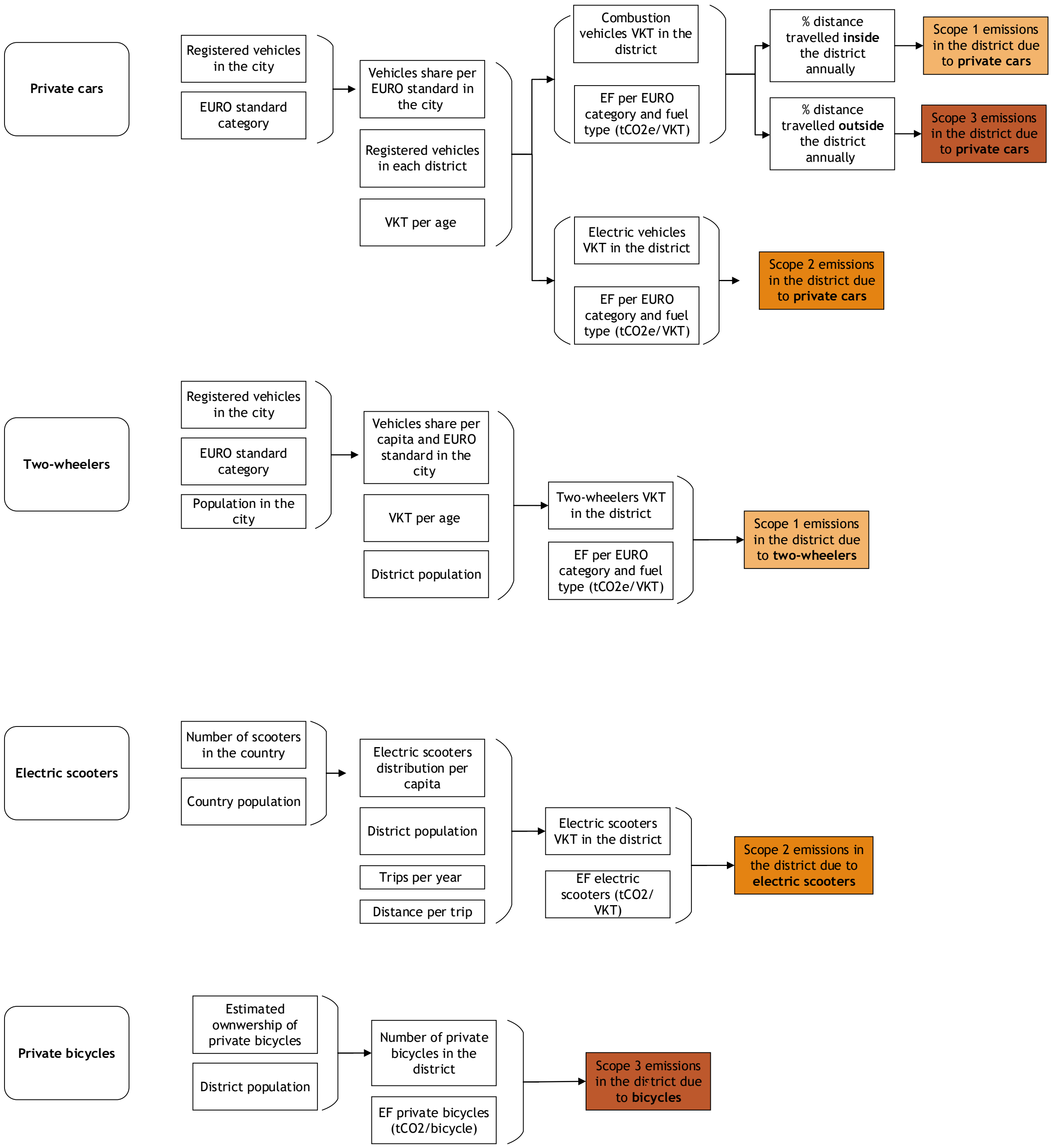



**Figure 11:** Private transport calculation methodology (source: author's elaboration).

As said before, the carbon footprint calculation comprises the activity data and the emission factor. For vehicles, the activity data is referred to as VKT, and therefore, data has to be adapted and reorganized to obtain this activity value for each vehicle type. This is the case for private cars, two-wheelers, and electric scooters, whereas in the case of personal bikes, the emission factor can be referred to as the unity of bicycles, and the obtention of activity data is less complex.

In the case of private cars (first part of the diagram), the vehicles registered in the city are considered and distributed according to standard European regulations. The VKT can be obtained using average values of distance traveled according to the age of the vehicle. According to the European standard, emission factors for private vehicles can be obtained from databases such as EcoInvent or the IPCC. In the case of two-wheeled vehicles and electric scooters (second and third part of the diagram), the same procedure would be followed with the exception that electric scooter statistics may be more challenging to obtain and hence, the number of scooters at the national level can be allocated per capita and then obtain the VKT by the usage pattern and the number of trips. Also, two-wheelers and electric scooters are considered to run within the city boundaries. For bicycles for private use (last part of the diagram), it is necessary to know the number of bicycles and apply the emission factor referred to as the unity of bicycles. In this case, emission factors are also collected in databases, although obtaining the number of private bicycles in cities can be more complex.

However, it is necessary to highlight that this methodology contemplates the evaluation of these emissions based on the vehicles registered and the average kilometers driven annually due to their technical characteristics. A possible improvement to this methodology would be the possibility of having data on the frequency of use of each vehicle and traffic intensity in each of the city's areas to be able to estimate the emissions from the use of each vehicle in each of the districts.

Public transport

In the case of public transportation, obtaining activity data referring to districts and neighborhoods becomes more complicated. However, understanding public transport as a source of emissions that are not only localized in one place, since buses, subways, and taxis travel through all neighborhoods, it is possible to obtain the number of vehicles in the city and distribute them per capita in each neighborhood. The methodology followed is shown in Figure 12.

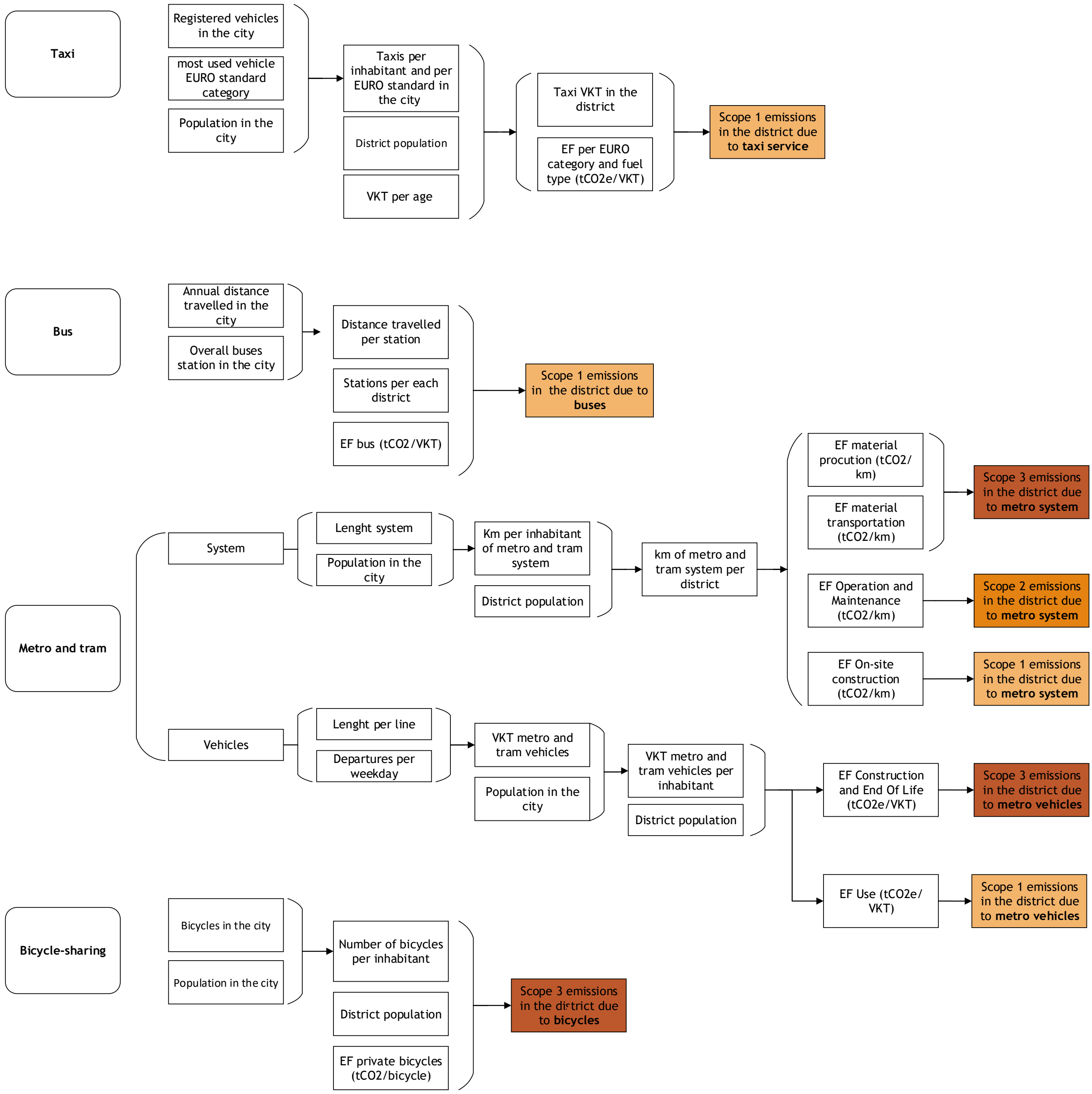



**Figure 12:** Public vehicles calculation methodology (source: author's elaboration).

For taxis (first part of the diagram), the calculation can be done the same way for private vehicles but also distributed per capita. For buses (second part of the diagram), the average annual distance traveled in the city is allocated per vehicle, and then, considering the number of stations per each district can be obtained the number VKT traveled per buses in each district. For metro and tram (third part of the diagram), emissions due to the metro can be separated into those caused by the construction of the network, stations, and vehicle use. In the case of vehicles, all trips made annually are considered to obtain the VKT and then distributed per capita for each of the neighborhoods and districts. In the case of the network, the distance in kilometers of the network is considered, also distributed by capita, and in the case of the stations, the same length as the network is considered. For shared bicycles (last part of the diagram), the same procedure is used as for private bicycles, but distributing the total number of bicycles in the city on a per capita distribution.

### 3.3.2 Energy

The energy sector, as explained before, can be differentiated between electricity, natural gas, and butane consumption. The activity data of the energy is referred to as the kWh consumed and the emission factor to the emissions that the consumption of energy produces. In this sense, the emissions are, in most cases, territorial as they account not only for the usage phase but not more for the energy production and transportation emissions. The diagram that represents the energy carbon footprint calculation is presented in Figure 13.

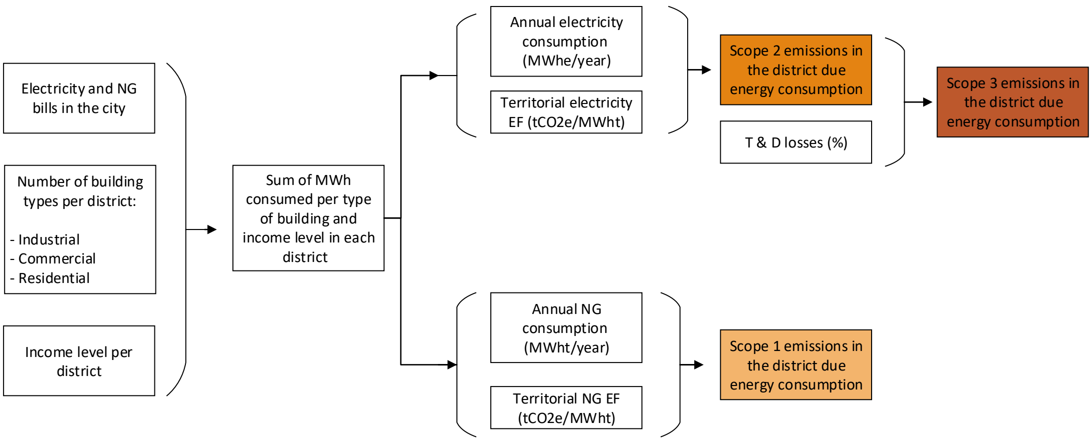



**Figure 13:** Energy consumption calculation methodology (source: author's elaboration).

Activity energy consumption data can be obtained from annual city bills. In addition, as energy consumption is highly dependent on the use of buildings, this methodology presents the distinction between commercial, industrial, and residential buildings. It takes into account the income level of the urban area. Total consumption can then be divided by building type and correlated with income using local statistics. Subsequently, a distinction is made between electricity consumption and fuel consumption. With its corresponding emissions factor, it is possible to obtain the carbon footprint referred to as its consumption in each city district. In addition, from the electricity emissions and applying the corresponding value of loss in transport and distribution of electricity, it is possible to know the scope of emissions due to energy consumption.

### 3.3.3 Built environment

In the case of built environment, the central part of emission factors considers the functional unit of the square meter. So to obtain the carbon footprint of the built environment, it is necessary to know the area of each of the three land uses. Typically, the land area of each space can be obtained in the districts through statistics or GIS tools through the cadastre.

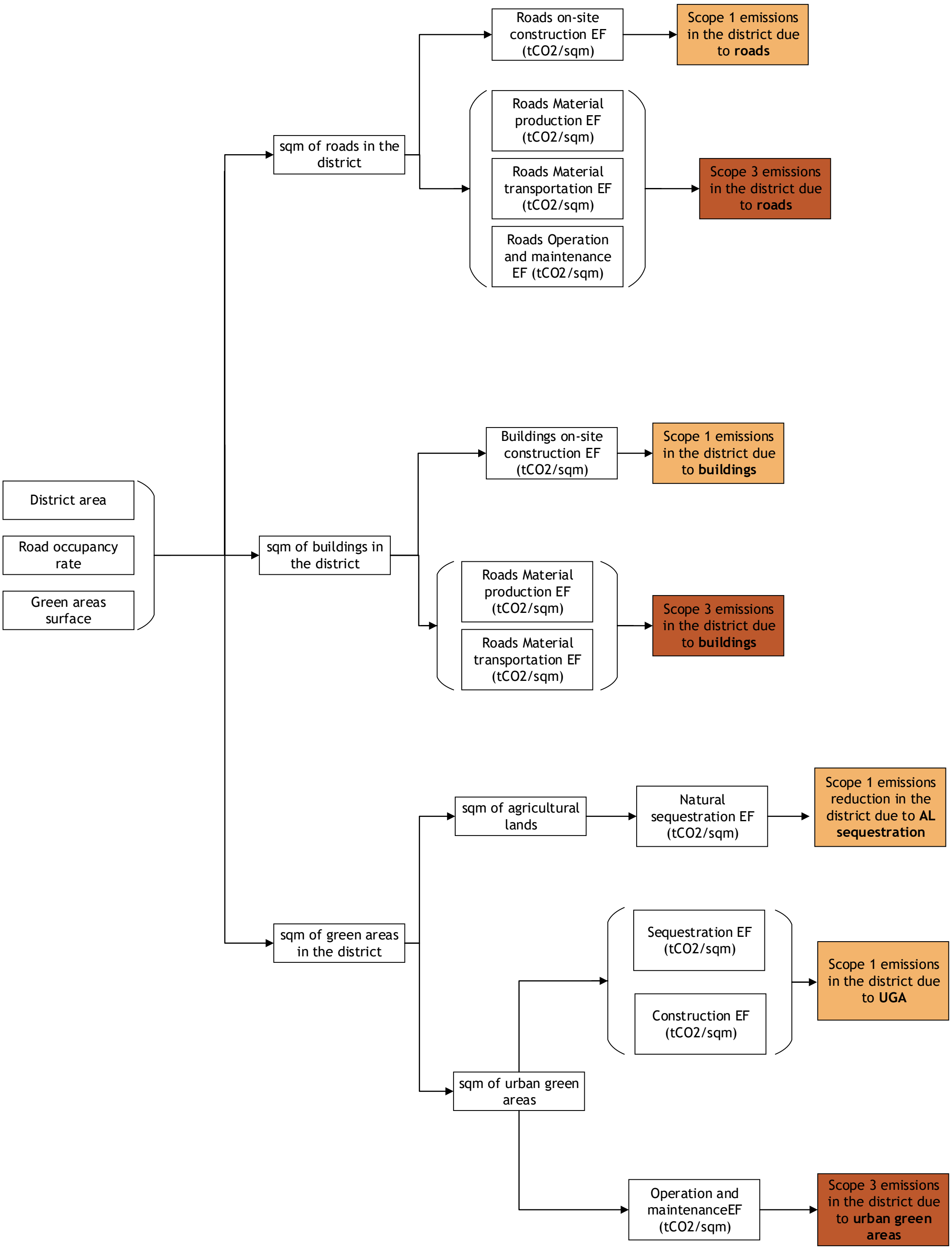



**Figure 14:** Built environment calculation methodology (source: author's elaboration).

The proposed calculation to obtain the built environment's carbon footprint considers the area of green infrastructure and buildings. The area occupied by roads is more complex and uses a percentage of occupation of these that can be obtained through statistics or studies. Once the area of each zone is obtained, it is multiplied by its corresponding emission factor, which is differentiated according to the construction on the site and the factors corresponding to the downstream and upstream activities as well as maintenance. In the case of green infrastructure, the emissions factor relating to emissions sequestration is included. This depends on the vegetation type and must therefore be considered. Two types of green infrastructure can be differentiated: urban and agricultural green areas, which in many cities can be located within municipal boundaries.

In the case of buildings, the methodology accounts for the useful life of a building, which is 50 years. Therefore, the emissions are not only estimated for the constructed buildings in 2019 but also for the buildings with less than 50 years. In this sense, the building emissions are cumulative in time.

### 3.3.4 Consumption

Consumption, as mentioned above, can be divided into food, manufactured products, and clothing. In manufacturing products and clothing, the emission factors refer to the inhabitants as an indicator of $CO_2$ equivalent emissions per capita. In the case of food consumption, the emission factors are referred to the weight of food and, therefore, it is necessary to obtain the kg. of food per type consumed per district. Figure 15 shows the process used to calculate the carbon footprint due to the consumption of goods.

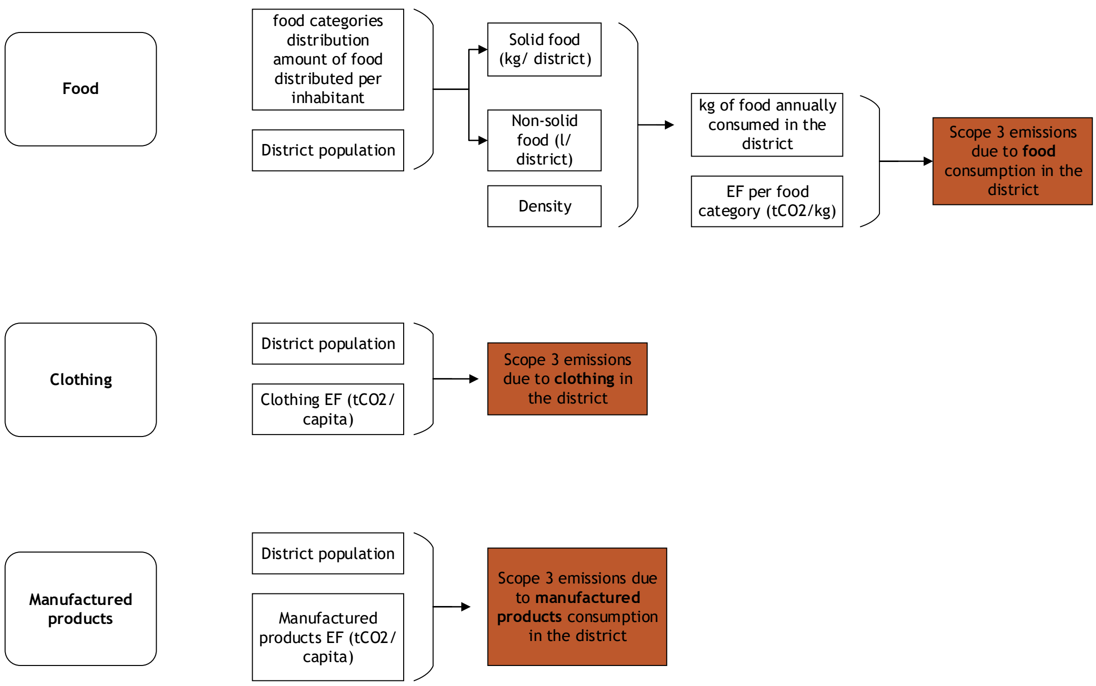



**Figure 15:** Consumption calculation methodology (source: author's elaboration).

The activity data in the case of food is obtained by distributing by food categories, which are referred to the inhabitants (kg/inhabitant) and multiplied by the resident population of the district. Many countries and regions have average statistical data on food consumption that can be used. In the case of non-solid food, it has been multiplied by its corresponding density to obtain the weight. The emissions factor is multiplied by the district's population in manufacturing goods and clothing.

### 3.3.5 Waste

Available data on waste fraction distribution in urban areas can be difficult to be obtained. Therefore, the total amount of waste is considered to be distributed per treatment category. Taking into account the amount generated per inhabitant and multiplying by the emission factor of each treatment category give the carbon footprint due to waste. Figure 16 shows the process followed.

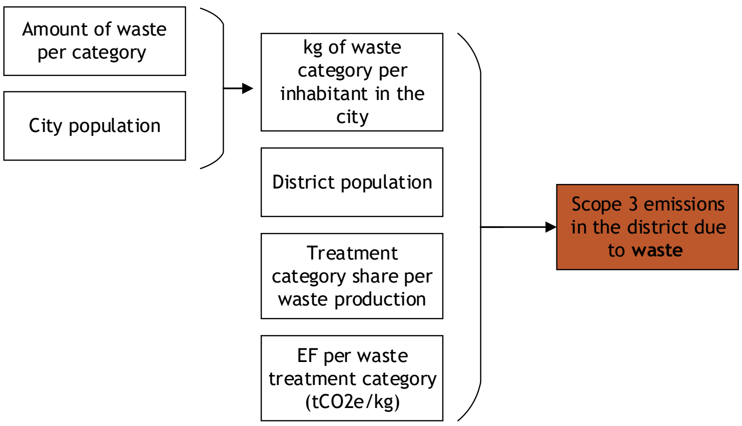



**Figure 16:** Waste calculation methodology (source: author's elaboration).

## 3.4 Results interpretation and driving reductions

The results are intended to be the more complete possible, which is why the results are analyzed on three scales: city, district, and neighborhood. City analysis aims to reflect the general emissions cause (scopes and sectors). District analysis is useful in identifying the areas of the city that present more emissions as a whole and in specific sectors. Neighborhood analysis is intended to reflect the causes more locally compared with the district scale. Considering the neighborhood diversity and peculiarities in terms of user behavior, type of buildings, and use of the buildings in the different neighborhoods. With a detailed study of the causes and the areas that present the most emissions, it is possible to continue with the following steps to develop an effective decarbonization strategy.

Geographic Information Systems (GIS) are proposed to interpret the results in the districts and neighborhoods. GIS has many advantages in representing, evaluating, and making strategic decisions in implementing measures for the desired transition. The combination of geographic information tools with economic, environmental, and social indicators allows the determination and identification of critical points for evaluating actions in the sustainable transition. GIS tools are greatly used to conduct climate impact studies and identify vulnerable areas. Many research studies in green areas availability evaluation [76], renewable energy potential [114], and energetic characterization of building stock [115, 116, 117] confirm its usability. Moreover, geo-referenced public and cadastral data allows for easier data processing and a better linkage with specific indicators, enabling more complex inventories [118]. This facilitates the possibility of conducting studies of neighborhood patterns [119, 120, 121]. For this reason, it has been used several times to provide information to decision-makers [115, 122, 123].

At this stage, it is wanted to show the use of spatial geolocation tools that have already proven to be useful in other occasions both for carbon footprint studies and for the analysis and evaluation of strategies [98]. Mapping the carbon footprint in cities is carried out as a way of prioritizing and analyzing in advance for decision-making in the implementation of urban strategies for carbon footprint reduction. Using this tool to visualize the areas clearly, a series of maps have been made that include the total carbon footprint and each activity sector. By mapping the results, it is possible to visualize and prioritize those areas that produce the highest GHG emissions annually, analyze which activities contribute the most to this, and then propose strategies for their reduction. Thus, once the maps have been obtained, the study of specific measures has been proposed.

## 3.5 Actions evaluation

Once the carbon footprint results have been obtained, a methodology is presented to help the decision-making process in the proposal and evaluation of actions. By analyzing the results, it is possible to identify the areas with the highest emissions and the sectors of activity that contribute most to the carbon footprint. Based on this understanding, it is possible to propose measures to reduce emissions. However, as each city presents differences, each action proposal should be based on the characteristics of the municipality.

There are numerous actions that can be proposed to reduce greenhouse gas emissions in the districts. However, for the validation of this tool, the 15 key actions from Climate-KIC [45] have been used as a guideline. Therefore, the proposed actions are based on the transport sectors, energy consumed in buildings, and renewable electricity production. To verify the methodology, the evaluation of the strategies is considered both technically and environmentally. The total number of actions evaluated is five and are shown below:

- **Action 1:** Transition to electric mobility
- **Action 2:** Migration to public transport

- **Action 3:** Implementation of the 15 minute district concept
- **Action 4:** Electrification of thermal demand
- **Action 5:** Photovoltaic self-consumption

### 3.5.1 Transportation actions

In the case of transportation, emissions are related mainly to the upstream and downstream activities of life cycle vehicle use. In addition, cars for personal use are the most contributing to emissions. Reducing the need to own a high-emission private vehicle is therefore essential. Three alternatives are proposed for this purpose. The first, conservative, is to replace the current stock of cars in the city with the progressive replacement of electric cars. The second is to shift private transport to the public, and the third is to reduce the need for mobility through the concept of the 15-minute city. The first two strategies have been evaluated in order to use the tool to determine the efforts required. That is the number of cars that need to be replaced and the number of public transport vehicles that need to be added to the current public system to meet a target emission reduction. In this case, the target emission assessed is 20% of $CO_2$ equivalent emissions.

The first two strategies have been evaluated in order to use the tool to determine the efforts required. That is the number of cars that need to be replaced and the number of public transport vehicles that need to be added to the current public system to meet a 20% emission reduction. Of the three strategies, the one that requires the most effort is the third one since the generation of a 15-minute district means a great sum of resources and private and public financing to have all the services available in the district. The other two actions are not mutually exclusive; therefore, seeking the optimal solution between private investment to purchase electric vehicles and public investment to improve public transportation is necessary. However, the combination of both can occur simultaneously and progressively, obtaining more significant emission reductions or, on the contrary, reducing the necessary funding.

**Action 1: Transition to electric mobility**

In this action, it is proposed to reduce emissions by 20% by replacing combustion cars with electric cars. This measure has been calculated considering the number of existing combustion vehicles in each district and their category according to European standards. For this purpose, an iterative process has been carried out to obtain the number of replacement vehicles needed to reach the number of avoided emissions, considering their corresponding emissions factor. The iterative process followed is shown in Figure 17.

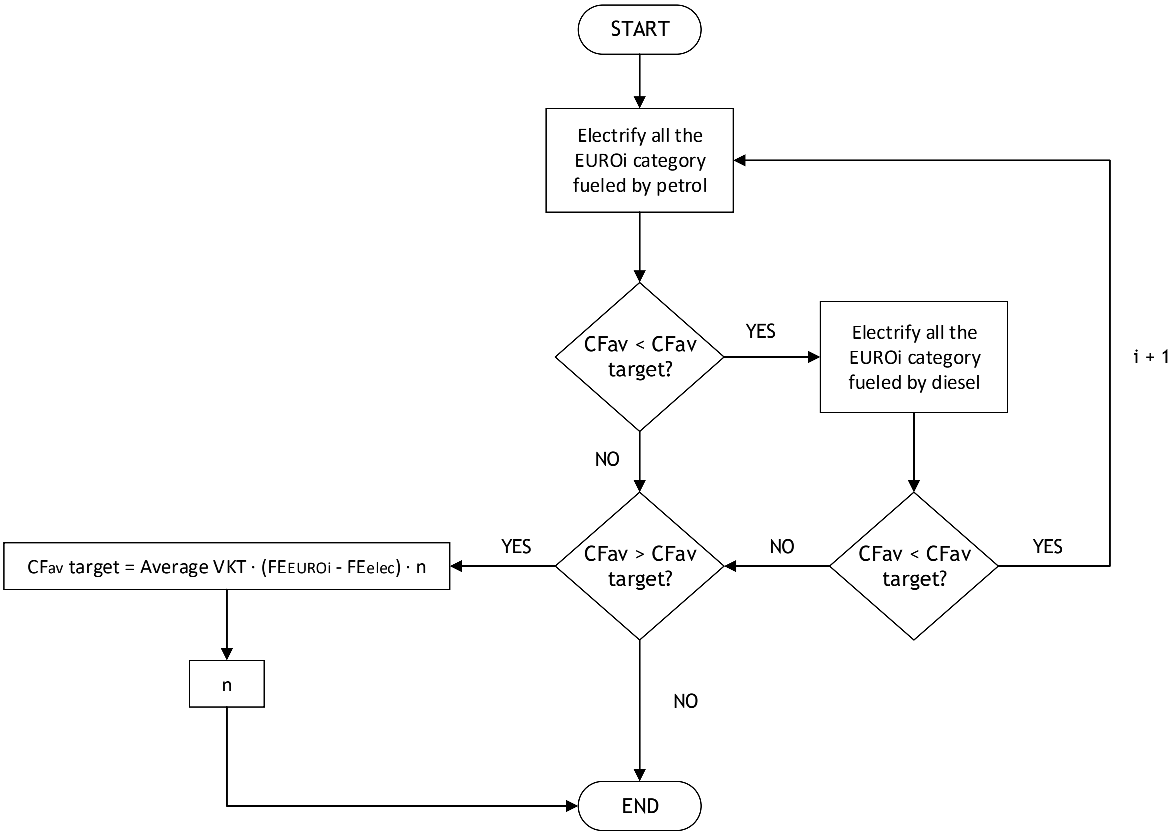



**Figure 17:** Number of cars replacement procurement (source: author's elaboration).

It is considered that the replacement of vehicles will be done by renewing the fleet of the district's vehicles from the oldest cars. Therefore, the process starts with replacing the vehicles registered in the district from the oldest category (pre-EURO) with petrol-fueled cars, then moves to replace the cars of the same category but fueled by diesel. When the replacement of vehicles in that category exceeds the carbon footprint reduction target, a calculation is made to obtain the number of cars in this category needed to complete the reduction. The average Vehicle Kilometer Traveled (VKT) during a year for the entire city is considered. Also, to evaluate this measure, the annual rate of vehicle replacement is considered in order to obtain an idea of the years that are needed to obtain the desired emissions reduction.

**Action 2: Migration to public transport**

In this action, it is proposed to increase the frequency and network of public transport. The number of buses or metro vehicles that need to be increased to reach the reduction of 20% of $CO_2$ equivalent emissions is determined. For this purpose, vehicle kilometers traveled (VKT) and the average occupancy rate for vehicle types are considered. To evaluate this action, first, the $tCO_2$ to be reduced by 20% was obtained, and then the VKT per person in each means of transport. The emission factors for each of them were also considered to balance emissions in transportation. All distribution to the bus, metro, and tram has been evaluated. In addition, a statistical distribution coefficient between these two public means of transport can be obtained to offer a more realistic public transport usage.

**Action 3: Implementation of the 15-minute district**

Going even further into the focus of the transportation issue, the implementation of the 15-minute district is proposed. The 15-minute district concept highlights the reduction of mobility needs. A 15-minute district can be achieved through various actions, such as teleworking or generating more local commerce. Thus, a 15-minute district has enabled more significant social and economic benefits in the neighborhood. As the evaluation is intended to reflect the emissions reduction, it has been considered that emissions due to transportation can be reduced by 20%.

### 3.5.2 Energy consumption in buildings

The building sector is one of the largest annual greenhouse gas emitters in urban areas, primarily related to energy consumption. Electricity and fossil fuels can satisfy a house's thermal demand, with natural gas being one of the primary fuels used for cooking, heating, and Domestic Hot Water (DHW). Also, fuel-based equipment tends to be less efficient than electric equipment and, in addition, generates much higher emissions. Based on the emissions produced due to natural gas consumption in buildings, the action proposed is to switch from natural gas consumption to electricity.

The measures evaluated in the energy sector have considered two fundamental aspects: switching from natural gas consumption to electricity and photovoltaic self-production. Electrification of thermal demand allows for emission reductions due to two vectors. First, the reduction of the emissions factor per MWh consumed and, second, the reduction of energy consumption due to the increased efficiency of electrical equipment. Photovoltaic self-consumption also improves the emissions factor due to the non-consumption of electricity from the national or territorial grid, with a high degree of electricity production with non-renewable energy sources and, on the other hand, a higher degree of energy independence in cities.

**Action 4: Electrification of thermal demand**

For this action, the residential sector's three types of thermal consumption are considered: heating, cooking, and domestic hot water (DHW). In addition, this action evaluates not only the modification in the factor emission but the reduction in consumption due to the increase in the efficiency of the electrical installations is also considered. For heating, replacing the current equipment is considered to be done with air-source heat pumps, with an estimated nominal COP of 3.5. Each kW of electricity consumed generates 3.5 kW of thermal capacity. In the case of domestic hot water, replacing gas boilers with electric water heaters has been considered, with similar efficiency. In contrast, replacing gas boilers with induction stoves has been considered in the case of cooking with a 50% of energy consumption reduction. Once the distribution of new consumption of both natural gas and electricity was obtained, the emissions were recalculated.

### 3.5.3 Renewable energy production

Photovoltaic self-consumption installations are a trend in the decarbonization of cities. They offer multiple advantages, such as the reduction of emissions and energy independence of cities. Therefore, generating electricity through photovoltaic systems has been proposed as an action. Photovoltaic self-consumption can be both individual and collective. This action is not intended to make differences between both modes of implementation but to evaluate the potential of the installable capacity of photovoltaics in the city by districts to supply residential demand. Photovoltaic self-consumption also improves the emissions factor due to the non-consumption of electricity from the national or territorial grid, with a high degree of electricity production with non-renewable energy sources and, on the other hand, a higher degree of energy independence in cities. The evaluation of this action is done considering the suitable rooftops of the city buildings.

**Photovoltaic self-consumption**

Using geographic information systems proposes estimating the photovoltaic potential of the roofs in a city. This has been decided due to the availability of referenced data of the buildings both through the Infrastructure for Spatial Information in Europe (INSPIRE) [124] and land registry data and the elevation of the buildings that are available through the Digital Elevation Model (DEM) data [125]. The general methodology through these systems is shown below:

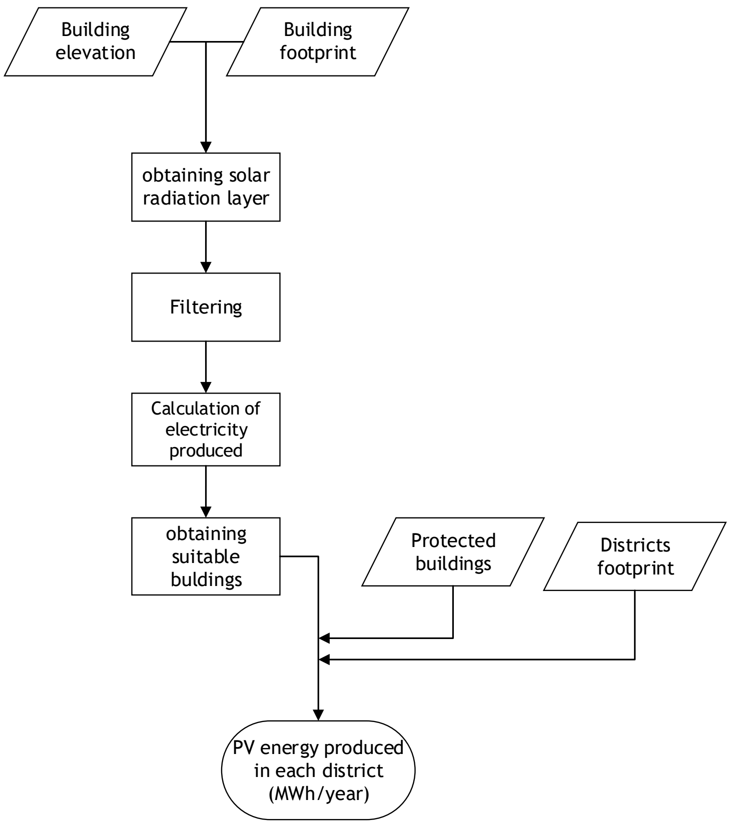



**Figure 18:** Photovoltaic production calculation methodology (source: author's elaboration).

With building elevation input data and the footprint of buildings available in the land registry, it is possible to obtain rooftop solar radiation. Therefore, once a layer of solar radiation is obtained, it is necessary to filter the results to obtain the best cells that fit the conditions. In this methodology, three different conditions are used: discard the cells with an annual radiation lower than 800 $kWh/m^2$; discard the cells with an inclination greater than or equal to 45 degrees; discard the cells oriented to the north. In this way, we ensure that we obtain the highest possible production. Hence, the next step is to obtain the electricity production of each building. For that, a tool of the GIS program should be used to sum all the cells located within a rooftop and then apply the photovoltaic efficiencies to convert solar radiation to electricity. The module and photovoltaic system efficiencies used are published by NREL and are considered 16.3% solar panel efficiency of PV module and 86% performance ratio with 14% system losses [126]. Finally, to know the energy that each of the districts can produce, the data obtained overlaps with the districts' footprints.

Subsequently, the new emissions calculation for energy would be as follows, leaving two scopes 2, one for grid use and the other for photovoltaic consumption.

$$CF_E PV(S2) = (PV_{elect \cdot District} \cdot EF_{PV}) \tag{2}$$

$$CF_E Grid(S2) = (elect._{consumption} - PV_{elect \cdot District}) \cdot EF_{Grid} \tag{3}$$

$$CF_E(S3) = CF_E Grid(S2) \cdot 9.6\% \tag{4}$$

Furthermore, in this methodology, it has been considered that the photovoltaic production of the buildings would be in a shared self-consumption regime, being able to share energy among the different consumers and, therefore, the photovoltaic production diurnal, in residential buildings, could be compensated by the neighboring businesses and other services such as schools, hospitals, etc. I.e. all the electricity generated is self-consumed, nos is deliverated to the grid.

# 4 Case study

The case study for the application of the methodology is the City of Valencia, Spain. The city of Valencia is extensively involved in the development and adaptation to accelerate sustainable growth and reduce emissions. This is reflected in the multitude of initiatives in which Valencia is a member, such as the Covenant of Mayors since 2009, through which the Sustainable Energy and Climate Action Plan (SECAP) has been updated several times [127], and through which diverse important commitments have been developed, such as the Climate Contract or the Urban Strategy 2030. In this line, numerous innovation projects with a high technological and social character have been generated, such as studies for the development of strategies for the reduction of energy poverty [128], or projects that contemplate the integration of green infrastructure on roofs or the implementation of green corridors in the city [129]. In addition, the city council has launched the energy poverty observatory and the energy observatory. Also, Valencia counts for energy offices available to inform citizens and has recently implemented its first local energy community. Nowadays, it is the European Green Capital and will be one of the 100 Climate-Neutral and smart cities by 2030. Therefore, responsible for conducting diverse strategies to accomplish this goal.

## 4.1 Scoping

For the case of Valencia, the boundaries selected are the administrative districts and neighborhoods of the city. The decision of the boundaries is due to two main factors: (1) the availability of data is usually to a greater extent in the administrative boundaries, and (2) the possibility of implementation of actions is more direct and simple from the institutions in administrative areas. Hence, the methodology has been applied to 19 administrative districts and 87 neighborhoods.

## 4.2 Data collection

The major part of activity data has been collected from the statistical database of the city [130]. Nevertheless, only some of the desired data has been available at the bottom level, then other sources have been considered. Therefore, it can be said that the data collection methodology used in this project is hybrid, with a greater consideration of bottom-up. To better understand the data type collection, the Annex is presented all the data activity and factor emissions collected, considering the level and the sources.

## 4.3 Carbon footprint calculation

As each of the sectors considered has its differences and the carbon footprint inventory calculation can differ from one sector to another based on the data availability, the general method described above presents its particularities. Therefore each one of the activities emissions calculation is going to be explained in detail in the next pages.

### 4.3.1 Transportation

Private cars
For private cars (PC), first, the share per EURO category following the European Standards [131] and the distance traveled yearly per age were obtained. The distribution taking into account the registered passenger cars for each district, was done. The factor emission of each category has been collected from EcoInvent 3.5 database [132].

The share of passenger cars in the city per European regulations and fuel type is as follows:

**Table 3:** Distribution of cars per European regulation and fuel in Valencia (1)

| | **Total** | | **Petrol** | | **Diesel oil** | |
|---|---|---|---|---|---|---|
| | Number | Share | Number | Share | Number | Share |
| Pre Euro | 44,579 | 12.7% | 41,022 | 92.0% | 3,556 | 8.0% |
| Euro 1 | 7,646 | 2.2% | 5,726 | 74.9% | 1,920 | 25.1% |
| Euro 2 | 24,534 | 7.0% | 13,065 | 53.3% | 11,469 | 46.7% |
| Euro 3 | 77,813 | 22.1% | 33,374 | 42.9% | 44,439 | 57.1% |
| Euro 4 | 98,660 | 28.0% | 35,348 | 35.8% | 63,312 | 64.2% |
| Euro 5 | 56,401 | 16.0% | 20,232 | 35.9% | 36,129 | 64.1% |
| Euro 6 | 47,927 | 13.6% | 24,647 | 51.4% | 23,086 | 48.2% |
| Total | 352,151 | 100.0% | 173,414 | 49.2% | 183,911 | 52.2% |

**Table 4:** Distribution of cars per European regulation and fuel in Valencia (2)

| | **Electricity** | | **LPG** | | **CNG** | |
|---|---|---|---|---|---|---|
| | Number | Share | Number | Share | Number | Share |
| Pre Euro | 1 | 0.0% | - | 0.0% | - | 0.0% |
| Euro 1 | - | 0.0% | - | 0.0% | - | 0.0% |
| Euro 2 | - | 0.0% | - | 0.0% | - | 0.0% |
| Euro 3 | - | 0.0% | - | 0.0% | - | 0.0% |
| Euro 4 | - | 0.0% | - | 0.0% | - | 0.0% |
| Euro 5 | 13 | 0.0% | 26 | 0.0% | 1 | 0.0% |
| Euro 6 | 109 | 0.2% | 67 | 0.1% | 18 | 0.0% |
| Total | 123 | 0.0% | 93 | 0.0% | 19 | 0.0% |

The factor emissions used integrates all the life cycle of the vehicles: materials production, material transportation, cars production, use phase, and disposal phase. As is the case, for the scopes allocation, it was assumed that 20 % of the distance traveled occurs within the district boundaries, following the previous work [113]. Therefore, 20% is scope 1, and 80% is scope 3, whereas scope 2 corresponds to the electric vehicles in districts. The expressions used to calculate the carbon footprint are the following ones:

$$CF_{PC(S1)} = \sum^{N} PC_{District,(f,y)} \cdot VKT \cdot EF_{EU_{standard}} \cdot 0.2 \tag{5}$$

$$CF_{PC(S2)} = \sum^{N} PC_{District,(elec,y)} \cdot VKT \cdot EF_{EU_{standard}} \tag{6}$$

$$CF_{PC(S3)} = \sum^{N} PC_{District,(f,y)} \cdot VKT \cdot EF_{EU_{standard}} \cdot (1-0.2) \tag{7}$$

Two-wheelers

For two-wheelers (TW), the same procedure as private cars were followed but allocating the number of two-wheelers per capita in the city and then distributed in each district. The distribution of two-wheelers in the city is as follows:

**Table 5:** Distribution of two-wheelers per European regulation and fuel in Valencia

| | **Total** | | **Petrol** | | **Diesel oil** | | **Other** | |
|---|---|---|---|---|---|---|---|---|
| | Number | Share | Number | Share | Number | Share | Number | Share |
| Pre Euro | 621 | 20.9% | 613 | 20.9% | 3 | 20.9% | 5 | 20.9% |
| Euro I | 546 | 18.4% | 540 | 18.4% | 2 | 18.4% | 4 | 18.4% |
| Euro II | 346 | 11.6% | 341 | 11.6% | 2 | 11.6% | 3 | 11.6% |
| Euro III | 1,165 | 39.3% | 1,151 | 39.3% | 5 | 39.3% | 9 | 39.3% |
| Euro IV | 289 | 9.8% | 286 | 9.8% | 1 | 9.8% | 2 | 9.8% |
| Euro V | - | 0.0% | - | 0.0% | - | 0.0% | - | 0.0% |
| Total | 2,968 | 100.0% | 2,931 | 100.0% | 13 | 100.0% | 23 | 100.0% |

The factor emissions also consider all the phases of the life cycle and the fuel type. The majority of two-wheelers are fueled by petrol and diesel. Also, since the distance traveled by these vehicles is shorter than private cars, it does occur within district boundaries. Hence, the scope allocation is scope 1. The expression used is presented here:

$$CF_{TW(S1)} = \sum^{N} TW_{District,(f,y)} \cdot VKT \cdot EF_{EU_{standard}} \tag{8}$$

The distance traveled per age of each type of vehicle (private cars and two-wheelers) is presented here:

**Table 6:** Annual distance traveled per vehicle type (km/year)

| Age | Passenger cars | Two-wheelers |
|---|---|---|
| 0-4 | 19,689 | 4,656 |
| 5-9 | 15,301 | 3,243 |
| 10-14 | 12,399 | 2,867 |
| 15-19 | 10,532 | 2,462 |
| >20 | 8,472 | 1,698 |
| Average | 12,266 | 2,903 |

Electric scooters

In the case of electric scooters (ES), the number was estimated for the country, then distributed per capita and allocated by the district. For the traveled distance, it was estimated per usage pattern [133] and kilometer per trip [134]. The next equation shows the calculation method for electric scooters:

$$CF_{ES(S2)} = \sum^{N} ES_{District,(f,y)} \cdot trip/year \cdot km/trip \cdot EF_{ES} \tag{9}$$

Private bicycle

In the case of bicycles, the average is based on the 40% assumption of the population having a private bike [135], and then distributed per capita in each district. The factor emission of bicycles considers all its manufacture and final disposal. So, the scope allocation considered is 3.

$$CF_{PB(S3)} = \sum^{N} \%bikes/inhab. \cdot inhab._{district} \cdot EF_{B} \tag{10}$$

Taxis

For taxis, the same procedure as private cars has been considered but considering the city's most used car according to European standards. In addition, since taxis travel throughout the city, the distribution of vehicles for the whole city has been allocated per capita. Also, the distance traveled can not be considered the same as private cars, and an estimation of distance traveled per taxi and the day was used [136].

$$CF_{TX(S1)} = \sum^{N} TX_{District,(f,y)} \cdot km/day \cdot days/year \cdot EF_{EU_{standard}} \tag{11}$$

Bus

For the carbon footprint of buses, it is estimated that the presence of stations is highly related to the presence of buses. Therefore, the kilometers annually traveled by the buses from statistical data of the city and the overall stations have been used to obtain an average distance traveled per station and then multiplied per the stations in each district. The emission factor considers the life cycle of a bus, and the emissions are linked to scope 1.

$$CF_{BUS(S1)} = \sum^{N} \frac{km_{buses}/year}{total_{stations}} \cdot stations_{district} \cdot EF_{bus} \tag{12}$$

Metro

The metro and tram network is comprises 9 lines for the entire city, each of different lengths and pattern usage depending on the weekday. Furthermore, the system and the vehicles can divide the metro and tram emissions. The system includes the infrastructure of the network and the stations. For the system calculation, it has been considered to distribute the entire length of the lines per capita and then multiply for its respective factor emission. In the case of vehicles, the distance per line length and the pattern usage has been considered to obtain an average VKT per vehicle. Then, following the same consideration as system calculation, it has been allocated per capita and multiplied per the corresponding factor emissions.

The length of the nine lines of the metro in Valencia are as follows:

**Table 7:** Lenght of metro lines

| | Length (km) | Stations |
|---|---|---|
| Line 1 | 72,145 | 40 |
| Line 2 | 39,445 | 33 |
| Line 3 | 24,691 | 26 |
| Line 4 | 16,999 | 33 |
| Line 5 | 13,293 | 18 |
| Line 6 | 3,571 | 21 |
| Line 7 | 15,497 | 16 |
| Line 8 | 1,230 | 4 |
| Line 9 | 24,859 | 23 |
| Total | 156,388 | 138 |

The departures per day type for the overall vehicles are shown in the next table:

**Table 8:** Departures per type day.

| | Departures |
|---|---|
| Workday | 2,566 |
| Weekend | 1,135 |
| Holiday | 3,658 |

The factor emissions collected from metro and tram are differentiated between material production and transportation, referred to in scope 3 for stations and constructions and end of life for vehicles. Scope 2 is referred to as the use phase as they run on electricity, and the on-site construction, operation, and maintenance of stations correspond to scope 1. For vehicles, it is considered 100 years of service life. This means that the emissions due to the construction and use of materials related to the vehicles are distributed over the 100 years of vehicle use.

The calculations done for obtaining the CF of the metro and tram are the following ones, calculating first the activity of the metro and tram as $A_{metro}$:

$$A_{metro} = \sum^{N} \frac{km_{line} \cdot (t_{workdays} + t_{weekends} + t_{holidays}}{inhab._{city}} \cdot inhab._{district} \tag{13}$$

$$CF_{metro(S1)} = A_{metro} \cdot EF_{use} \tag{14}$$

$$CF_{metro(S2)} = A_{metro} \cdot (EF_{const} + EF_{OM})_{stations} \tag{15}$$

$$CF_{metro(S3)} = A_{metro} \cdot [(EF_{m.prod.} + EF_{m.transp.})_{stations} + (EF_{const})_{vehicles}] \tag{16}$$

Bicycle-sharing

For the bicycle-sharing case, the total number of bicycles in the city is considered and allocated per average per capita. In this case, kilometers done per bicycle are not considered, as the emissions are related to the construction and disposal phase. To allocate the emissions, the factor emission is obtained considering a useful life of 10 years [137].

$$CF_{B_s(S3)} = \sum^{N} B - s_{district} \cdot inhab._{district} \cdot EF_B \tag{17}$$

### 4.3.2 Energy

Firstly, the data on energy bills for the entire city was obtained, separating natural gas and electricity consumption. Then, the energy consumed for each sector and district was calculated considering the building units and typology. Furthermore, considering that not all commercial industries or dwellings consume the same amount of energy, a correlation based on the income level per district was used based on the family budget survey of the National Institute of Statistics (INE) for the 2019 year [138]. Once the annual electricity and natural gas consumption per district was obtained, it was multiplied by the corresponding emission factor. In the case of transmission and distribution losses, the coefficient for the national grid was used [139] to obtain the related CF. The $CO_2$ emissions per MWh were obtained from the energy factor emissions for the territorial area [140].

The following expressions were used to obtain the CF due to energy consumption:

$$CF_{NG(S1)} = MWh_{NG}/year_{district} \cdot EF_{NG} \tag{18}$$

$$CF_{E(S2)} = MWh_{E}/year_{district} \cdot EF_{E} \tag{19}$$

$$CF_{E(S3)} = MWh_{E}/year_{district} \cdot EF_{E} \cdot \%T\&Dlosses \tag{20}$$

### 4.3.3 Consumption

Consumption activity was divided into three main groups: manufactured products, clothing, and food consumption. The manufactured products are appliances, electronics, furniture, machines, and household commodities. For the calculation of CF due to food consumption, average consumption per capita was obtained for Spain divided within different food categories [141]. Among the report categories, those that could be in the same group were also identified and then grouped using an average factor emission. That is the case for beverages, different oil types, some meats, fresh vegetables, and fruits and rest. With these aggregations, the final categories obtained per food type were 27. Moreover, those food types that were not solid as beverages, wine, and oil, have been converted to weight with the corresponding densities [142, 143, 144, 145]. Moreover, the category ready-to-eat was obtained from 7 different patterns [146, 147] by adding the weight to the regular portion. The food categories grouped were as follows:

**Table 9:** Food grouped per type of food.

| Oil | Beverages | Other meat | Fresh fruit | Fresh vegetables | Rest |
|---|---|---|---|---|---|
| Olive oil | Beer | Chicken | Orange | Tomato | Sugar |
| Virgin olive oil | Non-alcoholic beer | Goat | Mandarin | Pepper | Broths |
| Extra virgin olive oil | Bottled water | Rabbit | Peach | Zucchini | Sweeteners |
| Rape seed oil | Sodas | Processed meat | Apple | Onion | Spices and condiments |
| | Other alcoholic beverages | | Pear | Salad | Honey |
| | Juice | | Melon | Mushrooms | Salt |
| | | | Banana | Ready-to-eat | Sauces |
| | | | Strawberry | | |
| | | | Ready-to-eat | | |

The final annual consumption per capita obtained is presented in the following table:

**Table 10:** Annual food consumption per capita (kg/inhabitant)

| Food category | kg/inhab. | Food category | kg/inhab. |
|---|---|---|---|
| Oil: | 8.49 | Fresh fruit: | 4.98 |
| Olives: | 2.96 | Processed fruit & vegetables: | 1.63 |
| Rice: | 5.05 | Dried fruit: | 3.98 |
| Beverages: | 151.93 | Fresh vegetables: | 1.40 |
| Wine: | 6.82 | Egg: | 40.67 |
| Cereals: | 1.60 | Milk: | 3.21 |
| Cookies: | 4.98 | Dairy products: | 33.45 |
| Coffee & infusions: | 1.63 | Legumes: | 3.39 |
| Beef: | 3.98 | Bread & pastry: | 37.07 |
| Lamb: | 1.40 | Flour: | 2.55 |
| Other meat: | 40.67 | Potato: | 4.51 |
| Chocolate: | 3.21 | Ready-to-eat: | 15.05 |
| Fish: | 21.37 | Rest: | 8.10 |
| Pasta: | 4.51 | | |

The expression used for CF due food consumption in the district is the next one:

$$CF_{F(S3)} = \sum^{N} kg_{food}/year \cdot inhab._{district} \cdot EF_F \tag{21}$$

The process is more straightforward in clothing and manufactured products as the factor emission is $tCO_2e/capita$, and only the district population is needed. The equations used are the next ones:

$$CF_{C(S3)} = inhab._{district} \cdot EF_C \tag{22}$$

$$CF_{MP(S3)} = inhab._{district} \cdot EF_{MP} \tag{23}$$

### 4.3.4 Built environment

The built environment in the city of Valencia is divided between buildings, roads and streets, urban green areas, and agricultural lands. The factor emissions from built environment are represented per $tCO_2e/m^2$; therefore, the activities' CF calculation is based on its respective areas. In the case of roads, the area was unavailable; hence, a study that considers a 33% of the urban area corresponds to roads is used [148]. For roads, the scopes allocations were differentiated between material production and material transportation as scope 3, and on-site construction and operation and maintenance of roads as scope 1.

$$CF_{R(S1)} = (A_{total} \cdot \%R) \cdot EF_{const.R} \tag{24}$$

$$CF_{R(S3)} = (A_{total} \cdot \%R) \cdot (EF_{m.prod.} + EF_{m.transp.} + EF_{OM}) \tag{25}$$

In the case of UGA, the area is collected from the statistical data of the city council, whereas in the case of AL, it was collected from a territorial report [149]. For UGA, the scope emission allocation is scope 1 but considering construction and operation and maintenance as negative emissions and sequestration as positive. The emission factor for sequestration was obtained by considering an average in urban areas due to parks and urban trees. In the case of Agricultural lands is only considered sequestration but taking into account the average food production in the city.

$$CF_{UGA(S1)} = A_{UGA} \cdot (EF_{sequestration.UGA} - EF_{const.UGA}) \tag{26}$$

$$CF_{AL(S1)} = A_{AL} \cdot -EF_{sequestration.AL} \tag{27}$$

For buildings, the area was considered the rest of the urban space. Moreover, in buildings CF, it was considered that the material production and transportation is scope 3 and on-site construction is scope 1 but allocated within the lifetime of 50 years for a building [150].

$$CF_{B(S1)} = [(1 - \%R) \cdot A_{total} - A_{UGA} - A_{AL}] \cdot EF_{const.B} \tag{28}$$

$$CF_{B(S3)} = [(1 - \%R) \cdot A_{total} - A_{UGA} - A_{AL}] \cdot (EF_{m.prod.} + EF_{m.transp.}) \tag{29}$$

#### 4.3.5 Waste

The waste sector's carbon footprint was obtained by considering the total weight of waste produced in the city and then distributed per capita. The total waste produced in the city was obtained from waste fraction data. The following table presents the waste fraction generated per capita in the city of Valencia:

**Table 11:** Waste fraction production per capita.

| Waste fraction | kg/inhab. |
|---|---|
| Municipal solid waste: | 368.412 |
| Organic: | 14.997 |
| Glass: | 16.405 |
| Paper: | 20.592 |
| Plastic and light packaging: | 14.627 |
| Vegetable oil: | 0.044 |
| Batteries: | 0.004 |

In addition, an average share of the treatment categories (TC) used in the city was considered: landfilling, composting, and recycling. The share of the waste management categories are as follows:

**Table 12:** Treatment category share.

| Treatment category | Share |
|---|---|
| Landfill: | 56.7% |
| Recycled: | 18.3% |
| Energy: | 13.5% |
| Composting: | 11.5% |

In this case, the energy generation treatment category is not considered as the energy generated from waste is already included in the grid electricity generation emissions. The expression used for the calculation of CF from waste is presented here:

$$CF_{W(S3)} = \sum^{TC} kg_{waste}/inhab. \cdot \%TC \cdot inhab._{district} \cdot EF_{TC} \quad (30)$$

## 4.4 Results interpretation and mapping carbon footprint

To interpret the results, they are evaluated and analyzed at the city level. Then the carbon footprint is mapped by administrative districts and neighborhoods of the city. The GIS tool used for mapping this case study was ArcGIS. The base map of the city areas was produced based on the construction of polygons from data obtained from the city council. Once all the polygons were uploaded in ArcGIS, the obtained carbon footprint was translated and represented. Since there are many polygons, to quickly identify each one of the neighborhoods and districts, they are labeled according to what is established by the city council. Districts are assigned a single number, while neighborhoods are assigned two numbers, the first one being the identification of the district in which they are located and the second one the number of the neighborhood within the district. The assigned labels and the names of districts and neighborhoods are shown below:

**Table 13:** Label of districts and neighborhoods of Valencia.

| **1. Ciutat Vella** | **2. l'Eixample** | **3. Extramurs** | **4. Campanar** |
|---|---|---|---|
| 1.1. la Seu | 2.1. Russafa | 3.1. el Botànic | 4.1. Campanar |
| 1.2. la Xerea | 2.2. el Pla del Remei | 3.2. la Roqueta | 4.2. les Tendetes |
| 1.3. el Carme | 2.3. Gran Via | 3.3. la Petxina | 4.3. el Calvari |
| 1.4. el Pilar | | 3.4. Arrancapins | 4.4. Sant Pau |
| 1.5. el Mercat | | | |
| 1.6. Sant Francesc | | | |
| **5. la Saïdia** | **6. el Pla del Real** | **7. l'Olivereta** | **8. Patraix** |
| 5.1. Marxalenes | 6.1. Exposició | 7.1. Nou Moles | 8.1. Patraix |
| 5.2. Morvedre | 6.2. Mestalla | 7.2. Soternes | 8.2. Sant Isidre |
| 5.3. Trinitat | 6.3. Jaume Roig | 7.3. Tres Forques | 8.3. Vara de Quart |
| 5.4. Tormos | 6.4. Ciutat Universitària | 7.4. la Fontsanta | 8.4. Safranar |
| 5.5. Sant Antoni | | 7.5. la Llum | 8.5. Favara |
| **9. Jesús** | **10. Quatre Carreres** | **11. Poblats Marítims** | **12. Camins al Grau** |
| 9.1. la Raiosa | 10.1. Montolivet | 11.1. el Grau | 12.1. Aiora |
| 9.2. l'Hort de Senabre | 10.2. En Corts | 11.2. el Cabanyal-el Canyamelar | 12.2. Albors |
| 9.3. la Creu Coberta | 10.3. Malilla | 11.3. la Malva-rosa | 12.3. la Creu del Grau |
| 9.4. Sant Marcel · lí | 10.4. la Fonteta Sant Lluís | 11.4. Beteró | 12.4. Camí Fondo |
| 9.5. Camí Real | 10.5. na Rovella | 11.5. Natzaret | 12.5. Penya-roja |
| | 10.6. la Punta | | |
| | 10.7. Ciutat de les Arts i les Ciències | | |
| **13. Algirós** | **14. Benimaclet** | **15. Rascanya** | **16. Benicalap** |
| 13.1. l'Illa Perduda | 14.1. Benimaclet | 15.1. Orriols | 16.1. Benicalap |
| 13.2. Ciutat Jardí | 14.2. Camí de Vera | 15.2. Torrefiel | 16.2. Ciutat Fallera |
| 13.3. l'Amistat | | 15.3. Sant Llorenç | |
| 13.4. la Bega Baixa | | | |
| 13.5. la Carrasca | | | |
| **17. Pobles del Nord** | **18. Pobles de l'Oest** | **19. Pobles del Sud** | |
| 17.1. Benifaraig | 18.1. Benimàmet | 19.1. el Forn d'Alcedo | |
| 17.2. Poble Nou | 18.2. Beniferri | 19.2. el Castellar-l'Oliverar | |
| 17.3. Carpesa | | 19.3. Pinedo | |
| 17.4. Cases de Bàrcena | | 19.4. el Saler | |
| 17.5. Mauella | | 19.5. el Palmar | |
| 17.6. Massarrojos | | 19.6. el Perellonet | |
| 17.7. Borbotó | | 19.7. la Torre | |
| | | 19.8. Faitanar | |

## 4.5 Actions proposal and evaluation

As said in the methodology, the evaluation of 5 main actions is proposed. For each one of them different available data is used.

### 4.5.1 Action 1: Transition to electric mobility

The Carbon Footprint avoided target ($CF_{av}target$) is 20% of CF due to private cars in each district. The 12,266 average annual vehicle kilometers traveled (VKT) has been considered. The number of cars in each EURO category and their respective factor emissions were considered. For example, the following table shows the data used for Quatre Carreres district.

**Table 14:** Data to replace the fuel-based passenger cars in Quatre Carreres district.

| EU standard | Fuel type | Distribution | EF ($kgCO_2/VKT$) | Nr of cars | CF$_{av}$(t$CO_2e$) |
|---|---|---|---|---|---|
| **Pre- EURO** | Petrol | 92% | 0.419 | 3,505 | 8,010.50 |
| | Diesel | 8% | 0.368 | 305 | 513.45 |
| **EURO 1** | Petrol | 75% | 0.403 | 490 | 1,026.93 |
| | Diésel | 25% | 0.356 | 163 | 251.92 |
| **EURO 2** | Petrol | 53% | 0.387 | 1,117 | 2,131.64 |
| | Diésel | 47% | 0.344 | 980 | 1,373.78 |
| **EURO 3** | Petrol | 43% | 0.371 | 2852 | 4,905.10 |
| | Diésel | 57% | 0.332 | 3,798 | 4,787.23 |
| **EURO 4** | Petrol | 36% | 0.355 | 997 | 1,526.81 |
| **EURO 6** | Electricity | 100% | 0.225 | - | - |

### 4.5.2 Action 2: Public transport migration

For this purpose, vehicle kilometers traveled (VKT) were considered. The average occupancy rate for a private car is 1.18 people per car, and the available places for bus and metro were also considered, 66 people for the bus [151], and 400 people for the metro and tram vehicles [152]. Also, the statistical distribution coefficient between these two public means of transport was obtained from the INE [153].

The following table shows the data used for the assessment:

| | Transport type (VKT/person) | factor emissions ($tCO_2e/VKT$) | Emissions per person ($tCO_2e/person$) |
|---|---|---|---|
| Private car | 9983.42 | 0.00038 | 3.789 |
| Bus | 644.00 | 0.00033 | 0.213 |
| Metro/tram | 14.52 | 0.0104 | 0.151 |

**Table 15:** Data calculation for migrating transport.

### 4.5.3 Action 4: Electrification of thermal demand

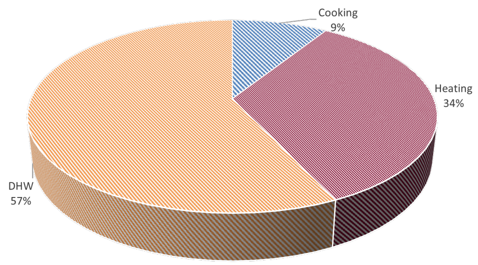
The Spahousec project [154] developed per IDAE shows that domestic thermal demand is distributed in the Mediterranean area of Spain, where Valencia is located, as seen in Table 16.

| | NG consumption | Electricity consumption |
|---|---|---|
| Heating | 32% | 46% |
| DHW | 40% | 22% |
| Cooking | 31% | 30% |

**Table 16:** Thermal consumption distribution in the Mediterranean area.

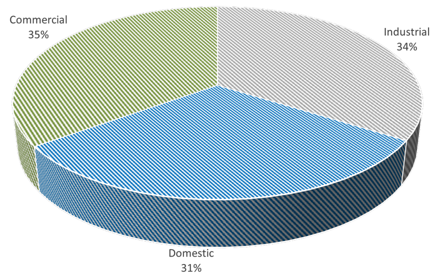
As shown in the table above, natural gas consumption is high in this European region. Therefore, Valencia has great potential to reduce energy consumption emissions by replacing natural gas equipment with electric equipment. In this action, following a study by Massip et al., [155], the conversion of natural gas consumption to electricity is proposed, thus accounting for the migration of emissions and their reduction with the use of the characteristic emission factor for electricity and natural gas. The analysis has considered the distribution of natural gas consumption in the residential sector. The distribution in Valencia is as follows:

**Figure 19:** Residential natural gas consumption distribution.




However, since the distribution of natural gas consumption in the city's sectors follows an almost balanced distribution between commercial, residentia,l and industrial [130] (see Figure 20), the implication of replacing the equipment used in the city's commercial could be analyzed.

**Figure 20:** Natural gas consumption in the city.




As seen in the graph, the distribution by sector in the city is practically the same in each sector (residential, commercial, and industrial). Since commercial consumption usually has similar characteristics to residential consumption in thermal consumption and equipment, two different cases are proposed for the study. Assuming that most of the consumption is due to heating in the commercial sector and applying the same efficiency considerations as before.

### 4.5.4 Action 5: Photovoltaic self-consumption

The GIS software used was ArcGIS and the emission factors used are, in the case of the grid, the emission factor of the territorial grid. In the case of photovoltaic production, those obtained in the study of Ligardo et al.[156]. This emission factor takes into account the production of the module and the scope three of its disposal as well.

Furthermore, using Geographic Information Systems (GIS) such as ArcGIS makes it possible to perform a more detailed building-by-building study. Therefore, to obtain the photovoltaic energy production capacity of each of the districts by counting the buildings, ArcGIS was used. The input data for the calculation were the cadastral references of the buildings that can be obtained from the INSPIRE database and the data from the Digital Building Surface Model, with a mesh size of 2.5 $m^2$ [157]. With this data, the program tools can calculate the annual solar radiation received by each of these 2.5 $m^2$ cells. Subsequently, filtering is performed to eliminate those not located on the south side to obtain all the cells that are susceptible to being used.

# 5 Results and discussion

This section shows the results obtained. First, the carbon footprint results are shown, followed by the results obtained from the evaluation of the actions.

## 5.1 Results interpretation and mapping carbon footprint

### 5.1.1 City scale

Results at the city level provide an overview of the most emitting sectors and each scope's contribution to the overall city. The following two graphs show the contribution of the scopes and weight of each sector of activity in the carbon footprint.

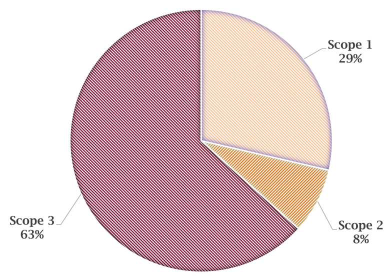



**Figure 21:** Scopes distribution.

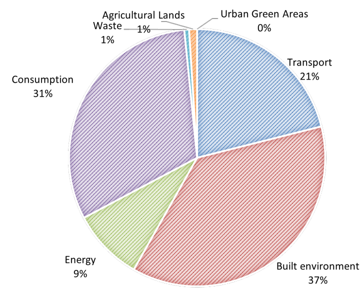



**Figure 22:** Activity sectors distribution.

As seen in the pie charts, scope 3 represents 63%. Thus, more than half of emissions in the city are caused outside the city boundaries but are closely related to the activities that take place in the city. In the case of the activity sectors, there is a large contribution in the built environment (37%) and consumption (31%), followed by transportation (21%) and energy (9%). Also, it can be seen that the contribution of green urban areas is negligible, but agricultural lands sequestrate as much $CO_2$ as the produced by waste yearly.

However, each sector has a different contribution to the 3 scopes. To analyze this in more detail, Figure 23 is shown below.

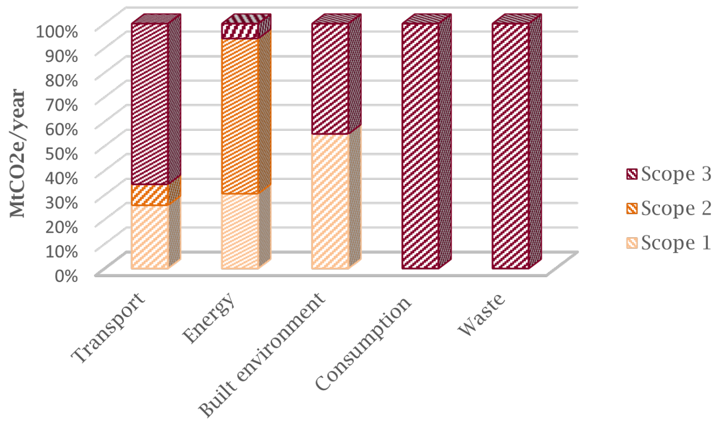



**Figure 23:** Weight per scopes of activity sectors.

As shown in the Figure 23, it is verified that the major contribution is scope 3 in all the sectors except per energy consumption. Scope 3 emissions are difficult to reduce because they correspond mostly to consumption patterns and habits. They are caused by the production of materials and their transport to cities. Therefore, this scope includes the construction of vehicles, the extraction of the materials needed for their manufacture, and their final disposal at the end of their useful life. The same applies to the built environment since the extraction of materials for road and building construction and their transport to cities is included in this scope. The same pattern can be observed in the consumption and waste sector. In the case of consumption, the 3 scope emissions are related to the transportation and procurement of goods consumed in the city. In contrast, in the waste sector, the treatment of the waste generated inside the city boundaries is considered to happen outside the city and therefore corresponds to the same scope. In contrast, Scope 1 is weighted in the built environment, primarily due to the on-site construction phase of buildings and roads and the fuel-based energy consumption during this phase. Also, scope 1 is present in energy and transport. The energy emissions are due to the consumption of fuels for thermal comfort in buildings and in transport due to the use of means of transport fueled by petrol and diesel. The lowest ranked scope in the results is Scope 2, which is due to the electricity coming from the power grid, mainly used in cities due to the electricity consumption for household appliances and cooling and also of the electric-based vehicles used in the city.

### 5.1.2 District scale

This section will present the carbon footprint results in a clear and simple visualization. The city's carbon footprint will be explained from the most general to the most concrete, giving a clear idea of the emissions produced by each district.

#### Global carbon footprint

First, the total carbon footprint per district is presented to give a clear idea of the most polluting districts and the sectors involved.

The global carbon footprint of the city at a district scale is presented here. The maps are made to depict the total carbon footprint in the background, while the pie charts represent the contribution of each sector activity in the districts:

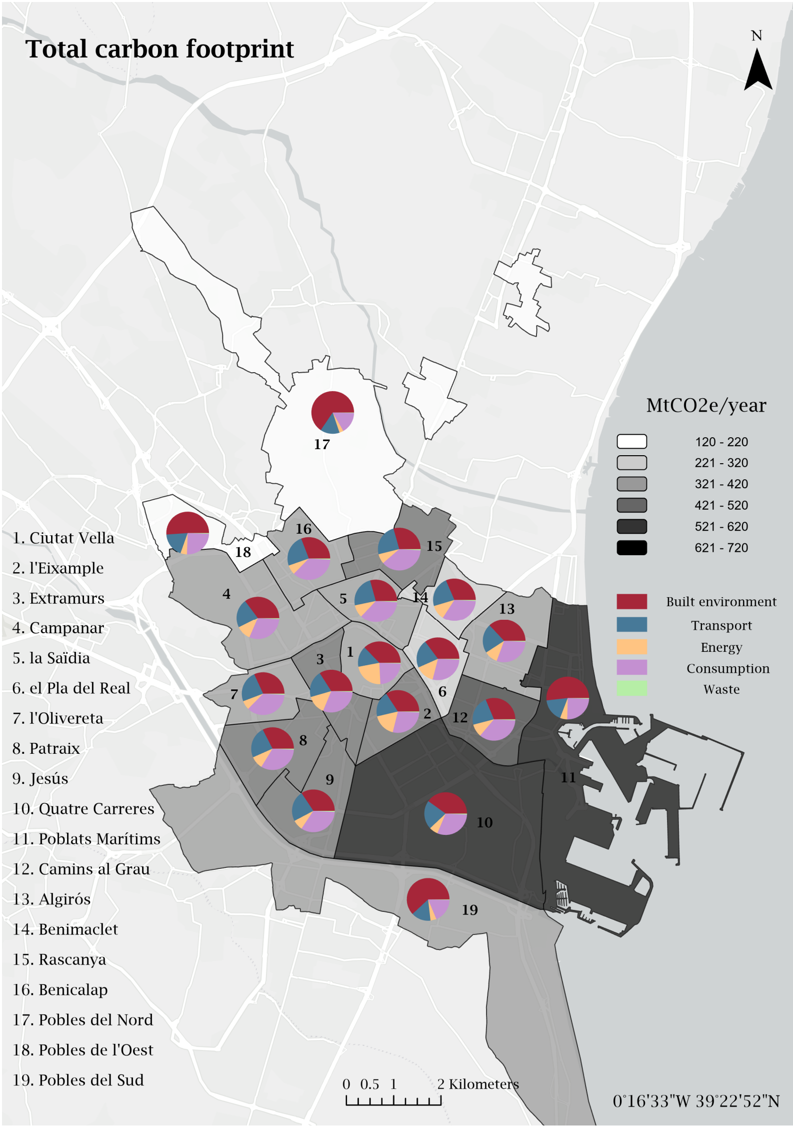



**Figure 24:** Total carbon footprint districts and activity sectors.

As can be seen in the map, the darkest districts produce more $CO_2$ emissions annually. It is shown that the districts of Quatre Carreres (10) and Poblats Marítims (11) produce a large number of emissions, while Poblats del Nord (17) and Poblats del Sud (19) do not contribute as much compared to the other districts. Furthermore, the pie charts show that the emission produced by each sector is not equally built environment and consumption. In addition, generally, the third contributor corresponds to the transport sector. Still, there are some districts where the energy sector weight is more significant or similar to that of transportation, as Ciutat Vella (1), Eixample (2), and Extramurs (3).

This lower weight in transportation in the areas that constitute the city's urban core may be due to the local government's efforts in recent years to reduce traffic. Examples of these actions are the increased incorporation of bicycle lanes, parking areas reserved for district residents, and pedestrianized commercial areas, especially in Ciutat Vella (1).

Since the transportation and energy sectors are more relevant in Scope 1 and 2, they are analyzed in more detail. In this way, it is intended to facilitate the proposal of solutions at the local level. Scope 3 is more difficult to change with decision-making proposals from the local government, although, in scopes 1 and 2, it is possible to act more directly from local policies. However, the contribution of energy consumption and transportation depends on the district and will be analyzed in more detail. Moreover, urban green infrastructure has advantages due to the direct reduction of emissions through $CO_2$ sequestration. For this reason, the annual sequestration due to urban green areas and agricultural land and their dispersion in the districts is also studied in more detail.

**Transportation**

Figure 25 focuses on the results of the equivalent carbon dioxide emissions due to transport at the greyscale and the diverse general activities shown in the pie charts.

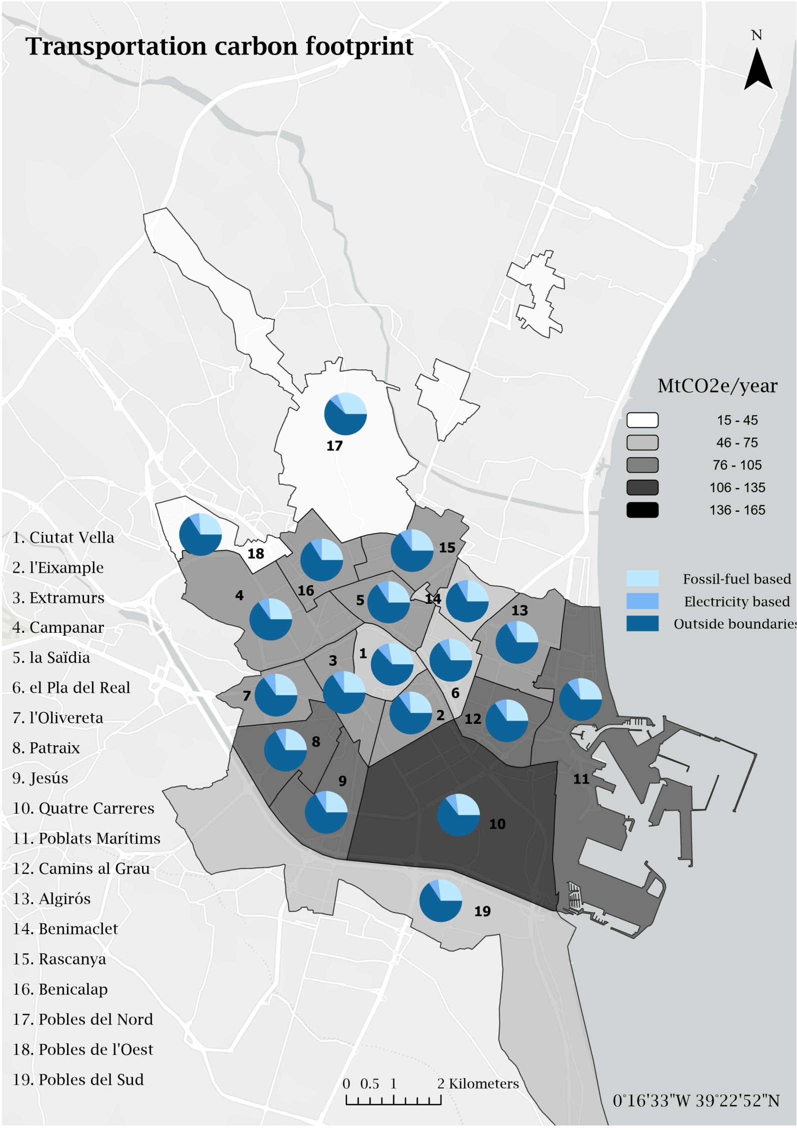



**Figure 25:** Transport carbon footprint districts and activity sectors.

The map above represents the total amount of $CO_2$ equivalent emissions related to transport, distinguishing between fuel-based transport (scope 1), electric-based transport (scope 2), and outside boundaries emissions (scope 3). The activities referred to as fuel-based are those related to the use phase in private cars, taxis, and buses. In contrast, electric-based transport means the use of electricity in the usage phase as subway, tram, and electric vehicles such as scooters and private electric cars. Outside boundaries represent the material production, transport, and disposal of all the vehicles and railways of metro and tram considered, and the 80% of fuel-based transport in the districts considered to occur outside the district boundaries.

As can be seen in Figure 25, the district with the most emissions throughout a year produce is Quatre Carreres (10), followed by Patraix (8), Jesús (9), Poblats Marítims (11), and Camins al Grau (12). Therefore, it is necessary to focus on those areas if the actions focus on reducing transport emissions. In addition, the most contributing activity is transportation outside the district's boundaries. The map also shows the significant impact of fuel-based transportation compared to electricity-based. So, in transport, the importance is then related to fossil-fuel-based transport such as cars, motorbikes, or buses.

Furthermore, it is known that not all vehicles and means of transport emit the same. Hence, the following map (Figure 26) shows the emissions divided by vehicle type.

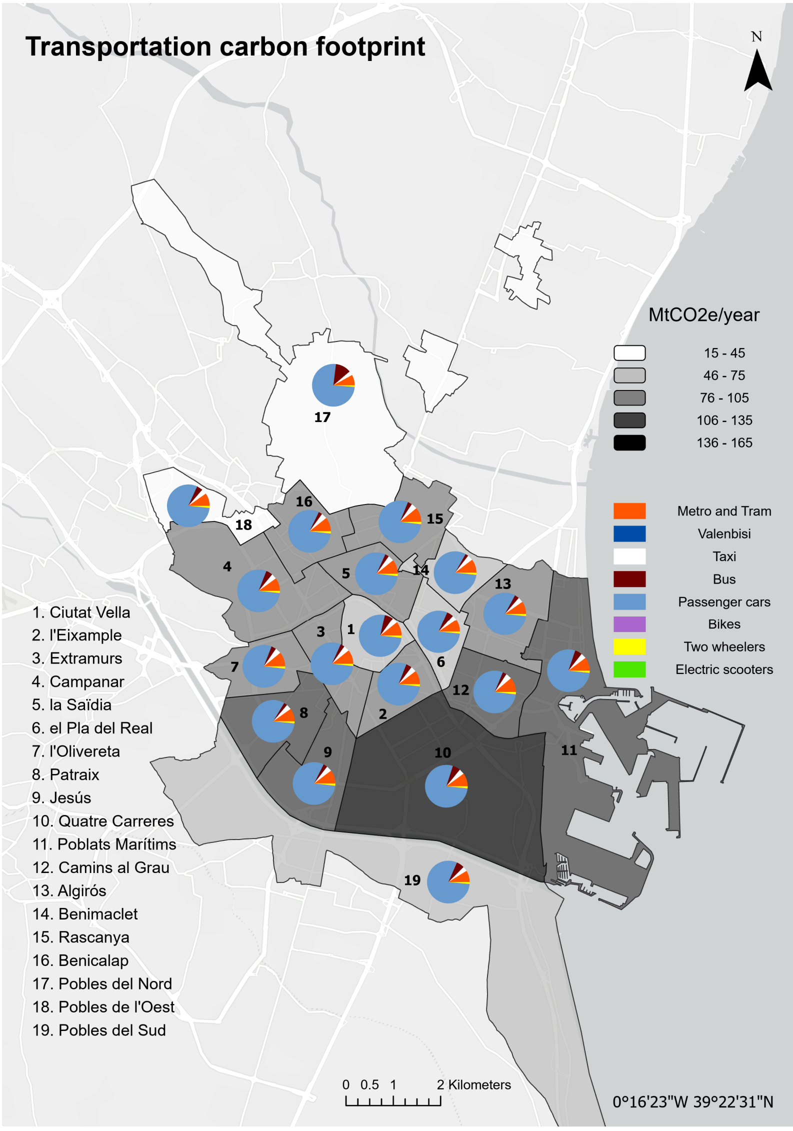



**Figure 26:** Transport carbon footprint districts and transportation mode.

This map shows that most of the emissions are related to private transport, primarily by passenger cars, while public transport emissions are related mainly to metro, bus, and taxi. Nevertheless, its contribution is negligible compared to private cars. In addition, the emissions proportion is similar in each district per transportation activity except per district 17, where the contribution of buses is more significant.

### Energy consumption

The last of the sectors that counts the most is energy consumption, taking into consideration the three scopes, for the overall city counts for the 9% of the emissions produced but has the more considerable contribution between city boundaries, meaning in the scopes 1 and 2.

In this case, as the maps showed previously, the emissions related to energy consumption are in the background, whereas the pie charts show the contribution of the activities on energy.

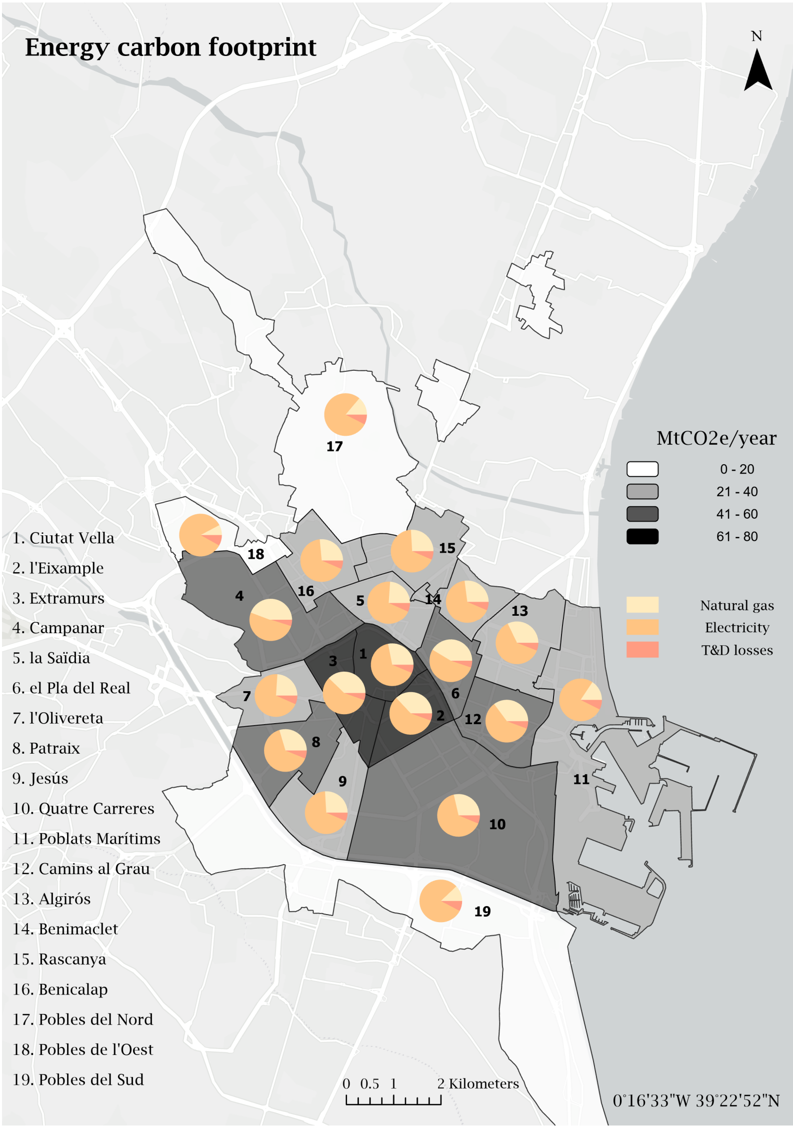



**Figure 27:** Energy carbon footprint districts and activity sectors.

The map represents the three emission scopes due to the energy sector. As explained, the clearest one is due to natural gas, representing scope 1. Electricity emissions are in the middle, scope 2, and transmission and distribution of electricity losses due the energy consumption, represent scope 3. As can be seen in the map above, the highest number of GHG emissions due the energy consumption is produced in the districts of Ciutat Vella (1), Eixample (2), and Extramurs (3). Therefore, if actions are intended to address emissions from the energy sector, those measures should be applied to a greater extent in these three districts. In addition, the distribution in the contribution is observed that have a greater weight in electricity consumption. However, there is also a greater contribution in some districts in natural gas consumption, highlighting the districts mentioned above but also Pla del Real (6), Campanar (4), Camins al Grau (12), Quatre Carreres (10) and Patraix (8).

According to the procedure for calculating the emissions produced due to energy consumption, the central areas of the city (districts 1, 2, and 3) consume more energy due to their high income. Therefore, an increase in emissions due to income level could be established following previous studies [100, 101]. Another possible explanation lies in the characteristics of the buildings since, being these districts with an old building stock, they could be in poor insulation conditions and, therefore, require higher energy demand. However, a study carried out on energy certificates in the city of Valencia by Van As et al. [158] discards this possibility, considering that the energy certificates of dwellings located in the districts of Ciutat Vella (1), Eixample (2), and Extramurs (3) are not excessively low. Thus, there is still work to be done to identify what these emissions and consumptions are subject to.

**Green areas**

While the construction of buildings and roads strongly produces greenhouse gas emissions from the built environment, the distribution of green areas in the city represents a low rate of emissions reduction but with a great potential for environmental, social, and biodiversity improvement. For this reason, this study shows the contribution of this reduction in emissions and its distribution in the city. On the other hand, as it is known, the effect on emissions sequestration is different depending on the type of vegetation, and, it is represented in both Urban Green Areas (UGA) and Agricultural Lands (AL).

The following maps show the Carbon emissions reductions due to the green areas distributed in the districts.

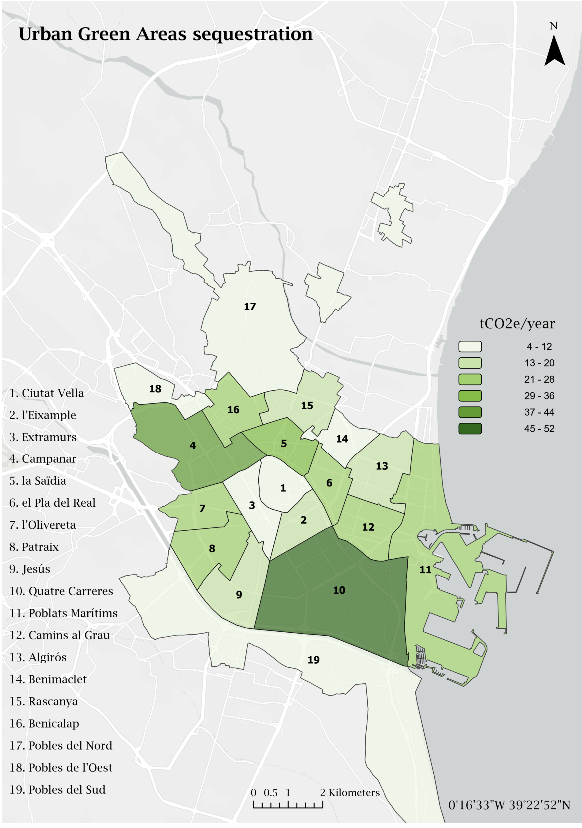



Figure 28: Urban green areas sequestration.

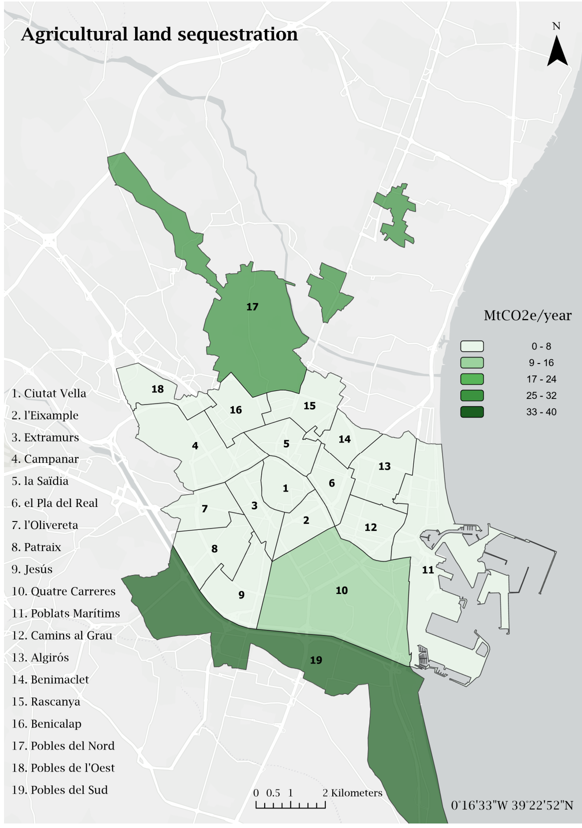



Figure 29: Agricultural lands sequestration.

The results and their representation can be differentiated into several topics. One of them is the difference in the amount of sequestration, and the agricultural lands reflect Mtons, whereas UGA is reflected in tons. Also, the AL is allocated in the city's periphery districts with large quantities of agricultural land, whereas the UGA is distributed within the city. So, based on that, agricultural land is beneficial for carbon emissions reduction in cities and is preferable to urban green areas. Taking care of the existing agricultural areas in the city can be favorable to carbon emission reduction, and exploring the vegetation type implication for urban green areas should be considered. In this sense, the city is developing initiatives that contemplate green areas. On the one hand, some initiatives promote the implementation of urban agriculture in areas with more significant heat island effects in the city. On the other hand, Valencia has been named European Green Capital 2024, and the city council has considered implementing local NBS measures.

### 5.1.3 Neighbourhood scale

The calculations have been adapted to the city's neighborhoods to conduct a more detailed analysis. Studying emissions at the neighborhood level aims to conduct a more local emissions analysis. It serves as an important part of the prioritization process in decision-making for areas where the local government can implement emission reduction strategies and, at the same time, establish those neighborhoods where a more detailed analysis at the household level would be advisable.

The following map presents the sum of the three emission scopes per each neighborhood:

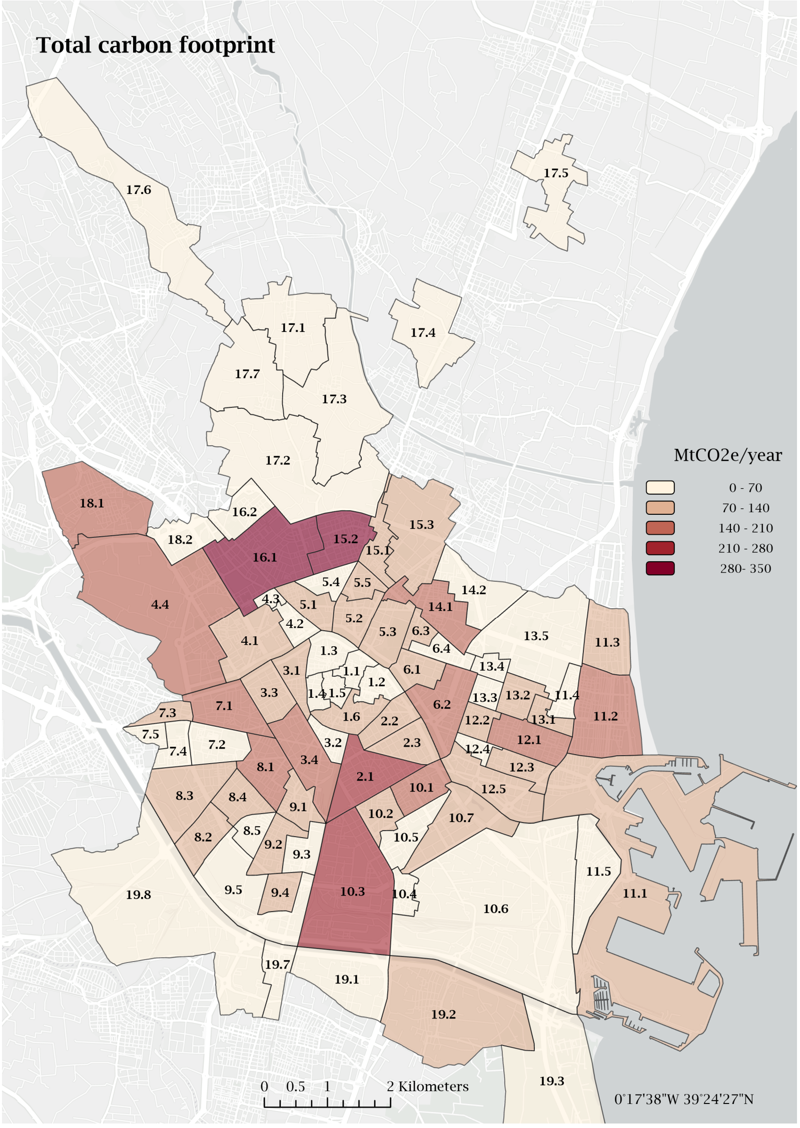



**Figure 30:** Overall scopes carbon footprint of neighborhoods

As can be seen, this map reflects that the distribution of the carbon footprint in the city is different in neighborhoods than in districts. The neighborhoods that emit the most GHGs over a year are Benicalap (16.1) and Torrefiel (15.2), followed by Malilla (10.3) and Russafa (2.1). In the case of Benicalap, the emissions could be based on the high-density population as it is the neighborhood with the highest number of inhabitants per square meter. From these results, it is remarkable that the neighborhoods with the highest emissions are not located in the districts with the highest emissions. It is also noteworthy that two neighborhoods have high emissions while a large part of the city's neighborhoods has medium-low emissions (below 140 $MtCO_2$ equivalent). Accordingly, in the case of the study applied to neighborhoods, it would be interesting to focus on those with the highest overall emissions and apply decarbonization measures to guide the development of carbon-neutral neighborhoods for enhancing carbon-neutral districts.

Moreover, it is shown in Figure 30 that although the district of Quatre Carreres (10) is the most emission in the city, the largest neighborhood is a poor emissions producer. The only neighborhood in the district with high emissions is Malilla (10.3). Hence, from this analysis and the difference between district and neighborhood scales, it can be said that focusing efforts on a neighborhood scale would be more beneficial and efficient.

Furthermore, a more detailed analysis of the energy and transportation sectors is done to consider the specific zones of the city to apply efforts in those sectors.

The following map represents the transport carbon footprint per neighborhood:

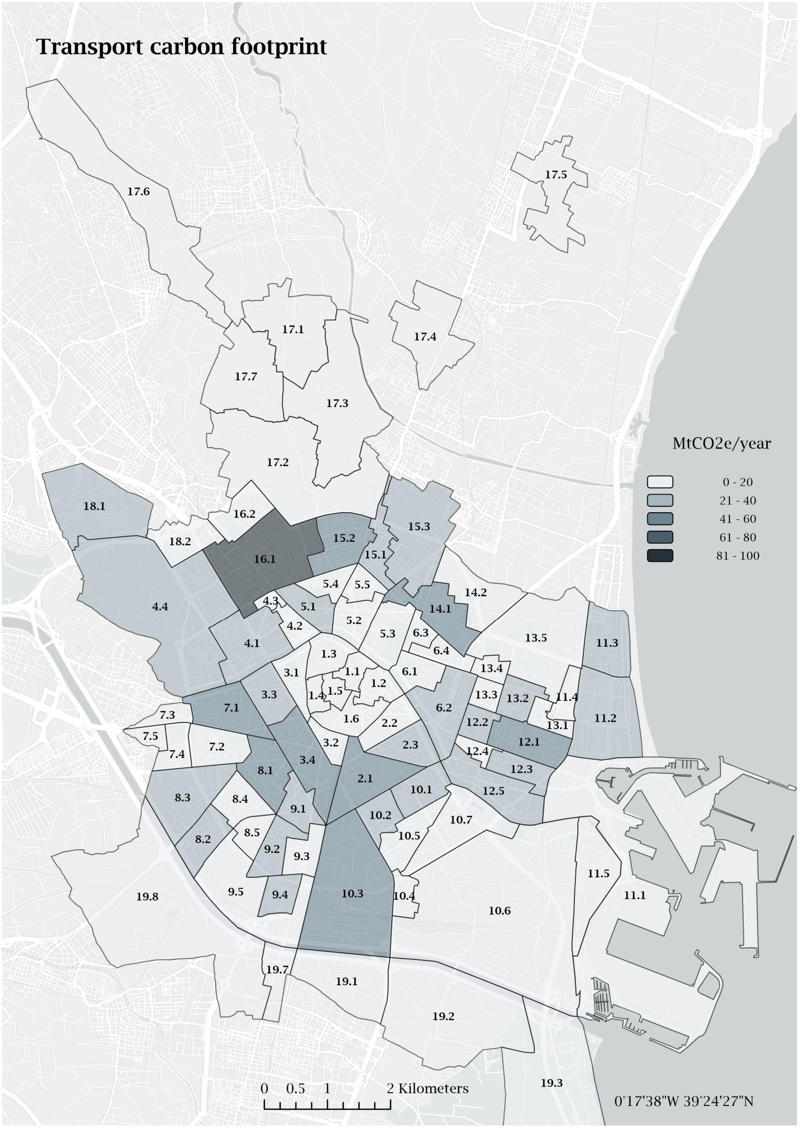



**Figure 31:** Transport carbon footprint of neighborhoods.

As observed in the map above, there is only one super emitter neighborhood in the transportation sector, Benicalap (16.1). Also, it can be highlighted that the center of the city and the outermost neighborhoods have minimal emissions due to transport.

The next step is to analyze the energy carbon footprint. The overall energy emissions are represented here below:

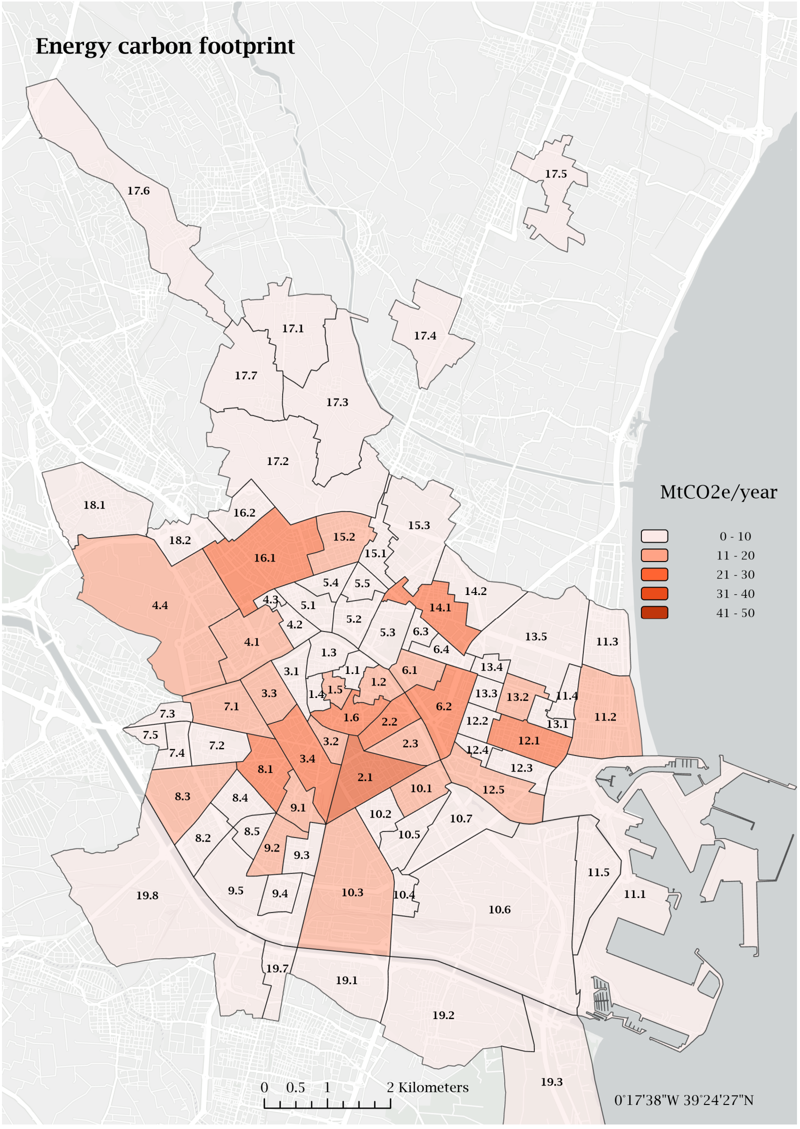



**Figure 32:** Energy carbon footprint of neighborhoods.

As seen above, as observed in the map, the energy is more distributed than the transport carbon emissions. It is more intense mainly in neighborhoods belonging to districts 1 (Ciutat Vella), 2 (Eixample), and 3 (Extramurs), which are located in the city center, an also in neighborhood 16.1 (Benicalap).

The possible interpretation of these results is in Benicalap (16.1) based on the high population density and in the other neighborhoods on the income, as explained in the results of the district scale.

Finally, coming back to the city scale, the scope with the highest emissions in the case study city is scope 3 (63%), which refers to the indirect emissions that occur due to the activities carried out in a city. The sectors with the most significant emissions in the city are built environment (37%), consumption (31%), and transportation (21%). In fourth place are emissions due to energy consumption (9%). The results show that indirect emissions, which are largely related to the consumption patterns of the inhabitants, are relevant and need to be taken into account if the objective is to generate a carbon-neutral city. However, strategies that promote behavior change take time to implement and are incremental. Therefore, they must be present in the development of a sustainable city. Education in the areas of consumption, above all, is essential. Of the different strategies that can be put into practice, it is important to offer information on more sustainable habits, favoring local consumption, reducing excessive energy consumption, and using active means of transport.

To reduce consumption-based emissions, strategies to change citizens' habits that promote responsible and local consumption should be favored. In this sector, manufactured products, clothing, and food are considered; reducing its need would be required to reduce its cause emissions. In manufacturing products and clothing, the cities' circularity has been studied, highlighting that the city industry could decrease this related scope 3 emissions by product manufacturing and clothing production [100, 101]. Also, Extending the useful life of these to reduce the purchase of them could be a possible action to reduce their associated emissions, such as the extraction of materials and transportation to the consumer. In the case of food consumption-based emissions, the emissions are largely related to the type of food and the amount consumed by citizens. In this sense, shifting food consumption towards a more sustainable and healthy way of eating and buying locally produced vegetables in Valencia has great reduction potential. Taking advantage of the fact that we live in the Mediterranean area, generating more interest in this diet and favoring the purchase of products on a more local scale would be necessary. In addition, several studies have shown dietary implications on emissions [159, 160]. The Mediterranean diet, with lower consumption of meat and dairy products, is beneficial for both health and the environment.

In the case of the built environment, as explained in the methodology section, emissions correspond to a large extent to buildings already constructed. These emissions depend on the useful life of the building; therefore, these emissions are still being accounted for now. It is currently not possible to reduce them, but this impact can be considered to reduce them in future buildings. Consider more sustainable production processes for new buildings would be advisable. Scope 3 emissions of buildings correspond to the materials extracted and brought to the city and, on the other hand, their construction process. In the case of materials, reducing the use of concrete and opting for sustainable materials such as lumber should be prioritized. In the case of the construction process, renewable energy should be used as it is the part with the greatest impact. In addition, we need to consider future buildings as efficient buildings, highlighting insulation to reduce energy demand and incorporating renewable energy on roofs, such as photovoltaic systems and solar collectors for domestic hot water.

The third activity sector contributing to the city's GHG emissions is transportation. Although the impacts of combustion and the use of vehicles in the city are notorious, its contribution to Scope 3 is even more since it represents 60% of the emissions from using a vehicle. In addition, cars for personal use are the most contributing. Reducing the need to own a high-emission private vehicle is therefore essential. A person who does not need to own a car will not generate emissions from its use, let alone its production. Also, transportation actions implemented over the years in the city center have proven to reduce emissions effectively. Nevertheless, it is necessary to reduce transport needs at the local level, but above all at the regional and global levels. Encouraging the use of sustainable transport is an important basis for any government.

The last sector with a significant contribution to the city's emissions is energy, with 9%. However, this does not mean it is less critical since many of these emissions are produced by the building sector. The best way to tackle energy-based emissions would be to reduce energy demand by incorporating energy efficiency measures and renewable energy systems to produce electricity through photovoltaic systems—the shift from fuel-based heating and cooling systems to electricity-based ones.

Furthermore, the analysis carried out in the districts and neighborhoods shows that the emissions differ between areas. In addition, different alternatives have been analyzed through the tool that helps to understand the efforts and potentials a city requires or has to obtain its neutrality. The results show that out of the 19 districts, two present high emissions when at the neighborhood level, the same occurs. In other words, emissions in a city are not generalized and are established in some specific points with greater intensity. Therefore, prioritizing those areas with the highest emissions is a task that can be useful in several ways: first, because of the evidence that they need to be taken into account and, second, because of the possibility of generating pilot districts and neighborhoods that can serve as an example for the rest of the city. In addition, studying in more detail the socioeconomic levels as well as the various technical characteristics that lead to a higher level of emissions would be advisable, thus favoring a more effective implementation of strategies for the decarbonization of the city.

## 5.2 Actions evaluation

This part presents the results obtained in reducing the carbon footprint by applying the 5 measures described in the methodology section, belonging to the 15 key actions to achieve a climate-neutral city[45].

### 5.2.1 Action 1: Transition to electric mobility

The annual replacement of vehicles in each of the city's districts to achieve a 20% reduction in private transportation emissions is shown in Figure 33.

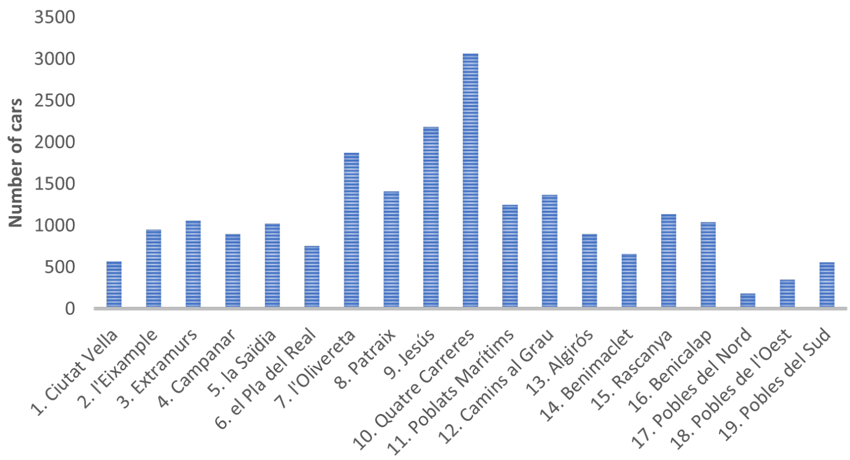



**Figure 33:** Annual vehicle replacement in the city districts (source: author's elaboration).

As can be seen in the graph, the districts where most cars need to be replaced annually to achieve a 20% reduction in emissions are Quatre Carreres (10), Jesús (9), and Olivereta (7). The total number of cars to be replaced annually to achieve in each district is between 40-45% of the registered passenger cars in the district, and the annual replacement rate is between 5-6%. In addition, if the vehicles' replacement follows the city's trend, it is a 3% rate of replacement [130], and the time needed to replace all the cars is 15.5 years. Therefore, in order to reach the selected emission reduction point, it is necessary to duplicate the annual replacement rate of vehicles.

The map representing the total emissions reduction in 2030 with this measure is shown below:

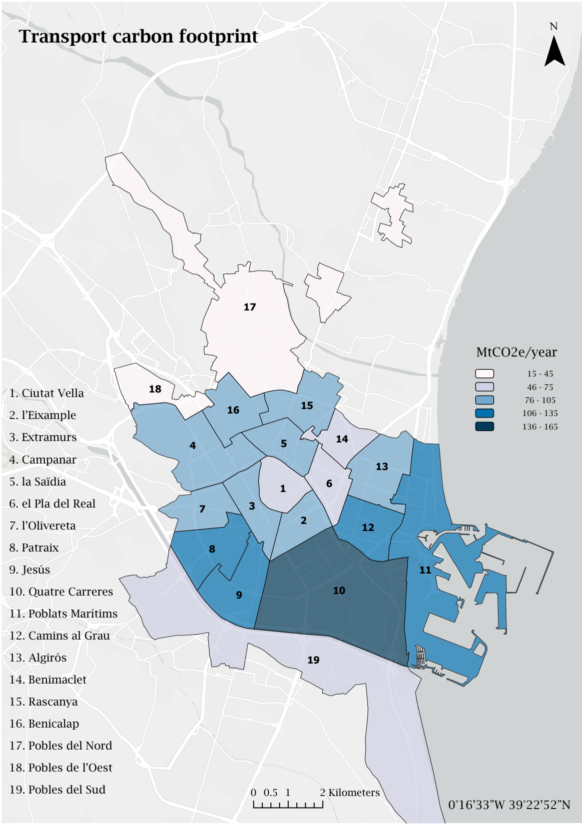



Figure 34: Current transportation carbon footprint.

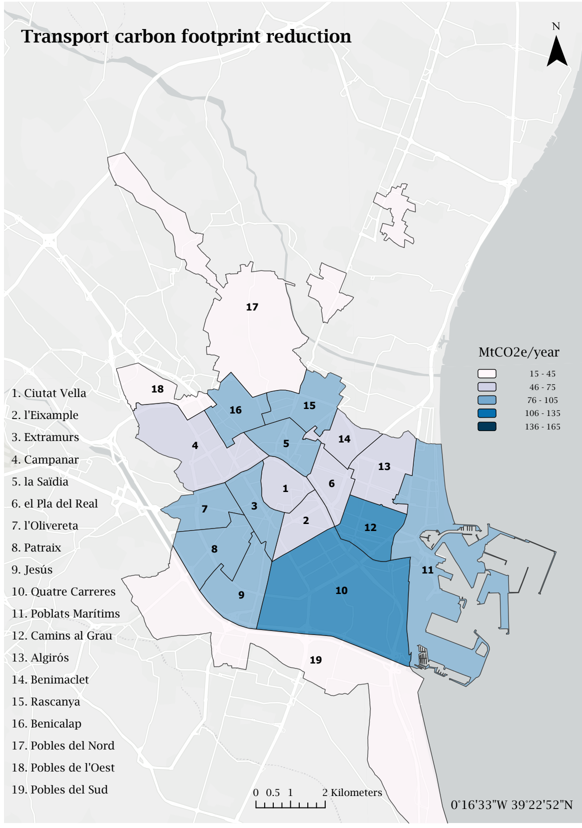



Figure 35: 20% in private cars carbon footprint reduction.

As can be seen, the reduction is great as there is no intense dark district left. However, the effort and investment to achieve this reduction is high and requires, following the trend, a long implementation time.

### 5.2.2 Action 2: Public transport migration

The results obtained with the statistical distribution of transport are as follows:

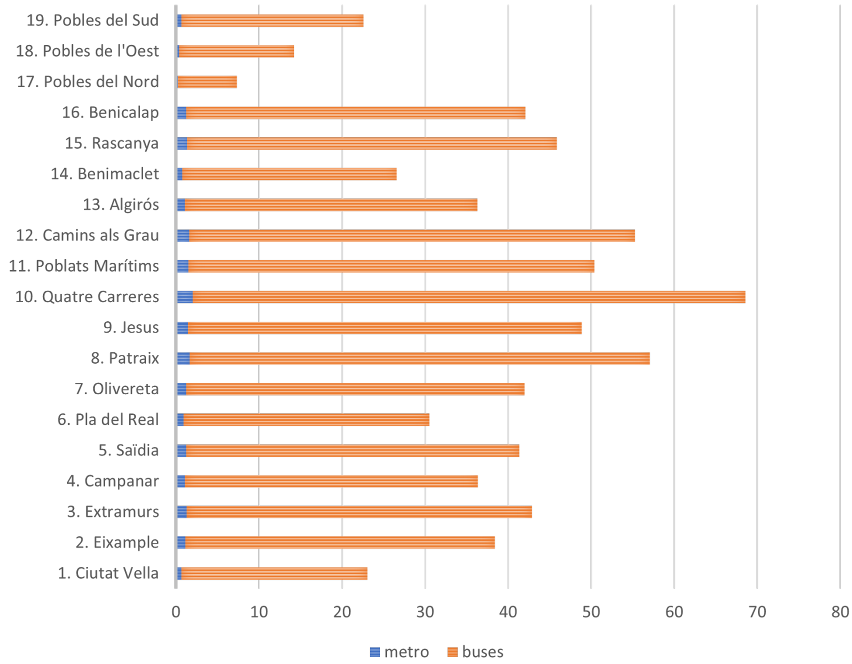



**Figure 36:** Number of annual vehicle replacement procurement (source: author's elaboration).

As the bus occupancy rate is several times lower than the metro, the number of vehicles to be increased is higher. It should be noted that the current circulation frequency needs to be considered when talking about the number of buses. This means that if the frequency of buses is considered, the number of buses to implement would be lower since the bus needs can be met by the number of times the bus passes through the district. If the incorporation of buses is carried out progressively, incorporating the same number of buses each year until 2030, the most significant number of buses needed would be 67 in the district of Quatre Carreres (10), the smallest, 7 in Pobles del Nord (17). The total number of vehicles needed for the municipality would be 708 buses and 21 metro wagons annually.

The map depicting the emissions after implementing this strategy is the same as observed in the previous measure. However, considering that both calculated actions can be complementary, the new map is presented with a 40% reduction in transport emissions due to the use of private vehicles.

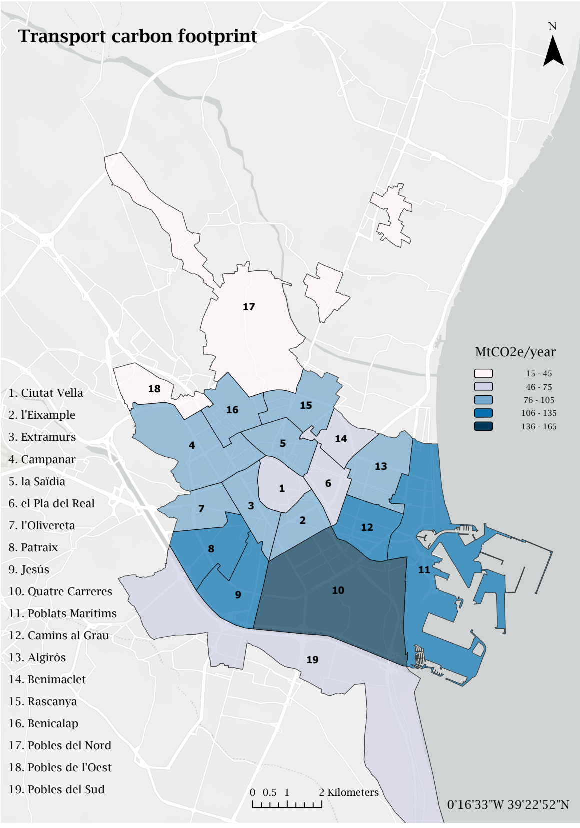



**Figure 37:** Current transportation carbon footprint.

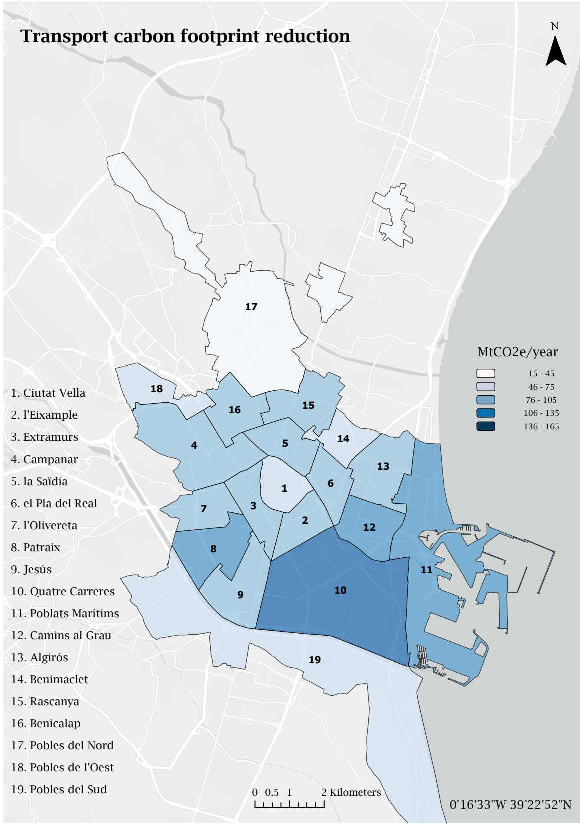



**Figure 38:** 40% in private cars carbon footprint reduction.

This last map shows that by implementing the two actions together, emissions in the districts could be substantially reduced. However, the district with the highest emissions would still be Quatre Carreres. Therefore, it is shown that implementing both measures would be satisfactory to achieve a significant reduction in transport emissions by 2030.

### 5.2.3 Action 3: Implementation of 15-minute district

In this case, the measure has been calculated considering a 20% reduction in all transport-related emissions since a 15-minute district leads to a reduction in both public and private mobility needs. The carbon footprint map expected by 2030 is presented in Figure 40.

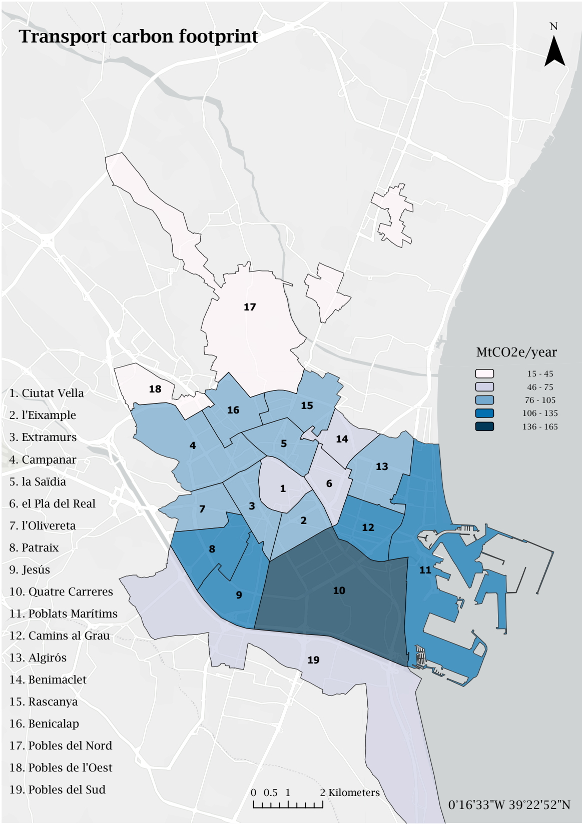



**Figure 39:** Current transportation carbon footprint.

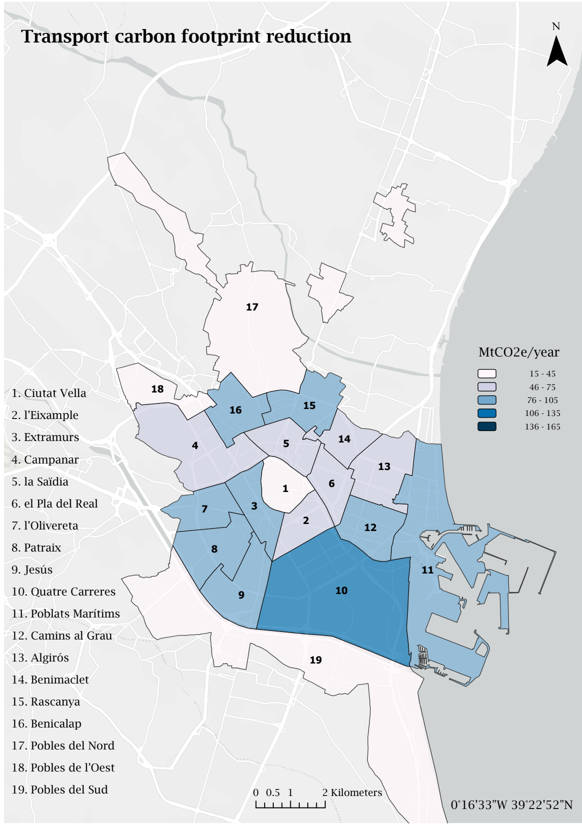



**Figure 40:** 15-minute transport carbon footprint reduction.

For this measure, emissions in the districts would be reduced more sharply than in the previous two actions. In this case, two districts would be incorporated to have low emissions (Quatre Carres (10) and Pobles del Sud (19)), but Quatre Carreres would remain the district with the highest emissions. Nevertheless, this action involves more resources than the previous ones since it integrates not only the technical part but also more economic actions and changes in habits. This action includes pedestrian zones, the availability and improvement of local commerce, and the creation of more jobs at the neighborhood level. All this is from a sustainable and socially acceptable perspective.

### 5.2.4 Action 4: Electrification of thermal demand

For the action of electrification of thermal demand, two results are shown. The first one, with residential electrification (Figure 42), and the second one, adds commercial electrification (Figure 44).

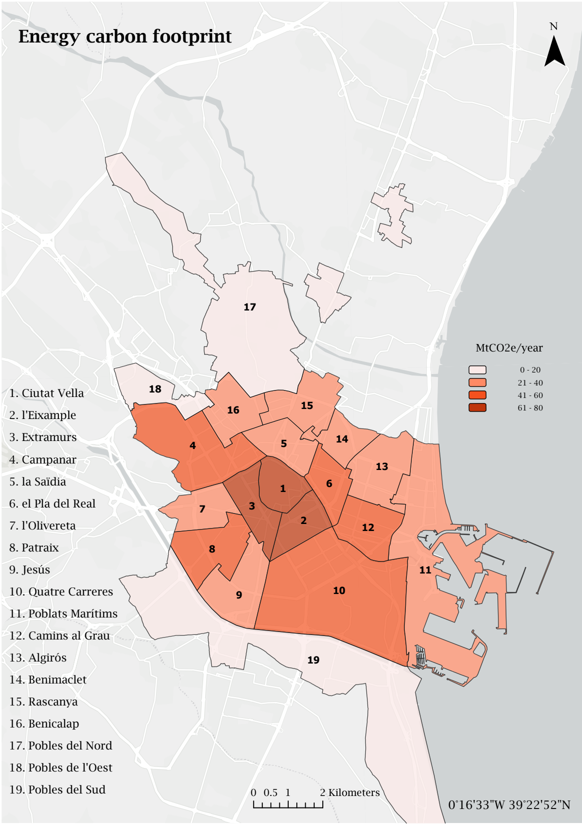



**Figure 41:** Current energy carbon footprint.

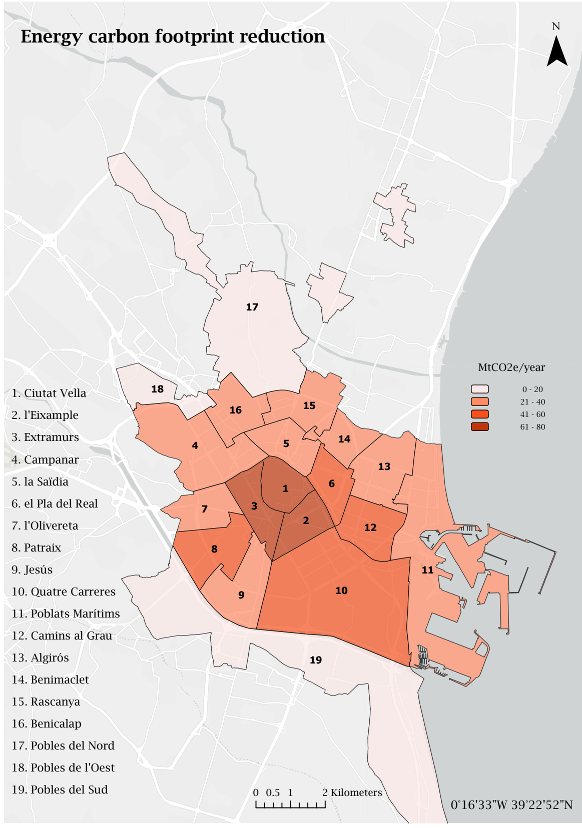



**Figure 42:** Carbon footprint after residential electrification.

In this first case, considering the residential sector, the decrease in energy-based emissions has not a relevant reduction in the city as the calculation shows a 5% overall emission reduction. The only district that shows a reduction in emissions is Campanar (4), while the rest remain on a similar scale. Therefore, more than residential sector equipment electrification would be required to reduce emissions due to the district's energy sector. Nevertheless, the figure below shows the potential for adding commercial thermal consumption into the action.

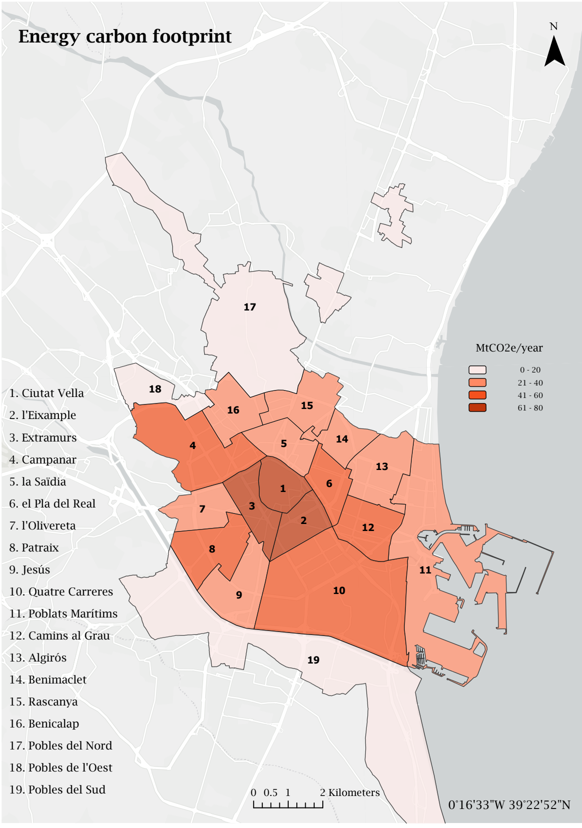



Figure 43: Current energy carbon footprint.

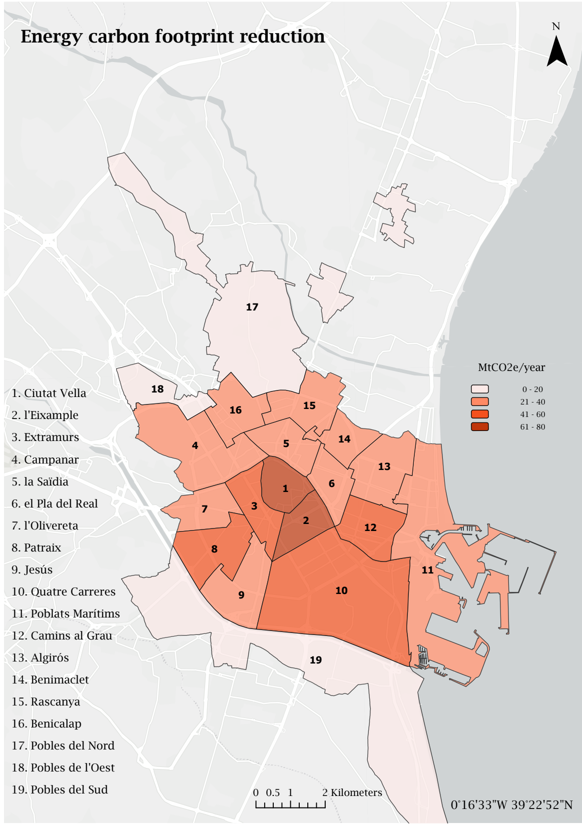



**Figure 44:** Carbon footprint after residential and commercial electrification.

As seen in the map above, adding the commercial sector improves the emission reduction from the energy sector. The emissions are reduced in Campanar (4), El Pla del real (6), Patraix (8), and Extramurs (2). However, the emissions caused by energy consumption in the districts are still high, especially in Ciutat Vella (1) and Eixample (2).

Moreover, it should be noted that one of the consequences of switching from gas to electricity is the modification of the emissions scope distribution. The new distribution can be seen in the following table 17.

**Table 17:** Scopes distribution in the city.

| | Current | Electrification |
|---|---|---|
| Scope 1 | 30.5% | 10.5% |
| Scope 2 | 63.4% | 81.6% |
| Scope 3 | 6.1% | 7.8% |

As can be seen, Scope 1 has only 10.5% of emissions, i.e., it has been reduced by 20%. Moreover, these have been transferred to Scope 2, which is responsible for purchasing electricity from the grid. This means that most of the emissions come from electricity consumption from the grid. However, following the current national trend to implement more energy from renewable sources, emissions from the grid would decrease.

In addition, the avoided emissions per district for both cases are shown in the table 18.

**Table 18:** Carbon footprint avoided in relation to the energy current carbon footprint.

| | CF avoided (%) | |
|---|---|---|
| District | Residential | Residential + commercial |
| 1. Ciutat Vella | 3.8% | 10% |
| 2. l'Eixample | 5.9% | 15% |
| 3. Extramurs | 6.3% | 16% |
| 4. Campanar | 6.5% | 22% |
| 5. la Saïdia | 3.9% | 10% |
| 6. el Pla del Real | 6.7% | 22% |
| 7. l'Olivereta | 5.3% | 10% |
| 8. Patraix | 4.7% | 13% |
| 9. Jesús | 4.5% | 10% |
| 10. Quatre Carreres | 5.7% | 13% |
| 11. Poblats Marítims | 3.5% | 6% |
| 12. Camins al Grau | 5.8% | 17% |
| 13. Algirós | 5.7% | 14% |
| 14. Benimaclet | 4.4% | 11% |
| 15. Rascanya | 4.6% | 12% |
| 16. Benicalap | 4.6% | 13% |
| 17. Pobles del Nord | 1.7% | 3% |
| 18. Pobles de l'Oest | 3.2% | 6% |
| 19. Pobles del Sud | 4.4% | 7% |
| TOTAL | 5.1% | 13% |

As it is shown in the Table 18, adding the commercial sector to the electrification action is beneficial as the reduction is duplicated. Electrification of thermal demand has moderately impacted the residential sector (Figure 42). First, domestic thermal consumption has a low consumption profile in the city, and second, it accounts for 31% of natural gas consumption in all sectors. However, adding commercial thermal consumption favors the results, and electrification also reduces Scope 1 emissions, i.e., the most direct and harmful emissions. The challenge in thermal demand does not lie in changing the energy vector but rather in reducing consumption. It will be necessary to apply greater efforts in the insulation and improvement of the housing envelope as well as in the efficiency of equipment to reduce energy consumption by a considerable amount and, thus, reduce emissions.

### 5.2.5 Action 5: Photovoltaic self-consumption

Following the methodology for calculating photovoltaic production on rooftops, an annual production of 1,171 GWh was obtained. Corresponds to supplying 44% of the city's total electricity and fully satisfying residential consumption. This result appears to be consistent with the findings of a previous study developed by Gómez-Navarro et al. [161] in which the residential electricity consumption of the city of Valencia could be almost completely satisfied by photovoltaic production taking advantage of the roofs of residential, industrial, commercial, and public buildings. In addition, it was found that three of the city's districts produce more energy annually than they consume: Pobles del Nord (17), Pobles de l'Oest (18), and Pobles del Sud (19). The results of the PV production rate of the overall electricity consumption in each district are presented in Table 18.

**Table 19:** Photovoltaic production rate per district.

| District | PV production rate |
|---|---|
| 1. Ciutat Vella | 23% |
| 2. l'Eixample | 26% |
| 3. Extramurs | 28% |
| 4. Campanar | 47% |
| 5. la Saïdia | 31% |
| 6. el Pla del Real | 26% |
| 7. l'Olivereta | 44% |
| 8. Patraix | 48% |
| 9. Jesús | 49% |
| 10. Quatre Carreres | 71% |
| 11. Poblats Marítims | 68% |
| 12. Camins al Grau | 35% |
| 13. Algirós | 49% |
| 14. Benimaclet | 32% |
| 15. Rascanya | 44% |
| 16. Benicalap | 49% |
| 17. Pobles del Nord | 270% |
| 18. Pobles de l'Oest | 109% |
| 19. Pobles del Sud | 150% |
| TOTAL | 44% |

The results in emission reductions obtained are shown in the following map:

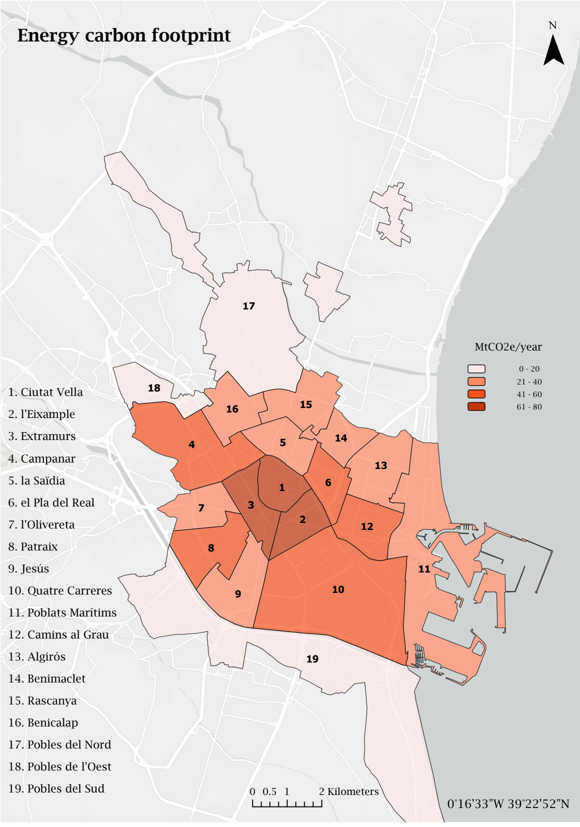



Figure 45: Current energy carbon footprint.

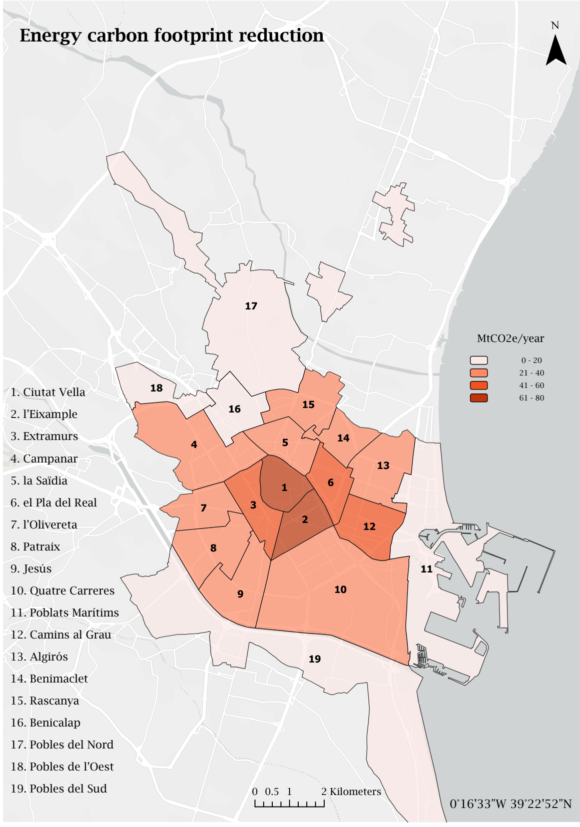



Figure 46: Energy carbon footprint with PV production

As seen in the map, the reduction in emissions is very noticeable, obtaining a total emission reduction of 22%. As can be seen, the districts with the oldest buildings and a high degree of protected buildings have a minor reduction in emissions (1 and 2). However, this action leads to a reasonable reduction of emissions as, after the use of all the photovoltaic potential of the districts, there would be only two highly emitting districts and three moderately emitting districts due to energy consumption. However, in these districts, other measures could be applied to reduce emissions by adapting the buildings to reduce thermal and electrical demand and increasing the efficiency of retrofitting the buildings to reduce consumption.

Furthermore, since the energy actions calculated are not mutually exclusive, they can be implemented together. For this reason, a map of the emissions that would be achieved in 2030 in Valencia with these actions evaluated could be the one shown in Figure 48.

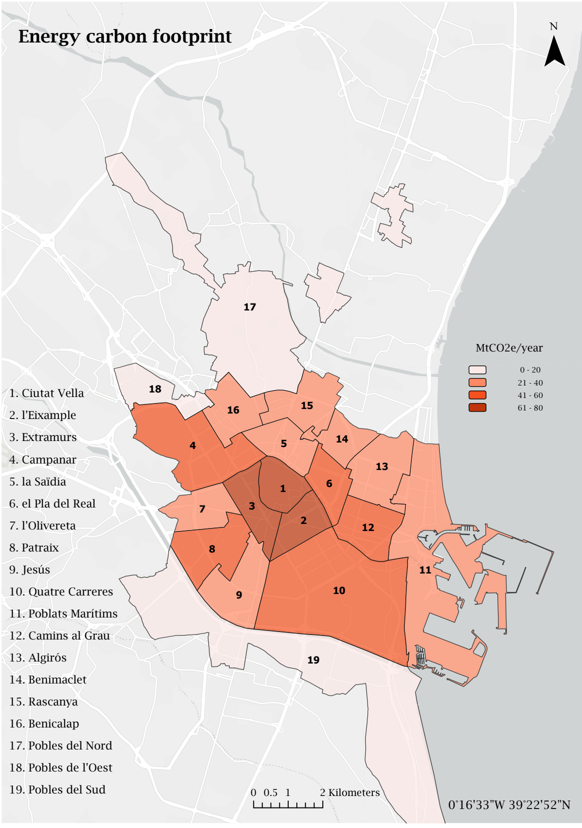



**Figure 47:** Current energy carbon footprint.

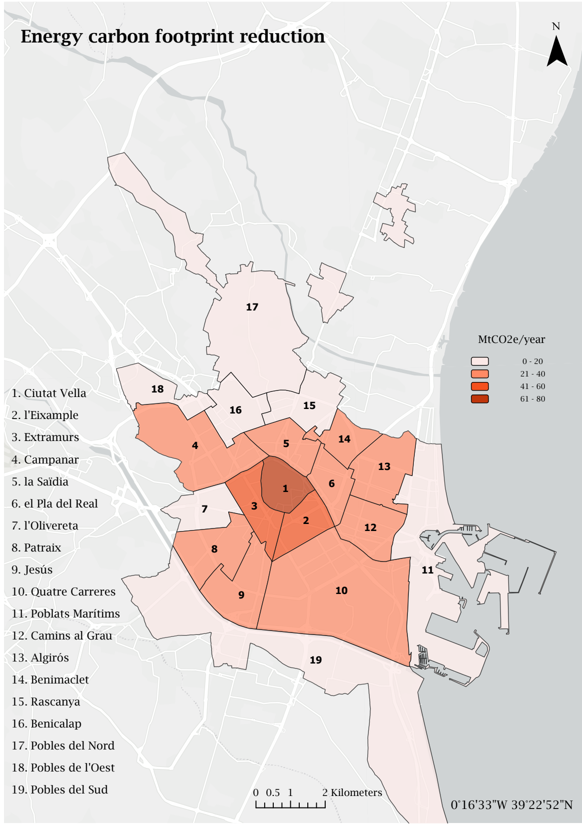



**Figure 48:** Energy carbon footprint reduction.

Together, these two measures in the energy sector would avoid 34% of energy emissions in 2030. As can be seen in the map, of the 19 districts of the city, 7 of them would produce a low amount of emissions annually (less than 20 Mtons of $CO_2$ equivalent). Also, districts with high intense energy emissions have been reduced from 3 to 1. However, the district of Ciutat Vella (1), with the highest emissions, has reduced its emissions from 78 Mtons annually to 61 Mtons (22%).

Once we have seen the impact of the measures on the reduction of emissions through the maps, it is possible to analyze all of them to determine which of these 5 analyzed measures is more beneficial and efficient for developing a carbon-neutral city. In Table 20, the percentages of reduction of each action concerning its sector, direct emissions, and total emissions of the city are represented in the following table. In addition, in order to determine the real decarbonization potential of these emissions, those related to the construction of the buildings have been discarded from the direct emissions. In this way, the cumulative emissions in the years of construction of the buildings are not considered, assuming that, over time, these will disappear and, in the coming years, buildings with a lower environmental impact will be constructed.

**Table 20:** Percentage emission reduction per action and scope.

| | % emissions reduction in the specific sector | % reduction in direct emissions (scope 1 and 2) | % reduction in total emissions (scope 1, 2 and 3) |
|---|---|---|---|
| **Action 1: Transition to electric mobility** | 15.9% | 3.9% | 3.4% |
| **Action 2: Shift to public transport** | 3.1% | 1.4% | 0.7% |
| **Action 3: Implementation of 15-minute district** | 20.0% | 8.8% | 4.3% |
| **Action 4: Thermal demand electrification** | 13.3% | 8.1% | 1.3% |
| **Action 5: Photovoltaic self-consumption** | 23.2% | 12.1% | 2.3% |

The action that presents the most significant reductions in the transportation sector is the implementation of 15-minute districts, followed by the transition to electric vehicles, actions 3 and 1, respectively. These results are explained by the ambit that is targeted in the reductions. In the implementation of 15-minute districts, the reduction applies to all public or private transportation; therefore, as the need for mobility decreases, the emissions related to it decrease directly. In the transition to electric mobility, the reduction is applied to personal vehicles; therefore, the reduction is relatively minor. However, as many of the emissions in transportation are from private cars, the reduction is still high. Shift to public transport, on the contrary, is applied to 20% of personal vehicle use, i.e., scope 1 and 2, since a decrease in car use in the district does not imply that the cars are not used for out-of-town travel. Hence, as explained before, since 60% of private vehicle emissions are due to indirect emissions, the reductions in this action are very low.

The action that produces the most significant reductions in the energy sector is Action 5: Photovoltaic self-consumption. Although the action that promotes the electrification of thermal demand (action 4) also has outstanding results. In both cases, the reduction in emissions is due to the emission factor change. In photovoltaic self-consumption, the electricity consumption remains the same; the difference is that 44% of the electricity needed is produced by PV panels (with the lowest energy production emission factor), whereas the rest is obtained from the grid. In contrast, electrification of thermal demand considers the residential and commercial thermal demand. The electricity consumed by the grid now covers the energy demand. Therefore, the emission factor is also reduced. However, the grid still has a higher emissions factor than PV production.

In the case of reducing the city's direct emissions (scopes 1 and 2), the measures that have shown the best results are photovoltaic self-consumption, implementation of 15-minute districts, and electrification of thermal demand in the order of emissions reductions. Therefore, it is shown that energy measures have a higher benefit when reducing direct emissions in the city. This is because a city's energy sector has a higher weight in scopes 1 and 2 (natural gas and electricity) than in scope 3 (transport and distribution losses).

However, if the reduction in emissions is intended to contemplate indirect emissions (Scopes 1, 2, and 3), the best solution would be to implement 15-minute districts, followed by the transition to electric mobility. It shows that even if direct emissions are not mainly reduced in transportation, implementing actions in this sector indirectly reduces global impact emissions.

Consequently, it can be stated that to reduce emissions in a city, no single action should be considered separately, as all of them are necessary. However, depending on the scope to be achieved, it will be better to focus on some actions or others.

## 5.3 Future scenario

A possible future scenario can be done with the combination of all the actions evaluated. Since the 15 key measures proposed by Net Zero Cities mainly cover Scopes 1 and 2 and the emission inventories usually carried out in cities, two maps have been represented separately. One, with Scopes 1 and 2, to see if these actions are relevant when grouped together, and the other, with the sum of all scopes, to show the impact of these actions on direct and indirect emissions. Figure 50 shows the expected emissions reduction in Scopes 1 and 2.

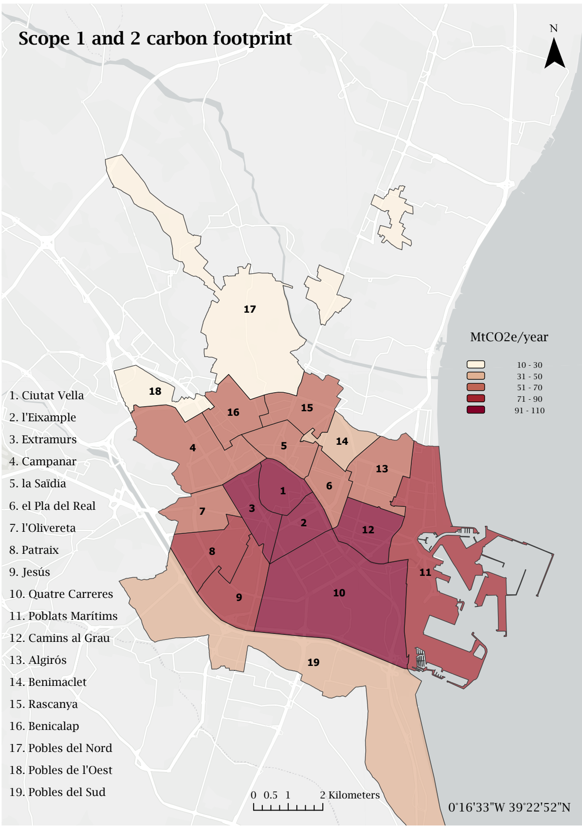



**Figure 49:** Current scope 1 and 2 carbon footprint.

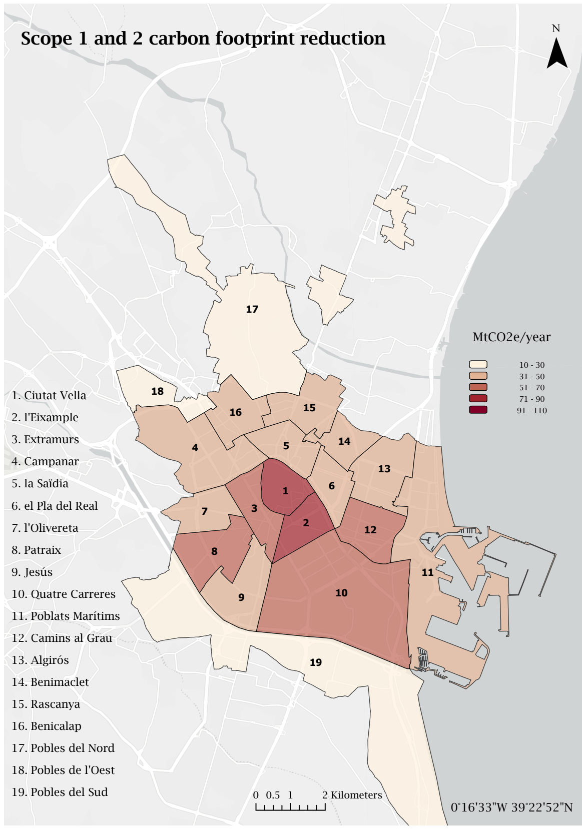



**Figure 50:** Scope 1 and 2 carbon footprint reduction.

From the above map, it is clear that the combination of these measures benefits the city of Valencia. With the joint implementation of the measures, Valencia will move from 5 districts with high emissions in 2019 to two districts with moderately high emissions in 2030. Thus, with these actions, the city would be possible to achieve the reduction of 32% emissions in Scopes 1 and 2. Nevertheless, if the objective is to be a climate-neutral city, with these five actions, we are far from achieving it. Thus, the rest of the measures proposed by NetZeroCities must be evaluated for Valencia and incorporate effective measures or carbon footprint offsetting strategies.

Previous figures did not consider Scope 3, which is essential to understand a city's global emissions. Therefore, Figure 52 shows the future scenario of the total carbon footprint in the city in 2030.

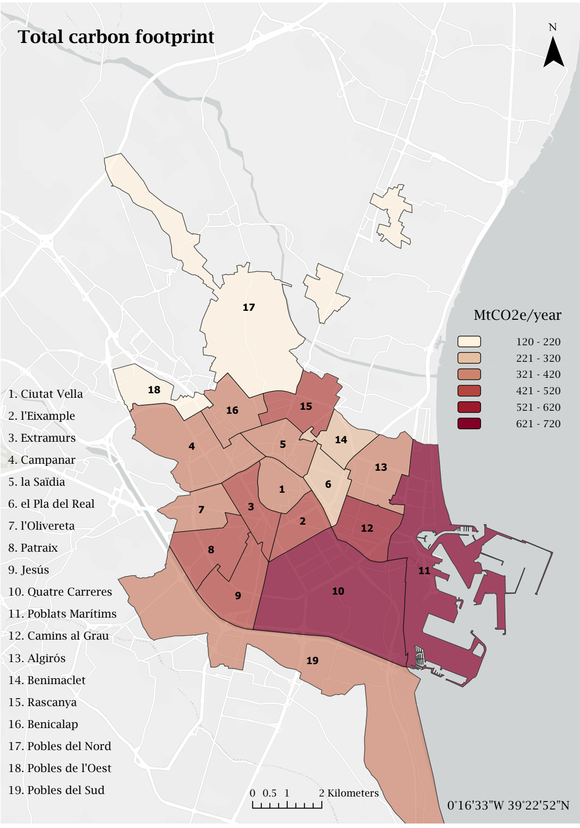



**Figure 51:** Current total carbon footprint.

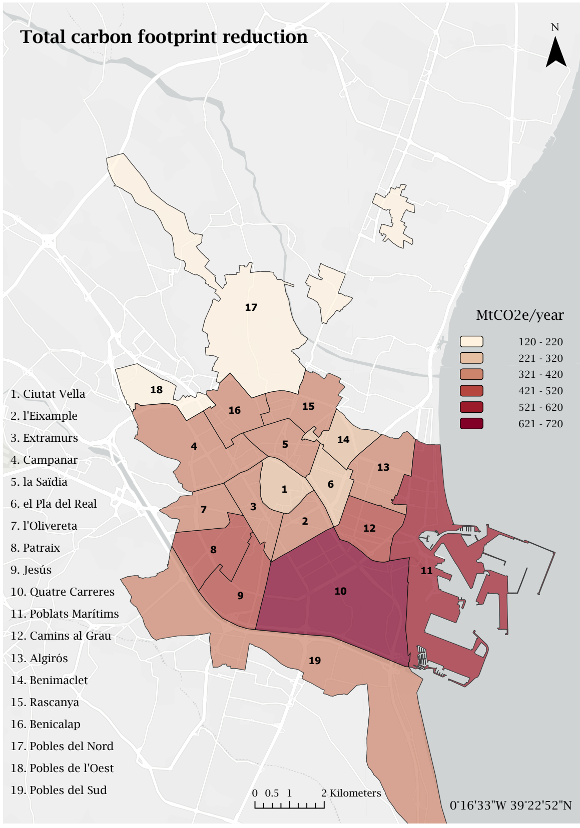



**Figure 52:** Total carbon footprint reduction.

As seen in the map, the reduction of emissions with the proposed actions, considering the three scope emissions, is low in some districts, compared with the scope 1 and 2 emissions scenario. However, most of them have reduced emissions by around 10%, and the Quatre Carreres district (10) still has the highest emissions. Although the measures analyzed have determined that it is possible to reduce a large part of the emissions if Scope 3 is considered, there is no excessive reduction. Therefore, European initiatives focusing on reducing and considering only Scope 1 and 2 need to include scope 3 calculation as a fundamental part of climate neutrality.

# 6 Conclusions

Achieving carbon neutrality has become a goal for many cities. To this end, numerous initiatives have been proposed for decades to establish a plan to achieve this ambitious objective. This master's thesis combines several of them to obtain a tool to evaluate actions from both technical and environmental aspects.

This project has developed a methodology to evaluate specific actions contributing to creating a climate-neutral city. First, the carbon footprint inventory for the districts/neighborhoods of Valencia was obtained. Based on the results, to validate the proposal, 5 out of the 15 key measures proposed in the plan for 100 carbon-neutral cities by 2030 have been analyzed. Thanks to this, it has been possible to conduct a diagnostic analysis of the carbon footprint at the city, district, and even neighborhood levels. This has allowed us to analyze the causes of these emissions and evaluate the impact of the different actions to reduce them.

The results show that the five measures can potentially reduce 32% of direct emissions in the city. In addition, a district-by-district study shows that emissions intensity by 2030 would be reduced significantly in each district, leaving only two of the 19 districts with moderately high emissions. In the specific case of Valencia, photovoltaic self-consumption has the best benefits for reducing direct emissions in the city. Among the possible implications of this measure, it would be necessary to generate greater awareness of community PV systems in cities and streamline understanding and regulatory procedures to reach the city's potential as soon as possible.

When adding indirect emissions produced due to scope 3, the reductions decrease to 10%. Although none of the measures alone have shown more than 5% reductions, implementing a 15-minute district will be the most beneficial action if the target is to reduce indirect and direct emissions. The 15-minute concept offers great benefits in cities. However, getting all areas that constitute the cities to be like this takes a lot of work. Therefore, it would be necessary to put more effort into determining which services are available in the neighborhoods and districts and which need to be improved. Other needs would include a more detailed study of the area's mobility, with a better understanding of the established social and economic dynamics.

Also, with these results, it is possible to conclude that European initiatives are leaving out many emissions that should be considered regarding climate-neutral cities. More studies that integrate scope three emissions would be needed to overcome these emissions, and strategies that integrate social and economic aspects, such as behavioral change and education, must be evaluated.

Furthermore, the model used to calculate the carbon footprint has limitations that have complicated an accurate determination of emissions. This model of the city's GHG emissions could not be fully based on primary data nor geolocalized data (see annex for a discussion of the scale of data sources). Therefore, its three main areas for improvement are showing a fixed annual emissions balance, the imperfect quantification of emitting activities, and the need to use conversion factors to GHG emissions instead of measuring emissions directly. In return, it has two major advantages. On the one hand, it is easily editable to refine calculations and estimates. On the other hand, it can be combined with a future monitoring system of activities in the city to get near-real-time GHG emissions at the neighborhood scale and to find out their causes. Also, the high requirement for reliable data at the local scale and the lack of availability of such data have required the use of other studies and the adaptability of other scale data. This has been slightly unfavorable for a fully bottom-up methodology. Therefore, it would be necessary to increase the data at the neighborhood and district scale as much as possible to develop more reliable and accurate emission inventories.

The tool developed in this project and its results suggest possible future work toward its validation, application, or improvement:

- Evaluate the rest of the 15 actions proposed by Net Zero Cities for Valencia and assess whether it would be possible to achieve climate neutrality with the key actions proposed.
- Evaluate other emission reduction actions relevant to the case study, such as a change to the Mediterranean diet or net-zero new building construction to consider scope 3 reductions.
- Improve the tool and incorporate an evaluation of the measures from a multi-scale perspective, considering economic and social indicators to provide a broader vision of the positive implications at other scales in the transition to the sustainability of cities
- Evaluate the reduction of the 5 actions assessed through a more detailed neighborhood level to know more accurately the potential of each one of them and compare with district scale reduction potential.
- Validate the study for cities, comparing other cities' emissions and carbon footprint reduction potential in the Mediterranean and European regions.

Finally, this project has developed a proven tool to assist in the decision-making process to achieve a climate-neutral city. This tool allows the creation of more specific urban strategic plans helping in the prioritization of the actions to be implemented by policymakers.

# 7 References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**Part II**

# Annexes

# Annex I. Case study data collection.

| **Data Sector** | **Level** | **Source** |
|---|---|---|
| **General data** | | |
| Surface | Neighbourhood | [130] |
| Population | Neighbourhood | [130] |
| **Energy** | | |
| Natural gas consumption | City | [130] |
| Electricity consumption | City | [130] |
| Income statistics | National | [138] |
| Number of building type | District | [130] |
| Coefficient of T&D losses | National | [139] |
| Emissions | Territorial | [140] |
| **Transport** | | |
| **Private Vehicles** | | |
| Number of cars | District | [130] |
| Average distance travelled per vehicle (VKT) | Europe | [162] |
| Distribution inside boundaries | Estimation | [131] |
| Emissions | Europe | [131] |
| **Two-wheelers** | | |
| Number | City | [130] |
| Distribution inside boundaries | Europe | [163] |
| Annual distance travelled | Europe | [162] |
| Emissions | Europe | [163, 132] |
| **Electric Scooters** | | |
| Number estimations | Country | [164] |
| Usage pattern | Study | [133] |
| Average annual distance | Study | [134] |
| **Private Bicycles** | | |
| Number | Estimation | [135] |
| Emissions | Study | [137] |
| **Bike - sharing** | | |
| Number | City | [165] |
| Emissions | Study | [137] |

| **Data Sector** | **Level** | **Source** |
|---|---|---|
| **Metro and Tram** | | |
| Total length | City | [130] |
| Departures per day | City | [130] |
| Line Length | City | [130] |
| Emissions | Study | [166] |
| **Bus** | | |
| Number of stations | District | [130] |
| Lenght/Distance travelled by buses | City | [130] |
| Emissions | Study | [167] |
| **Taxi** | | |
| Number | City | [130] |
| Average distance travelled | Study | [136] |
| Emissions | Europe | [131, 132] |

| **Land Use** | | |
|---|---|---|
| Urban Green Areas | District | [130] |
| Agricultural Land | City | [149] |
| % roads estimations | Study | [148] |
| Emissions UGA and AL | Study | [168, 169] |
| Sequestration | Study | [170, 171] |
| Emissions roads | Study | [172] |
| Buildings emissions | Study | [150, 173] |

| **Consumption** | | |
|---|---|---|
| Food consumption per capita | National | [141] |
| Densities | Study | [142, 143, 144, 145]. |
| Emissions | Study | [146, 147, 174] |

| **Waste** | | |
|---|---|---|
| Distribution waste per capita | City | [130] |
| Share of treatment | Study | [175] |

# Annex II. Relation of the work with the sustainable development goals of the agenda 2030.

**Table 21:** The degree to which the work is related to the Sustainable Development Goals (SDG).

| Sustainable Development Goals | High | Medium | Low | Not applicable |
|---|---|---|---|---|
| **SDG 1. No poverty** | | | | x |
| **SDG 2. Zero hunger** | | | | x |
| **SDG 3. Good health and well-being** | | x | | |
| **SDG 4. Quality education** | | | | x |
| **SDG 5. Gender equality** | | | | x |
| **SDG 6. Clean water and sanitation** | | | | x |
| **SDG 7. Affordable and clean energy** | x | | | |
| **SDG 8. Decent work and economic growth** | | x | | |
| **SDG 9. Industry, innovation, and infrastructure** | | x | | |
| **SDG 10. Reduced inequalities** | | x | | |
| **SDG 11. Sustainable cities and communities** | x | | | |
| **SDG 12. Responsible production and consumption** | x | | | |
| **SDG 13. Climate action** | x | | | |
| **SDG 14. Life below water** | | | | x |
| **SDG 15. Life on land** | | | x | |
| **SDG 16. Peace, justice, and strong institutions** | | | x | |
| **SDG 17. Partnerships for the goals** | | | x | |