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Research Paper

Assessing food self-sufficiency of selected European Functional Urban Areas vs metropolitan areas

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HIGHLIGHTS

- Potential capacity of local food systems to provide vegetable diet supply was analysed.
- Metropolitan Foodshed and Self-Sufficiency Scenario model was used.
- 3 out of 9 FUA and metropolitan areas are capable to satisfy the food demand.
- These 3 cities (Berlin, Wroclaw, Ostend) represent different types of urban centers.
- High share of agricultural areas does not guarantee food self-sufficiency.

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ABSTRACT

The resilience of the local food system is being underlined as one of the most important strategic goals for a sustainable future. However, since the question of what constitutes the local scale of food production depends largely on the type of product and supply chain, the associated foodshed can range from a site scale, city and city region up to wider region and country level. As a proof of concept whether functional urban areas (FUAs) can serve as references for local food systems, we provide evidence on their capacity to provide vegetarian diet supply to their residents. Applying the Metropolitan Foodshed and Self-Sufficiency Scenario (MFSS) model methodology we estimate the level of potential food self-sufficiency of the FUAs. We quantitatively compare the results for FUAs with the results of local planning documents of metropolitan areas. The approach is applied to 9 city regions representing different European countries: Wrocław (PL), Ostend (BE), Berlin (DE), Avignon (FR), Copenhagen (DK), Bari (IT), Brasov (RO), Athens (EL), Barcelona (ES). The results show that vegetarian and local food demand could be satisfied in first five FUAs of these city regions. However, if the same number of calories as current diet delivers is to be maintained only the first three FUAs have enough agricultural land to supply vegetarian ingredients to this diet. The results for metropolitan comparison return the same three cities plus Bari. We discuss the use of FUA in defining foodshed area and the role of consumers' dietary choices in regional food self-sufficiency.

1. Introduction

The European Farm to Fork Strategy addresses the growing urban population demands for sustainable, healthy and local food that would increase the resilience of the food system in the European Union. International organisations (FAO, IFAD, UNICEF, WFP, & WHO, 2021; OECD, 2020) also report the need for strengthening the resilience of food systems and reducing both their ecological and carbon footprints. The resilience of agri-food systems is increasingly important when considering multiple risks (Darnhofer, 2021) and crises such as Covid-19 (Béné, 2020; LeGreco, Palmer, & Levithan, 2021; Vittuari et al., 2021) as well as challenges with sustainable development. These types of crises

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are particularly challenging as they combine aspects of food security, nutrition, and human health, the viability of ecosystems, climate change, and social justice (Caron et al., 2018). Resilient food systems constitute a challenge with the increasing urbanization of rural regions throughout Europe. The predominantly rural regions are losing inhabitants, but also intermediate regions experience shrinking (ESPON, 2020a). Those intermediate regions, also called peri-urban areas, provide important ecosystem services (Spyra, La Rosa, Zasada, Sylla, & Shkaruba, 2020), food supply being one of the most relevant (Sylla, Hagemann, & Szewrański, 2020). However, agricultural land is most often changed into an urban fabric laden with construction sites, industrial or commercial units and grey or green infrastructure (ESPON, 2020b). Therefore, the analysis of food systems at the landscape level is crucial in order to create a governance system that supports food production while ensuring that public goods (biodiversity and ecosystem services on which they depend) are protected and enhanced (Erisman et al., 2016; Holt, Alix, Thompson, & Maltby, 2016). Food systems are no longer perceived as just a rural issue and should be part of the urban planning agenda (Cabannes & Marocchino, 2018; Morgan, 2009, 2015; Sarker, Bornman, & Marinova, 2019). The food system highly impacts resource consumption and specific sectors. The food system also interacts and generates impacts to other natural resources such as water and energy consumption (food-water-energy nexus) (Bijl, Bogaart, Dekker, & van Vuuren, 2018). The food system affects the socio-economic sector, including economic development, transportation, public health or social justice (Morgan, 2015).

There is an increasing interest in food system analyses for city regions (Blay-Palmer et al., 2018; Jensen & Orfila, 2021; Monaco et al., 2017; Moschitz & Frick, 2021) – also known as metro regions, metropolitan regions, metropolitan areas (Eurostat, 2013; Tosics, 2007). According to the City Region Food Systems approach (FAO, 2019), city region food systems can be defined using jurisdictional boundaries (e.g., municipality, sub-region, Province) or natural boundaries (e.g., rivers, sea, mountain ridges, watersheds). In addition, factors such as the mutual city region influence, physical or socio-cultural interactions, transport distance, mode and sustainability of transport to the city, and the production potential of the city in relation to food demand.

Functional definitions of metropolitan food systems combine two conceptual approaches: references developed by geographical and planning analyses such the characterisation of urban sprawl (Deng, Huang, Rozelle, & Uchida, 2010; Glaeser & Kahn, 2003; Solecka, Sylla, & Świąder, 2017), central place theory (Christaller, 1933), accessibility (Alonso, 1964), mobility and transport (Wascher, Van Eupen, Corsi, Sali, & Zasada, 2016); and the production capacity of agricultural land to satisfy all, or the majority of the urban food demand (Gerbens-Leenes, Nonhebel, & Ivens, 2002; Rees & Wackernagel, 1996). This capacity varies according to several factors, such as food products, seasonality, soil quality and yield, the latter depending also on productive inputs and specific agro-climatic variables. Taking quantitative data on the typical diets of a city's population as a starting point, the required amount and location of 'local hectares' of agricultural areas meeting these demands are considered as defining the potential 'foodscape' around city centres.

One of the main methods for food system assessment is the foodshed of a region – defined by the carrying capacity of a local foodshed (de Zeeuw & Dubbeling, 2015), local food production capacity or production capacity (Butler, 2013). A foodshed is geographically defined as area that provides enough food products to ensure sustenance for its population (Świąder, Szewrański, & Kazak, 2018). The foodshed area could be delimitated based on the administrative boundaries, morphological characteristics (Vicente-Vicente, Sanz-Sanz, Napoléone, Moulery, & Piorr, 2021), or indicative areas, such as Functional Urban Areas (FUA) and Metropolitan areas. The foodshed delimitation could be conducted using three approaches: (i) food flows, (ii) agricultural capacity, or (iii) hybrid approach (Schreiber, Hickey, Metson, Robinson, & MacDonald, 2021; Świąder et al., 2018; Vicente-Vicente, Doernberg, et al., 2021). The food-flows approach includes the distribution network which relies on the relationship between food producers (food origins) and its consumer market (Karg et al., 2016). The agricultural capacity is an assessment of the agricultural production capacity that ensures the demands of the population, which could be also named as the foodshed self-sufficiency (Zasada et al., 2019).

The aim of the article is to provide evidence on whether food city regions (FUA and metropolitan) in Europe can provide a vegetarian diet supply to their citizens. To achieve our goals we use the approach of the Metropolitan Foodshed and Self-Sufficiency Scenario (MFSS) model, developed by Zasada et al. 2019. The MFSS model provides the methodology to assess the level of the regional food self-sufficiency. This model enables comparisons between several scenarios, including the changes in the share of organic farming, population estimates, food loss and waste. In this study, we use MFSS model to make the base line assumption of two options: current and reduced number of calories. Our foodshed area is restricted by the FUA and metropolitan areas' boundaries, as they are two of the most commonly used territorial typologies that are closest to the definition of a city-region.

2. Materials and methods

2.1. City-region food consumption and production

The Farm to Fork Strategy advocates sustainable diets that are healthy and environmentally friendly. While the switch to a plant-based diet is recommended, no direct suggestion for specific foods to consume is made. The Farm to Fork Strategy underlines the negative impacts of meat consumption, both in terms of health and greenhouse gas emissions related to land use (Caro, Davis, Kebreab, & Mitloehner, 2018). According to the Strategy about 68 % of the total agricultural land in the EU is devoted to producing animal feed. Also, the EU is aiming at combating overfishing that leads to the unsustainable use of water food resources. Therefore, in this study we apply the definition of a vegetarian diet that consists of no meat or fish but includes dairy products and eggs. The Farm to Fork Strategy promotes short food supply chains that could help to reduce long-distance transportation. Agricultural products that can be produced locally, depending on the climate zone are also included in this study. For instance, olives are included in the analysis for cities located in the Mediterranean countries where olives grow naturally, i.e. Greece, France, Spain and Italy. The same applies to coffee and tea, which are not grown in Europe and are therefore excluded from our analysis.

The case study areas differ in terms of agricultural productivity. Belgium is the European Union's leader in tomato production in comparison to Romania and Poland which have significantly lower tomato production yields (Giannakis & Bruggeman, 2015). Germany reports the highest yield rates for cereals. Romania has the highest productivity in nuts and oil-crops (Turek Rahoveanu, Turek Rahoveanu, & Ion, 2018).

2.2. City-region self-sufficiency

According to the MFSS model, to assess the level of regional food system self-sufficiency-two aspects are confronted: the food demand/consumption and food supply (Fig. 1). Food demand is estimated in kg per person per year and recalculated into agricultural area needed to satisfy this demand. This area is then compared to the available utilisable agricultural area in the given foodshed area (FUA/metropolitan area).

2.3. Materials

Firstly, food demand or food consumption data was retrieved. National datasets containing food demand are often assembled using different methodologies and units; therefore our goal was to achieve comparable results by using international databases that could guarantee central methodology. We follow the MFSS model approach and

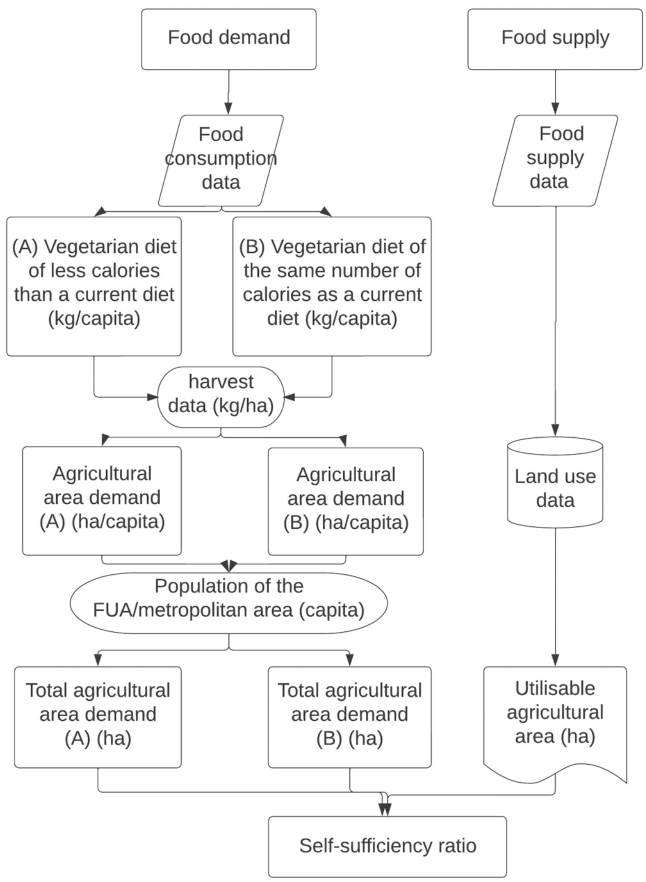


Fig. 1. Flowchart adapted from (Zasada et al., 2019).

use Food and Agricultural Organisation of the United Nations (FAO) Food Balances statistics for 2018. Alternatively, the EFSA Comprehensive European Food Consumption Database can be used. However, the use of a comprehensive database was limited due to two reasons: the database did not include data for all our cases study areas for 2018, and most importantly, the database is dedicated to health studies whereas we focus on landscape capacity to provide food in the sustainable food systems.

Secondly, for consistency, the data for food production also comes from FAO Food Balances statistics for each food item and for each country of the case study regions. We verified FAO yields values with national statistical records for randomly selected food items. Due to significant fluctuation between the years, the average yield values are calculated for 2017, 2018, and 2019.

Each consumed food item's value (kg/capita/yr) is linked to its harvest data (kg/ha/yr) in order to estimate the agricultural area needed to satisfy food demand. Consumed food items are classified into seven categories: cereals and cereal products, pulses, roots and tubers, sugar crops and sweeteners, nuts and oil-bearing crops, vegetables and fruits, alcoholic beverages (beer and wine), animal products (dairy and eggs). The categories are delineated based on the database, FAO commodity groups, classification of individual consumption by purpose (COICOP) and food categories from Zasada et al. (2019). Food consumption (kg) per capita are then multiplied by the population numbers for each FUA and metropolitan area. Consumption is converted from food weight values to kilocalories. Food consumption results are multiplied by the nutritive factors provided by FAO (2017).

For several food items we apply conversion factors (Appendix 1) for their complexity and food waste and loss. Food waste and loss is significant in the global (Chen, Chaudhary, & Mathys, 2020; Kummu et al., 2012) as well as European context and, therefore, is included in the MFSS model. Food waste and loss conversion factors enlarge the area needed to satisfy the consumption. Food waste and loss factors are applied according to the food categories with no distinction in terms of different countries. All the percentages are derived from the calculation for European market based on FAO data (Caldeira, De Laurentiis, Corrado, van Holsteijn, & Sala, 2019).

2.4. FUA areas

Delimitation of the European Functional Urban Areas dates back to over 20 years ago and was related to the concept of polycentricity (ESPON, 2002, 2007). Different approaches and indicator frameworks were applied, and the results enhanced the regional development and spatial planning. The delimitation results of FUAs during 2006 in Poland fed into "The National Spatial Development Concept 2030" (Truskolaski, Busłowska, & Waligóra, 2017). FUAs were further developed in cooperation of the European Commission and the Organization for Economic Co-operation and Development (Schmidheiny & Suedekum, 2015). The Tercet Legislative initiative launched by Eurostat harmonised and integrated FUA typologies enabling consistent data gathering, presentation and processing. According to Tercet typology, FUA consists of a city and its commuting zone. The shapefiles of FUA were downloaded from European Commission's GISCO server. They are also available via a mapping online tool provided by ESPON FUORE project (https://fuore.espon.eu/), which aims at facilitating benchmarking and analysis of different territorial trends across functional areas. ESPON FUORE tool supports research and informs policy with disaggregated data available at different NUTS level to FUA level, for instance population, education, and employment data. For this analysis, the most helpful was the population data. However, this tool lacks the environmental component.

2.5. Metropolitan areas

FUA case study areas are compared with another type of spatial delimitation of urban core and its surrounding areas – metropolitan areas. In this research, the boundaries of nine metropolitan areas (Fig. 2) were adapted from strategic documents and/or scientific articles presenting the administrative boundaries of the selected metropolitan areas of the core cities.

We reviewed strategic documents and research articles describing metropolitan case study areas (Table 1). Secondly, digital image files were associated with locations in physical space (georeferenced) using the 'Georeferencing' tool available within ArcGIS software (version 10.8.1). Finally, having georeferenced rasters, it was possible to obtain spatial data representing the metropolitan boundaries using Local Administrative Units (LAU) 2019 – geodatabase from Eurostat.

2.6. Comparison of case study areas

The analysis was applied to 9 city regions, each representing different European country: Wrocław (Poland), Athens (Greece), Berlin (Germany), Copenhagen (Denmark), Bari (Italy), Brasov (Romania), Ostend (Belgium), Avignon (France), Barcelona (Spain) (Fig. 2). Case study areas vary significantly in terms of their size, population density, and local characteristics (Table 2). Berlin, together with its' FUA, is the city with the largest population size and the biggest area. The smallest city and FUA is Ostend in Belgium. In relation to Berlin, Ostend's FUA population is 40 times smaller while its FUA area is 81 times smaller. The second most populated core city is Athens, but Barcelona has more people living within its FUA than Athens. Copenhagen and Wroclaw are very similar in terms of the number of core city inhabitants being approximately 600 thousand. However, Copenhagen is a capital city with a FUA about 600 km^2 and the FUA population is 2.2 times greater than that of Wroclaw. Bari and Brasov core cities have a population of around 300 thousand inhabitants, while Avignon has about this within

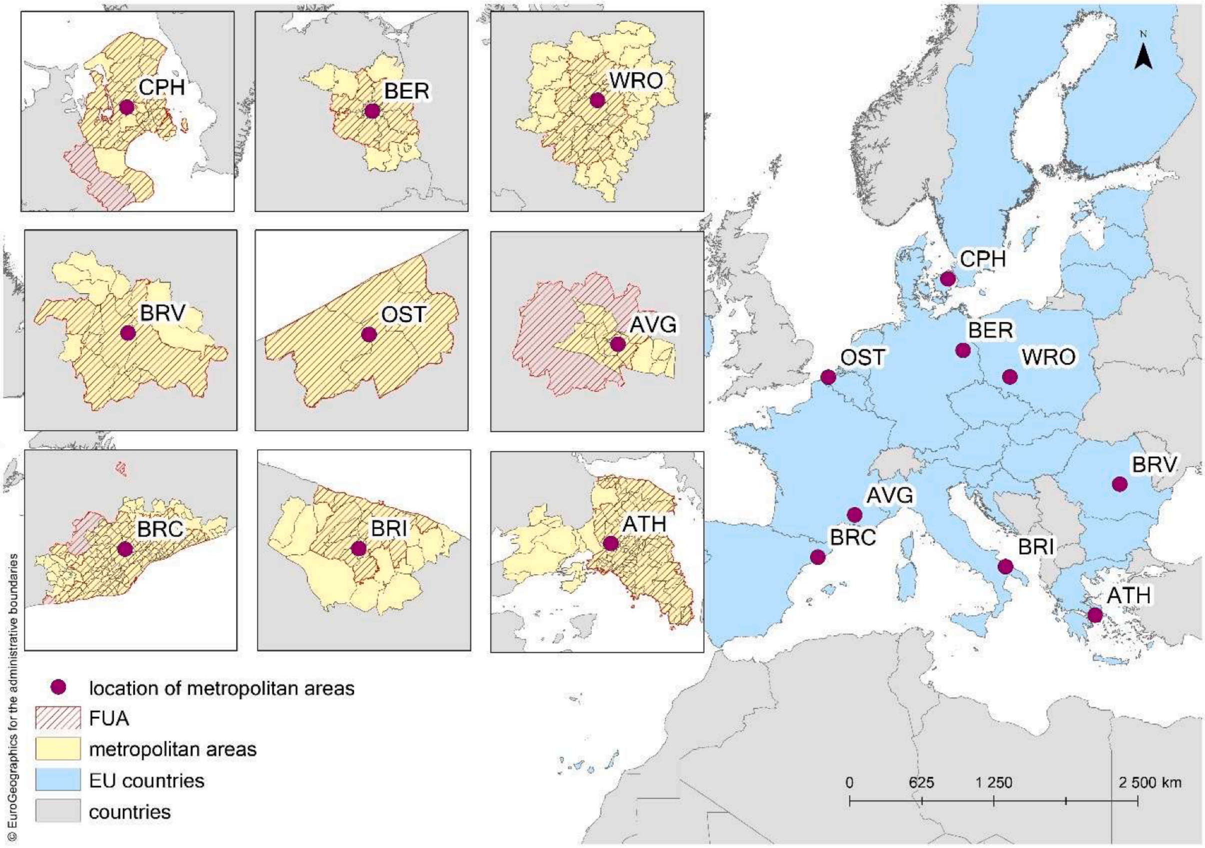


Fig. 2. FUA and metropolitan case study areas.

Table 1
Source materials of the metropolitan case study areas.

No.	Metropolitan region	Source materials of city-region area: Strategic document	Research article	Reference
1	CPH	✓		The Finger Plan (Stysiak, Jensen, & Mahura, 2015)
2	BER		✓	Berlin-Brandenburg (Arlinghaus, Bork, & Fladung, 2008; Hersperger, Bürgi, Wende, Bacău, & Grădinaru, 2020)
3	WRO	✓		(Instytut Rozwoju Terytorialnego, 2018)
4	BRV	✓	✓	(Brasov Metropolitan Agency for Sustainable Development, 2012; POPESCU & CORBOS, 2010)
5	OST		✓	(Canters, Vanderhaegen, Khan, Engelen, & Inge, 2014)
6	AVG		✓	(Sanz Sanz, Martinetti, & Napoléone, 2018; Sanz Sanz, Napoléone, & Hubert, 2017)
7	BRC		✓	(Catalan, Sauri, & Serra, 2008; Cebollada & Miralles-Guasch, 2010; García-Coll & López-Villanueva, 2018)
8	BRI		✓	(Spanò, Leronni, Lafotezza, & Gentile, 2017)
9	ATH		✓	(Rontos, Mavroudis, & Georgiadis, 2006)

its FUA.

The food is mainly produced in the utilisable agricultural areas (UAA) which was calculated using the Corine Land Cover 2018. UAA consisted of eight distinct types of agricultural land use: non-irrigated arable land, permanently irrigated land, vineyards, fruit trees and berry plantations, olive groves, pastures, annual crops associated with permanent crops, and complex cultivation patterns. The biggest share of UAA is in Ostend, while in absolute terms the largest UAA is around Berlin. Wroclaw is the leader in UAA per capita (m^2), leaving the last one - Barcelona- with 21 times more m^2 of UAA per capita. The highest above the see level city is Brasov, opposed to Ostend which sits at the seaside and only one meter above it. Ostend also gets the most annual rainfall. Central and Eastern European cities from our list face biggest changes in terms of development of urban land use. When comparing 2000 to 2018, there were about 300 m^2 of urban areas more per person living in Brasov FUA and 282 m^2 in Wroclaw. Athens shows the least change in this regard (ESPON, 2020b). The morphological structure of the NUTS3 regions of the case studies could be described by three main forms according to the ESPON SUPER projects results: "compact (usually walkable large dense cities that are dominant in their regions), polycentric (clustered development, usually well-served by public transport) and diffuse (low density car-oriented scattered development)". Wrocław and Brasov are described as diffuse, while the rest of city-regions are mainly polycentric (Table 2).

In comparison to FUAs, the population of the metropolitan areas is larger in seven out of the nine city regions (Table 2). Ostend has the same FUA and metropolitan areas, therefore its population as well as area are identical. Avignon metropolitan area has lower number of inhabitants, which it is due to smaller area of the metropolitan region in comparison to FUA. Population density of metropolitan areas is smaller than in FUA in six out of nine city regions. In metropolitan areas of Avignon and Copenhagen, population density is higher in FUA due to

Table 2
Population, area and local characteristics of the FUA and metropolitan case study areas.

	Copenhagen	Berlin	Wrocław	Brasov	Ostend	Avignon	Barcelona	Bari	Athens
Population									
FUA	1,919,370	5,259,363	885,638	401,516	130,055	330,250	4,991,133	744,564	3,632,388
Metropolitan	2,053,445	6,156,743	1,232,924	443,956	130,055	207,325	5,106,916	1,053,496	3,711,920
Core city	613,288	3,613,495	636,050	289,360	71,451	109,451	1,620,343	323,370	2,641,511
FUA Population density	592.4	300.8	334.4	408	631.8	367.7	1902.4	661.1	1882.6
Metropolitan Population density	671.7	201.6	183.4	296.8	631.6	601.5	1575.6	370.6	1222.7
Area									
FUA Area (in km2)	3239.9	17482.9	2648.2	984.1	205.9	898.2	2623.5	1126.3	1929.5
Metropolitan Area (in km2)	3057.0	30545.3	6722.7	1496.0	205.9	344.7	3241.3	2843.0	3035.9
FUA Utilised Agricultural Area (UAA, in km2)	1604	7964.2	1701.2	299.8	150.3	568.1	444.6	916.1	398
Metropolitan UAA	1364.5	15249.8	4172.4	579.5	150.3	189.2	655.6	2333.9	650.6
% of UAA in FUA area	0.5	0.5	0.6	0.3	0.7	0.6	0.2	0.8	0.2
FUA UAA per capita (m2)	835.7	1514.3	1920.9	746.7	1155.9	1720.2	89.1	1230.3	104
Metro UAA per capita (m2)	664.5	2476.9	3384.1	1305.3	1155.7	912.5	128.4	2215.4	175.3
Local characteristics									
Elevation (m. a.s.l.)	6	30	117	619	1	30	10	7	70
Annual rainfall (mm)	728	669	700	794	929	752	614	575	378
Development of urban use per capita for the period 2000–2018 per FUA (m2/capita)	210.8	224.4	283.2	306.1	201.6	245.7	236.3	258.2	192.8
Morphology of NUTS3 hinterlands: compact, polycentric, diffuse	polycentric	polycentric	diffuse	diffuse	polycentric	polycentric/ compact	polycentric	polycentric	polycentric

difference in the metropolitan municipalities' population and location (Fig. 2). Both Avignon and Copenhagen metropolitan areas are the only ones that are smaller in terms of coverage area than FUA. Not only is the total area of metro region generally higher than FUA, but also the area of arable land follows this pattern. Therefore, the available agricultural area per capita is higher in metropolitan areas than in FUAs, except in Avignon and Copenhagen.

3. Results

3.1. Food consumption and demand

The annual average food consumption per capita in all case study regions has been analysed in terms of weight value of food, provided calories and the area needed to satisfy this demand per person in 2018. The heaviest value of food is consumed in Brasov, and it is mainly due to the highest share of vegetable and fruits as well as cereals (Fig. 3). The highest intake of beverages (beer) is in Berlin, Wroclaw and Ostend (Fig. 3). Nuts and oil crops are significant in the regions located in Southern Europe, i.e. Athens, Barcelona and Bari. Sugar consumption is the highest in Ostend, followed by Copenhagen. Copenhagen and Berlin have the lowest consumption of fruits and vegetables. The consumption data follows the specific dietary differences between regions in Europe that derive from climate conditions and cuisine culture.

When consumption values are multiplied by nutritive factors (Fig. 4), the food category that provides the biggest share of kcal (average 53 % of all per day) is cereals followed by nuts and oil-bearing crops. The consumption (or overconsumption) of sugar is also a major contributor of caloric intake per day in the diets of Europeans residing in the countries analysed in this study. Fruits and vegetables are relatively low in calories and therefore, even when consumed in large quantities they do not provide many calories. The total daily calories intake of the vegetarian diet (no meat or fish and climate relevance of a crop cultivation) varies from 2,448 kcal for an average Copenhagen resident and 3,248 kcal for an average Brasov resident (Fig. 4). This type of diet provides about on average 22 % less calories than diet including fish, meet and imported goods, yet not dropping below 2000 kcal a day. Lower values are mainly caused by the meat and fish elimination from the diet which account for on average 660 calories.

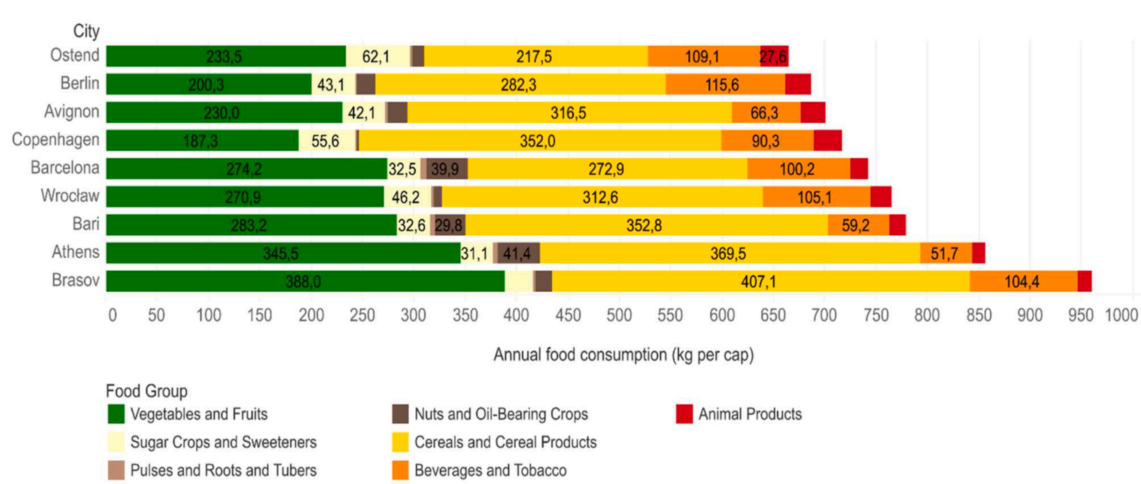


Fig. 3. Annual per capita food consumption (kg) in 2018 without meat, fish and food not grown in Europe's climate.

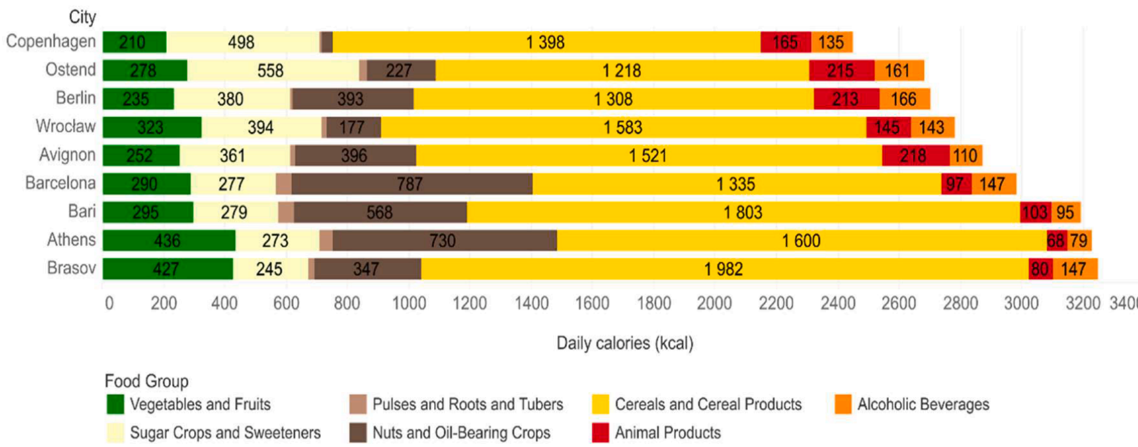


Fig. 4. Daily calories (kcal) intake in 2018 according to different food categories, excluding meat, fish and food not grown in Europe's climate.

3.2. Agricultural area demand within FUA

The selected FUA regions vary in terms of agricultural production capacity (Table 3). The share of arable areas within total FUA area differs significantly with the highest share value of 81 % in Bari where as the lowest is 17 % in Barcelona. Interestingly, the fact of being a coastal FUA (Oostende, Copenhagen, Bari and Barcelona) does not influence the agricultural production capacity as much as the number of inhabitants. The share of agricultural areas decreases with the increase in population. Based on the land use type, we also identified food items specific to certain regions (Table 3). Vineyards and olive groves are only present in four case study areas located in the Mediterranean region. Three of the land use types are present in all FUAs: non-irrigated arable land, pastures, and complex cultivation patterns.

3.3. Agricultural area demand within metropolitan regions

Metropolitan areas are delimitated in accordance with official strategic documents or based on research papers. In comparisons to FUA, six out of nine metropolitan areas are larger in terms of a coverage area. Ostend's FUA and metropolitan area are the same, while Copenhagen and Avignon's metropolitan areas are smaller than their FUAs. The six city regions, which are largest in terms of area, have increased their share of UAA, all together by 17 %. The total share of UAA in all nine city regions is almost the same as in FUA, with only a 2 % difference (Table 4). In absolute terms, the total agricultural area in metropolitan areas increased by 1.2 million ha which means it almost doubled in comparison to FUA.

3.4. FUA and metropolitan food self-sufficiency

The agricultural area needed to satisfy the vegetarian and local diet of all FUA residents was estimated and compared to the available UAA in 2018 to calculate a potential food self-sufficiency (Fig. 5). If a city region exceeds 100 % of food self-sufficiency, it means that there is enough agricultural area to satisfy the local vegetarian diet to all inhabitants. Four out of nine case study FUAs cannot provide the vegetarian and local food supply for their citizens. For Athens (4 %) and Barcelona (4 %) it is mainly due to the very small share of UAA in total area of urbanised and densely populated capitals. Bari (74 %) and Brasov (47 %) have high agricultural possibility and a relatively high foodshed per person Between 0.18 and 0.16 ha of agricultural land is needed per average citizen in Barcelona, Bari, Brasov and Avignon. Copenhagen (107 %) and Avignon's (110 %) FUA would use almost all their agricultural area available to produce food for their citizens. Wrocław (166 %), Berlin (153 %) and Ostend (161 %) could devote about 60 percent of the agricultural land use to satisfy food demand of their citizens. If the local vegetarian diet was applied, but the number of calories would be maintained the same, only Berlin (121 %), Wroclaw (131 %) and Ostend (128 %) would be placed above 100 % of self-sufficiency (Fig. 5). Avignon would be close to self-sufficiency, reaching about 90 % self-sufficiency.

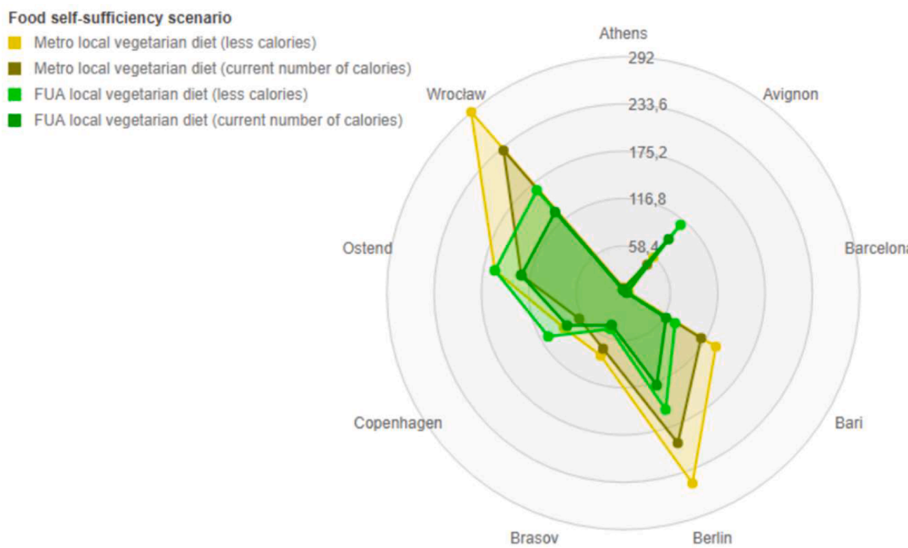
The metropolitan self-sufficiency is different from FUA, not in terms of cities, but magnitude. Berlin, Wroclaw and Ostend achieved self-sufficiency in both FUA and metropolitan areas. However, in metropolitan areas the level of self-sufficiency is almost doubled for Wroclaw and Berlin. It could be expected that for those cities with metropolitan areas larger than FUA, their level of self-sufficiency would increase. This is true, for Barcelona and Athens, as the levels of food self-sufficiency increased by 1–2 %. This is also true for Brasov and Bari, which almost doubled its results. Bari exceeds 100 % self-sufficiency level (Fig. 5) due to a metropolitan area that is more than 2.5 times bigger than FUA and therefore, could supply enough food resources. The self-sufficiency of Brasov increases from 47 % for FUA to 82 % for metropolitan region with the local vegetarian diet with less calories than the current diet, but does not reach full self-sufficiency. The two leaders of

Table 3
Share of the agricultural utilisable areas (UAA) in total FUA area and its' land use types.

	Non-irrigated arable land	Perm. irrigated land	Vine-yards	Fruit trees and berry plant.	Olive groves	Past-ures	Annual crops as. perm. crops	Compl. Cult. patterns	UAA total (ha)	FUA UAA %
Ostend	7679.2	0.0	0.0	0.0	0.0	2214.3	0.0	5139.7	15033.1	73 %
Berlin	565089.4	0.0	0.0	2644.0	0.0	228400.4	0.0	290.6	796424.5	46 %
Copenhagen	152029.9	0.0	0.0	109.2	0.0	3946.7	0.0	4315.3	160401.1	50 %
Athens	1175.0	451.6	5673.2	0.0	7676.6	1120.3	0.0	23700.7	39797.4	21 %
Barcelona	15569.5	4449.8	11710.8	1928.4	791.1	3146.2	0.0	6859.8	44455.5	17 %
Avignon	5241.7	0.0	16234.7	8063.1	223.2	181.3	0.0	26866.1	56810.1	63 %
Bari	4108.8	0.0	13174.3	495.3	60766.2	631.8	1552.3	10876.9	91605.6	81 %
Wrocław	150681.9	0.0	0.0	862.0	0.0	14828.8	0.0	3747.6	170120.3	64 %
Brasov	20301.9	47.9	0.0	185.2	0.0	8287.0	0.0	1157.8	29979.8	30 %

Table 4
Share of the agricultural utilisable areas (UAA) in total metropolitan area and its' land use types.

	Non-irrigated arable land	Perm. irrigated land	Vine-yards	Fruit trees and berry plantations	Olive groves	Pastures	Annual crops as. with perm. crops	Compl. cult. patterns	UAA total (ha)	Metro UAA %
Ostend	7663.5	0.0	0.0	0.0	0.0	2182.7	0.0	5162.5	15008.7	73 %
Berlin	1096930.3	0.0	0.0	3547.7	0.0	423972.7	0.0	533.3	1524984.1	50 %
Copenhagen	128116.2	0.0	0.0	109.2	0.0	3566.3	0.0	4663.3	136454.9	45 %
Athens	3898.5	3348.9	6896.2	226.2	14268.8	3279.2	0.0	33144.5	65062.4	21 %
Barcelona	15836.2	6245.6	29423.8	1859.6	663.1	3341.3	0.0	8192.7	65562.3	20 %
Avignon	1183.9	0.0	2786.0	4126.2	0.0	245.0	0.0	10577.7	18918.7	55 %
Bari	64508.5	0.0	25393.2	11569.3	86955.8	2631.6	7035.8	35297.5	233391.6	82 %
Wrocław	367476.0	0.0	0.0	1075.7	0.0	39614.0	0.0	9070.9	417236.6	62 %
Brasov	39237.9	47.9	0.0	335.0	0.0	16307.2	0.0	2021.9	57949.9	39 %



City	Food self-sufficiency scenarios: FUA local vegetarian diet (current number of calories)	FUA local vegetarian diet (less calories)	Metro local vegetarian diet (current number of calories)	Metro local vegetarian diet (less calories)
Athens	4%	4%	6%	7%
Barcelona	4%	5%	5%	7%
Brasov	42%	47%	73%	82%
Avignon	87%	110%	46%	58%
Copenhagen	80%	107%	63%	85%
Bari	61%	74%	111%	132%
Ostend	128%	161%	128%	161%
Berlin	121%	153%	197%	250%
Wrocław	131%	166%	230%	292%

Fig. 5. Comparison of FUA and metropolitan food self-sufficiency ratio.

food self-sufficiency are Wroclaw and Berlin. It was revealed that their metropolitan regions had to use 40 % of the agricultural land to satisfy food demand of their citizens.

Self sufficiency ratio can also be disaggregated into municipality level in order to analyse the spatial distribution of the level of food self-sufficiency. Fig. 6 presents the level of self sufficiency at the municipal level for two best scoring city regions – Wroclaw and Berlin. As it is expected, core urban cities are below the 50 % sufficiency. For Berlin, almost every second municipality adjacent to city borders is beyond 100 %. In the case of Wroclaw, the urban sprawling has not yet undermined the 100 % self-sufficiency of neighbouring municipalities. Only highly and medium urbanised municipalities are not self-sufficient (Fig. 6). In general, both examples exhibit the pattern showing that the further away from the core city the higher the level of self-sufficiency.

4. Discussion

This study compares functional urban areas with metropolitan areas in terms of level of food self-sufficiency. Both FUAs and metropolitan areas include functional dependencies of core cities with their rural hinterlands. The level of rural–urban linkages might influence the food self-sufficiency. Therefore, the city-region food system could be sustainable and resilient considering the inseparability of urban development and food systems from rural development due to the multiple impacts of urban areas on their surroundings (Dubbeling et al., 2017). The agroecological systems surrounding cities have the capacity to

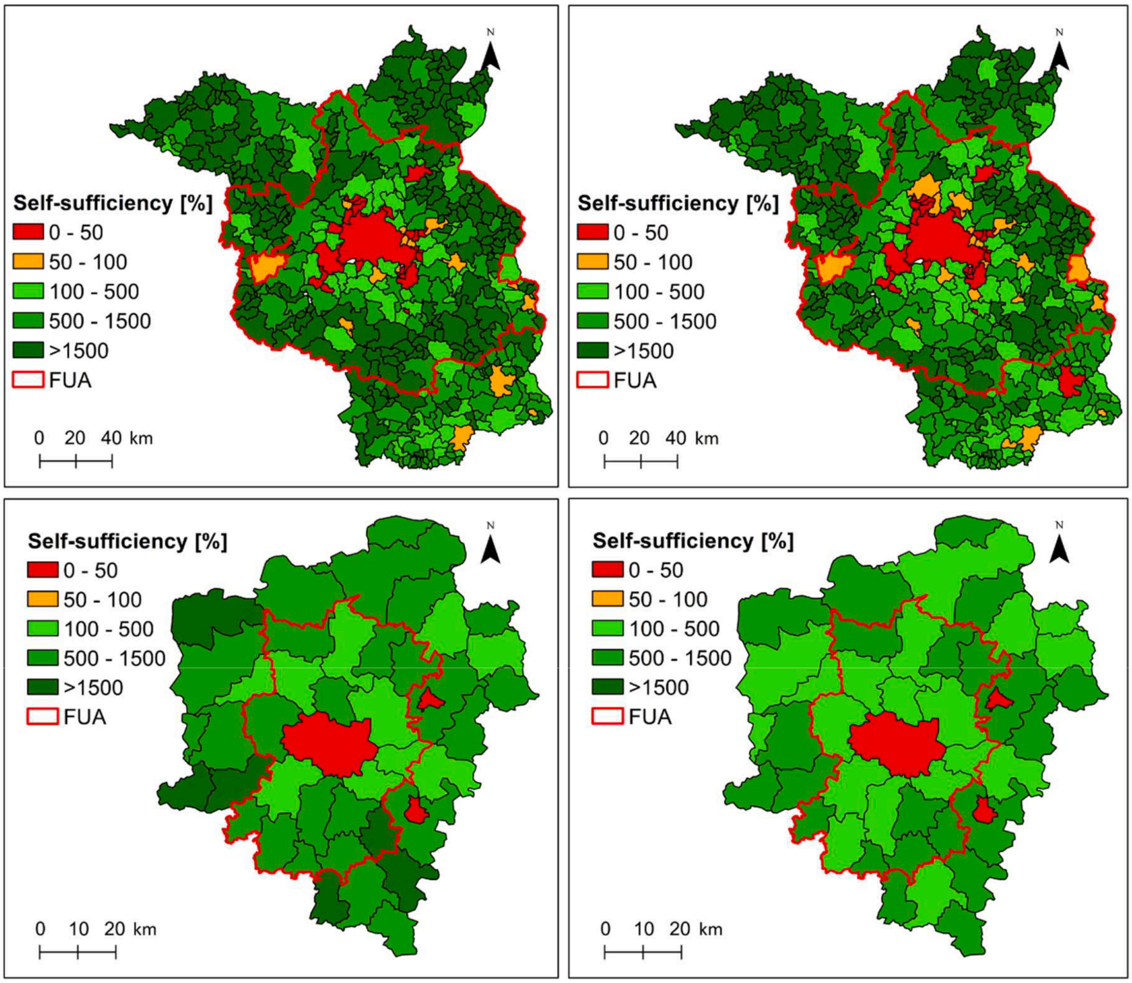


Fig. 6. Self-sufficiency level at municipality level for Berlin (upper) and Wroclaw (lower) satisfying local vegetarian diet with less calories (left) and keeping the current number of calories (right).

provide a wide variety of vegetarian food commodities and thus, contribute to an increase in the food self-sufficiency potential as well as balancing food production, ecosystem services and biodiversity in agri-food system. The city-region food policy combined with the foodshed assessment, is an important multidisciplinary issue. The promotion of change in food system is relevant in context of food policy in general, spatial policy and management, as well as resilient socio-environmental system considering current and future environmental risks and crises. It allows the creation of a complex approach for development of entire area - metropolitan and rural, as well as a sense of community (Stein & Santini, 2021).

4.1. Food self-sufficiency of city regions

The results of this study contribute to the growing evidence concerning difficulty in achieving self-sufficiency in European city regions (Jensen & Orfila, 2021; Kaufmann et al., 2022). Out of nine case study city regions, three are capable of satisfying the food demand in all the variants analyzed in this research. Interestingly, these three cities represent different types of urban centers. First, Berlin is a multimillion inhabitant capital city of a rich and highly developed European country. Second, Wroclaw is a medium size European city located in a highly diverse agricultural landscape. Third, the last is the small coastal city of Ostend surrounded by intensive agriculture. All three cases have at least 50 % of the total land use that is agricultural land devoted for food production. However, the high percentage of UAA in total areas does not guarantee self-sufficiency. In our study Bari is a very good example of not meeting the self-sufficiency level despite having a share of above 80 % of agricultural land.

This study provides a comprehensive insight into FUAs and metropolitan areas food self-sufficiency. However, certain limitations should be acknowledged. First, the lack of data concerning citizens diets or food consumption at the city region level made it necessary to use nation-level food balances. Because of that, the city regions' differences within one country were lost. However, to address this limitation, we analysed FUA and metropolitan areas across different countries. The same problem applies to the caloric intake, as it is calculated based on consumption data. Second, the biases in the data sets of Corine Land Cover and FAO Food Balances are beyond the control of the authors but the risk of biases is acknowledged. Third, some of the diet's ingredients were not considered in the analysis. This mainly concerns food not grown in Europe's climate such as coffee and tea. As analyses of the global food flows report, European citizens consume a lot of food products not specific to a temperate climate.

The potential food self-sufficiency of the selected city regions is analysed in terms of satisfying the intake of calories by the inhabitants. This approach focuses on the quantity of different produce but do not cover the quality of food that is often equally important for consumers. It is advised to balance the quantity and quality of food produce (in terms of vitamins and minerals) to sustain a healthy diet. We also acknowledge that food preferences and tastes are personal choices, Food constitutes an important part of the cultural heritage, but its unsustainable production might have adverse impacts on landscapes, biodiversity, and ecosystems. Although the environmental impacts of different types of diets varies significantly, the carbon footprint and water footprint of meat is the highest of all types (Chai et al., 2019; Poore & Nemecek, 2018).

4.2. Defining foodsheds

In this contribution, we tested the use of FUA and metropolitan areas in defining foodsheds. The results from nine case study regions show that there is not an easy answer as to whether a FUA or a metropolitan area is more suitable for defining foodsheds. If we take a criterium of number of city regions capable to satisfy local and vegetarian diet with the current number of calories, there are four metropolitan areas vs three FUAs. However, when a local vegetarian diet with less calories (but still above 2000 kcal) is analysed, there are five FUAs vs four metropolitan areas that are self-sustained. Both delimitations were primarily intended to capture functional and economic interdependencies between the core city and its hinterland. The agricultural production is usually not considered in the indicator framework related to defining FUAs or metro region. However, it seems that both can successfully be used in analyzing foodsheds. The added value of using the FUA or metro regions, are research results and implications for spatial planning and management. Metropolitan regions in Europe have already established governing institutions and strategies. Adding the food self-sufficiency component would enlarge the holistic approach to strategic planning. This study is focused on conducting quantitative food modeling in order to figure out the amount of land needed to meet the current demand and to study the potential foodsheds. However, the shape of the foodshed is related to some biophysical (e.g., local pedoclimate) and socio-economic conditions affecting the area and conforming the foodshed. A socio-ecological holistic approach would allow planners to identify the most suitable areas for each type of crop. For instance, animal products should be prioritized to be produced extensively, namely in soils having some difficulties for commercial crop production (e.g., high slope, low depth). Furthermore, considering the increasing demand on sustainable energy consumption, a suitable land use allocation of for instance low-nutrient requirement second-generation bioenergy crops in marginal lands (e.g., Miscanthus (Tavakoli-Hashjini, Piorr, Müller, & Vicente-Vicente, 2020)) would avoid competition for land with food production and at the same time foster other ecosystem services (e.g. soil organic carbon sequestration and biodiversity).

4.3. Governing city region food system – the role of consumers behaviour

Another way to increase the food self-sufficiency is by modifying consumers' behavior. That is, I) to adapt the diets to the local pedoclimatic and socio-economic conditions, and ii) to reduce land footprint.

1. Shifting to regional and seasonal diets

Our results show that five out of nine case study FUAs can meet the vegetarian and local diets with the currently available agricultural area. However, when maintaining the current level of calorie consumption, only three cities would be able to fulfil the demand for vegetarian and local diets. Nevertheless, even though the remaining five cities would not be theoretically food self-sufficient under this scenario, two of them – Brasov and Bari – would manage to achieve relative high degrees of self-sufficiency (74 and 47 %). In the special cases of Barcelona and Athens, the amount of the utilisable agricultural area is extremely low, being the main driver of the very low self-sufficiency, and therefore the role of shifting diets could be considered as negligible.

2. Reduce land footprint

Reducing the land footprint linked to food consumption is another effective strategy to increase the food self-sufficiency. Currently there are three main strategies to address this. First, to shift to more plant-based diets. This might change the spatial structure of agricultural land use where the feed crops are dominating landscapes of many Western European countries. Secondly, reduce food waste in households. Food losses and food waste are different concepts. While losses refer usually to food wastage in agricultural production (Augustin, Sanguansri, Fox, Cobiac, & Cole, 2020), whereas food waste refers to consumers' behaviour in households. Chen et al., (2020) estimated a land footprint from food waste of around 131 m^2 per capita per year, a value in line with the average value estimated by Vicente-Vicente et al. (2021) of 177 m^2. However, there are differences between the different food products. While the main amount of food waste corresponds to fruit and vegetables the highest impact on the land footprint belongs to cereals and meat. Vicente-Vicente et al. (2021) explain that the reason is that cereals are highly consumed compared to the other plant-based products, whereas the land footprint per kilogram of animal product is much higher than the land footprint of the plant-based products.

Finally, the third way to reduce the land footprint is to reduce the food consumption. (Rodríguez-Rodríguez, Kain, Haase, Baró, & Kaczorowska, 2015) defined the optimal food demand as the balanced amount of energy for a person to maintain good health. That should be 2200 kcal per capita per day, but currently is much higher, achieving the amount of 3456 kcal per capita per day for European urban areas. Therefore, just by adjusting the consumption per capita to healthy values it would imply a significant decrease in the land footprint.

5. Conclusions

Local food systems are recognised for playing a significant role in the pathway towards sustainable future. Food systems include the whole supply chain and consumption, ending at wood waste and recycling. In this contribution landscape perspective was applied, with land use being one of the key factors. We analysed the potential capacity of local food systems to provide vegetarian diet supply to citizens of functional urban areas and metropolitan areas. We applied the Metropolitan Foodshed and Self-Sufficiency Scenario (MFSS) model methodology to estimate the level of food self-sufficiency for FUAs across nine different case study city regions in Europe. Two alternatives of local vegetable supply were considered: general reduction in the number of consumed calories due to elimination of meat and imported food items that are not sustainable to grow within FUA boundaries, and the maintenance of the current level of consumed calories. Both alternatives give positive self-sufficiency levels for Berlin, Wroclaw and Ostend. The lowest results of self-sufficiency were obtained for Athens and Barcelona.

The results of the analysis provide support and evidence for decision makers in designing local food strategies. Many European cities, especially those who signed the Milan Food Policy Pact, aim their policies at reconnecting to rural surrounding (Marull et al., 2021), shortening of the food supply chains, and making citizens more aware of the consequences of their dietary choices. In order to maintain the current levels of food self-sufficiency, the trend of reducing the agricultural land use area and transforming it into different types of land use must be reversed. However, the role of small-scale farmers and other stakeholders in strengthening rural–urban linkages is significant.

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Declaration of Competing Interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104584.

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