Mapping Urban Food and Nutrition Insecurity: A Spatial Index for Barcelona

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Abstract

Despite growing attention to sustainable food systems, food insecurity is still under-addressed in European cities, often sidelined in urban policy agendas and constrained by limited conceptual and spatial frameworks. The aim of this study is to develop a Food Insecurity Vulnerability Index (FIVI) with a spatial foundation, estimated at the census tract level, using a model that balances simplicity with strong explanatory power. The selected indicators span the six dimensions of food security and nutrition as defined by HLPE (2020) — availability, access, utilisation, stability, sustainability, and agency — and are spatially operationalised and adapted to the context of a Mediterranean European urban area, specifically Barcelona. A generalised linear model (GLM) with a quasi-binomial distribution was used, accounting for zero-inflation in the dependent variable —the prevalence of childhood obesity among boys aged 0 to 12 years (%). This proxy for malnutrition was selected due to the high-quality data systematically collected during scheduled paediatric check-ups. The model includes socioeconomic and food environment predictors, fitted using data from Barcelona and projected to Madrid using an equivalent dataset and the estimated coefficients. Key predictors include a lower income, a younger population profile, and greater access to organic food outlets, all significantly associated with reduced vulnerability. In contrast, higher voter abstention—used as a proxy for agency—was positively associated with vulnerability. These findings underscore the relevance of socioeconomic status, agency, and food access in shaping food insecurity risk. The resulting hotspot and coldspot mapping based on the index enhances understanding of food insecurity dynamics and their links to territorial, socio-economic, ecological, and health factors, offering valuable insights for local-level planning and the monitoring of targeted interventions.

Keywords

Food insecurity; synthetic index; hotspot mapping; Barcelona; Madrid.

1. Introduction

Despite increasing attention to sustainable and healthy food systems, food insecurity remains a largely overlooked issue in European cities (Garratt, 2020; Long et al., 2020; Penne & Goedemé, 2021). Food insecurity may appear to refer exclusively to developing countries, but moderate and severe food insecurity levels have also affected almost 9% of the population in Europe and North America, and could even reach values of 10–15% in specific regions (Carrillo-Álvarez et al., 2021; FAO 2020, 2021). This is particularly evident in Mediterranean contexts, where the persistence of malnutrition, diet-related diseases, and unequal access to healthy food environments is frequently underestimated (Moragues-Faus & Magaña-González, 2022; Marchetti & Secondi, 2022). Food insecurity—understood as inconsistent access to adequate and nutritious food—acts as a key driver of malnutrition, including undernutrition, overweight, obesity, and micronutrient deficiencies.

Recent data from Mediterranean countries show that food insecurity is far from marginal. In Italy, 22.3% of the population is at risk of food poverty or food insecurity, with regional disparities ranging from 14.6% in Umbria to 29.6% in Abruzzo (Marchetti & Secondi, 2022). In Greece, the 2020 Income and Living Conditions Survey (SILC) reported that 13.2% of the population worried about not having enough food, 12.8% could not maintain a healthy and nutritious diet, and 6.2% were forced to skip meals (Hellenic Statistical Authority, 2021). In Spain, the first nationally representative survey using the Food Insecurity Experience Scale (FIES) found that 13.3% of households (2.5 million) experienced food insecurity in 2021 during the COVID-19 pandemic (Moragues-Faus & Magaña-González, 2022). Food insecurity was most prevalent among households with lower socioeconomic status, economic difficulties, and precarious employment, and was often associated with chronic illness or disability within the household.

In Catalonia, the 2024 Health Survey reported that 2.6% of the population could not afford a meal with meat, fish, chicken, or a vegetarian equivalent every two days, with prevalence rising sharply among those with only primary education (8.0%) or in lower social classes (4.1%) (Schiaffino & Medina, 2025). The most recent data on malnutrition indicate that 33.8% of boys and 28.4% of girls aged 2–17 were affected by obesity, overweight, or underweight (IDESCAT, 2025). Simultaneously, food price anomalies have surged since the pandemic, with bread, cereals, and other food items exceeding €126 in 2023, compared to levels below €100 prior to 2020 (IDESCAT, 2025).

These figures, while illustrative, point to deeper structural issues. Recent reviews have emphasized that food insecurity is shaped by the interplay of structural, spatial, and social factors, and that many existing indicators fail to capture its full scope (Righettini & Bordin, 2023). Global assessments already suggest that the world is off track to achieve Sustainable Development Goal 2 ("Zero Hunger") by 2030, as the prevalence of food insecurity continues to rise even in high-income regions (FAO et al., 2024). In wealthy countries, food insecurity does not stem from food scarcity, but from deepening inequalities and increasing barriers to affording healthy diets, driven by poverty, job precarity, and the rising cost of living (Schiaffino & Medina, 2025). These conditions have fuelled new forms of deprivation, visible in the growing reliance on food assistance and charitable food distribution (Caraher & Furey, 2018). In Europe, around 21% of the population (94.6 million people) were at risk of poverty or social exclusion in 2023 (Eurostat, 2024). Such figures reflect a paradox of abundance: while food availability is not a structural problem, unequal access to healthy and affordable food has become a major determinant of diet-related inequalities.

Urban areas are where these inequalities and barriers to food access are most evident. Over three-quarters of the world's food-insecure population now live in cities (Battersby et al, 2024), yet urban food insecurity remains systematically underexplored. Food insecurity is now measured at multiple levels—individual, household, national, regional, and global—but few instruments exist for analysing it at the urban scale, where disparities are widening, often reflected in growing inequalities in health due to malnutrition. Such inequalities are partly mediated by the characteristics of local food environments, which shape people's everyday opportunities to access, afford, and consume healthy foods, thus amplifying the effects of income and social disadvantage. Evidence consistently shows that low-income and racial or ethnic minority communities tend to live in poorer-quality food environments, where healthy options are scarce and cheap, unhealthy foods are more accessible, exacerbating both food insecurity and nutrition-related health inequalities (Larson et al., 2009; Walker et al., 2010; Odoms-Young et al., 2024).

This complexity—rooted in the multidimensional and context-specific nature of food insecurity—demands not only a solid conceptual foundation but also robust and adaptable measurement tools. This reinforces the need for spatially sensitive and locally adapted approaches that reflect the lived realities of urban populations. In response to this need, our work focuses on the development of a Food Insecurity Vulnerability Index (FIVI) that is both parsimonious and spatially grounded. We depart from the HLPE's (2020) extended definition of food security, which encompasses six dimensions—availability, access, utilisation, stability, agency, and sustainability—and operationalise these into spatially-based indicators. Drawing on the insights of La Rota-Aguilera & Moragues-Faus's (2025) adaptation of the HLPE framework to urban contexts, the aim is to construct a composite index that is simple and allows for the localisation and monitoring of food insecurity in urban settings.

The remainder of this working paper is structured as follows. Section 2 reviews the theoretical framework and state of the art. Section 3 details the methodological approach for constructing a new food insecurity index using data from the urban area of Barcelona, including indicator selection, model development, and spatial mapping of hotspots and coldspots. Section 4 presents the results and the exercise of projecting the index onto a second urban area. Finally, Section 5 discusses the findings, implications, and limitations of the study.

2. Background and Theoretical Framework

2.1 Conceptualising and Measuring Food Insecurity

Due to the multidimensional and context-specific nature of food insecurity—especially in urban settings—understanding and addressing it requires not only a solid conceptual foundation but also robust and adaptable measurement tools. The concept of food insecurity has evolved since it was first understood as the mere absence of hunger, and so have the approaches used to measure it. The most extended definition of food security refers to "a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2000:26). As defined by the Food and Agriculture Organization (FAO) and the High Level Panel of Experts on Food Security and Nutrition (HLPE), it encompasses six dimensions: availability, access, utilization, stability, agency, and sustainability HLPE (2020).

Availability refers to the sufficient supply of safe, culturally appropriate food through domestic production or imports primarily measured at national or regional levels. At the EU level, for instance, the European Food Security Crisis Preparedness and Response Mechanism (EFSCM) monitors food supply and security in times of crisis. It tracks trends in key indicators, external alerts, and provides a qualitative assessment of the EU agri-food sector. All EU Member States benefit from this mechanism within the framework of the common market. As such, these dimensions are of limited relevance when measuring vulnerability to food insecurity at the local or urban scale.

Food access concerns individuals' or households' physical and financial ability to obtain adequate food without compromising other basic needs, ensuring inclusion of vulnerable groups. Utilization involves adequate diets, clean water, sanitation, and healthcare to achieve nutritional well-being. Stability reflects the ability to maintain consistent access to food despite shocks or cyclical events. Sustainability relates to food systems that protect environmental, social, and economic resources for future generations. Finally, agency highlights people's capacity to participate in decisions affecting their food security, supported by appropriate policies and institutions. Together, these dimensions offer a comprehensive framework for addressing the complex nature of food insecurity (FAO, 2021; WFP, 2020).

The stability dimension poses challenges when applied to city-scale analysis within a European context. However, in line with the extended definition of food security, it should also reflect the ability to maintain access to adequate food at the household level, particularly during periods of economic or inflationary crisis. Events such as rising unemployment or the increasing cost of living can compromise food security, even when food is physically available (Balistreri, 2016). In such situations, ensuring a stable food supply for vulnerable populations often depends on interventions that buffer the impact of reduced purchasing power, such as food assistance services (Loopstra & Tarasuk, 2015). We therefore propose that this dimension of stability should also include the use of food aid programmes —such as food vouchers, wallet cards, school meal schemes, soup kitchens, food banks, or pantries. These mechanisms help secure continued household access to adequate nutrition when financial shocks undermine people's ability to afford food. As Gracia-Arnaiz (2022) suggests, the uptake of food assistance can serve as a proxy indicator of vulnerability to food insecurity, signalling unmet needs and disruptions in food access during economic stress.

While food security is often addressed at national or global levels, its six dimensions—availability, utilization, stability, sustainability, agency, and access—can also be meaningfully interpreted at the local scale. Availability and utilization are shaped by local infrastructure, services, and supply chains, while stability can be reflected in the presence of food assistance programs that buffer economic shocks. Sustainability and agency are increasingly embedded in municipal food strategies and participatory governance. Access is arguably the dimension most relevant at the local scale, as it is directly shaped by the spatial distribution, affordability, and availability of food outlets in a given territory. Local food environments—understood as the physical and economic conditions that determine where, how, and what food is available—play a central role in shaping dietary opportunities and constraints.

The food environment includes the foods available for people in their daily life, and factors such as nutritional quality, safety, price, convenience, labelling and promotion of these foods (Downs et al. 2020). Food environments can have a significant influence on both access to and consumption of nutritious, adequate, and affordable foods by individuals. Consequently, they may affect the quality of people's diets, nutrition status, and health outcomes (Wang et al., 2022; Eskandari et al. 2022; Swinburn et al., 2013; Caspi et al. 2012; Engler-Stringer et al. 2014). Food environments shape patterns of food acquisition and consumption, directly affecting access to healthy and affordable foods, and potentially altering the quality of their use. Some recent research reinforces the connection between food security and food environment. Evidence from peri-urban Flanders (Inaç et al., 2024) showed that perceived availability and affordability of fruit and vegetables, neighbourhood social cohesion, and housing conditions significantly influence the odds of experiencing food insecurity. Findings from the US highlight how under-resourced food environments disproportionately affect low-income and racial/ethnic minority populations, contributing to higher rates of food insecurity and diet-related chronic diseases such as obesity, diabetes, and cardiovascular conditions (Odoms-Young et al., 2024). Systematic reviews further reinforce this association, underscoring the role of the local food environment in shaping food insecurity outcomes. Households experiencing food insecurity tend to have greater exposure to unhealthy food options, rely more frequently on convenience stores and small retailers for food purchases, and report limited access to fresh and nutritious foods such as fruits and vegetables (Bezerra et al., 2024).

Despite a growing body of evidence, there remains a significant gap in the availability of spatially grounded indices—based on secondary data—that can localize and monitor food insecurity in urban areas. Existing tools often fail to capture the complex, multi-dimensional nature of food insecurity as it manifests across different urban contexts. Yet such indices are essential for identifying vulnerable neighbourhoods, informing place-based interventions, and guiding resource allocation in municipal/urban food policies. To address this gap, we propose the development of a Food Insecurity Vulnerability Index (FIVI), designed to capture the spatial dimensions of food insecurity at the local scale through a parsimonious set of indicators. This study builds on a previous analytical framework grounded on the HLPE's six-dimensional approach applied to the case of Barcelona (LaRota-Aguilera et al. 2025), and outlined in Table 1.

Table 1. Conceptual framework for measuring food insecurity in urban areas, including proposed dimensions, attributes, and indicators.

Dimension	Attribute	Indicator
Availability: Having a quantity and quality of food sufficient to satisfy the dietary needs of individuals, free from adverse substances and acceptable within a given culture, supplied through domestic production or imports.	Sufficiency	Healthy food availability
Access: Having personal or household financial means to acquire food for an adequate diet at a level to ensure that satisfaction of other basic needs are not threatened or compromised; and that adequate food is accessible to everyone, including vulnerable individuals and groups.	Economic access	Income
	Social access	Foreign
		Youth
	Physical access	Healthy food access
Stability: Having the ability to ensure food security in the event of sudden shocks (e.g. an economic, health, conflict or climatic crisis) or cyclical events (e.g. seasonal food insecurity).	Food aid	School meal program
		Food aid program
Utilization: Having an adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met	Adequate diet	Prevalence of stunting among children under 5 y
		Prevalence of malnutrition among children under 5 y (wasting and overweight)
		Prevalence of anaemia in women 15-49 y by pregnancy status
Agency: Individuals or groups having the capacity to act independently to make choices about what they eat, the foods they produce, how that food is produced, processed, and distributed, and to engage in policy processes that shape food systems. The protection of agency requires socio-political systems that uphold governance structures that enable the achievement of food security and nutrition for all.	Capacity to act	Voter abstention (proxy of political participation)
Sustainability: Food system practices that contribute to long-term regeneration of natural, social and economic systems, ensuring the food needs of the present generations are met without compromising the food needs of future generations.	Sustainability	Organic food access

Source: Adapted from HLPE (2020) definition of food security encompassing six dimensions, and extended with insights from LaRota-Aguilera et al. (2025).

2.2 Rationale for a Spatial, Localised Food Insecurity Index

Although food insecurity has been widely studied, spatially grounded indices that allow for fine-grained analysis at the subnational or urban scale remain relatively rare. The majority of existing tools rely on so-called experience-based food insecurity scales, such as the FAO's Food Insecurity Experience Scale (FIES) or the USDA food insecurity scales, which are based on household- or individual-level surveys (Carrillo-Alvarez et al., 2021; Ballard et al., 2014; Balistreri, 2016). At the global level, the FIES represents an important advance in psychometrically validated measurement (Ballard et al., 2014), but its reliance on surveys and national-level resolution limits its utility for urban and neighbourhood-level analysis. Moreover, as Ballard et al. (2014) note, the FIES provides a valuable tool for advancing knowledge on the relationship between the lived experience of food insecurity and indicators of malnutrition. However, it is not itself a measure of malnutrition and cannot detect nutritional deficiencies or obesity, making it unsuitable for assessing nutrition-specific outcomes of food security policies or programmes. These limitations highlight the need for approaches capable of capturing the spatial heterogeneity of food insecurity within urban areas.

At a more conceptual level, recent reviews of food security indices (Manikas et al., 2023; Al-Ansari et al., 2025) highlight the importance of integrating complementary indicators that reflect multiple dimensions of food security (availability, access, utilisation, stability), while arguing that experience-based indicators are especially suited for rapid assessments but insufficient for structural or spatial analyses. A further challenge of these indices stems from potential biases in ranking, which show profound divergences across tools (Al-Ansari et al., 2025). Poudel and Gopinath (2021) compared outputs from several global food security indicators—from FAO, UNDP, IFPRI, and USDA—between 1991 and 2018, and found major variations in prevalence estimates. They provide further evidence that macro-structural drivers—such as GDP growth, literacy, urbanisation, and internet access—play differentiated roles depending on income levels, reinforcing the need for context-sensitive tools that can be applied at multiple scales, including the urban. Similarly, in a recent scoping review of individual- and household-level measures of food insecurity in high-income countries, Carrillo-Alvarez et al. (2021) identified 23 different instruments and highlighted recurring correlates of food insecurity—sociodemographics, health, social stressors, and environmental factors—along with persistent inequalities by gender, race, and geography. While valuable, these approaches fall short of providing standardised, replicable, and validated indices that capture the multidimensional and structural drivers of food insecurity across diverse urban contexts. Together, these findings underscore the absence of spatially explicit, comparable, and scalable tools for assessing food insecurity in cities.

At the urban level, Odoms-Young et al. (2024) argue that under-resourced neighbourhood food environments disproportionately affect low-income and minority populations, and call for moving beyond individual and household drivers to address broader structural determinants—such as neighbourhood conditions, systemic poverty, and policy-level influences. They emphasise the need for context-sensitive tools that capture these multilevel drivers of urban food insecurity and support equity-oriented interventions. Urban food environment indices, such as the Retail Food Environment Index and its modifications, are widely used in health studies (Odoms-Young et al., 2024), but they capture only the distribution of food outlets rather than food insecurity itself, and they lack standardised, validated links to food outcomes. Several efforts illustrate both progress and limitations. Local governments and research institutions in the U.S., UK, and Canada have created neighbourhood- or municipality-level indices (e.g., Toronto Food Strategy; Feeding America's county-level estimates). However, these instruments often rely on proprietary or survey-based data, lack methodological transparency, and are rarely replicable beyond their original context (Loopstra & Tarasuk, 2015). Similarly, the USDA Food Access Research Atlas employs secondary data to map low-income, low-access census tracts, but it provides only indirect measures of potential access rather than actual food insecurity experiences. These limitations highlight the opportunity to develop a transparent, replicable, and spatially sensitive tool that can operate at fine urban scales.

Given the growing awareness of the spatial dimensions of food insecurity, this section makes the case for a new, context-sensitive, and exportable index. It highlights the need for a parsimonious model tailored to urban settings and underscores the added value of spatial analysis—particularly *hotspot* and *coldspot* mapping—for understanding territorial disparities and informing place-based policy responses. To address these limitations, this study develops the Food Insecurity Vulnerability Index (FIVI), a spatially grounded parsimonious tool designed to locate populations experiencing chronic food insecurity. The FIVI assesses five of the six dimensions of food security (access, stability, utilisation, agency, and sustainability) and enables the identification of areas of high incidence (hotspots) within urban settings. The notion of parsimonious here refers to a model that captures the complexity of food insecurity with a minimal yet sufficient number of variables, facilitating its application across diverse urban contexts. By integrating indicators from multiple domains—socioeconomic, health, and food environment—the FIVI provides a contextually sensitive and exportable framework that captures the spatial patterns of food insecurity at the census tract level. It therefore serves as a valuable tool for urban policy and planning, allowing local governments to identify vulnerable areas, monitor changes over time, and design targeted interventions to ensure equitable access to adequate and nutritious food.

3. Methodology

3.1 Variable selection

Selected indicators spanned demographic, socioeconomic, health, and food environment domains, consistent with the six dimensions —availability, access, utilization, stability, sustainability, and agency— included in the definition of food security and nutrition (HLPE, 2020). Initially, some 20 indicators were extracted from on a thorough literature review conducted during the last trimester of 2023 (Table 2). From this long list, around 12 indicators were collected in cartographic format and assessed for statistical suitability (Table 1). The final FIVI, however, is a curated index composed of six predictors—household income, foreign population, young population (16–29 years), voter abstention, availability of healthy food outlets, and availability of organic food outlets—with the dependent variable defined as the prevalence of obesity in boys aged 0–12, expressed as a proportion. We prioritised long-term, preferably annually updated indicators available for Spain at the census tract level, or those that could be readily constructed. Variable selection involved correlation analysis and multicollinearity testing using the Variance Inflation Factor (VIF), accepting predictors with VIF values below 5 to ensure robustness.

Table 2. Main indicators identified from literature review for measuring food insecurity in urban areas.

Risk Factor	Indicators selected from literature review	References	Data availability
Food environment	Presence of community gardens & food coops	Drisdelle et al. (2020); Morgan (2020); Taylor & Ard (2015); Westbury et al. (2021)	Yes
	Access to organic food (density or proximity of organic food stores)	Downs et al. (2020); Wang et al. (2019); Eskandari et al. (2022); Swinburn et al. (2013); Caspi et al. (2012); Engler-Stringer et al. (2014); Turner et al. (2020)	Yes
	Total access to food (density or proximity of food stores)		Yes
Poverty	Household income	Moragues-Faus & Magaña-González (2022)-Spain; Leitz (2018)-US; Garratt (2020)-Europe	Yes
	Poverty rate		Yes
	Population receiving social benefits		No
High housing costs (residential vulnerability)	Housing affordability	Leitz (2018)-USA; Garratt (2020)-Europe	Yes
Unemployment or underemployment	Unemployment rate	Moragues-Faus & Magaña-González (2022)-Spain; Leitz (2018)-US; Garratt (2020)-Europe	Yes
Limited access to affordable food	Affordability of healthy food options		No
Inadequate social support	Access to school meal programs	Leitz (2018)-US; Garratt (2020)-Europe	Yes
	Availability or use of food assistance programs		Yes
Education level	Education level or school drop -out	Moragues-Faus and Magaña-González (2022)-Spain; Leitz (2018)-US; Garratt (2020)-Europe	No
Social and cultural inequalities (racial and ethnic minorities, immigrants, individuals with disabilities)	Elderly population	Leitz (2018)-US; Garratt (2020)-Europe García et al. (2020)-Barcelona; Lee & Frongillo (2001)	Yes
	Foreign population (immigration)	Moragues-Faus and Magaña-González (2022)-Spain	Yes
	Gender (head of household)	Moragues-Faus and Magaña-González (2022)-Spain	No
	Homeless population		Yes
	Political participation	Olabiyi, O. M. (2020)	Yes
Health conditions	Prevalence of mental disorders in the general population	Coleman-Jensen et al. (2013); Moragues-Faus and Magaña-González (2022)-Spain; Eskandari et al. (2022); Swinburn et al. (2013); Caspi et al. (2012)	Yes
	Prevalence of stunting among children under 5 y	NLIS (WHO, 2017; 2019)	Yes
	Prevalence of malnutrition among children under 5 y (wasting and overweight)	NLIS (WHO, 2017; 2019)	Yes
	Prevalence of anaemia in women 15-49 y by pregnancy status	NLIS (WHO, 2017; 2019)	Yes

Data were retrieved at scale of the census tract for selected indicators. The city of Barcelona has some 1.6 million inhabitants and was administratively divided into 1,067 census tracts in 2021/22, each comprising approximately 1,500 individuals. The reference period for the analysis is 2021–2023; specifically, health data from 2023 were used to minimize the effects of the COVID-19 pandemic (e.g., disruptions to regular check-ups). All variables were harmonised to 2021/22 census tracts. Indicators were selected to ensure data generality and homogeneity across Barcelona while maximizing territorial detail to capture internal variations within the city.

Socioeconomic and demographic data—household income, proportion of foreign population, and proportion of young residents (aged 16–29)—were retrieved from the Spanish National Institute of Statistics (INE). The income indicator corresponds to the household income median, based on the 2022 edition of the *Atlas de Distribución de Renta de los Hogares* (INE, 2022). The foreign population indicator is defined as the percentage of residents originating from low- or middle-income countries, according to World Bank classifications, using data from the *Ministerio del Interior*, 2021 and *Estadística del Padrón Continuo a 1 de enero de 2020, INE*. Voter abstention data were obtained from municipal statistical offices, in turn based on the Ministerio del Interior (2020), and referring to the 2019 municipal elections for both Barcelona and Madrid City Councils. In Spain, foreign residents can vote in municipal elections if they are citizens of countries that grant reciprocal voting rights to Spaniards through a treaty.[1] Additionally, all EU citizens residing in Spain who meet the same requirements as Spanish voters and formally declare their intention to vote are also eligible to participate in local elections.

The indicators on food access include two variables: HealthyFA and OrganicFA. The HealthyFA (Healthy Food Access) indicator captures the presence of healthy food outlets per census tract, including grocery shops (butchers, fishmongers, fruit and vegetable shops, and organic stores), organic supermarkets, and general supermarkets which might or might not offer organic produce. The OrganicFA (Organic Food Access) indicator refers specifically to the availability of specialised organic shops, organic supermarkets, food cooperatives and groups. Data on food outlets for Barcelona were obtained from the *Census of ground-floor commercial premises in the city of Barcelona* (Barcelona City Council, 2022). For Madrid, data were sourced from the *Census of Premises and Activities* (Madrid City Council, as of September 2023), except for organic food outlets, which were retrieved from the *Mapping of Alternative Food Networks* (MAE – Madrid Agroecológico, 2024). The classification of food retail outlets was based on an adaptation of prior work by Garcia et al. (2020) and Garcia-Sierra et al. (2021) in Barcelona, and Bilal et al. (2018) and Díez et al. (2019) in Madrid. Using the opportunities provided by each city's retail census, a harmonised classification system was created to enable comparability across both urban foodscapes. This is further described in the Supplementary Information SI.2.

Finally, health indicators, used as dependent variable, were based on those from the WHO Nutrition Landscape Information System (NLIS) (WHO, 2017; 2019), and which further coincide with the Sustainable Development Goal (SDG) Indicators for SDG2: End hunger, achieve food security and improved nutrition, and specifically those from 2.2. These indicators were retrieved from the Information System for Research in Primary Care (SIDIAP; www.sidiap.org) from Catalonia, Spain (Bolíbar et al., 2012). The SIDIAP database is a large pseudo-anonymised database comprising the electronic health records from primary care visits collected since 2005 in centres managed by the Catalan Health Institute. It covers approximately 5.5 million individuals, representing around 74% of the population of Catalonia. SIDIAP includes individual-level demographic information, clinical variables, immunisations, referrals to specialists, prescriptions and dispensation records, sick leave history, and any acute or chronic health conditions recorded during primary care visits. This study was approved by the ethics committee of the Jordi Gol i Gurina Institute for Research in Primary Care (IDIAPJGol: 23/238-P).

Health indicators included:

- Prevalence of iron-deficiency anaemia in women of reproductive age (15-49 years), by age and pregnancy status (n, % crude and standardized)
- Prevalence of iron-deficiency anaemia and severe anaemia in children aged 6-59 months (under 5 years), by age and gender (n, % crude and standardized)

[1] These currently include Bolivia, Cape Verde, Chile, Colombia, South Korea, Ecuador, Iceland, Norway, New Zealand, Paraguay, Peru, the United Kingdom, and Trinidad and Tobago.

- Prevalence of malnutrition in children under 5 years – Population aged 0-5 years with stunting, wasting or underweight, overweight, by age and gender (n, % crude and standardized)
- Prevalence of malnutrition in school-age children (6-12 years) – Population aged 6-12 years with overweight and obesity, by age and gender (n, % crude and standardized)
- Prevalence of malnutrition in adults aged 18-74 years – Population aged 18-74 years with underweight, overweight, and obesity, by age and gender (n, % crude and standardized)

These indicators are defined as follows (WHO, 2017):

- stunting – height-for-age <-2 SD of the WHO Child growth standards median;
- wasting – weight-for-height <-2 SD of the WHO Child growth standards median;
- overweight – weight-for-height >+2 SD of the WHO Child growth standards median; and
- underweight – weight-for-age <-2 standard deviations (SD) of the WHO Child growth standards median.

The selection of children with ages from 0 to 12 registered in the SIDIAP database and living in the municipality of Barcelona in 2023 resulted in the extraction of data of 113,377 individuals (54,874 women and 58,503 men) corresponding to 68,42% of the age group in the city of Barcelona in the same year, some 165.702 individuals. At the census tract level, sample sizes were too small to separate data into the WHO/UN-recommended age groups (0–5 and 6–12 years). As a result, data for children aged 0–12 were combined and grouped into three malnutrition categories: undernourishment (including stunting, wasting or underweight), overweight, and obesity. Obesity being defined as weight-for-height >+3 SD of the WHO Child growth standards median.

3.2. Model specification and mapping

To construct the Food Insecurity Vulnerability Index (FIVI), we began by developing a statistical model aimed at explaining childhood obesity prevalence at the census tract level, using it as a proxy for malnutrition. The dependent variable—obesity rates among boys aged 0 to 12—was selected due to its relevance and the availability of reliable anthropometric data collected during routine and systematic paediatric check-ups linked to the national vaccination schedule. This approach aligns with established international practices, such as the Global Hunger Index (GHI), which is based on child malnutrition to measure food insecurity at the country level (Sreehari & Babu, 2023). The model used was a generalized linear model (GLM) with a quasi-binomial distribution, selected to account for zero inflation in the dependent variable resulting from the absence of recorded obesity cases in some census tracts. Socioeconomic and food environment variables served as predictors selected through correlation analysis and multicollinearity testing (VIF < 5) to ensure model robustness. Our objective was to build a parsimonious index combining model simplicity with strong explanatory power, prioritizing models with low complexity to avoid overfitting. The model was calibrated using Barcelona data and then projected to Madrid using an equivalent dataset and the estimated coefficients. The variables that emerged as statistically significant in explaining childhood obesity were then used to construct the FIVI, allowing for spatial monitoring of food insecurity at the local level. This approach ensures that the index is empirically grounded and sensitive to the specific spatial dynamics of urban food insecurity.

We mapped the index at the census tract level for both Barcelona and Madrid, grouping values into quintiles to identify areas of varying vulnerability. Quintile 5 represents high-vulnerability zones (hotspots), while Quintile 1 indicates low-vulnerability zones (coldspots). The maps were generated using harmonized datasets based on 2021/22 census tract boundaries. Health data correspond to 2023, and predictor variables were selected for their consistency, availability, and territorial resolution. This spatial representation, based on a GLM-based model identifying key predictors of childhood obesity, provides the empirical foundation for a spatially explicit Food Insecurity Vulnerability Index (FIVI) and supports targeted interventions and evidence-based urban food policy.

4. Results

4.1 The Food Insecurity Vulnerability Index (FIVI)

The Food Insecurity Vulnerability Index (FIVI) model shows a McFadden pseudo R-squared of 0.2743, indicating that the model explains 27.43% of the variance. The predictive variables include a set of socioeconomic and demographic indicators: income, foreign population, young population (16-29 y), voter abstention, as well as variables related to food environment—namely, availability of healthy food outlets and organic food outlets. The dependent variable is the prevalence of obesity in boys aged 0 to 12, expressed as a proportion. This variable was selected as a proxy for malnutrition due to both its relevance and the high quality of available data, as anthropometric measurements in this age group are routinely collected by health professionals during scheduled paediatric appointments linked to the national vaccination calendar. All variables are standardised using z-scores at the census tract level to ensure comparability. Moreover, Moreover, variable selection was guided by correlation analysis and VIF multicollinearity testing, with VIF ≈ 1 indicating no multicollinearity, VIF < 5 considered acceptable and VIF > 5 indicating potential issues (Table *3*). The model used is a generalised linear model (GLM) with a quasi-binomial distribution, accounting for zero-inflation in the dependent variable. Model estimates are shown in Table *4*. The model is fitted for Barcelona, though we created a "twin" dataset for Madrid and replicated the estimation process using the same coefficients, applying them to Madrid's data as an exercise in index projection.

Table 3. Variance Inflation Factor (VIF) values for explanatory variables.

Variable	Valor VIF
Income	2.479972
Young	1.778643
Abstention	1.606912
Foreign	2.514387
OrganicFA	1.279403
HealthyFA	1.077779

Notes: VIF ≈ 1 indicates no multicollinearity; VIF < 5 is considered acceptable; VIF > 5 suggests potential multicollinearity concerns.

Table 4. Generalised Linear Model (GLM) estimates for predictors of childhood obesity prevalence among boys aged 0–12 years.

term	estimate	std.error	statistic	p.value	
(Intercept)	-11,0549	0,7506	-14,7281	0,000	***
Income	-5,8679	0,9945	-5,9001	0,000	***
Young	-2,7110	0,9450	-2,8687	0,004	**
Abstention	1,9364	0,6024	3,2145	0,001	**
Foreign	-1,7213	0,9622	-1,7889	0,074	
OrganicFA	-7,4251	3,1889	-2,3284	0,020	*
HealthyFA	-0,4572	0,6543	-0,6988	0,485	

Notes: Significance levels at 0,001 (***); 0,01 (**); 0,05 (*).

The model reveals several statistically significant predictors of childhood obesity prevalence among boys aged 0 to 12 years. Income shows a strong and highly significant negative association (estimate = -5.87, $p < 0.001$), suggesting that higher-income areas tend to have lower rates of childhood obesity. Similarly, the proportion of young residents is negatively associated with obesity prevalence (estimate = -2.71, $p = 0.004$), indicating a possible protective demographic effect. Voter abstention, used here as a proxy for agency, is positively associated with childhood obesity (estimate = 1.94, $p = 0.001$), potentially reflecting broader patterns of social disengagement or structural disadvantage. The proportion of foreign-born residents shows a negative association, though not significant ($p = 0.074$).

Regarding food access variables, OrganicFA (access to organic food outlets) is significantly and negatively associated with childhood obesity (estimate = -7.43, $p = 0.020$), suggesting that better access to organic food may contribute to healthier outcomes. In contrast, HealthyFA (general healthy food access) does not show a significant effect ($p = 0.485$), which may indicate limited differentiation in the spatial distribution of these outlets across neighbourhoods. Overall, the model highlights socioeconomic status, agency, and organic food access as key predictors of food insecurity vulnerability, as proxied by childhood obesity prevalence.

4.2 Spatial Distribution of Food Insecurity in Barcelona

Using the estimated Food Insecurity Vulnerability Index (FIVI) for Barcelona (Figure 1a) and its projection to Madrid (Figure 1b), we analyse the spatial distribution of food insecurity, identifying high-risk (hotspots) and low-risk (coldspots) areas and comparing them with existing patterns of territorial vulnerability. Figure 1a presents the spatial distribution of the FIVI across Barcelona, disaggregated by census tract and grouped into quintiles. It highlights significant territorial disparities in food insecurity throughout the city. Census tracts in Quintil 5 (darkest brown) represent the areas with the highest levels of food and nutritional insecurity, while Quintil 1 (lightest beige) indicates zones with the lowest vulnerability. Some 359,848 residents, representing 22.3% of Barcelona's population in 2022, live in Quintile 5 areas—the most food-insecure zones of the city (Table 5). This finding is consistent with recent studies using the FIES scale to measure food insecurity, such as Moragues-Faus & Magaña-González (2022) and the latest data from the Barcelona Health Survey (Schiaffino & Medina, 2025). Moreover, a clear spatial pattern emerges, with higher vulnerability concentrated in peripheral and southern neighbourhoods, such as Nou Barris, Ciutat Meridiana, Zona Franca, and parts of Sants-Montjuïc and Sant Martí. In contrast, central and western neighbourhoods, including Sarrià-Sant Gervasi, Les Corts, and parts of Eixample, show consistently lower levels of food insecurity. This spatial polarization suggests a strong association between food insecurity and socioeconomic inequalities, urban marginality, and unequal access to food. The absence of data in some peripheral tracts (shown in white) reflects limitations in the availability of health indicators.

Similarly, Figure 1b shows the projected distribution of FIVI in Madrid, where 639,008 residents (19.6% of the total population in 2022) fall into Quintile 5, signalling a substantial concentration of food insecurity in specific urban districts (Table 5). A clear spatial pattern emerges, namely high-vulnerability areas are concentrated in southern and eastern neighbourhoods, and in some cases in northern peripheries where urban expansion has not been fully consolidated. Hotspots align with underserved areas—such as zones where urban development plans have been approved but not yet executed—, as well as and low-income neighbourhoods, including Usera, Aluche, Estrecho, San Blas, Villa de Vallecas, Carabanchel, San Diego, and La Elipa. In contrast, central and northwestern tracts show consistently lower levels of vulnerability, particularly in Chamartín, Salamanca, and parts of Moncloa-Aravaca, which align with higher socioeconomic status and better access to services. A few peripheral tracts appear in white, reflecting missing or incomplete data, especially in zones of low residential density. Overall, these maps effectively visualize the territorial dimension of food insecurity in both Barcelona and Madrid, providing a critical tool for targeted interventions and urban food policy planning.

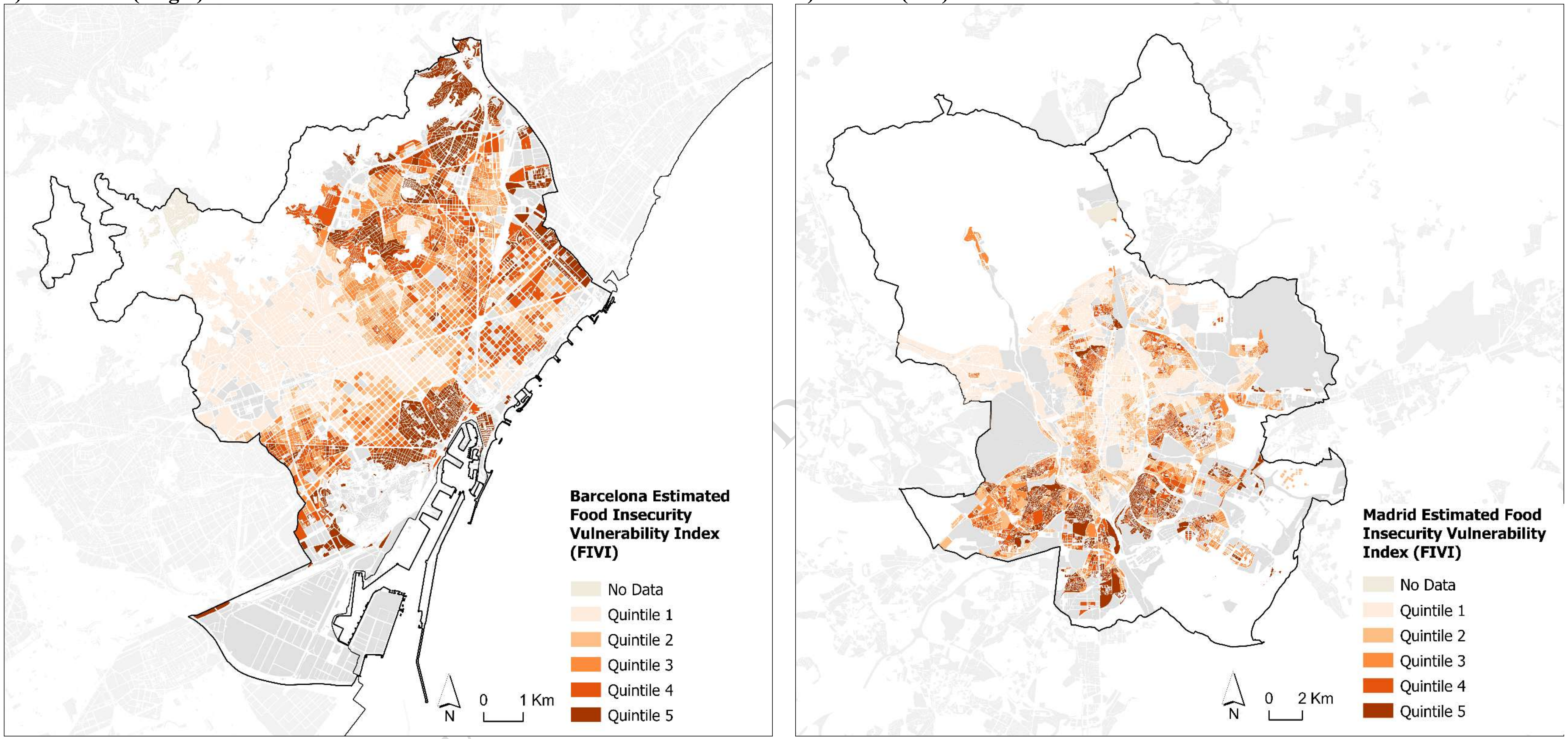
Table 5. Population by FIVI quintile in 2022, cities of Barcelona (target) and Madrid (test).

FIVI Quintile / Map Legend	**Barcelona – Population (2022)**	**Barcelona – % Total**	**Madrid – Population (2022)**	**Madrid – % Total**
No Data	1,769	0.11%	18,063	0.55%
Quintile 1 (least vulnerable)	311,451	19.28%	713,025	21.82%
Quintile 2	308,046	19.07%	653,554	20.00%
Quintile 3	318,508	19.72%	632,992	19.38%
Quintile 4	315,502	19.53%	610,385	18.68%
Quintile 5 (most vulnerable)	359,848	22.28%	639,008	19.56%
Total Population (2022)	**1,615,124**	**100.00%**	**3,267,027**	**100.00%**

Note: Population data by single year of age at the census tract level, as of 1 January 2022, were obtained from the National Statistics Institute (INE). Quintile 5 represents the most vulnerable population group according to the FIVI index.

Figure 1. Estimated Food Insecurity Index (FNI) for: (a) Barcelona (target) and (b) Madrid (test).

a) Barcelona (target) **b) Madrid (test)**



5. Discussion

5.1 Interpretation of Findings

The Food Insecurity Vulnerability Index (FIVI) developed in this study advances the spatial assessment of food insecurity in Mediterranean urban contexts by linking socioeconomic conditions, local food environments, and agency-related factors. The model's results highlight three particularly salient predictors: household income, political participation (voter abstention), and access to organic food outlets. Together, these dimensions reflect the multidimensionality of food insecurity as conceptualised by the HLPE (2020)—where economic access, agency, and sustainability intersect.

The negative association between income and childhood malnutrition aligns with extensive literature linking material deprivation to dietary inequality and poor health outcomes (Darmon & Drewnowski, 2015; Loopstra & Tarasuk, 2015). Income remains a primary determinant of diet quality and diversity in high-income countries, as low-income households are constrained in their ability to afford healthy and minimally processed foods (Rehm et al., 2019). In the context of Barcelona and Madrid, these findings reflect the territorial reproduction of socio-economic inequality, particularly across peripheral neighbourhoods where food access and health outcomes co-vary with social disadvantage.

Equally important is the positive relationship between voter abstention and vulnerability. This finding supports arguments that political disengagement can serve as a proxy for weakened agency and institutional trust (Prats et al., 2024). Food insecurity, as Gracia-Arnaiz (2022) and Moragues-Faus & Magaña-González (2022) argue, is not merely a condition of material scarcity but a manifestation of structural and political exclusion. The inclusion of voter abstention thus operationalises the "agency" dimension of food security, signalling how the capacity to act, politically and socially, shapes vulnerability.

The significant negative association between organic food access and vulnerability also deserves attention. While organic stores alone do not guarantee affordability or equity, their spatial distribution can serve as a proxy for sustainable and health-oriented food environments (Downs et al., 2020; Eskandari et al., 2022). The concentration of such outlets in wealthier and central areas of both cities illustrates the uneven geography of sustainable food consumption, mirroring patterns described in other European capitals (Sonnino & Coulson, 2021). Conversely, peripheral and socioeconomically deprived areas tend to host more convenience and fast-food retailers, reinforcing a dual food environment and widening nutritional inequalities.

The projected distribution of the FIVI in Madrid, based on Barcelona's model coefficients, confirms the consistency and transferability of the approach. The spatial overlap between high-vulnerability areas and known pockets of urban deprivation—such as Usera, San Blas, and Vallecas—supports the index's validity. These findings are consistent with previous urban studies identifying similar north–south or centre–periphery divides in food access and health outcomes (Bilal et al., 2018; Díez et al., 2019). Together, these patterns point to the embeddedness of food insecurity within broader urban inequalities in income, infrastructure, and governance.

5.2 Strengths and Limitations of the Index

The FIVI contributes conceptually and methodologically to the measurement of urban food insecurity in urban contexts by translating complex, multidimensional phenomena into spatially explicit, empirically derived indicators. Its parsimony enhances interpretability and facilitates replication across cities with comparable data systems. By grounding the model in routinely collected socioeconomic data and harmonised health indicators, the index avoids some limitations of survey-based approaches—such as recall bias and limited temporal coverage—while enabling longitudinal monitoring at the local scale.

Nevertheless, several limitations must be acknowledged. First, childhood obesity, though a robust proxy for malnutrition, captures only one aspect of nutritional vulnerability and does not fully reflect other manifestations such as undernutrition, micronutrient deficiencies, or dietary inadequacy. Second, while the model includes a set of predictors representative of the six dimensions of food security, data availability at the census-tract scale constrained the inclusion of other potentially relevant indicators, such as housing costs, food prices, or the use of formal and informal food assistance programs. Finally, while the projection to Madrid demonstrates the transferability of the model, future work should include validation with independent, experience-based measures such as the Food Insecurity Experience Scale (FIES) or household surveys, to strengthen external validity (Ballard et al., 2014; Carrillo-Álvarez et al., 2021).

This study had some limitations. First, while the index offers clear advantages—particularly by being spatially grounded, which helps overcome one of the main limitations of survey-based indices (i.e., their cross-sectional nature and inability to capture transitions into and out of food insecurity)—it still faces constraints. However, by anchoring the analysis to territorial units, the index allows for longitudinal monitoring of how households in a given area fare over time. It also facilitates the identification and tracking of the structural factors contributing to persistent food insecurity within specific neighbourhoods.

5.3 Implications for Public Policies

Spatialising food insecurity has significant implications for urban governance and policy design. The FIVI enables local authorities to identify and monitor food insecurity hotspots, supporting targeted interventions that integrate social, health, and food policies. This approach resonates with calls for "nutrition-sensitive urban planning" (Battersby et al., 2024) and for the inclusion of food security metrics in local sustainability strategies (FAO, 2024). In cities like Barcelona and Madrid—where local food policy frameworks already exist (Ajuntament de Barcelona, 2022; Ayuntamiento de Madrid, 2023)—the FIVI can support evidence-based decision-making by guiding investments in healthy food retail, urban agriculture, or school meal programmes.

Importantly, the findings highlight the need to address structural inequalities underpinning food insecurity, rather than focusing solely on food provisioning. Policy responses should thus integrate redistributive measures, community food initiatives, and participatory governance mechanisms that reinforce local agency (Doustmohammadian et al., 2022; Moragues-Faus, 2024). Strengthening community-led food projects and integrating them into municipal food strategies may also enhance both the stability and sustainability dimensions of urban food security (Candel & Pereira, 2017; Sonnino & Coulson, 2021).

With this in mind, future research should focus on three main areas. First, incorporating temporal data to analyse the evolution of FIVI over time would allow for monitoring transitions into and out of food insecurity and evaluating the impact of policy interventions. Second, expanding the indicator set to include measures of food affordability, food aid utilisation, and diet quality would capture a broader spectrum of vulnerability. Third, integrating participatory or citizen-generated data could help operationalise the "agency" dimension more effectively and bridge quantitative indicators with lived experiences.

All in all, this study underscores that food insecurity in European cities is not an isolated problem but a systemic outcome of spatial inequality, socioeconomic stratification, and uneven urban development. It therefore contributes to the growing body of literature calling for greater attention to structural, multilevel factors affecting food insecurity and inequalities in malnutrition and health (Al-Ansari et al. 2025; Odoms-Young et al., 2024; Poudel & Gopinath, 2021).

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Supplementary Information

SI.1. Health indicators in a nutshell.

Prevalence of iron-deficiency anaemia:

- Indicator of prevalence of iron-deficiency anaemia in women of reproductive age (15-49 years), by age and pregnancy status (n, % crude and standardized)
- Indicator of prevalence of iron-deficiency anaemia and severe anaemia in children aged 6-59 months (under 5 years), by age and gender (n, % crude and standardized)

Prevalence of malnutrition:

- Indicators of prevalence of malnutrition in children under 5 years – Population aged 0-5 years with stunting, wasting, overweight, or underweight, by age and gender (n, % crude and standardized)
- Indicators of prevalence of malnutrition in in school-age children (6-12 years) – Population aged 6-12 years with overweight and obesity, by age and gender (n, % crude and standardized)
- Indicators of prevalence of malnutrition in adults aged 18-74 years – Population aged 18-74 years with underweight, overweight, and obesity, by age and gender (n, % crude and standardized)

Indicator Calculation Notes:

Indicator of prevalence of iron-deficiency anaemia in women of reproductive age (15-49 years), by age and pregnancy status (n, % crude and standardized)
Definition: Women of reproductive age (15–49 years) with iron-deficiency anaemia by age and pregnancy status (n, % crude and standardized) *Calculation of anaemia in women of reproductive age (15-49 years), by pregnancy status:* (Number of women aged 15 to 49 years with a diagnostic code for iron-deficiency anaemia DD50 **OR** with a haemoglobin concentration <120 g/L for non-pregnant women and lactating women at sea level, **AND** <110 g/L for pregnant women at sea level) / (Women aged 15−49 years assigned to the primary care team and who had haemoglobin concentration assessed during a specified period) * 100.
Calculation at the scale of census tract from SIDIAP data (n, % crude and standardized): **SIDIAP data:** age (years), gender, pregnancy status (non-pregnant women, lactating women, pregnant women), haemoglobin concentration in clinical analytics, and diagnostic code (CIM-10) for iron-deficiency anaemia DD50 (latest year with available data). Territorial division: Barcelona's census tracts.

Indicator of prevalence of iron-deficiency anaemia and severe anaemia in children aged 6-59 months (under 5 years), by age and gender (n, % crude and standardized)
Definition: Children aged 6−59 months (under 5 years) with iron-deficiency anaemia and severe anaemia by gender (n, % crude and standardized) *Calculation of anaemia in children aged 6-59 months:* (Number of children aged 6−59 months with a haemoglobin concentration <110 g/L at sea level) / (Total number of children aged 6−59 months assigned to the primary care team and who had haemoglobin concentration assessed) * 100.

Calculation at the scale of census tract from SIDIAP data (n, % crude and standardized):

SIDIAP data: age (months), gender, haemoglobin concentration in clinical analytics, and diagnostic code (CIM-10) for iron-deficiency anaemia DD50 (latest year with available data).

Disaggregation by gender. Territorial division: Barcelona's census tracts.

Indicators of prevalence of malnutrition in children under 5 years – Population aged 0-5 years with stunting, wasting, overweight, or underweight, by age and gender (n, % crude and standardized)

Definition: Children aged 0-5 years with stunting, wasting, overweight, or underweight by gender (n, % crude and standardized).

Calculation of stunting (WHO indicator): (Population aged 0-5 years with stunting according to WHO tables) / (Population aged 0-5 years assigned to primary care) * 100.

Calculation of wasting/underweight (WHO indicator): (Population aged 0-5 years with wasting according to WHO tables) / (Population aged 0-5 years assigned to primary care) * 100.

Calculation of overweight (WHO indicator): (Population aged 0-5 years with overweight according to WHO tables) / (Population aged 0-5 years assigned to primary care) * 100.

In children aged under 5 years these indicators are defined as follows:

- stunting – sex-specific height-for-age <-2 SD of the WHO Child growth standards median;
- wasting – sex-specific weight-for-height <-2 SD of the WHO Child growth standards median;
- overweight – sex-specific weight-for-height >+2 SD of the WHO Child growth standards median; and
- underweight – sex-specific weight-for-age <-2 SD of the WHO Child growth standards median.

The WHO Child growth standards can be found for age groups here: WHO tables for the age groups of 0-2 and 2-5 years.

Note: (*) For the purposes of this study, an intermediate calculation of overweight (excluding obesity) is also included.

Calculation at the scale of census tract from SIDIAP data (n, % crude and standardized):

SIDIAP data: age (months), gender, weight (in kilograms), height (in meters).

Disaggregation by gender. Territorial division: Barcelona's census tracts.

Indicators of prevalence of malnutrition in in school-age children (6-12 years) – Population aged 6-12 years with overweight and obesity, by age and gender (n, % crude and standardized)

Definition: Children aged 6-12 years with overweight and obesity (n, % crude and standardized).

Calculation of overweight (WHO indicator): (Population aged 6-12 years with overweight or obesity according to WHO tables) / (Population aged 6-12 years assigned to primary care) * 100.

Calculation of obesity (WHO indicator): (Population aged 6-12 years with obesity according to WHO tables) / (Population aged 6-12 years assigned to primary care) * 100.

In school-age children and adolescents aged 5–19 years these indicators are defined as follows:

- overweight – sex-specific BMI-for-age (equivalent to BMI 25 kg/m^2 at 19 years) >+1 SD of the WHO Child growth standards median; and

- obesity – sex-specific BMI-for-age (equivalent to BMI 30 kg/m^2 at 19 years) >+2 SD of the WHO Child growth standards median.

In children and adolescents (5 to 19 years), BMI is age and sex-specific. The WHO Child growth standards for BMI-for-age (5-19 years) can be found here: WHO table for the age group of 5 to 19 years.

Calculation of Body Mass Index (BMI) = weight (in kilograms)/height2 (in meters).

Note: (*) For the purposes of this study, an intermediate calculation of overweight (excluding obesity) is also included.

Calculation at the scale of census tract from SIDIAP data (n, % crude and standardized):

SIDIAP data: age (months), gender, weight (in kilograms), height (in meters).

Disaggregation by gender. Territorial division: Barcelona's census tracts.

Indicators of prevalence of malnutrition in adults aged 18-74 years – Population aged 18-74 years with underweight, overweight, and obesity, by age and gender (n, % crude and standardized)

Definition: Population aged 18-74 years with moderate and severe thinness, underweight, overweight, and obesity by gender (n, % crude and standardized).

Calculation of underweight (WHO indicator): (Population aged 18-74 years with a BMI < 18.5) / (Population aged 18-74 years assigned to primary care) * 100.

Intermediate calculation of overweight:* (Population aged 18-74 years with a BMI > 25 **AND ≤ 30 ORor a diagnostic code for abnormal weight gain) / (Population aged 18-74 years assigned to primary care) * 100.

For overweight in adults, it will be considered that the patient has a last value of BMI (Body Mass Index) >25 or the diagnostic code (CIM-10) R63.5 abnormal weight gain.

Calculation of obesity: (Population aged 18-74 years with a BMI > 30 **OR** a diagnostic code for obesity) / (Population aged 18-74 years assigned to primary care) * 100.

For obesity in adults, it will be considered that the patient has a last value of BMI (Body Mass Index) >30 **OR** one of the following diagnostic codes (CIM-10): E66 obesity, E66.0 obesity secondary to excess calories, E66.1 drug-induced obesity, E66.2 extreme obesity with alveolar hypoventilation, E66.8 morbid obesity (BMI > 40), E66.9 unspecified obesity.

Calculation of overweight (WHO indicator): (Population aged 18-74 years with overweight or obesity) / (Population aged 18-74 years assigned to primary care) * 100.

Calculation of Body Mass Index (BMI) = weight (in kilograms)/height2 (in meters).

The population aged 75 years and older does not have a clear reference value, which is why they are excluded from this analysis.

Note: (*) For the purposes of this study, an intermediate calculation of overweight (excluding obesity) is also included.

Calculation at the scale of census tract from SIDIAP data (n, % crude and standardized):

SIDIAP data: age (years), gender, weight (in kilograms), height (in meters), diagnostic code (CIM-10) for abnormal weight gain R63.5 (latest year with available data) and diagnostic codes (CIM-10) for obesity E66 (latest year with available data).

Disaggregation by gender. Territorial division: Barcelona's census tracts.

SI.2. Socioeconomic and food environment indicators.

Data sources

The population data by single year of age at the census tract level, corresponding to the annual population census as of 1 January 2022 and 1 January 2023, were obtained from the National Statistics Institute (INE). The socioeconomic data on household income (median) were sourced from the Household Income Distribution Atlas (*Atlas de distribución de renta de los hogares*) of the National Statistics Institute (INE, 2021). The data sources for the analysis of food environments in Madrid and Barcelona are detailed below in Tables 1.SI and 2.SI, respectively.

Table 2.SI. Data sources for the analysis of food environments in Barcelona.

Food environment, Barcelona	Source	Year	Scale
Food retail outlets	Cens d'activitats econòmiques en planta baixa de la ciutat de Barcelona (Ajuntament de Barcelona, 2023)	2022	Coord. UTM
Organic food outlets	Cens d'activitats econòmiques en planta baixa de la ciutat de Barcelona (Ajuntament de Barcelona, 2023)	2022	Coord. UTM
Cooperatives and consumer groups	Institut Metropoli (producción propia)	2019	Coord. UTM
Community urban gardens	Base de dades d'horts urbans de l'Ajuntament de Barcelona (Direcció d'Espais Verds i Biodiversitat Medi Ambient i Serveis Urbans – Ecologia Urbana, Ajuntament de Barcelona, 2021)	2021	Coord. UTM
Municipal urban gardens	Base de dades d'horts urbans de l'Ajuntament de Barcelona (Direcció d'Espais Verds i Biodiversitat Medi Ambient i Serveis Urbans - Ecologia Urbana, Ajuntament de Barcelona, 2021)	2021	Coord. UTM

Tabla 1.SI. Data sources for the analysis of food environments in Madrid.

Food environment, Madrid	Source	Year	Scale
Food retail outlets	Censo de Locales y Actividades (Ayuntamiento de Madrid – Datos 09.2023)	2023	Coord. UTM
Organic food outlets	Censo de Locales y Actividades (Ayuntamiento de Madrid) – Datos 09.2024; Mapeo Alternative Food Networks (MAE – Madrid Agroecológico)	2023	Coord. UTM
Cooperatives and consumer groups	Mapeo Alternative Food Networks (MAE – Madrid Agroecológico)	2023	Coord. UTM
Community urban gardens	Ayuntamiento de Madrid	2023	Coord. UTM
School gardens	Ayuntamiento de Madrid	2023	Coord. UTM
Municipal urban gardens	Ayuntamiento de Madrid	2023	Coord. UTM

Classification algorithms for food retail outlets

The classification of food retail outlets is based on an adaptation of previous work by Bilal et al. (2018) and Díez et al. (2019) in Madrid, and by Garcia et al. (2020) and Garcia-Sierra et al. (2021) in Barcelona. A comparable classification has been developed for the two urban foodscapes using the opportunities provided by each city's census data. The classification algorithms for food retail outlets in both cities are shown in Figure 1A (Madrid) and Figure 2A (Barcelona). The identification of outlets specialising in organic food is based on business codes [In Madrid: ID 472901 = Herbalist. In Barcelona: ID 2003000 = Herbalist], a list of specialist supermarkets and major chains (Garcia-Sierra et al., 2021), and keywords — such as eco, bio, vegan, vegeta, etc.

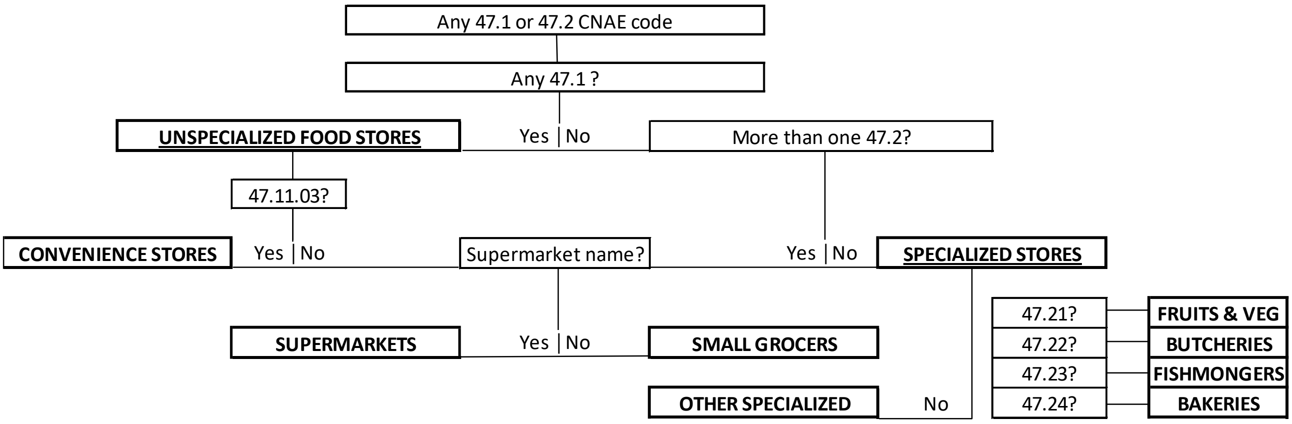

Figure 1.SI. Classification algorithms for food retail outlets in Madrid. Source: Adapted from Bilal et al. (2018) and Díez et al. (2019). Notes: Codes ID 561002 and ID 561007 are categorised as "Takeaway (e.g., small fast-food businesses for takeaway)" or "Fast Food (large chain)" in the first case, and as "Café (e.g., sale of packaged food, hot chocolate, ice cream, etc.)" in the second case. Codes ID 472902 to 472904 (ice cream parlours) are also included in this latter category.

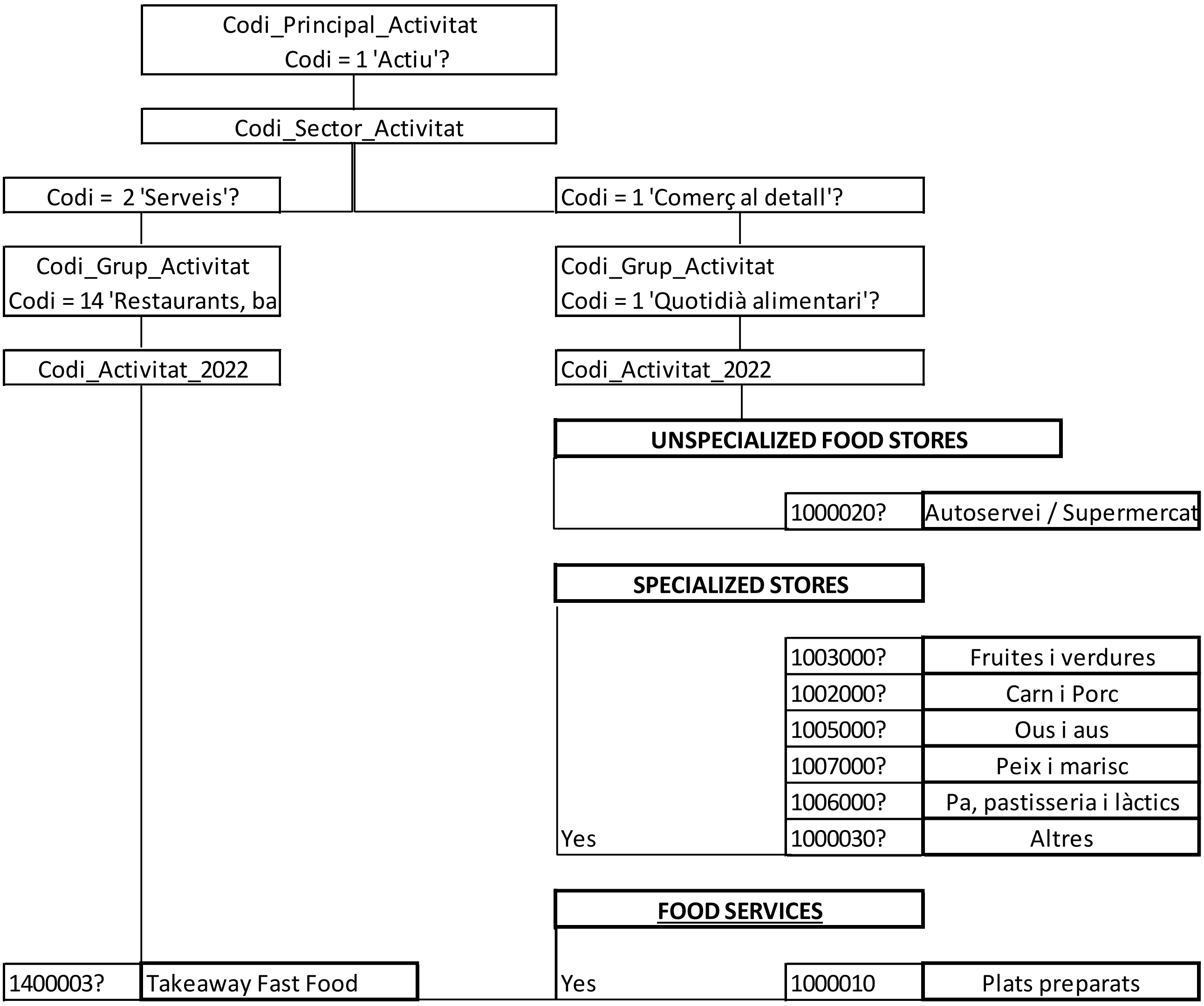

Figure 2.SI. Classification algorithms for food retail outlets in Barcelona. Source: Adapted from Garcia-Sierra et al. (2021).