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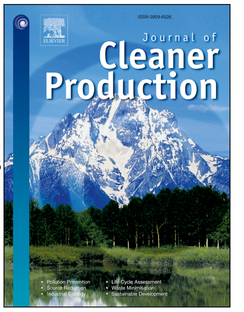

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Methodology for Estimating Indirect Emissions from Scope 3 and Mitigation Proposals Applied in the neighborhood of Benicalap, Valencia (Spain)

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Abstract

Cities account for 70% of global greenhouse gas emissions, while occupying just 3% of the Earth's surface, positioning them as critical actors in climate crisis and a key element for decarbonization strategies. Yet, Scope 3 emissionsremain poorly quantified and under-addressed in urban planning. To fill this gap, this study develops a novel, scalable methodology for accounting and mitigating Scope 3 emissions at the neighborhood level, offering granular insights for localized decarbonization strategies. Unlike prior approaches, this research fills the methodological void by integrating a state-of-the-art review of Scope 3 accounting methods with an assessment of emission factors to ensure accuracy and consistency. A key innovation is the introduction of sector-specific reduction ranges based on sensitivity analyses and robust indicators, enabling planners to evaluate mitigation strategies under diverse scenarios. The methodology is applied to the Benicalap neighborhood in Valencia, Spain, delivering a baseline CO_2 inventory, evaluating mitigation measures, and presenting an implementation roadmap. Results highlight the food and beverage sector as the dominant contributor to Scope 3 emissions (36.6%), followed by clothing and transport (14% each), automobiles (11%), construction (6%), and waste (5.5%). Proposed measures demonstrate the potential to reduce emissions by 17% by 2035, equivalent to 21,785 tons of CO_2 annually. The urgency of addressing Scope 3 emissions underscores the novelty and impact of this work. This work advances urban emission reduction planning by addressing the neglect of Scope 3 emissions in existing frameworks. Its scalability and adaptability allow replication across other neighborhoods and cities, making it a pioneering tool for localized climate action.

Keywords: Carbon footprint; Decarbonization strategies; GHG Emissions; Indirect emissions; Scope 3.

NOMENCLATURE

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A	Activity
C	Consumption per capita
CO_2	Carbon Dioxide
CV	Valencian Community
EF	Emission Factor
GHG	Greenhouse gases
HH	Households
Inhab	Inhabitants
L	Percentage of losses
MITECO	Ministry for the Ecological Transition and the Demographic Challenge
SOTA	State-of-the-art analysis
T	Trips
Tr	Replacement Rate
UNFCCC	United Nations Framework Convention on Climate Change
W	Waste

1 INTRODUCTION

Since the middle of the 20th century, particularly in the past four decades, carbon dioxide levels increased, and the rise of CO_2 emissions associated with climate change has been exponential (NASA, 2019), being a global threat.

Being responsible for more than 70% of total emissions (United Nations Sustainable Development Action, 2015) and more than two-thirds of the world's energy demand, cities are the main hubs and originators of the climate crisis. In turn, avoided emissions in cities result from the comparisons of a baseline scenario (current situation) are divided into three Scopes to indicate the degree to which an entity is contributing to a low-carbon transition (Scope 3) and Scopes 1 and 2 for the assessment of the quantified efforts implemented by the entity to lower carbon footprints.

Corporate climate actions are key drivers of low-carbon economies and green transition (O Krabbe et al., 2015) with hundreds of cities worldwide to develop prominent decarbonization strategies and initiatives, such as the Covenant of Mayors or the platform of C40, to minimize their impacts (Cuesta-Fernandez et al., 2023). There is, actually, a wide range of techniques, from simplified calculations to advanced optimizations to asset sustainability and reducing the footprint of holdings (Alessandrini et al., 2021), but also to abide by the preliminary steps towards an effective emission reduction design plan (Schulman et al., 2021).

Currently, cities must perform accounting and mitigation plans for Scope 1 (direct GHG emissions) and Scope 2 (indirect GHG emissions associated with purchased electricity, district heating, or other). However, Scope 3 (other indirect GHG emissions that occur outside the city boundaries because of activities happening in it occurred from sources in the value chain) is still under exploration (Kean Fong et al., 2021). Scope 1 emissions refer to direct emissions that physically occur within the geographical boundaries, targeted in international treaties and engagements, such as the UNFCCC (1992) (United Nations, 1992), Kyoto Protocol (1998) (United Nations, 1998), or Paris Agreement (2015) (United Nations Climate Change, 2015).

Scopes 1 and 2 are usually accounted for by bottom-up statistics and emissions factors (Bovensmann et al., 2010). It includes all the GHG emissions derived from activities directly by the sources (e.g., fuel combustion) (World Business Council for Sustainable Development, 2004), while Scope 2 incorporates the indirect emissions for energy production. Overall, Scope 1 and 2 are accounted from bottom-up emissions related to business input (e.g. concrete, steel, etc.) (Bovensmann et al., 2010), but also upstream emissions requiring an important amount of data. The GHG Protocol, the most widely used methodology to manage and mitigate emissions (Kean Fong et al., 2021), provides guidelines for sectors to consider within Scope 3 in cities. Some of the most relevant sectors to be considered are food and beverage, waste management and treatment (outside the city boundaries), and consumption of goods and services, such as clothes, furniture, and appliances (Task Group on Data Support for Climate Change Assessments (TG-Data, 2023).

Unfortunately, there is no commonly accepted framework for reporting the financial requirements of these Scopes with only a few considerations, e.g. the Task Force on Climate-Related Financial Disclosures (TFCD) (TCFD-Task Force on Climate-Related Financial Disclosures, 2017) to promote monitoring climate-related financial disclosure practices or the Carbon Disclosure Project (CDP) (Evercity, n.d.) to corporate transparency of the related processes.

Due to the analysis of Scope 3 being less explored with no clear inputs to develop it, few studies have been conducted, and the topic remains underdeveloped. Although there are protocols to analyze it, they are still vague with no defined methodology for calculating indirect emissions leading the investors to darkness and less accurate results regarding the carbon footprint measurements (Anquetin et al., 2022). Since Scope 3 concentrates on CO_2 emissions, to achieve carbon neutrality, it is essential to go deeper into indirect emissions and to have a procedure that makes it possible to account for them. On the other side, it seems crucial to dedicate mitigation efforts to the most relevant points, which represent an additional challenge in their strategies since they relate to a large percentage of the population's consumption habits.

Several efforts are recorded in the existing literature related to this issue and streams of the literature, including a study of 11 cities worldwide in 2019, which found that Scope 3 emissions represent between 27% and 47% of total emissions (Ghaemi and Smith, 2020). A study conducted in 49 cities in Japan determined that the average percentage is 31%, but there is a high variation between towns (Long et al., 2017). Downie and Stubbs (Downie and Stubbs, 2013) discussed the problem focused on Australia in a small-scale study of emissions in 20 companies underlying the lack of methodological corporations. Radonjic and Tompa (Radonjic and Tompa, 2018) from their side targeted a methodology for indirect emissions assessments of Scope 3 in the sector of telecommunications. Other relevant studies proposed by Hertwich and Wood (Hertwich and Woord, 2018) work within five fields (energy, transport, industry, buildings, agriculture, and forestry) in line with a matrix development of an input and output emissions' evaluation account that Scope 3 was responsible for more than 50% of the total emissions. In a broader spectrum of the study of carbon footprint, Goldhammer et al. (2017) based their study on an estimation technique using simplified variables, such as the size, the capital intensity, and other related ones (Goldhammer et al., 2017). To move beyond, Nguyen et al. (2021) encompassed the same problem in introducing machine learning models (Nguyen et al., 2021). As reported by Nyambuu and Willi (2020) (Nyambuu and Willi, 2020), the study on Scope 3 has a straightforward relation with economic growth and investments. Other scholars also provide complementary studies in this line, e.g. Roundy et al. (Roundy et al., 2017), Bengo et al. (Bengo et al., 2021) and Block et al. (Block et al., 2021) to cite some of them, who focused their works on the investors' impacts. The urgently needs to incorporate scope 3 in climate actions, as they represent the most significant portion of companies' GHG inventories (Farsan et al., 2018). Sanchez argued that focusing only on scopes 1 and 2 can deviate GHG estimations as scope 3 consists of an important part of the overall footprint (Sanchez et al., 2010), while Huang et al. estimated the scope 3 emissions for up to 70% of the total direct and indirect emissions of the majority of businesses (Huang et al., 2009).

On the other hand, estimation uncertainty arises whenever greenhouse gas emissions are quantified, typically associated with parameters like activity data and emission factors. This uncertainty can be assessed through statistical analysis, measurement precision, and expert judgment. The GHG Protocol provides a methodology for aggregating statistical uncertainty using the Gaussian method, corresponding to Tier 1 of the IPCC Good Practice Guidance and Uncertainty Management (Penman et al., 2000). While we used reliable sources for emission data, uncertainty is generally analyzed for Scope 1 and 2 emissions using a single software in large cities or countries. Including Scope 3 emissions, using different databases and focusing on a neighborhood level, makes a detailed uncertainty analysis outside the scope of this study. To provide an approximate estimation, previous studies on carbon footprint at the city level found uncertainty ranging from 47-68% for all scopes in 13,000 cities worldwide (Moran et al., 2018) and 8-38% for Scope 1 and 2 in 305 cities in China (Cai et al., 2019).

The discussion about Scope 3 requires a succinct presentation of the protocol used by Carbon4Finance (carbon4 finance, 2023) to quantify Scope 3 emissions (Carbon Impact Analysis-CIA). CIA developed a methodology to evaluate GHG emissions and as a second step the strategies to reduce them and measure the financial portfolio of numerous companies.

According to scientific reports, scopes 1 and 2 are not enough for a realistic analysis of CO_2 emissions. (Kean Fong et al., 2021) estimate the CO_2 emissions as 41,6% (considering only transportation, industrial agriculture, waste, and energy) in Wuyishan China, (Rivera-Marin et al., 2023) estimate the Scope 3 emissions in around 71% in a neighborhood in Spain. In the case of Spain, MITECO, in its report on the national inventory of greenhouse gases (2021), determines that 47% of the country's emissions belong to Scope 3 ((Ministerio para la Transicion Ecologica y el reto demografico, 2024). It is estimated that, for the city of Valencia, approximately 63% are indirect emissions; 60% of these are generated by the transport sector, public and private, that is not registered in the locality but circulates through it; 40% of the emissions generated in construction, 1% of emissions from electricity generation, where mainly are considered the losses in the network. Finally, with the largest share, this Scope includes all the emissions generated by consuming goods, primarily food, clothing, other manufactured products, services, and waste treatment (Rivera-Marin et al., 2023). In the case of the Benicalap neighborhood, it was estimated that 77% of the total emissions correspond to Scope 3 in 2021 (Izquierdo De Andés, 2022).

Outside European borders, the Australian Government defines Scope 3 as *"indirect GHG emissions occurred as consequences of intensive human activities (e.g. transportation)"* (Australian Government. Clean Energy Regulator. National Greenhouse and Energy Reporting, 2023)and are upstream related to business inputs basically (Green, 2010).

The novelty of this work lies in developing a comprehensive and scalable methodology for accounting and reducing Scope 3 emissions at the neighborhood level, addressing a critical gap in localized emission assessments. Unlike existing approaches, this methodology integrates a state-of-the-art review of Scope 3 emission calculation methods and a critical evaluation of emission factors, opting, when possible, for cradle-to-market emission factors to ensure consistency and accuracy in estimating environmental impacts (see Section 3: Methodology). A key contribution is introducing feasible reduction ranges for emissions across multiple products and subsectors (Table 4) based on sector-specific indicators (Table 6). These ranges, derived from an extensive literature review, allow for sensitivity analyses under various scenarios, enabling more robust planning and evaluation of mitigation strategies. The application of the methodology at the neighborhood scale—demonstrated in the Benicalap district of Valencia, Spain—further enhances its novelty. This level of granularity is rarely addressed in current studies, primarily due to data limitations and the complexity of local-scale analysis. By providing an initial CO2 emissions inventory, mitigation proposals, and an implementation roadmap, this work offers a practical framework for urban decarbonization.

Moreover, the methodology's transferability is a standout feature. It incorporates adaptable emission factors and mitigation measures that can be directly applied to other neighborhoods in Valencia and easily replicated in Spanish and Mediterranean cities. This adaptability promotes broader adoption and supports regional and international efforts to achieve net-zero emissions in urban areas. This work provides a replicable, scalable, and locally adaptable tool for addressing Scope 3 emissions, filling a critical research and policy gap in neighborhood-level sustainability planning.

2 METHODOLOGY

In the first phase of the work, a general SOTA (state-of-the-art analysis) was performed (in section 1) to understand the existing methodologies for calculating Scope 3 emissions in cities, relevant sectors (that can include several subsectors), considered emission factors, and implemented mitigation measures. Once the neighborhood activities to be considered in Scope 3 are clear, information is sought for each activity, and a specific approach is defined to determine the emissions in each sector (as previously described), which is also explained in detail. Subsequently, different mitigation measures are proposed, carrying out a social and environmental analysis. Finally, a roadmap is presented, and the potential reduction of the Scope 3 emissions is determined. Figure 1 provides the scheme of the proposed methodological approach.

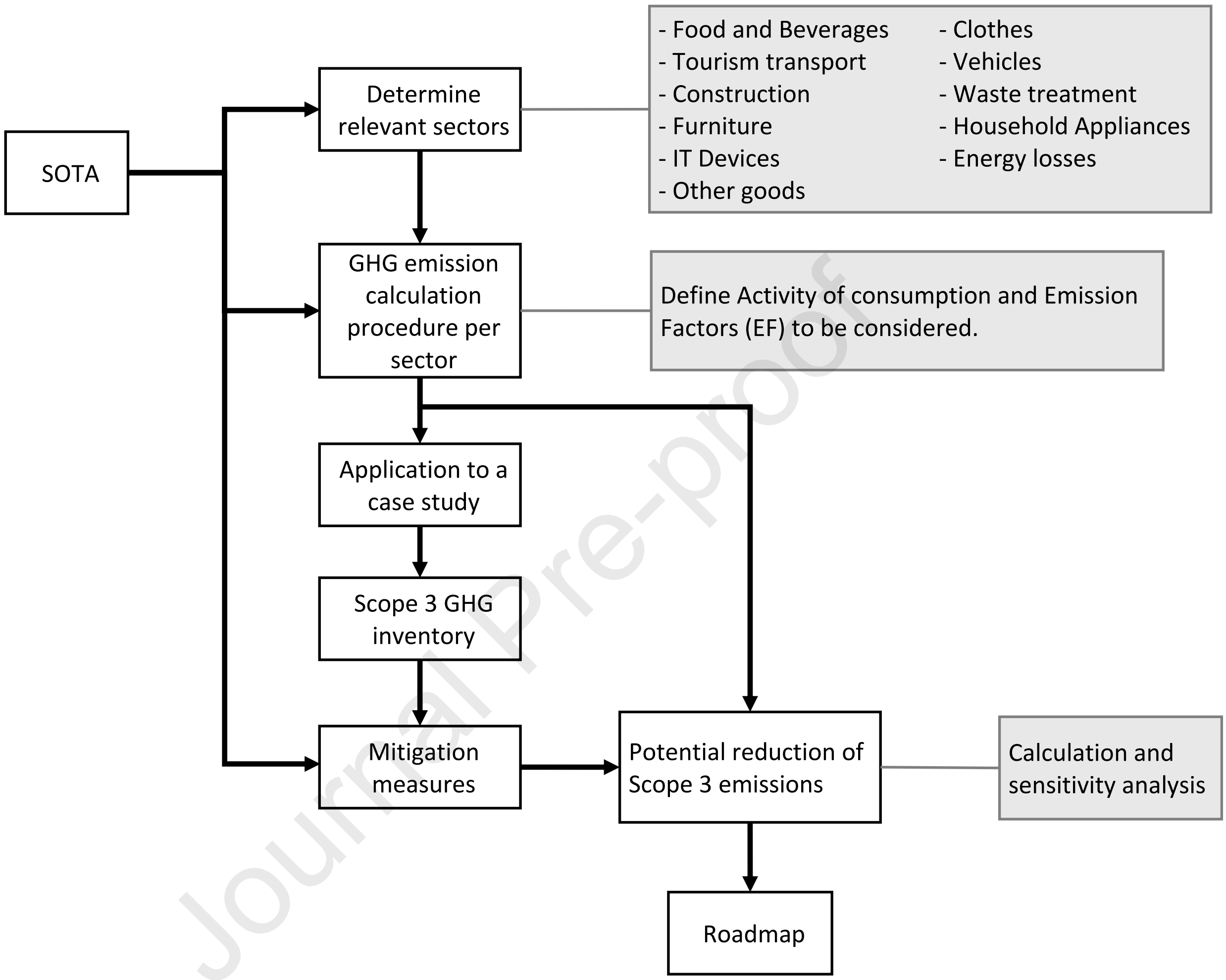

Figure 1. General Methodology

2.1 GHG emissions calculation and inventory

The GHG emissions calculation adapts existing methodologies for calculating city annual emissions regarding Scope 3 activities. The targeted neighborhood's general social, economic, and environmental frameworks are analyzed to identify key variables as total area, population, main economic activities and other relevant data.

As a second step, each sector's emissions accounting is carried out. Each calculation methodology is determined according to the guidelines recommended by the GHG protocol in cities, bibliography, data, statistics, and information from the city council. The method used to create the emission inventory procedure is shown in Figure 1. The specific methodology for each sector will be described in this section. The addition of the emissions of each considered subsector obtains the Scope 3 GHG emissions inventory.

The estimations to determine emissions in each subsector are based on the general equation for determining GHG emissions according to equation 1, where A is the activity (it can be mass of consumed products, mass of produced waste, consumed electricity, traveled distance,…), and EF is the emission factor of this activity. Usually, annual statistics about consumption of food, goods or energy are provided per inhabitant or household, and it is different for every country (and even for every city). To calculate the total amount for a neighborhood, it will be necessary to use data about the total population or number of dwellings of the selected neighborhood. Detailed calculation procedures and some examples for clarification are included in sections 3.1.1 to 3.1.11.

$$GHG_{emissions} = A \times EF \quad (1)$$

Since local governments or studies do not always provide comprehensive information, certain limitations must be acknowledged. One limitation of this work is the lack of emission factors available at the neighborhood level in some cases. Consequently, regional, national, or European data were used to address these gaps. To improve the accuracy of future analyses, governments should develop and provide emission factors at more localized levels. The sources of the emission factors used in this study are diverse, including government studies at local, regional, national, and continental levels and specialized databases commonly employed in life cycle assessment (LCA) analyses. These databases, such as SIMAPRO, OPEN LCA, and CARBONCLOUD, are widely recognized in scientific research. The selection of each Emission factor data source depends on the sector under analysis. For example, CARBONCLOUD is primarily used to estimate emission factors in agriculture and food systems. However, when specific products cannot be found within this database, alternative sources such as GreenDelta or SIMAPRO are utilized. The source of each emission factor is cited in the corresponding section of this work.

Results of the calculus of all the analyzed sectors are provided in the results section. Detailed calculations of some sectors have been analyzed. The chosen sectors are clothing, IT equipment, and household appliances. The calculations are detailed in the corresponding subsection.

2.1.1 Food and Beverage Consumption

The method used to determine the emissions generated by the consumption of food and beverages is based on analyzing consumption behavior by considering more than 40 types of food and their respective subdivisions (Table 6).

Once these values and their consumption by type of food have been obtained, the emission factors are determined for each one. The emission factors were obtained from SIMAPRO (SimaPro, 2023) , OPEN LCA (GreenDelta, 2006) and CARBONCLOUD (CarbonCloud, 2023). In this order, the values are initially searched at the local, city, region, country, continent, and global levels, prioritizing the minor scale. Additionally, it is analyzed if the quantification of emissions in each reference represents the same scope (e.g. product) and lifecycle boundaries: "Cradle to the farm gate,", "Cradle to factory gate,", "Cradle to the market gate" or "Cradle to grave" and an affectation is made on this emission factor so that all of them are comparable. The place of cultivation or manufacture of the food and the energy effects due to refrigeration, storage, and transport are considered for these effects.

In this section, Cradle-to-market emissions will be considered, which means that emissions from all activities from the initial stage of the food until it reaches the store are considered, including, among others, soil preparation, cultivation, processing, and transport to the store. This is done to avoid double counting emissions due to local food transportation, as this will be included in transportation in Scope 1, due to refrigeration and cooking process, as this will be counted in energy in Scope 1, and waste treatment, as this will be calculated in Scope 3.

The annual CO_2 emissions generated by the consumption of food and beverages are determined for Spanish and Valencian citizens according to their socioeconomic conditions, while the total emissions are calculated according to the number of inhabitants. It should be noted that the results obtained are based on the available information, and it is not possible to ensure that in some food, double counting of emissions is completely avoided; likewise, the recent emission factor found for food is considered, the software consulted are SIMAPRO, OPEN LCA, and CARBONCLOUD. However, it has been found that sometimes, these factors use information from the country's energy matrix without regular updating.

Equation 2 shows the calculation of total GHG emissions of the food and beverage sector, where C_i is the per capita consumption of each food type, EF_i is the emission factor for this food, and $Inhab$ is the number of inhabitants in the neighborhood.

$$GHG_{Food} = \sum_i [C_i \times EF_i] \times Inhab \quad (2)$$

2.1.2 Energy Consumption

The calculation of Scope 3 emissions due to electricity losses in the grid is based on the national percentage of transmission losses, the electricity consumption determined in Benicalap, and the Spanish national power matrix's emission factor.

On the other hand, the calculation of Scope 3 emissions generated by losses due to the supply of natural gas is carried out considering the estimations according to the Spanish market system, the natural gas consumption of the neighborhood, and the emissions factor taken according to the methodology proposed by the Intergovernmental Panel on climate change (Task Group on Data Support for Climate Change Assessments (TG-Data), 2023). This emission factor is much higher than the emission factor per combustion because of the methane released into the atmosphere.

Equation 3 shows the calculation procedure, where C_i is the consumption of the energy supply $i \%L_i$ is the considered percentage of losses for that energy supply and EF_i is the corresponding emission factor.

$$GHG_{Energy\ Losses} = \sum_i [C_i \times \%L_i \times EF_i] \quad (3)$$

2.1.3 Waste Treatment

The methodology to determine emissions due to waste management is carried out by integrating several bibliographic sources. This section considers average Spanish solid urban waste treatment; the percentage of waste composition is determined according to the classification: packaging, paper and cardboard, glass, Separate Collection Organic Fraction (FORSU), mixed waste, and the treatment received. Finally, the approximate emissions for each of these treatments are determined.

Equation 4 shows the calculation procedure, where W_{ij} is the generated mass (in kg) per inhabitant and per type of waste i and kind of treatment j; EF_{ij} is the corresponding emission factor, and $Inhab$ corresponds to the total inhabitants of the neighborhood.

$$GHG_{Waste} = \sum_{ij} [W_{ij} \times EF_{ij}] \times Inhab \quad (4)$$

2.1.4 Transport from Tourism and Work

This section estimates the emissions generated by transport due to tourism and trips made by the neighborhood's inhabitants but outside the limits of the neighborhood. It considers trips within the community, inside Spain (mainly Madrid and Barcelona), and to main European (mainly France, Portugal, Italy, United Kingdom, and Germany) and international destinations (mainly Morocco, United States, Turkey, Mexico, Egypt, and other) made by sea, land, and air transport.

To estimate the emissions, it is used the statistics of means of transport used for each of the four considered types (according to data availability and established separation in consulted statistics, see Transport category in Table 6): trips within the Valencian Region to the rest of Spain or on the continent and intercontinental ones.

Once the number of trips is defined, the type of transport used is determined according to a specific bibliography and Spanish traveling statistics. With this information, the traveled distance is taken from Google Maps, and the emission factors are taken from SIMAPRO. Then, all data is applied to the neighborhood, considering that the number of trips made by citizens in urban areas is 89% greater than those made by citizens in rural areas, according to previous studies (Universitat Politècnica de València, 2009).

It is essential to remember that the objective is to estimate the emissions generated by the use of the means of transportation due to the tourism activities of the neighborhood's citizens, not the emissions generated at the destination or other emissions derived from tourism. Under this projection, this work is a starting point and can be further developed in future research projects.

Equation 5 shows the calculation procedure where T_{ij} represents the number of trips in the neighborhood to destination i in means of transport j; D_i is the distance (in km) to the destination and EF_j is the emission factor of the transport j.

$$GHG_{Transport} = \sum_{ij} \left[T_{ji} \times D_i \times EF_j\right] \quad (5)$$

2.1.5 Other Consumption of Goods

This section considers the cradle-to-market gate emissions from using other products, such as cosmetics, personal care, cleaning products, cooking elements, toys, medicines, and pet food.

Undoubtedly, there are more consumer products than those mentioned above. However, these represent the main products and will allow an approximation of the total emissions of the neighborhood, considering that this work is the first one to detail what can be achieved in accounting for indirect emissions produced in a neighborhood. The emissions generated by these products are calculated based on general good consumption statistics in Spain (Table 6). Some emission factors are taken from the Ecoinvent database at Simapro, and others are from different bibliographic sources. Equation 6 shows the calculation procedure, where C_i is the consumption of product i per household, EF_i is its emission factor, and HH corresponds to the total number of households of the neighborhood.

$$GHG_{Goods} = \sum_{i} [C_i \times EF_i] \times HH \quad (6)$$

2.1.6 Clothing

Clothing is one of the most challenging categories because of its significant variation in terms of value and number of garments purchased per person in a year due to their purchasing power and level of environmental awareness, and how this influences their choice in terms of quality, number of garments, type of fabrics, origin of manufacture, among others. No average statistics were found at the regional or country level. Considering these limitations, the analysis in this section finds that the average European person purchases 34 new garments per year (Piontek et al., 2019).

In this section, emissions from cradle to market will be considered to avoid double counting emissions due to local transportation and washing and drying, as they are accounted for in Scope 1, and waste treatment, which is accounted for in the waste sector in Scope 3.

Another major challenge for this section is the diversity of regions where garments are manufactured, the different energy matrices, and environmental control. Equation 7 shows the calculation procedure, where C_i is the per capita consumption per type of clothes i, EF_i is its emission factor, and $Inhab$ is the number of inhabitants of the neighborhood.

$$GHG_{Clothe} = \sum_i [C_i \times EF_i] \times Inhab \tag{7}$$

- *Clothing calculating examples*

The calculations of GHG emissions due to clothes per inhabitant are estimated through equation 7.1. The emission per type of cloth and year is taken from (Muthu Subramanian, S., 2015; Piontek, F.M., Rapaport, M. Muller, M., 2019) and are detailed in Table 1.

$$\frac{GHG_{Clothes}\,(kg)}{Inhab \cdot year} = [C_a \times EF_a] + [C_b \times EF_b] + [C_c \times EF_c] + [C_d \times EF_d] + [C_e \times EF_e] + [C_{if} \times EF_f] + [C_g \times \\ + [C_h \times EF_h] + [C_i \times EF_i] + [C_j \times EF_j] + [C_k \times EF_k] + [C_l \times E_l] \tag{7.1}$$

$$= [1 \times 62.3] + [2 \times 24.7] + [1 \times 23.3] + [2 \times 22.0] + [3 \times 21.6] + [4 \times 17.3] + [2 \times 15.4] + [2 \times 13.6] + [5 \times 9.5] + [2 \times 9.0] + [4 \times 7.2] + [7 \times 3.9] = 448.3 \frac{kgCO2}{inhab \cdot year}$$

Table 1. Estimation of the CO_2 emissions per inhabitant due to cloth in the Benicalap neighborhood

Type of cloth	Subindex	Emissions per unit [kgCO_2]	Units per person	Total emissions per person
Overcoats	a	62.3	1	62.3
Jackets	b	19.0	1	19.0
Boots	c	23.3	1	23.3
Dresses	d	22.0	2	44.0
Jeans	e	21.6	3	64.8
Pants	f	17.3	4	69.1
Jumpsuits	g	15.4	2	30.8
Shoes	h	13.6	1	13.6
Pullovers & cardigans	i	9.5	5	47.5
Skirts	j	9.0	2	18.0
Shirts & blouses	k	7.2	4	28.8
T-Shirts	l	3.9	7	27.1
Total				**448.3**

The yearly CO_2 emissions are obtained with the CO_2 emissions per inhabitant times the number of inhabitants. As a result, the CO_2 emissions due to cloth are around 18,768 tonCO_2/year, as shown in Equation 7.1.

$$GHG_{Clothe_{Benicalap}} \left(\frac{kg}{year}\right) = \frac{GHG_{Clothes}\,(kg)}{Inhab \cdot year} \times Inhab = 448.3\ \frac{kgCO_2}{Inhab \cdot year} \cdot 41{,}868\ inhab = 18{,}768\ tonCO_2/year \tag{7.1}$$

2.1.7 IT Equipment

The methodology used to determine the emissions from acquiring electronic devices, such as smartphones, tablets, and laptops, uses the national statistics of Spain. The first part considers the percentage of households with at least one of these devices and their owners over 15 years old (Instituto Nacional de Estadística, 2023) . Then, the average lifetime is considered, thus determining the number of new devices purchased annually by the neighborhood's inhabitants as well as the emission factors of each of them.

In this section, emissions from cradle to market will be considered. This is to avoid double counting of emissions due to local transportation, as they will be accounted for in transport in Scope 1, due use, as they will be accounted for in energy in Scope 1, and due to waste treatment, as they will be accounted for in the waste sector in Scope 3.

Equation 8 shows the calculation procedure, where C_i is the number of devices i that are replaced in the neighborhood per yea, indicate and EF_i is the emission factor of the devices calculate C_i it is considered $Inhab_{15}$ that represent the number of inhabitants over 15 years old and Tr_i is the replacement rate. Here, the number of inhabitants over 15 years of age, divided by the percentage of the population with this type of device, is considered, and the approximate life cycle per type of device is divided.

$$GHG_{IT} = \sum_i [C_i \times EF_i] \quad (8)$$

$$C_i = I_{nhab15} \times Tr_i \quad (9)$$

- *IT equipment calculating example*

To estimate the CO_2 emissions due to IT equipment, first, it calculates the number of IT equipment and the total emission per equipment. The calculations of the number of IT equipment are estimated through equation 8.1 to 8.3. The CO_2 emissions due to IT equipment are calculated using Equation 8.4. Table 2 shows the information required for calculations, and Table 3 shows the CO_2 emission due to IT devices. In total, 1187 tonnes of CO_2/year are produced due to the IT equipment in Benicalap.

$$\frac{New\_smartphones}{year} = \frac{Inhabitants_{15} \times \%\ people\ with\ smarthphone}{Years\ to\ update\ smartphone} = \frac{35{,}850 \times 0.84}{2.5} = 12{,}046\,\frac{smartphones}{year} \tag{8.1}$$

$$\frac{New\_computers}{year} = \frac{HH \times \%\ of\ HH\ with\ laptop}{Years\ to\ update\ computers} = \frac{16{,}975 \times 0.814}{5.0} = 2{,}764\,\frac{computers}{year} \tag{8.2}$$

$$\frac{New\ tablets}{Year} = \frac{HH \times \%\ of\ HH\ that\ has\ a\ tablet}{Years\ of\ update} = \frac{16{,}975 \times 0.548}{4.0} = 2{,}326\,\frac{tablets}{year} \tag{8.3}$$

$$GHG_{IT} = \sum_i [C_i \times EF_i] = [C_{Sp} \times EF_{Sp}] + [C_l \times EF_l] + [C_t \times EF_t] = [12{,}046 \times 41.76] + [2{,}764 \times 174.53] + [2{,}326 \times 86.744] = 1187\,\frac{ton\ CO_2}{year} \tag{8.4}$$

Table 2. IT equipment consumption in Benicalap (Instituto Nacional de Estadística, 2023)

Total population in Benicalap	41,868
Inhabitants older than 15 years in Benicalap	35,850
Number of households	16,975
Smartphone	
% habitat with smartphone	84.0%
Nº of smartphones in Benicalap	30,114
Years of update	2.5
New smartphones per year in Benicalap	12,046
Computers	
% of households with a computer	81.4%
Households with computers	13,818
computers per households	1.0
Nº of computers in Benicalap	13,818
Years of update	5.0
New laptops per year in Benicalap	2,764
Tablets	
% of households with tablet	54.8%
Households with tablet	9,302
Tablet per households	1.0
Nº of tablets in Benicalap	9,302
Years of update	4.0
New tablets per year in Benicalap	2,326

325 Table 3. Total emissions due to IT equipment in Benicalap

Device	Emission Factor [kgCO_2]	Number of devices	Emissions [tonCO_2]
Smartphone	41.76	12,046	503.0
Laptop	174.53	2,764	482.3
Tablet	86.74	2,326	201.8
Total		17,135	1187.1

2.1.8 Furniture

For the calculation of emissions due to the purchase and use of different types of furniture, the consumption in Spain is determined according to Table 6 data sources type; this information makes an analysis based on the number of households in Benicalap. Then, the emissions per furniture type, including the kitchen, rooms, upholstery, office, garden, living room, bathroom, and auxiliary furniture are determined.

In this work, only emissions generated by the production of cradle-to-store gate furniture are considered, as emissions from use and cleaning or maintenance elements are included negligible, emissions from transport are considered under transport Scope 3, and emissions generated by final disposal will be considered under waste and waste management.

Equation 10 shows the calculation procedure, where Tr_i is the replacement rate (in units per year and household, the percentage of households with the type of device and its average lifetime are considered). EF_i is the emission factor, and HH is the number of households in the neighborhood.

$$GHG_{Furniture} = \sum_{i} [Tr_i \times EF_i] \times HH \qquad (10)$$

2.1.9 Household Appliances

First, the percentage of households that own each appliance is determined to calculate the cradle-to-store gate emissions due to the manufacture of household appliances. Subsequently, the life cycle for each appliance is considered, and it is assumed that at the end of each, the household will acquire them again. Finally, the emission factor is considered, and the total emissions for the neighborhood are determined. In this section, only emissions generated by the production of cradle-to-store gate furniture are considered, as emissions from use are considered primary energy in Scope 1, and emissions generated by final disposal will be considered under waste management in Scope 3.

Equation 11 presents the calculation procedure, where indices Tr_i is the replacement rate, and the percentage of households with this type of device and the average lifetime is considered as well. EF_i is the emission factor, and HH is the number of households in the neighborhood.

$$GHG_{Appliances} = \sum_i [Tr_i \times EF_i] \times HH \quad (11)$$

2.1.10 Construction and Building Retrofitting

This section considers the cradle end of construction emissions, e.g. due to the manufacturing process of materials and the construction, as such, emissions from the use and maintenance are considered in Scopes 1 and 2. According to different bibliographic sources, the number and characteristics of new constructions and retrofitting in the neighborhood per year are determined and multiplied by the emission factor per square meter.

During the retrofitting process, there will be additional emissions. However, these improvements are aimed at decreasing energy consumption in the future, specifically for heating and cooling cycles; therefore, there will be a decrease in the energy sector in Scopes 1 and 2 during the life cycle of the building.

Equation 12 presents the calculation procedure, where Area concerns the newly constructed buildings and EF_i is the emission factor per square meter.

$$GHG_{Construction} = Area \times EF \quad (12)$$

2.1.11 Automobile Production

In this methodology, only emissions generated by the production of cradle-to-store gate are considered, as emissions from fuel use are considered in the transport sector in Scopes 1 and 2. First, it determines the percentage of households that own a car and the average lifetime of the car in Spain. Finally, the emission factor is considered, and the total emissions for the neighborhood are determined.

Equation 13 shows the calculation procedure, where Tr_i is the replacement rate (units per year and household), calculated with the percentage of households with a car, and the average lifetime of the cars. EF is the average emission factor, and HH is the number of households in the neighborhood.

$$GHG_{Automobiles} = HH \times Tr_i \times EF_i \quad (13)$$

2.2 Mitigation strategies

A Pareto analysis is performed to understand the activities that generate the most significant impact in this area, and different mitigation measures and sensitivity analyses are proposed. An estimated CO_2 balance is performed to complete them, and a roadmap of the proposed actions is drawn up (Figure 2).

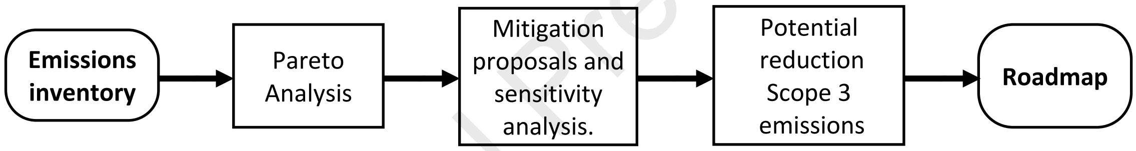

Figure 2. Methodological mitigation process

The same equations of the methodology employed for the initial emissions inventory are used to determine the new emissions due to the implementation of the proposed measures, which are affected by the reduction in consumption or the emissions factor. Table 4 shows the performed sensitivity analyses. Information is obtained from previous studies and bibliographic reviews in the different sectors. Most of the references were selected to guarantee the reliability, so published articles in JCR journals, widely used and accepted databases/software (Carboncloud, SimaPro, GreenDelta,…), and official/public sources have been used. The details of consulted bibliographic sources have been included in Table 4 and Table 6 and will be commented on in the following points.

Table 4. Sensitivity analysis mitigation proposals

Subsector	**Mitigation process**	**Range of reduction**	**References**
Food and beverages	Reduction of red meat consumption	0-45%	(European Commission, 2024)
Food and beverages	Reduction in food waste	30-50%	(FAO. Organizacion de las Naciones Unidas para la Alimentacion y la Agricultura, 2020; ONU, 2021)
Food and beverages	Increase local and seasonal consumption	80%	(Vargas et al., 2021)
Clothing	Less new purchases, second-hand	35%	(Millward-Hopkings et al., 2023)
Transport (Scope 3)	Delate some flights	12%	(Avogadro et al., 2021)
Transport (Scope 3)	Encourage public transportation (Train – Buses)	10-50% 5-20%	(Ajuntament d'Alcala de Xivert, Generalitat Valenciana, 2018a; Hahn et al., 2023)
Vehicles	Fewer vehicles acquisition	10-30%	(Arranz et al., 2023)
Construction	Decrease the emission factor	5-20%	(Greer and Horvath, 2023)
IT, furniture, appliances	Increase lifetime	50%	(European Commission, 2022)
Waste	Decrease waste generation	0-20%	(Ministerio para la Transición Ecológica y el Reto Demográfico, 2023)
Waste	Decrease landfill waste treatment	17%	

Finally, depending on the available data and information, each sector's general methodology is carried out with exhaustiveness, coherence, transparency, and the highest possible accuracy. In this way, city councils are encouraged to perform additional studies to continue improving, updating, and deepening the data, thus achieving a more accurate estimation.

2.2.1 Case Study

This section will analyze the case study, the used inputs, and the bibliographic information to be considered. Benicalap is the most significant neighborhood in the district, and it has the same name. There is a second neighborhood called Ciudad Fallera. Table 5 presents general information the València Town Hall provided for January 2022.

Table 5. General data of Benicalap neighborhood (Ayuntamiento de València, 2023; Padrón Barrio de Benicalap - Ayuntamiento de Valencia, 2023)

Description	Unit	Value
Population	[Inhab]	41,868
Surface	[km^2]	1.72
Population density	[Inhab/km^2]	24,341
Households	[HH]	16,975
Average, persons per household	[I/HH]	2.47
Number of properties	[N]	19,266

Of the total population, 17.4% are under 18 years old, 30% are students, and 36% are people with some vocational training. As for the distribution of the number of persons per household, 30% are composed of one person, 27% of two, 20.4% of three, 16% of four, and the remaining percentage are families with more than four persons.

Regarding the automotive situation, 22,739 vehicles are registered, of which 16,702 correspond to cars for private use. Regarding real estate, it has 19,266 properties, of which 40% were built between the 1960s and the 1980s and 40% between the 1980s and 2010. This distinction is made due to the technological change in the construction sector that has taken place in the different decades and how these changes modify the insulation and, therefore, the energy consumption for air conditioning.

As in most of the neighborhoods of the city, there are high differences, where there are areas with an outstanding social classification and others with a presence of vulnerability (Generalitat Valenciana, Institut Cartografic Valencia, 2023)

2.2.2 Data sources

In the case study, the sources consulted to calculate the emissions inventory and mitigation measures in the Benicalap neighborhood are shown in Table 6. Its study could serve as a guide to be replicated in other city neighborhoods with similar characteristics.

Table 6. Indicators to calculate annual emissions inventory and mitigation measures

Theme	Indicator	Unit	Values	Reference(s)
Food and Beverages	Consumption	[kg/Inhabit]	637.92	(Ministerio de Agricultura Pesca y Alimentación, 2022)
	Emission Factor	[$kgCO_2$/kg]	0.01 – 130.45	(CarbonCloud, 2023; GreenDelta, 2006; SimaPro, 2023)
	Mitigation potential	[%]	7 - 45	(Ajuntament d'Alcala de Xivert, Generalitat Valenciana, 2018b; European Commission, 2024; FAO. Organizacion de las Naciones Unidas para la Alimentacion y la Agricultura, 2020; Naciones Unidas, Centro Regional de Informacion, 2022; ONU, 2021; Vargas et al., 2021)
Energy	Consumption	[MWh]	77,085	(Izquierdo De Andés, 2022)
	Losses	[%]	9.0	(Comisión Nacional de los Mercados y la Competencia (CNMC), 2023; Red Eléctrica de España, 2023a)
	Emission Factor	[tCO_2/MWh]	0.172	(Red Eléctrica de España, 2023b; Task Group on Data Support for Climate Change Assessments (TG-Data), 2023)
Waste Treatment	Generation	[Ton]	19,816 Ton	(Instituto Nacional de Estadística (INE), 2023a; Ministerio para la Transicion Ecologica y el reto demografico, 2021)
	Emission Factor	[$kgCO_2$/kg]	0.02 – 2.28	(EPA United States Environmental Protection Agency, 2020)
	Mitigation potential	[%]	0 - 20	(Ministerio para la Transicion Ecologica y el reto demografico, 2021)
Transport	Travels and type of transport	[Nº/Inhabitant]	160.74 Including internal and external trips	(Instituto Nacional de Estadística (INE), 2023b; Ministerio para la Transicion Ecologica y el reto demografico, 2021)
	Distance	[km]	74 – 11,024	("Google Maps," n.d.)
	Emission Factor	[$kgCO_2$/km]	0.078 – 0.323	(SimaPro, 2023)
	Mitigation potential	[%]	0 - 20	(Rivera-Marín et al., 2023)
Other goods	Consumption	[kg], [pieces]	It depends on the type of product	(CarbonCloud, 2023; GreenDelta, 2006)
	Emission Factor	[$kgCO_2$/kg]	0.3 – 2.2	(Alexander et al., 2020; Belkhir and Elmeligi, 2019; Instituto Nacional de Estadística (INE), 2023c; Levesque et al., 2022)
Clothes	Consumption	[Nº/I]	34	(Piontek et al., 2019)
	Emission Factor	[$kgCO_2$/Piece]	7.2 – 62.3	(Muthu Subramanian, S., 2015)
	Mitigation potential	[%]	18 - 35	(Piontek et al., 2019)
IT Devices	Consumption	[Nº/Inhabitant]	1 – 2.5	(Instituto Nacional de Estadística (INE), 2023d)
	Emission Factor	[$kgCO_2$/device]	41.76 – 174.53	(SimaPro, 2023)
Furniture	Consumption	[Nº/HH]	25.2% of total households	(Instituto Nacional de Estadística (INE), 2023d)
	Emission Factor	[$kgCO_2$]	141 - 596	(Lauvland and Pettersen, 2021)
Households Appliances	Consumption	[Nº/HH]	1 - 2	(Carbonfact, 2023)
	Emission Factor	[$kgCO_2$/device]	6.2 – 373.8	(SimaPro, 2023)
Construction and building retrofitting	Area	[m^2/HH]	103.87 averages	(Instituto Nacional de Estadística (INE), 2023d)
	Emission Factor	[$kgCO_2/m^2$]	315 - 449	(Rabani et al., 2021)
	Mitigation Proposes	[%]	0 -20	(Instituto Nacional de Estadística (INE), 2023d)
Automobile	Consumption	[Nº]	1671	(Universidad de Alcala (Catadra de Etica Ambiental), n.d.)
	Emission Factor	[$kgCO_2$]	8750	(Buberger et al., 2022)
	Mitigation Proposes	[%]	0 -30	(Ministerio para la transición ecologica y reto demográfico, 2020)

3 RESULTS

The obtained results are shown in this section. In the first part, the emissions inventory is analyzed, and then the results of the sensitivity analyses are proposed for the mitigation measures. Finally, the proposed roadmap is presented.

3.1 GHG inventory

Figure 3 provides the overall result of CO_2 emissions obtained for 2022 in the neighborhood of Benicalap by applying the developed calculation procedure. It is observed that almost 37% of the emissions are due to food, followed by 14% for clothing and transportation of citizens outside the city of Valencia, and the remaining 35.4% is due to the consumption of personal and household goods, waste management and losses of the electricity grid and Natural Gas supply.

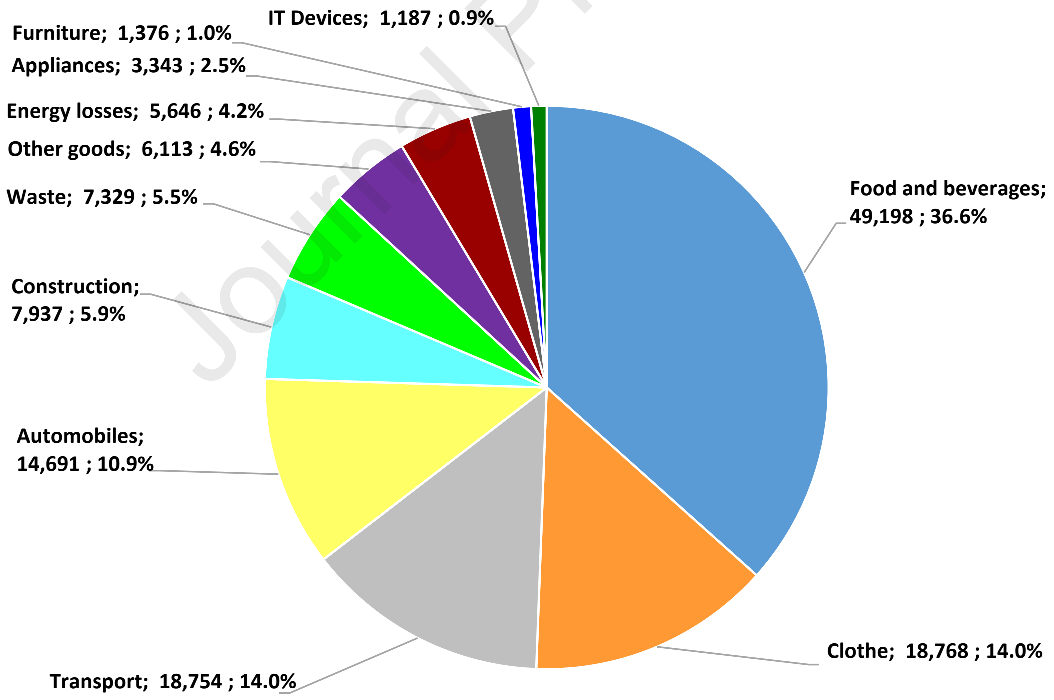

Figure 3. Scope 3 Emissions inventory results for Benicalap, ton CO_2 per year and percentage.

This corresponds to 3,207 $kgCO_2$ per person per year. On average, one person generates between 4,500 and 5,000 $kgCO_2$ per year. The Scope 3 emissions represent from 64 to 71% (Our World in Data, 2021).

3.2 Mitigation Proposes and Sensitivity Analysis

This chapter shows the results of the sensitivity analyses conducted in the methodology and carried out for each of the Scope 3 sectors. These will be the basis for determining the reduction targets of the proposed mitigation measures and subsequently proposing an action plan.

3.2.1 Sensitivity Analysis of Red Meat Consumption Reduction

This sensitivity analysis looks at the impact of reducing red meat consumption emissions from 15% to 45% of current consumption (Table A. 1). It can reduce Food and Beverage subsector emissions by 2.4% to 7.2%, respectively. This reduction range provides 1,176 to 3,527 tons of CO_2 savings.

3.2.2 Sensitivity Analysis of Food Waste Reduction

This sensitivity analysis shows that reducing food emissions by reducing food waste (Table A. 2) up to 50% can reduce Food and Beverage subsector emissions up to 1.7% (equivalent to 3,527 tons of CO_2).

3.2.3 Encourage Valencian Orchard – Local and Seasonal Food Consumption

The reduction in emissions from food by strengthening the Valencian orchard products' local and seasonal consumption is shown in Table A. 3. This increases the consumption of locally produced food like rice, citrus fruits, olives, some fruits, and vegetables and reduces the consumption of food produced in other continents, like chocolate, and other types of fruits and vegetables. This strategy can reduce up to 3,131 tons of CO_2 (equivalent to 6,4% of Food and Beverage subsector emissions)

3.2.4 Encourage Second-hand Clothing, Reduce Consumption, and Increase Lifetime

Table A. 4 shows what happens to emissions due to clothing when it goes from buying 34 new clothes per year to buying 20, by strengthening the circular economy and second-hand consumption. This strategy can reduce up to 6,576 tons of CO_2 (equivalent to 35% of Clothing subsector emissions).

3.2.5 Reduce Airplane Usage

Transport emissions by replacing Barcelona and Madrid flights by train (trains with a journey duration of less than two hours) shows a reduced impact on transport emissions. When eliminating these commercial flights the emission reduction is 6 tons of CO_2 (equivalent to 0.03% of Transport subsector emissions).

3.2.6 Reduce Private Car Usage in Valencian Community

A sensitivity analysis of emissions reduction due to reduction in emissions from transport by reducing private car usage and increasing railways and buses in journeys inside the Valencian Community (CV) are shown in Table A. 5 and Table A. 6. As stated in point 4, car usage can be reduced up to 50% and the emission reduction is up to 1,085 tons of CO_2 (equivalent to 5.8% of Transport subsector emissions) when using train, and 601 tons of CO_2 when substituting by buses.

3.2.7 Sensitivity Analysis of Private Car Usage in Spain

A sensitivity analysis of emissions reduction due to reduction in emissions from transport by reducing private car usage and increasing railways and buses in journeys inside Spain is shown in Table A. 7 and Table A. 8. As stated in point 4, car usage can be reduced up to 20% and the emission reduction is up to 607 tons of CO_2 (equivalent to 3.2% of Transport subsector emissions) when using train, and 528 tons of CO_2 when substituting by buses.

3.2.8 Sensitivity Analysis of Automobile Acquisitions

A sensitivity analysis of emission reduction from the automobile sector due to decreased households purchasing a car annually due to the strengthening of public transport and the 15-minute city approach is shown in Table A. 9. The number of purchased vehicles per year can be reduced up to 30%, and the obtained emissions reduction is up to 4,383 tons of CO_2 (equivalent to 30% of Vehicles subsector emissions).

3.2.9 Sensitivity Analysis of Building Construction Emission Factors

A sensitivity analysis of emissions reduction from the construction sector due to the decrease in the emission factor in the new constructions as a consequence of energy efficiency policies in the industry, new materials, a cleaner energy matrix, circular economy encouragement, and others. Table A. 10 shows feasible Emissions factor reduction in the range 0-20%, so up to 1,484 tons of CO2 emissions due to new constructions can be reduced.

3.2.10 Sensitivity Analysis of Furniture, IT Devices, and Household Appliances

Emissions reduction from the furniture, electronics, and home appliances sectors can be obtained by increasing the lifetime (for example, promoting a circular economy or reducing programmed obsolescence). It has been considered feasible for up to 50% increase in the lifetime of home appliances and doubling the lifetime of furniture and electronics. These strategies can reduce up to 2,117 tons of CO_2 (equivalent to 30% of IT, furniture, and appliances subsector emissions).

3.2.11 Reduce Waste Generation and Landfill Treatment

A sensitivity analysis of emissions reduction due to the lower generation of waste and lower use of landfills for waste management is shown in Table A. 11. Feasible waste generation reductions can be up to 20%, and Landfill use for mixed waste can be reduced from present 67% to 40%. These strategies can save up to 1,758 CO_2 emissions (equivalent to 31% of Waste subsector emissions).

3.3 Roadmap Proposal

The roadmap can define short-term partial objectives (2027, 5 years ahead), but to reach the final objective it is necessary to consider a medium/long-term approach, it has been considered 2035. For both, the partial and final objective, the measure that will be implemented is (pre) defined, and the percentage of reduction is indicated. Figure 4. Roadmap – sectors with the highest emissions shows the proposed roadmap of mitigation measures for the sectors with the largest share of emissions, while Figure 5. Roadmap of other sectors provides the information for the rest of them.

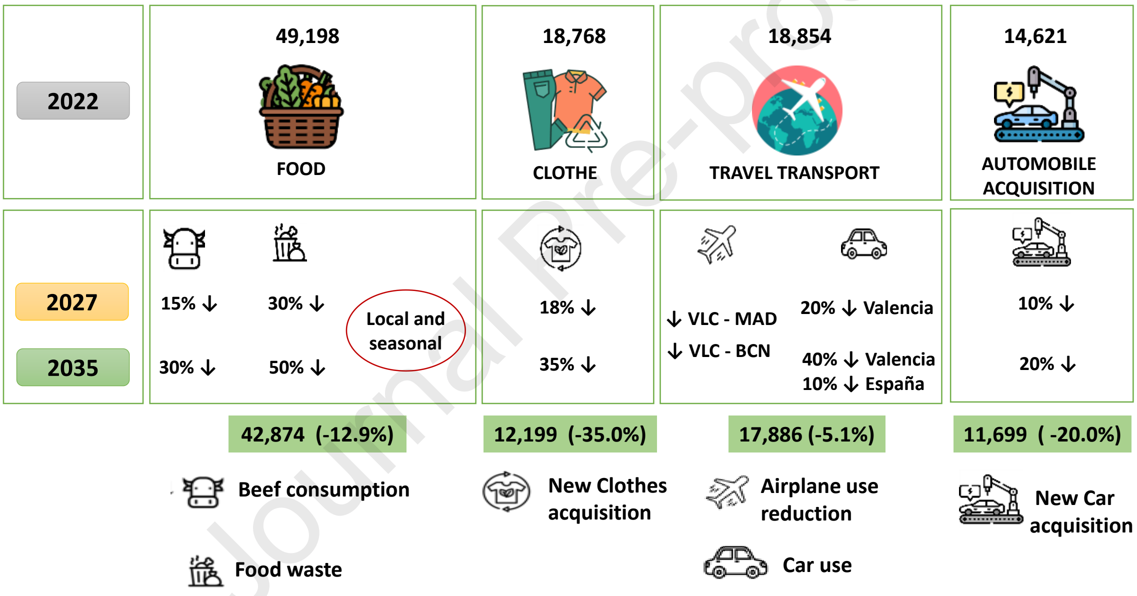

Figure 4. Roadmap – sectors with the highest emissions, ton CO_2 and percentage of reduction.

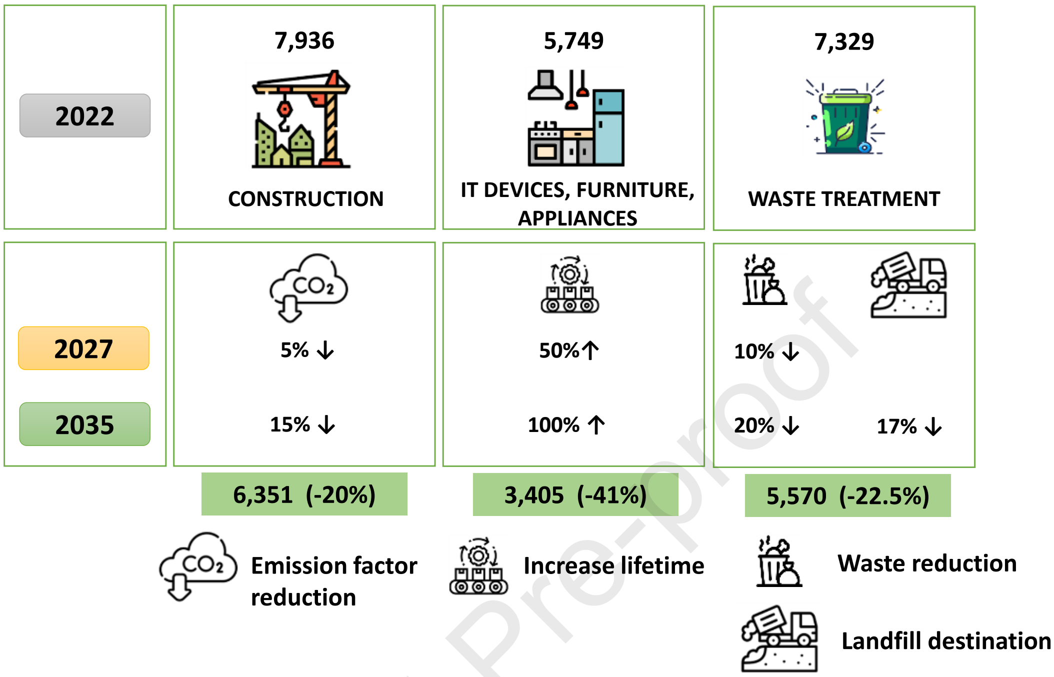

Figure 5. Roadmap of other sectors, ton CO_2 and percentage of reduction or increase.

By 2035, it is proposed for the food sector a 30% decrease in meat consumption, 50% less food waste, and seasonal consumption of local orchard products; for the clothing sector, a 35% decrease in the number of purchased garments per year is considered; for the transport sector it is proposed the elimination of short trips that can be covered by rail, a 40% decrease in the use of private cars for trips within the Valencian Community and a 10% decrease in trips within Spain. In addition, a 20% reduction in the purchase of new vehicles, a 15% reduction in the emission factor of construction, doubling the life cycle of furniture and electronic devices, as well as increasing the life cycle of household appliances by 50%, and finally, a 20% reduction in waste and 17% reduction in the use of landfills as a means of waste treatment.

3.3.1 Emission Reduction Potential

Table 7 provides the emission reduction potential. According to the proposed mitigation measures, the neighborhood's indirect emissions (Scope 3) could be reduced by 16.2%. The sectors with the most significant reduction are furniture, IT, and household appliances, with 35.8% due to the increase in the life cycle, clothing with 35% due to the decrease in new garments purchased per person, waste with 24%, automobiles 20% and construction with 14.1%, followed by food with 12.9%, where local and stationary consumption is 6.4%. The reduction in meat consumption is 4.8% and finally the transportation sector with 5.2% where almost all of its reduction is due to the reduced use of private cars.

Table 7. Emission reduction potential summary - Scope 3

Year	**2021**	**2035**		
Sector	**Emissions**	**Emissions**	**Reduction**	
	[ton CO_2]	[ton CO_2]	[ton CO_2]	[%]
Food	49,198	42,873	6,325	12.9%
Clothes	18,768	12,192	6,576	35.0%
Transport	18,754	17,788	966	5.2%
Automobile	14,621	11,699	2,922	20.0%
Construction	7,937	6,816	1,121	14.1%
Waste	7,329	5,571	1,758	24.0%
Other goods	6,113	6,113	0	0.0%
Furniture, IT, appliances	5,906	3,789	2,117	35.8%
Energy	5,646	5,646	0	0.0%
Total	**134,272**	**112,487**	**21,785**	**16.2%**

Table 8 shows the reduction potential from the point of view of total emissions (including all Scopes 1, 2, and 3 emissions); clothing and food provide the highest reduction percentage, 4.9% and 4.7%, respectively, followed by the production of automobiles with 2.2%, the increase in the lifetime of technological devices, furniture, and appliances with 1.7%, construction, and waste management with 1.2% each and finally with 0.7% the emissions from transport of Scope 3, due to tourism and work trips made by the inhabitants of the neighborhood.

Table 8. Reduction potential Scope 3 emissions per sector

Sector	**Reduction**	
	[ton CO_2]	[%]
Food	6,325	4.7%
Clothes	6,576	4.9%
Transport	966	0.7%
Automobile	2,922	2.2%
Construction	1,121	0.8%
Waste	1,758	1.3%
Other goods	0	0.0%
Furniture, IT, appliances	2,117	1.6%
Energy	0	0.0%
	21,785	**16.2%**

4 DISCUSSION

Humanity is currently facing environmental challenges due to the global warming. The search for sustainability policies, adaptation, and mitigation of the effects of climate change are becoming increasingly crucial in governmental guidelines. This study seeks to be an instrument to help researchers and governments and a mechanism to raise awareness among citizens, who sometimes distantly see mitigation policies and actions. In this work, the emissions corresponding to Scope 3 are studied in depth, motivated by the significant percentage representation that these emissions have over the total in cities; they are directly related to people's consumption habits and because they represent a novel study concerning the majority of works carried out on the accounting of emissions in cities.

This study presents a comprehensive methodology for Scope 3 emissions accounting and potential reduction at the neighborhood level, addressing gaps in existing literature. Unlike prior studies focusing on broader city or sector levels and omitting some Scope 3 sectors, this approach encompasses all Scope 3 sectors with detailed emission factors and mitigation strategies. It also includes analyses specific to a neighborhood in Valencia. A thorough review of current methodologies and emission factors defined feasible reduction ranges, and sensitivity analyses were performed under various scenarios. This replicable and adaptable methodology offers a robust tool for achieving carbon neutrality in diverse neighborhoods.

This document is a starting point in the accounting of indirect emissions in cities; it is rigorous, replicable, reproducible, and innovative. However, uncertainty of the methodology and its application is a critical factor that cannot be avoided. When measuring upstream emissions of purchased goods or services, we have to rely on supplier-specific carbon footprint declaration and statistics (that can also be outdated) about the country or origin of raw materials, transport distances, and many other assumptions that make uncertainty high. Additionally, statistics or indicators of consumption are, in many cases, available only at the country or even European level, so this lack of specific city or neighborhood data provides additional uncertainty. These uncertainties and lack of data at the neighborhood level are the main limitations of the methodology. Therefore, this work also aims to continue promoting this type of research, improving the input data, updating the emission factors to be consistent with the current energy matrix, improving consumption statistics, information provided by governments, among others. If carbon footprint declarations and lifecycle analysis of products or services are improved, updated, and accessible, the uncertainty and limitations of the methodology will be reduced.

Finally, this document also seeks to encourage environmental education and help make citizens aware of their daily consumption habits, calling on the inhabitants of the neighborhoods to remember that many small actions generate significant changes and that it is in our hands to help mitigate the effects of global warming and optimize natural resources.

5 CONCLUSIONS

A methodology for Scope 3 emissions assessment of relevant sectors, at the city's neighborhood level, has been defined, with emission factors for the different activities, supplies, or products. This methodology has also been applied to the Benicalap neighborhood in Valencia (Spain) to provide an initial CO_2 emissions inventory, impact evaluation of relevant proposed mitigation measures, and its implementation roadmap. Within the results obtained in the inventory of Scope 3 emissions, it is found that an average inhabitant produces 3.21 tons of CO_2 per year, representing between 64 and 71% of the total emissions per capita at the Spanish level. It should be noted that the emissions of 4 sectors, out of the 11 considered, accounted for 75.5% of the total indirect emissions of the neighborhood; these 4 sectors are the consumption of food and beverages (36.6% from total), the purchase of clothing (14%), the travel of the inhabitants due to leisure, tourism, and work (14%); and the purchase of private cars (10.9%).

Governments must adopt comprehensive policies to reduce GHG emissions effectively across all key sectors. The food sector should promote plant-based diets, reduce red meat consumption, and implement strategies to minimize food waste, such as tax incentives for businesses donating surplus food and public awareness campaigns. A circular economy can be advanced by encouraging second-hand markets, extending the lifespan of clothing, furniture, and electronics, and enacting regulations to combat planned obsolescence. Investment in public transit systems is crucial in transportation, along with subsidies for rail infrastructure to replace short flights and incentives for reducing private car use. Policies should also support shared mobility solutions, carpooling, and cycling infrastructure. For construction, governments should mandate energy-efficient building standards, promote sustainable materials, and advocate for urban planning initiatives like the 15-minute city to reduce commuting distances. Waste management policies should focus on enhancing recycling programs, reducing landfill dependency, and investing in waste-to-energy technologies. Additionally, robust environmental education programs are essential to raise awareness of sustainable consumption habits and empower citizens to participate actively in emission reduction efforts. These integrated policies can significantly lower emissions while fostering sustainable development and improving overall quality of life.

With this information, a series of general and sector-specific recommendations are made, and a roadmap is proposed for 2035 with an expected reduction of 16.2% of the neighborhood's Scope 3 GHG emissions, equivalent to 21,785 tons of CO_2 per year. Key mitigation strategies per sector, and expected emission reduction for the analyzed neighborhood is represented in the following paragraph.

In the clothing sector, reducing consumption of new clothes, promoting second-hand consumption and increasing the life cycle of garments can provide a 4.9 % reduction of emissions. Regarding the food and beverage sector, reducing the consumption of red meat, reducing food waste, and encouraging the local and seasonal consumption of vegetables and fruits can provide a 4.7% emissions reduction. In the automobile sector, the reduction of purchase of new vehicles can provide a 2.2% of emissions reduction. In the furniture, IT, and appliances sector, the increase in the life cycle of these products can provide a 1.7 % reduction in emissions. Finally, proposed mitigation measures provided between 0.7% and 1.2% of emissions reduction in construction, waste management and transport sectors.

This study also highlights the challenges posed by the lack of emission factors at the local level, which requires reliance on regional, national, and European data to address these gaps. While using diverse sources, including government studies and well-established LCA databases, ensures a robust foundation for the analysis, improving data accuracy at a local scale remains essential. Future efforts should focus on developing and disseminating localized emission factors to enhance the precision and applicability of similar studies. Additionally, future methodology improvements should include a cost-benefit analysis of mitigation measures, and the consideration of external factors such as economic development levels and relevant policies and regulations that can affect subsector activity indicators and emission factors. Additionally, an uncertainty analysis should be performed in future works.

Finally, it is important to note that while the specific results of this study are most applicable to neighborhoods similar to Benicalap, they may not be directly transferable to dissimilar areas without adjustments. It is essential to consider factors, such as consumption habits, the lifestyle of the community, and the level of territorial development, determined by internal conditions (e.g. urban characteristics, type of food, religious practices, type of building, average income and expenditures) and external factors (e.g.

geography or climate). However, the methodology used in this study is replicable and can be applied to other locations.

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Appendix A: Tables of Sensitivity Analysis Results of Mitigation proposes

Table A. 1. Sensitivity analysis of food emissions due to the reduction of red meat

Reduction of red meat consumption [%]	Meat consumption emissions **[Ton]**	New Food and Beverages Emissions **[ton CO_2]**	Reduction **[ton CO_2]**	**[%]**
0%	15,479	49,198	0	0.0
15%	14,303	48,022	1,176	2.4
30%	13,127	46,846	2,352	4.8
45%	11,951	45,671	3,527	7.2

Table A. 2. Sensitivity analysis of food emissions due to the reduction of food waste

Food waste reduction [%]	**Food waste [kg]**	**New Emissions [ton CO_2]**	**Reduction [ton CO_2]**	**[%]**
0%	1'008,386	49,198	0	0.0
30%	705,870	48,692	506	0.1
50%	504,193	48,356	842	1.7

Table A. 3. Analysis of food emissions due to increased local and seasonal consumption

Mitigation proposes	**New Food Emissions**	**Reduction**	
	[ton CO_2]	[ton CO_2]	[%]
Local and seasonal consumption	46,067	3,131	6.4

Table A. 4. Analysis of clothing emissions due to the reduction in new clothes purchase

Mitigation proposes	New Clothes Emissions	Reduction	
	[ton CO_2]	[ton CO_2]	[%]
Fewer clothes acquisition	12,192	6,576	35

Table A. 5. Sensitivity analysis of transport emissions due to the reduction of private car use in CV journeys and the increase in the use of railway

Reduction private car usage [%]	Transport Emissions	Reduction	
	[ton CO_2]	[ton CO_2]	[%]
0%	18,754	0	0.0
10%	18,537	217	1.2
20%	18,320	434	2.3
30%	18,103	651	3.5
40%	17,886	868	4.6
50%	17,669	1,085	5.8

Table A. 6. Sensitivity analysis of transport emissions due to reduced private car use in CV journeys and increased use of buses.

Reduction private car usage [%]	Transport Emissions	Reduction	
	[ton CO2]	[ton CO2]	[%]
0%	18,754	0	0.0
10%	18,633	121	0.6
20%	18,512	242	1.3
30%	18,392	362	1.9
40%	18,273	481	2.6
50%	18,153	601	3.2

Table A. 7. Sensitivity analysis of transport emissions due to the reduction of private car use in Spain journeys and the increase in the use of railway

Reduction private car usage [%]	Transport Emissions	Reduction	
	[ton CO_2]	[ton CO_2]	[%]
0%	18,754	0	0.0
5%	18,602	152	0.8
10%	18,450	304	1.6
15%	18,299	455	2.4
20%	18,147	607	3.2

Table A. 8. Sensitivity analysis of transport emissions due to the reduction of private car use in Spain journeys and the increase in the use of bus

Reduction private car usage [%]	Transport Emissions	Reduction	
	[ton CO_2]	[ton CO_2]	[%]
0%	18,754	0	0.0
5%	18,622	132	0.07
10%	18,490	264	1.4
15%	18,358	396	2.1
20%	18,226	528	2.8

Table A. 9. Sensitivity analysis of emissions reduction due to a decrease in new car purchases

Reduction in the number of new vehicles	New Vehicles per year	New Vehicles Emissions	Reduction	
[%]	[units]	[ton CO_2]	[ton CO_2]	[%]
0%	1,671	14,621	0	0.0
10%	1,504	13,160	1,461	10
20%	1,337	11,699	2,922	20
30%	1,170	10,238	4,383	30

Table A. 10. Sensitivity analysis of construction emissions due to EF reduction

EF reduction New Construction	EF	New Construction emissions	Reduction	
	[$kgCO_2/m^2$]	[ton CO_2]	[ton CO_2]	[%]
0%	449.00	7,472	0	0.0
5%	426.55	7,098	374	5
10%	404.10	6,725	747	10
15%	381.65	6,351	1,121	15
20%	359.20	5,978	1,494	20

Table A. 11. Sensitivity analysis of waste emissions due to waste generation and landfill treatment reduction

Annual waste per capita [kg]	**Reduction in waste generation**	**Landfill mixed waste**	**Emissions waste sector**		
			[ton CO_2]	**[ton CO_2]**	**[%]**
473.3	0%	67%	7,329		
		50%	7,099	230	3.1
		40%	6,963	366	5.2
425.97	10%	67%	6,596	733	10.5
		50%	6,389	940	14.3
		40%	6,267	1,062	16.6
378.64	20%	67%	5,863	1,466	23.4
		50%	5,679	1,650	28.1
		40%	5,571	1,758	31.0

Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: