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Foodshed, agricultural diversification and self-sufficiency assessment: beyond the isotropic circle foodshed – A case-study from Avignon (France)

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Abstract

Regionalization of food systems for shortening supply chains and developing local agriculture to feed city-regions presents particular challenges for food planning and policy. Existing foodshed approaches enable to assess the theoretical capacity of food self-sufficiency of a specific region, but they struggle to consider the diversity of existing crops in a way that could be usable for informing decisions and support urban food strategies. Most studies are based on the definition of the area required to meet local consumption, obtaining a map represented as an isotropic circle around the city, without considering the site-specific pedoclimatic, geographical and socio-economic conditions, which are essential for the development of local food supply chains. In this study we propose a first stage to fill this gap by combining the Metropolitan Foodshed and Self-sufficiency Scenario (MFSS) model, which already considers regional yields and specific land use covers, with spatially explicit data on cropping pattern, soil and topography. We use European-wide available data and apply the methodology in the city-region of Avignon (France), initially considering a foodshed with a radius of 30 Km. Our results show that even though a theoretical high potential self-sufficiency could be achieved for the whole food commodities consumed (>80%), when considering the specific pedological conditions of the area, this could be suitable only for domestic plant-based products, whereas for animal products an expansion of the initial foodshed to a radius of 100Km was required to provide >70% of self-sufficiency. We conclude that it is necessary to shift the analysis from the size assessment to the commodity-group specific spatial configuration of the foodshed based on biophysical and socio-economic features, and discuss avenues for further researches enabling to develop a foodshed assessment as a complex of complementary pieces: the foodshed archipelago.

Keywords: foodshed, archipelago, city-region, food modelling, food self-sufficiency, self-reliance, food security, agricultural diversification, food planning, regional food system.

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1. Introduction

Since the 1990's, a lack of confidence for conventional market based agriculture has arisen [1] together with a fear of long-distance food supply disruptions, emphasized by crises such as the covid-19 pandemic [2,3]. Feeding the city from a sustainable and healthy agriculture became a local policy concern [4] and the proximity is an effective way to enhance the confidence. Nevertheless, regional self-sufficiency has not been a focus of policy decision making until recently [5,6]. In other words, the social awareness about sustainable regional food security requests to increase regional – or domestic – food self-sufficiency levels [7–12]. Beyond implementing farming related concepts like ecological intensification, the challenge is to enhance the efficiency of food chains building upon proximity in all the diversity of emerging concepts, and linking local agricultural supply to the urban final demand [8]. There is no consensus on a definition of "local" and "regional food systems" in terms of distance between production and consumption and but the concept remains an elision implicitly contrasted to "global" [2]. Furthermore, the region is a social construct shaped by networks and connectivity, in which the formal territorial jurisdictional functions and capacities intersects with contingent interests [13]. Inspired by the relational approach of Clancy and Ruhf [14], the concept of "regional food system" is set in this article as the system in which as much food as possible is produced, processed, distributed and purchase to meet population's demands within a particular meaningful geographical space. Some existing methods analyze the main characteristics and drivers of regional food systems in a specific context. On one hand, qualitative methods, as socio-empirical surveys, are able to finely draw the stakeholders' behaviours [15]. On the other hand, quantitative food assessments can give an overview of the status of the food supply and demand [16–22], whereas other methodologies are focused on the current spatial distribution of crops and land use change dynamics (e.g. in urban areas) [23,24].

Specifically, quantitative foodshed approaches can assess the capacity, the flows, or both approaches at the same time [25]. In the capacity assessments, where the majority of the studies belong to, the theoretical food land footprint and the potential self-sufficiency are evaluated by taking into account the population, current dietary patterns, available farmland, land use cover and regional yields (e.g. the Metropolitan Foodshed and Self-sufficiency Scenario (MFSS) [26]). Such approach is very valuable to raise awareness of urban residents of the spatial impact of their current food diet, by highlighting theoretical changes in the extension of the land footprint depending on different scenarios (e.g. change in the land footprint if shifting to a more plant-based diet, or from conventional to organic food diet) [27,28] or to assess the role of public procurement on food self-sufficiency [29]. As foodshed models use data on food consumption and production and they take into account the land cover, the result is the achievement of a theoretical self-sufficiency level for all food commodities or for some of them. While the ones addressing all food commodities do not consider the real land allocation to specific crops, but just the type of land cover and yield level [26], others are focused on specific crops, but are able to allocate them [30,31]. The second type of the foodshed approaches, the ones assessing the flows [19,20,32], are specially valuable to study the distribution networks, by placing consumers and producers. Finally, the hybrid approaches combine the capacity and the flows assessments (e.g. [18,33,34] and, thus, are aimed at comparing the potential food self-sufficiency with the current levels and, therefore, assess the dependencies on foreign food sources, vulnerabilities of the food system and agricultural environmental impacts of the food system re-localization [25]. The vast majority of the foodshed assessments are developed at regional level, although some global-scale models have recently appeared (e.g. [35]).

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However, in order to enforce a local food policy responding to the willingness to establish regional food proximity, empirical evidence on the food self-sufficiency capacity is required taking into account the local agronomic heterogeneity of soils as well as various farming systems and marketing modes. In that way, public action could be located where it is most likely to be effective. Therefore, a foodshed is not a standard concept that could be applied to different cases in the same way, but different biophysical and socio-economic conditions should be considered. For instance, soil fertility features are usually a key determinant defining the kind and intensity of the agricultural production at a specific location. Very often they are not evenly distributed around the urban area in a gradient as the theoretical concept by von Thünen where the type of agriculture is determined by the distance to the city-center would suggest [26]. In contrast, the spatial distribution of agricultural production responds to the biophysical constraints and the particular history of each place in terms of urbanization, development of the agricultural sector, organization of activities (including agricultural sectors) and environmental protection [36,37]. Furthermore, the land use is influenced by farm structures, plot sizes, and, thus, different land covers co-exist, especially in the surroundings of urban areas while other land uses (e.g. extensive livestock farming) only take place in specific areas under suitable biophysical conditions. However, so far foodshed assessments have been developed in an isotropic way by considering administrative boundaries and biophysical constraints in a second step (notably, for the availability of monitoring data in high density and identical quality - e.g. population data). Indeed, foodsheds are usually defined by a radius around the city (i.e. centroid) and, therefore, represented as circles [25–27,35]. Accordingly, in order to consider the landscape heterogeneity and, furthermore, to include societal demands, the foodshed concept represented by just one circle around the city must be reconsidered. Therefore, in order to address these limitations, in this study we have modified the traditional foodshed concept and applied it to a specific Mediterranean city-region, the area of Avignon (France), surrounded by high-fertility soils dedicated mainly to commercial agriculture (vegetable, fruit trees and vineyards) and with a high heterogeneous geomorphology as the distance to the city increases, where soils dedicated to extensive livestock farming appear.

The overall goal of this study is to develop a hybrid foodshed assessment aimed at evaluating the potential and the current self-sufficiency of a proposed foodshed. For this purpose, the specific objectives of the study are threefold: i) to propose and assess a foodshed of 30 Km of radius for the city-region of Avignon that could potentially provide a high degree of self-sufficiency, ii) to assess the role of agricultural and livestock diversification in increasing the current self-sufficiency within the initial 30 Km-radius foodshed, and iii) to propose and discuss the expansion of the initial foodshed considering the landscape heterogeneity and anisotropy in order to develop a more realistic scenario in terms of achieving a high degree of food self-sufficiency.

Such an assessment could be used as a decision-support methodology concerning land use and food planning, as the *Plans Alimentaires Territoriaux* (https://agriculture.gouv.fr/comment-construire-son-projet-alimentaire-territorial), being developed in the region; or the specific urban food strategies, promoting local agriculture and short food supply chains (e.g. the initiative promoted by the municipality of Avignon to serve local and organic beef in the menus of the canteens in public schools).

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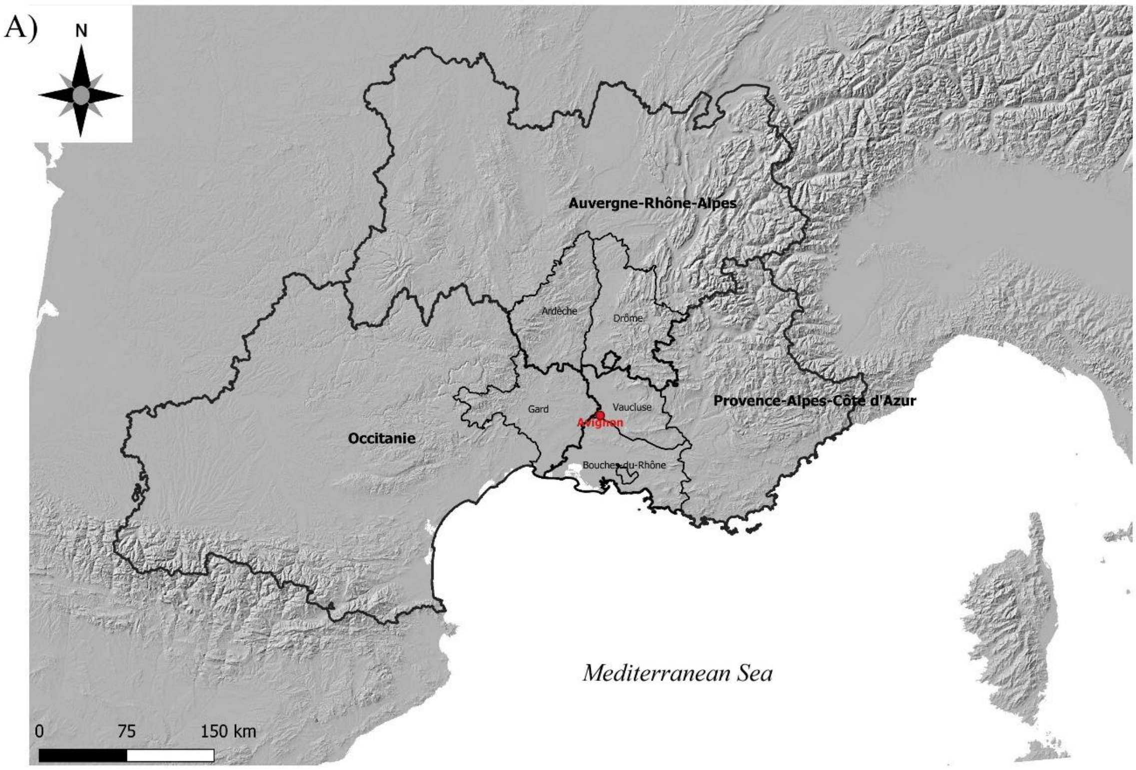
2. Materials and methods

2.1. Study area

We first selected a foodshed in a radius of 30km around Avignon. 30km is a non-normative distance set by French Senate to define the maximum spatial distance between the site of production and the point of sale for fresh fruit and vegetable short circuits. The selected initial foodshed, formed by a total of 171 communes (i.e. municipalities, comprises two different administrative regions and three different departments (similar to counties) in South-East France: Bouches-du-Rhône and Vaucluse in the region of Provence-Alpes-Côte d'Azur, and Gard in the region of Occitanie (figure 1A). Furthermore, the foodshed is close to the administrative region Auvergne-Rhône-Alpes, particularly to the two southern departments, Ardèche and Drôme. The municipality of Avignon is located within the Vaucluse department (figure 1B).



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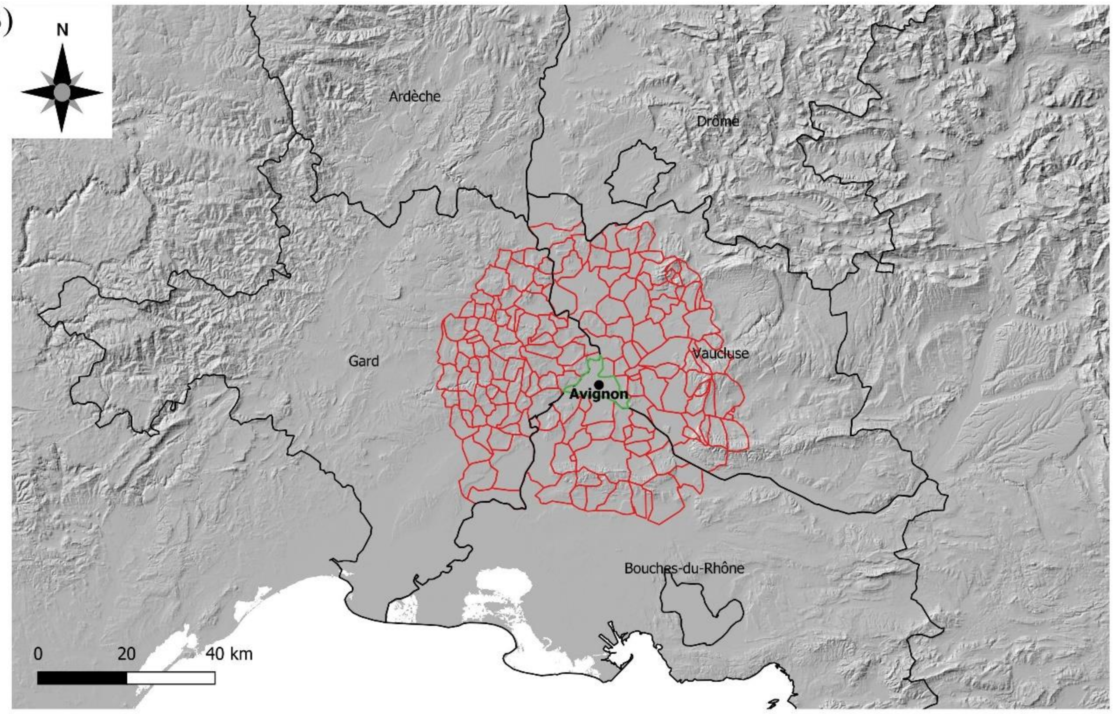

Figure 1. Location of Avignon (Vaucluse department) in South-East France, the surrounding departments and the regions (in bold) (A) and location of the municipalities/communes (in red color) forming the selected initial foodshed in a radius of 30km around the municipality of Avignon (in green color) (B). Note that the proposed foodshed belongs to other two departments (Gard and Bouches-du-Rhône), and it is nearby the departments of Ardèche and Drôme, to the North. Details on population and surface for each commune are given in the Supplementary Material (Tables S.1-3).

The area is relatively flat, typically between 0 – 400 m, crossed by the Rhône River from North to South. However, the altitudes become higher towards the West (Gard) and East (Vaucluse), and remaining low towards the South (Bouches-du-Rhône), where the river flows into the Mediterranean Sea. Soils in low altitudes are usually deeper, whereas with higher altitudes and slopes the depth significantly decreases. Thus, almost all the foodshed area in Bouches-du-Rhône is formed by deep or very deep soils, whereas this figure is about half of the area in Vaucluse, and around one fourth of the Gard area (figure 2).

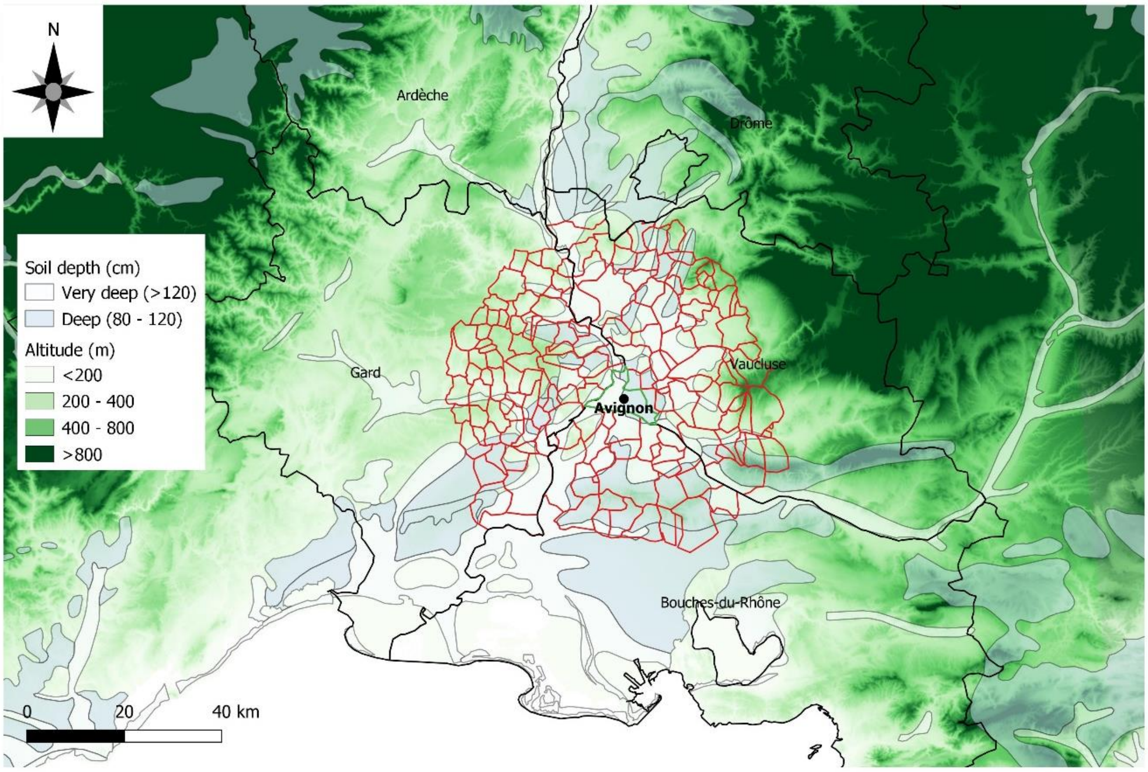

Figure 2. Location of the deep (80 – 120 cm) and very deep (>120 cm) soils in the foodshed area (in red color) and in the surrounding areas of the different departments. The rest of the area is covered by soils with shallow (0 – 40 cm) or moderate (40 – 80 cm) depth. The map shows also the altitudes in four categories (<200, 200 – 400, 400 – 800 and > 800 m over the sea level). Note that deep soils are usually located in low altitude areas.

2.2. Application of the MFSS model for the Avignon foodshed assessment: food land footprint and potential self-sufficiency of the foodshed

The Metropolitan Foodshed and Self-sufficiency Scenario (MFSS) model [26] incorporates the two dimensions driving the food self-sufficiency analysis: estimated demand and potential supply. The model also distinguishes between domestic and exotic products as well as between production systems: organic and conventional. However, for the first stage of the Avignon foodshed assessment, that is aimed to test whether the initial strategically defined foodshed is suitable for achieving a high degree of potential self-sufficiency, only one scenario, the business as usual (i.e. conventional and a mixture of regional- and imported-based diets) has been used.

Very briefly, the model takes into account the utilizable agricultural area (UAA), which represents the potential available area for agriculture. For the estimation of the UAA, the Corine Land Cover map has been used, and eight land uses were included: non-irrigated arable land, permanently irrigated land, rice fields, fruit trees and berry plantations, olive groves, pastures, annual crops associated with permanent crops and complex cultivation patterns. Vineyards were excluded from the UAA assessment, because we assume that their agronomic use will not change in the future due to the high profitability of wine´s industry in the study area. In addition, areas formed totally or partially by natural vegetation (e.g. forests or crops with significant patches of natural vegetation) were excluded from the assessment.

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The model estimates the area demand, that is, the area required to meet the food consumption, for each food commodity (i.e. food land footprint), by considering the yields. Data on food consumption have been taken from FAO statistics (http://www.fao.org/faostat/en/#data/FBS), whereas data on yields for domestic plant-based products are regional and were taken from national and regional reports [38–40] - see Table S.4 in the Supplementary Material). Data on yields for animal products (beef, eggs, poultry meat, pig meat, milk and dairy products, sheep and goat meat) and non-domestic food commodities have been taken from [26].

When applying the MFSS model, the aggregated area demand per department is spatially represented by a circle with a centroid of the administrative boundary polygon, in this case the municipality of Avignon. The process can be summarized as the combination of considering the UAA inside the municipal administrative boundaries and the UAA outside them. The potential food self-sufficiency of the foodshed is estimated then as the ratio between the food land footprint and the current UAA to meet the regional food demand. Thus, food self-sufficiency values higher than 100% mean that the complete area demand for food production can be met within the boundaries of the foodshed. On the contrary, values lower than 100% would require food imports.

2.3. Materials used for the current crop production and self-sufficiency level assessment of plant-based products

In order to evaluate the role of agricultural diversification in increasing food self-sufficiency it is necessary to assess the current crop production. This has been done by using the 2014 Land Parcel Identification System (LPIS) graphically represented in the French *Registre Parcellaire Graphique* (RPG) that geo-locates and informs about areas under different EU aid schemes of the Common Agricultural Policy (CAP). The area occupied by each commodity has been estimated by using GIS. Then, the current area dedicated for the different crops was compared with the food land footprint previously estimated for the foodshed by applying the MFSS model. Thus, the current level of self-sufficiency arises from the current dedicated area/area demand ratio, in percentage (figure 3).

The assessment has been done grouping the most commonly consumed plant-based products following the LPIS (RPG)-MFSS model categories, and excluding less relevant food products. Five food products were assessed: cereals, vegetables, pulses, fruits from temperate areas, and wine and grapes. Oilseeds and nuts were also assessed, but the results are shown only in the Supplementary Material (see section 3.2).

2.4. Materials used for the food land footprint and foodshed assessment of animal products

The current dedicated area for the production of animal products was estimated by assessing the information provided by the RPG map. Three categories were selected for the assessment: fodder, temporary grasslands and permanent grasslands. Summer pastures were excluded from the analysis, because they are available only during a short period of time in the study area. The area demand from the consumption of animal products was estimated by applying the organic scenario of the MFSS model. The selection of the organic product system instead of the conventional one is because the organic livestock farming is more often linked to extensive farming systems (i.e. use of grasslands or pastures as animal feed) in the nearby areas where the livestock farm is located. In the same way than that developed for the plant-based products, the current self-sufficiency for animal products within the 30-km radius foodshed was estimated (figure 3).

Since the study area is mainly dedicated for growing some commercial crops (mainly vegetables and fruits, see Table S.5 in the Supplementary Material), an expansion of the foodshed only for animal products was assessed considering only non-suitable soils for commercial crops (figure 3). To address this issue, one explanatory variable was selected, the soil depth, since pastures and fodder for extensive agriculture are usually placed in low-depth and weakly developed soils (AC-soil profile), whereas commercial crops are usually placed under high-depth and highly developed soils (ABC-soil profile). In the study area, soils closer to the river are classified as Luvisols or Cambisols, whereas Leptosols are the most common ones in mountainous areas, followed by Cambisols [41]. For this analysis, the European Soil Database was used. This database identifies soils according to different properties, where the category "soil depth to rock" is one of them. Thus, four categories of soils are distinguished: i) Shallow (< 40 cm), ii) Moderate (40 – 80 cm), iii) Deep (80 – 120 cm), and iv) Very Deep (> 120 cm). We considered that commercial crops are more likely to be grown under Deep and Very Deep soils (> 80 cm), whereas fodder and pastures are mostly located under Shallow and Moderate soils (< 80 cm).

After selecting the areas currently dedicated for feeding livestock and excluding those located in deep and very deep soils, two radius for the expanded foodshed were considered: 1) 60 Km, and 2) 100 Km (figure 3), and two other departments located in the Auvergne-Rhône-Alpes region towards the North but very close to the borders of the foodshed (Ardèche and Drôme) were included in the assessment. The first expanded radius, 60 Km, was selected in order to include only those mountainous areas that are very close to the initial foodshed of 30 Km, whereas the purpose of the second expanded radius, 100 Km, was to include the mountainous areas of the five departments surrounding the initial foodshed (figure 2).

2.5. Methodology used for the assessment

A summary of the methodology followed for developing the analysis is shown in figure 3. The area demand for the different products was extracted from the MFSS model [26]. Yields for plant-based products were taken from regional statistics [38–40]. The potential self-sufficiency analysis is based on the Corine Land Cover Map [42] and FAO data on food consumption (http://www.fao.org/faostat/en/#data/FBS), whereas the assessment of the current self-sufficiency for the plant-based products and the animal products for the current and expanded foodsheds (60 and 100 km radius) were based on the LPIS database that is graphically represented in the RPG map [43]. The assessment on soil depth was carried out by using the European Soil Database [44], whereas the elevation was taken from the Digital Elevation Model over Europe [45]. The land cover and crop area assessment, as well as the soil and expanded foodshed assessments have been developed by using QGIS 3.12.1 [46].

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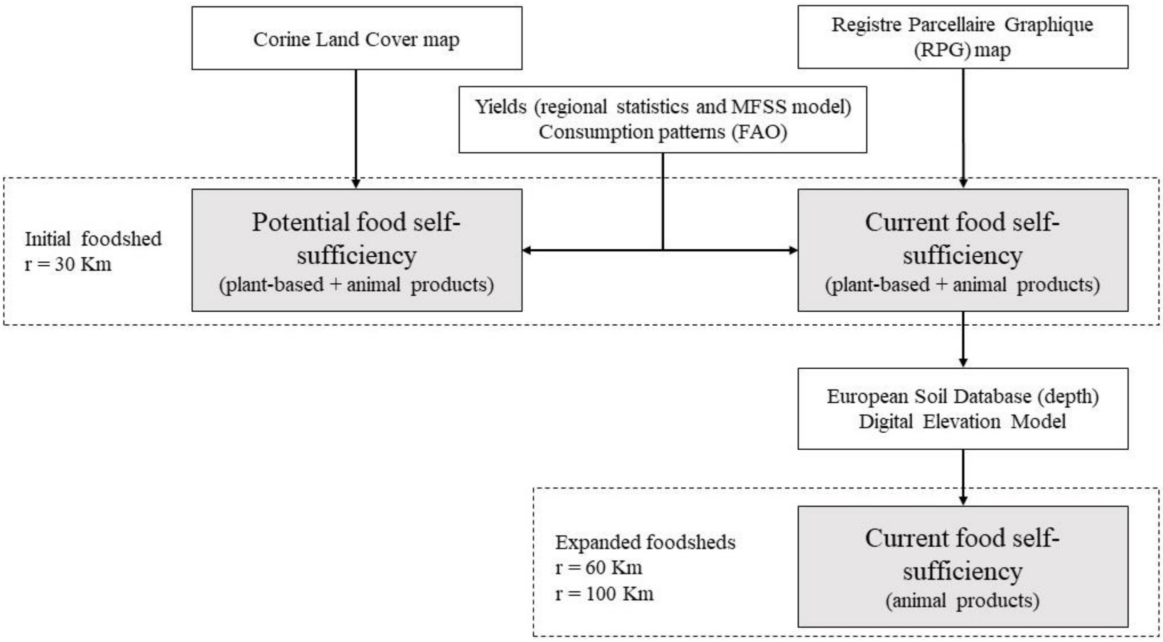

Figure 3. Scheme of the methodology followed in the study.

3. Results

3.1 Foodshed assessment and potential self-sufficiency for the proposed foodshed

Table 1 and figure 4 summarize the results of the area demand and potential food self-sufficiency. The communes within Bouches-du-Rhône department amounted the highest potential self-sufficiency, 189%, due to the high amount of UAA per capita (3,861 m^2) compared to the area demand per capita (2,047 m^2). However, for the communes – or municipalities – belonging to the other two departments, Gard and Vaucluse, self-sufficiency values were lower than 100% (65 and 62%, respectively), due to the relatively low UAA per capita. However, while in Gard the main restriction for achieving a high degree of self-sufficiency was the low total UAA (around 26,000 ha), in Vaucluse the UAA was relatively high (around 53,000 ha), but the population density was much higher (278 inhabitants per km^2) compared to the other two departments (around 150 inhabitants per km^2), mainly due to the fact that Avignon, the main city in the study area, is located in Vaucluse department. The estimated potential self-sufficiency for the whole study area is around 83%, and the estimated radius to meet the theoretical 100% of food self-sufficiency is 37 Km, which is slightly higher than the initial radius of 30km of the selected foodshed.

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Table 1. Total area (ha), utilizable agricultural area (UAA) (ha), population density (inhabitants per Km^2), total are demand (ha), UAA per capita (m^2 per capita), area demand per capita (m^2 per capita), radius (Km), and food self-sufficiency (%) values for the municipalities belonging to the three departments and for the whole foodshed (30km radius).

Department	Total area	UAA	Population density	Total area demand	UAA per capita	Area demand per capita	Radius	Self-sufficiency
Bouches du Rhone	77,556	44,792	150	23,752	3,861	-	9	189
Gard	123,599	26,010	158	40,103	1,328	-	17	65
Vaucluse	149,457	52,606	278	84,973	1,268	-	25	62
Foodshed	**350,613**	**123,408**	**207**	**148,827**	**1,698**	**2,047**	**37**	**83**

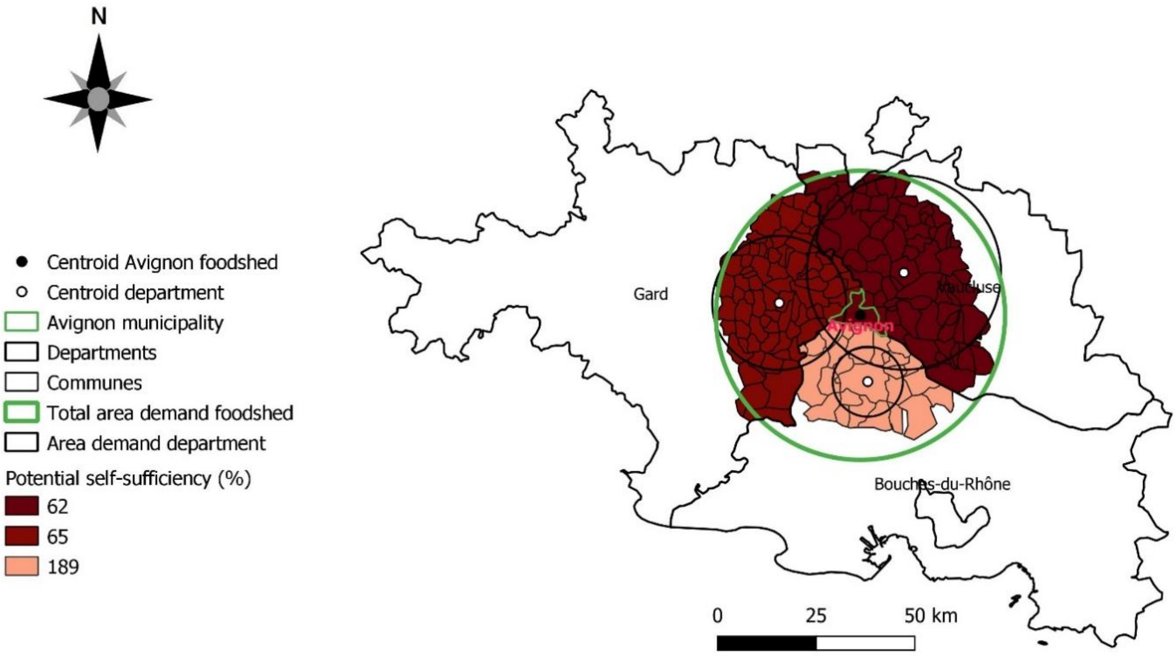

Figure 4. Mapping of the area demand (circles, in km) and food self-sufficiency (colors, expressed in %) for the initial proposed foodshed based on the 30Km-radius recommendation by French Senate

However, whereas de area demand is a relative accurate value, since it is based on the current consumption per capita, this is not the case for the UAA. The UAA represents the potential area that could be used for agriculture and livestock. Therefore, the estimated food self-sufficiency values do not show the current situation, but a theoretical one, which we compared to the current situation of the agricultural cropping pattern determined by the specific regional pedoclimatic and socio-economic characteristics (see following subchapters).

The estimation of the potential food self-sufficiency in the business as usual scenario does not consider any change in the food consumption patterns. This limitation must be pointed out regarding the fact that there are products currently consumed that cannot be produced regionally (e.g. bananas), and hence, importantly, the resulting food land footprint of the foodshed (2,047 m^2 capita^{-1}) does not take place 100% regionally. Nevertheless, these products, all plant-based or drinks based on plants, only represent 156 m^2 capita^{-1} of the total 563m^2 capita^{-1} of plant-based products land footprint, since the rest of the products could be theoretically produced in the region (Table S.5 in the Supplementary Material). Therefore, adapting diets has not been considered as a key driver in achieving a high level of food self-sufficiency in the region, and the focus was on the role of the regional spatial crop diversification and its drivers.

3.2. Current crop production and self-sufficiency of plant-based products

Since the consumption is not a key driver for increasing the food self-sufficiency level, the challenge is on the supply side. According to the RPG map, the total agricultural area currently used within the foodshed is estimated to be around 110,000 ha. This area, which includes vineyards, is lower than the UAA estimated previously (Table 1). This is due to the different way of estimating the cultivated area. While the UAA comes from the Corine Land Cover map, an estimation from remote sensing, the LPIS database – and the RPG map – is constructed from cadastral data related to the CAP payments and, therefore, some plots might not be included, leading thus to an underestimation of the real cultivated area. However, since the accuracy in terms of crop identification is greater in the LPIS database than in the Corine Land Cover map, the first one was selected for this part of the assessment.

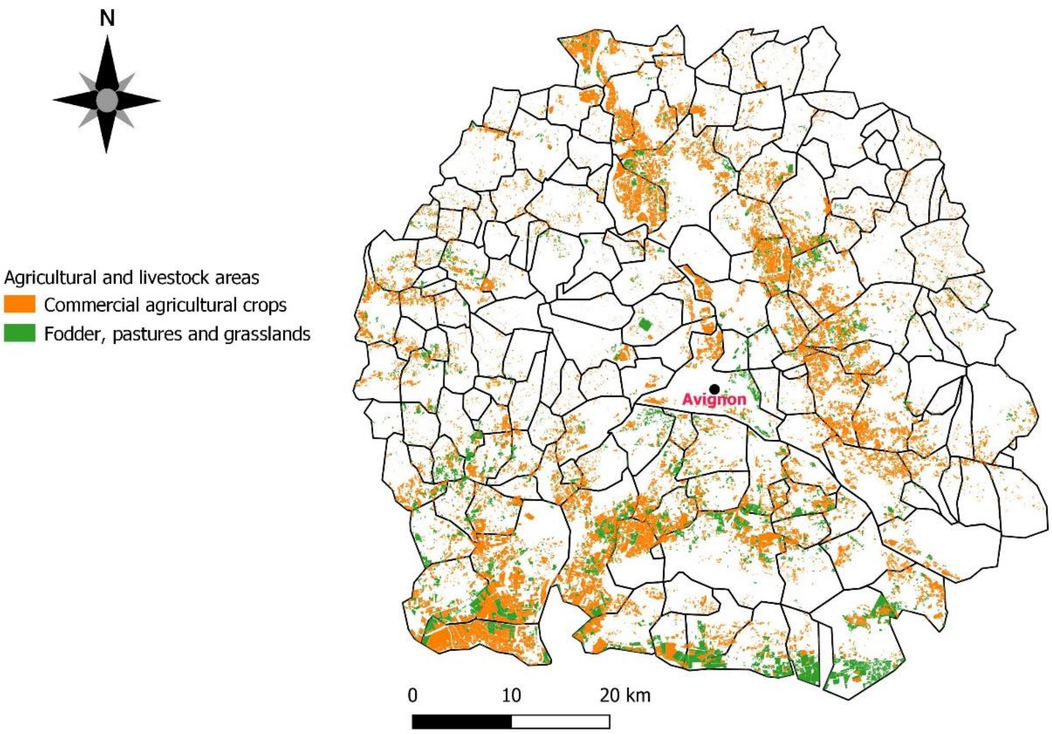

Figure 5. Distribution of commercial agricultural crops, excluding vineyards, and areas dedicated to feeding livestock (fodder, pastures and grasslands) in the foodshed. Based on the RPG map [43].

Considering the current consumption and production values in the foodshed area, we have estimated the current level of food self-sufficiency for cereals, vegetables, pulses, fruits from temperate regions, and wine and grapes. The results show that only cereals achieve a value lower than 100% (Figure 6 and Table S.5 in the Supplementary Material), whereas for the rest of the products 100 % food self-sufficiency is clearly achieved. Fruits accounted for the highest value (761%), followed by wine and grapes (498%), pulses (455%), and vegetables (220%). Even if the food sufficiency capacity for plant-based products is very high, they account only for 38% of the food products forming the average diet, whereas the other 62% belongs to the consumption of animal products. In the following section, we analyze the food self-sufficiency capacity for the animal products

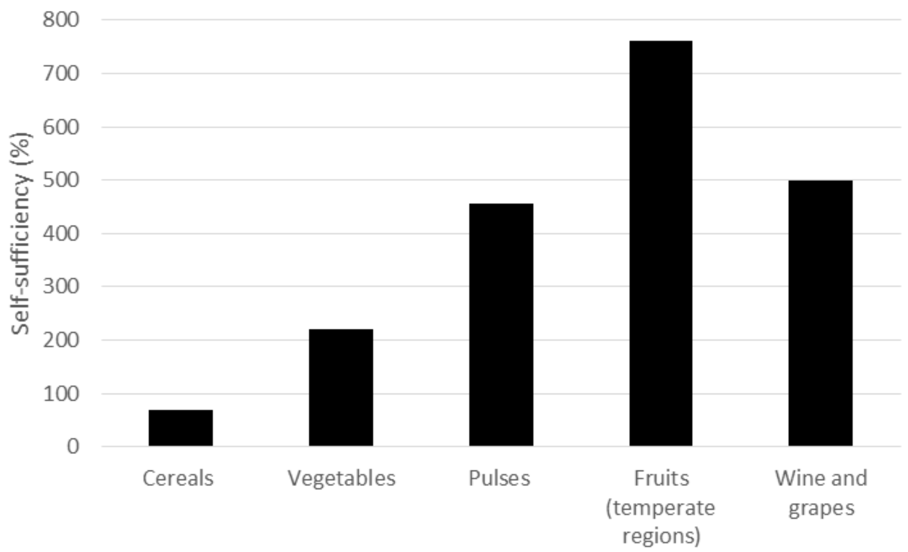

Figure 6. Current food self-sufficiency achieved by cereals, vegetables, pulses, fruits from temperate regions, and wine and grapes in the foodshed area. More information on the food groups and calculations is given in Table S.5 in the Supplementary Material.

3.3. Current livestock production and potential self-sufficiency of animal products

We estimated the total land footprint for organic animal products around 133,000 ha (Table 2).This value is 1.4 times higher than the estimated one for the conventional farming (92,700 ha), due to the higher area demand estimated by the model for organic livestock farming. This area represents around two thirds of the food land foot print of the whole diet. Of this area, around 39% is a consequence of the consumption of milk and dairy products, followed by beef consumption (26%), pig (18%), poultry meat (10%), eggs (5%), and sheep and goat (2%).

However, the current surface dedicated to pastures and fodder in the proposed foodshed of 30 km is of 14,120 ha, enabling thus an 11% of self-sufficiency of animal food products. There is also an unbalance between the different departmental areas within the foodshed. While the highest area demand takes place in the Vaucluse area, Bouches-du-Rhône accounts for the highest current dedicated area for livestock. In consequence, the highest self-sufficiency for animal products is achieved in Bouches-du-Rhône (32%), followed by Gard (12%) and Vaucluse (4%) (Table 2).

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Table 2. Area demand per capita of organic animal products (beef, eggs, poultry meat, pig, milk and dairy products, sheep and goat) (ha) of the population living within the foodshed of 30 km, estimation of the current area used for livestock farming within the foodshed (ha), and current food self-sufficiency (%) for the whole foodshed and the municipalities located in the three departments.

Product	Area demand of each product	Total area demand of each department	Current area used for pastures and fodder in the foodshed	Current self-sufficiency
Beef	34,787	-	-	-
Eggs	6,034	-	-	
Poultry	13,483	-	-	-
Pig	24,023	-	-	-
Milk and dairy	51,484	-	-	-
Sheep and goat	3,138	-	-	-
Total	**132,950**	**-**	**-**	**-**
Department				
Bouches-du-Rhone	-	21,218	6,826	32
Gard	-	35,824	4,300	12
Vaucluse	-	75,908	2,994	4
Total 30 Km-Foodshed	-	**132,950**	**14,120**	**11**

Since the available area for the production of animal products within the foodshed of 30km only covers around 11% of the total area demand, and extensive agriculture takes place under soils with medium to low fertility (e.g. high slope, low depth, high stoniness, low pH) an expansion of the proposed foodshed was considered in the following section.

3.4. Assessment of the expanded foodshed for animal products

Considering the pedological conditions and geomorphology, an expansion of the foodshed for animal products was simulated. For expanding the foodshed two buffers around the municipality of Avignon were considered: 60 km and 100 km. The immediate consequence is that the foodshed area must include other departments beyond the three ones so far considered. Geomorphologically, the foodshed is well connected to the two nearby departments to the North, Ardèche and Drôme, in the Auvergne-Rhône-Alpes region, accounting also for a high surface of dedicated area to extensive agriculture (figure 7) and at the same time avoiding competition with the nearby city of Marseille (South-East). In order to avoid land-use conflicts and avoid including areas with a high aptitude for commercial agriculture in the study, plots under deep or very deep soils (i.e. >80 cm depth) have been excluded from the assessment (Figure 8) and, therefore, only plots with a non-commercial agricultural suitability were included in the assessment.

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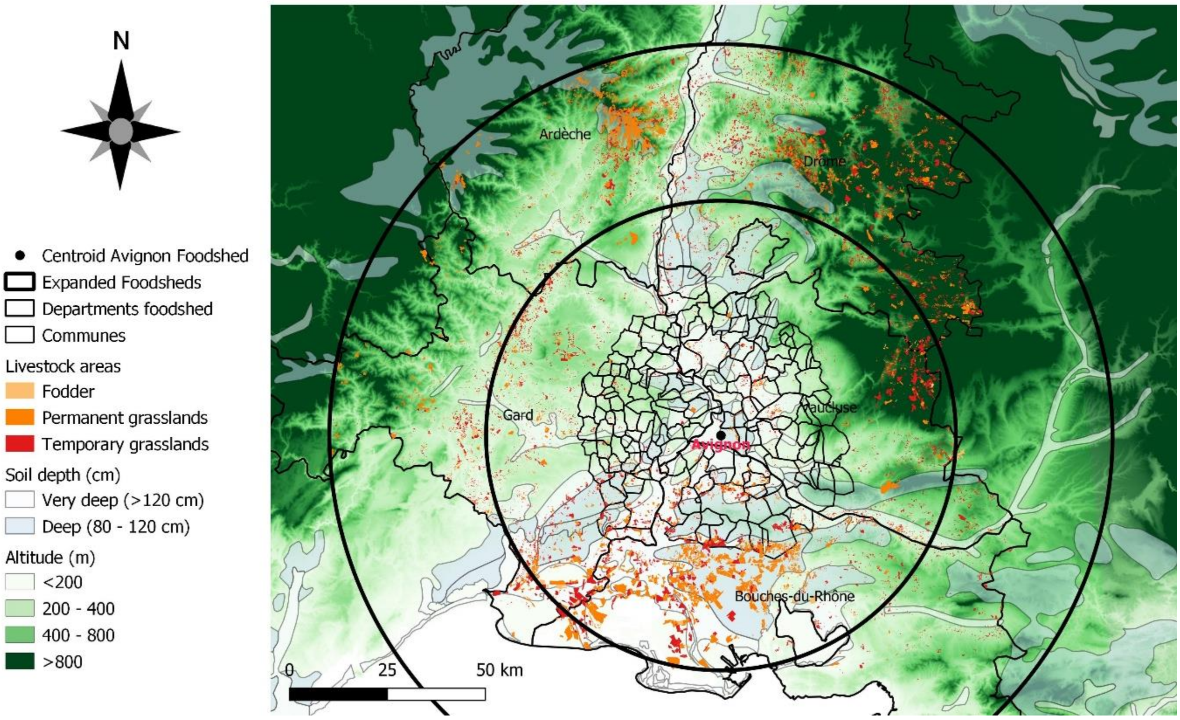

Figure 7. Current area used for extensive livestock farming in the five departments considered in the study in two radius around the city of Avignon: 60 km and 100 km. Information on soil depth and altitude is also shown.

Thus, the area available for extensive livestock farming resulting from the first buffer, a radius of 60 Km, is only of 38,000 ha and around 97,000 ha in the case of considering a radius of 100 Km, suggesting that it is especially after 60 km when plots used for extensive agriculture appear, whereas soils closer to the initial proposed foodshed are mostly used for commercial agriculture (figure 7). As a result of selecting the foodshed for animal products with a radius of 100 Km and excluding deep and well developed soils (figure 8), the food self-sufficiency for these products would be around 73%, without considering the population of these mountainous areas, accounting typically for a much lower population density than the areas closer to the river.

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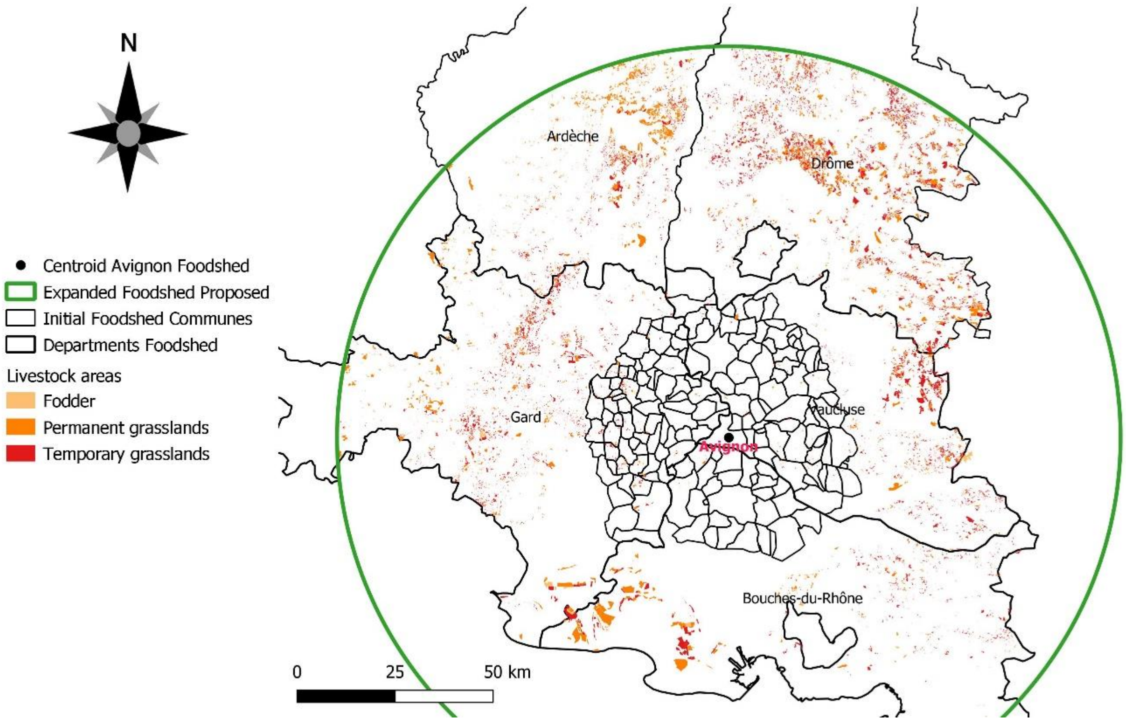

Figure 8. Current area used for livestock in the five departments considered in the study in the expanded foodshed proposed (radius of 100 Km). Areas under soils accounting for > 80 cm depth have been excluded from the assessment.

4. Discussion and conclusions

Our study shows that assessing the size of the foodshed both quantitatively – by applying the MFSS model and assessing the supply-demand balance –, and qualitatively – by combining these outcomes with the different biophysical maps – is an appropriate and realistic way of evaluating the theoretical potential and current food self-sufficiency degree at regional level (i.e. hybrid foodshed assessment [25]). The outcomes from the MFSS model can thus be, therefore, combined with different types of maps to obtain a more accurate overview of the regional food system, enabling food self-sufficiency issues and foodshed assessment to be addressed realistically. This more realistic approach has been recently addressed partially by some authors, for instance by including the economic dimension [47] or food traceability [48], but lacking on the accurate assessment on the amount and balance of the regional domestic supply-demand, which is indeed the final outcome of our assessment.

4.1. Taking into account crop diversification questions the spatial configuration of the foodshed

Higher food self-sufficiency is closely linked to the composition of crops (homogeneous vs diversified for instance) to provide sufficient diversity in marketed food products. However, crop diversification concerns not only agricultural cash crops providing food for human nutrition, but also the pasture and fodder areas required for livestock farming. In our study, we found that increasing pasture areas within the initial proposed foodshed of 30 Km radius was not realistic (table 1), due to the suitable soil conditions for commercial agricultural crops and, therefore, the lack of available area for extensive livestock farming (table 2). This leaves two alternatives: 1) expanding the initial foodshed to incorporate the closest pastoral areas (figures 7 and 8) and 2) considering the foodshed as a complex of complementary parts extending beyond the isotropic circle, and therefore shifting the discussion from the size to the spatial configuration of the foodshed.

Expanding the initial foodshed to a larger circle would make possible to include the closest area suited to the targeted production. In our case study, while the initial proposed foodshed of 30 Km radius is self-sufficient for many of the plant-based crops, the expanded foodshed of 100 Km including the surrounding mountainous areas (figure 8) would increase animal-product self-sufficiency values towards >70%. The new radius is an interesting illustration of the theoretical extent of spatial requirements for such Mediterranean cities' foodsheds.

From an empirical point of view, however, a foodshed assessment based on estimating distances in terms of radius around the city has difficulty accounting for precise consideration of the given land use and the diversity of existing crops. This information is needed to encouraging farmers to land use change and to inform decisions concerning food planning and urban food strategies, such as initiatives aimed at developing short supply chains for specific food products (in the Avignon case, beef for the school's canteens). The assessment is made by aggregating all different agricultural products used in the diet in one homogeneous foodshed area centered on the city. This yields a large foodshed containing too many diversified food production areas (mainly plant-based in our case). In addition, an extended foodshed radius in high urban density areas may generate overlaps due to cities' competing procurement needs [26,35], with inefficient results from a public action perspective. In summary, from an empirical perspective, it might not be suitable to limitlessly extend the size of the circle. Two main arguments should be kept in mind.

Firstly, there is a negative relationship between distance from the city and the likelihood of a production context favourable to the development of a local food supply chain [47]. For big cities, foodsheds may be so large that they incorporate highly varied production contexts, including some farms oriented toward local supply. The density of locally-oriented farms tends to decrease with distance from the city [49], whereas monocultures and intensive production farms devoted to the global market are mainly located in areas not under urban influence.

Secondly, there is a negative relationship between urban density at regional level and the likelihood of finding a production area targeting only one market location. In a polycentric setting (i.e. a dense network of cities) agricultural areas tend to combine all the demand from local markets within a food chain that supplies several cities. Thus, when big cities' foodsheds are as large as regional level, it is highly unlikely that a production area can be allocated to a single city.

4.2. Foodshed and self-sufficiency assessment: from the isotropic circle to the archipelago foodshed

An alternative way of supporting strategic discussions and decision making based on empirical evidence towards allocating agricultural areas and land use as to enhance regional self-sufficiency would be to create multiple foodsheds according to the main food production types. The foodshed pattern would not necessarily be centred on the city: geomorphological and pedoclimatic criteria do not necessarily select areas in physical contact with the city, and socio-economic and cultural habits may geographically determine market chains. For instance, the breeders supplying meat to Avignon are mainly located in the surrounding mountains (mainly in Southern Alps), where pastoral resources are spontaneously available (figure 7). This is a common Mediterranean city model, where cities are often located on a dry piedmont of mountains with more humid climates but historically integrated within the same economic and social territory [50].

There is, therefore, a major scientific challenge involved in shifting from a size (an isotropic circle) to a spatial configuration of the foodshed that would certainly imply a discontinuous assembly of interconnected parts – which we call the *archipelago foodshed*, some of them can already been perceived in our foodshed assessment after considering pedoclimatic and geomorphological constraints (figure 8). Our research perspectives are founded in a well-known concept from ecological sciences and planning approaches: the Biogeography of Islands theory [51,52]. This states that the specific richness of an island is correlated to its size and the distance from other island or continental sources of new species. Reasoning by analogy, when physical contact between urban and agricultural areas is not possible, the most appropriate production areas for connection with the city are those closest and large enough to provide sufficient agricultural produce to supply a food chain. In the landscape, urban, and regional planning field, the archipelago is a visual metaphor for an anisotropic space defined by the dimension of the islands (i.e. the different parts of the foodshed) and the distances between them [53–55]. Moreover, in regional economics the archipelago notion highlights the relational efficacy of production processes depending on the location of the production units [56]. Additionally, this socio-geographic concept could be enriched by linking it with other already existing ones, like the Functional Urban Areas (FUA) (https://ec.europa.eu/eurostat/web/cities/spatial-units) – defined as the city and its commuting zone – and by including or prioritizing those farms applying sustainable management practices, like agroecology [48,57,58] in the context of assessing and improving the environmental sustainability of the food system [7].

In this perspective, the theoretical food self-sufficiency assessments considering site-specific conditions of metropolitan city-regions, like the one presented in this study, become a suitable starting point for defining the size of the foodshed realistically, improve the knowledge on the current state of the food system or for informing policy-makers [4,26,30,31]. However, avenues for further research include rethinking the foodshed concept, as an archipelago of parts whose barycentre might be located in the production area that is socially, historically and/or agro-ecologically most closely connected with the city. The challenge is, therefore, to provide a robust and non-ambiguous indicator – or set of indicators – connecting the city with the farming areas within this archipelago foodshed. Further research could usefully select a set of production areas to meet the food self-sufficiency objective, by developing the “reserve-site-selection approach” [59,60]. This would involve selecting, first, the most efficient area in terms of foodshed supply, then the second best choice if necessary, continuing the procedure until the objective is fulfilled. In addition to mapping a more realistic foodshed pattern appropriate to guide public action and usable in decision-making, a multi-criterion indicator of agricultural areas’ connection with the city could inform policy, for instance, by showing how the foodshed pattern is impacted when the prices of environmentally-friendly produced food products are positively weighted.

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