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# Mapping the Lisbon Potential Foodshed in Ribatejo e Oeste: A Suitability and Yield Model for Assessing the Potential for Localized Food Production

**Andreia Saavedra Cardoso [1,*], Tiago Domingos [2], Manuela Raposo de Magalhães [1], José de Melo-Abreu [3] and Jorge Palma [2]**

[1] Landscape Architecture, Linking Landscape, Environment, Agriculture and Food (LEAF), Instituto Superior de Agronomia, Universidade de Lisboa, 1349-018 Lisbon, Portugal; mmrm@ist.utl.pt
[2] Environment and Energy, MARETEC, Department of Mechanical Engineering, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisbon, Portugal; tdomingos@tecnico.ulisboa.pt (T.D.); jorgempalma@tecnico.ulisboa.pt (J.P.)
[3] Agrometeorology, Linking Landscape, Environment, Agriculture and Food (LEAF), Instituto Superior de Agronomia, University of Lisbon, 1349-018 Lisbon, Portugal; jpabreu@isa.ulisboa.pt
* Correspondence: andreiasaavedra@gmail.com; Tel.: +351-213653314

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**Abstract:** Research on food planning has been recently proposed in North American and European planning to account for how cities might change their food provision to respond to the rising demands for a more sustainable and ethical food system. The purpose of this paper was to evaluate the agro-ecological potential of the Lisbon city region, Ribatejo e Oeste, to increase its Regional Food Self-Reliance (RFSR), through adopting demand restraint and food system relocalization approaches to food system sustainability. Three new diet scenarios were considered: meat-based, plant-based and strict vegetarian, defined in accordance with healthy dietary patterns. We used agro-climatic and agro-edaphic agricultural suitability models to evaluate the agro-ecological potential for RFSR, and proposed the use of Foodshed Landscape Plans within a landscape planning methodology. Results showed the extent of local food production that could improve food self-reliance, with 72%, 76%, 84% of total food needs in the meat-based, plant-based, and strict vegetarian scenarios, respectively. Thus, food system transformation by means of relocalization, is therefore ecologically feasible and would ensure the sustainable use of the ecological basis of food security. Additionally, a dietary transition would imply significant land sparing, which strengthens the demand restraint perspective for a transition to food system sustainability.

**Keywords:** territorial food systems; food planning; resilience; relocalization; foodsheds; landscape planning; GIS mapping

## 1. Introduction

Since the 1990s, there have been questions surrounding the legitimacy of the global industrial food regime developed after World War II, which has been defined as the set of stable relationships of power, production, and consumption in the world food economy [1]. The rise in demands from environmental, agri-food, animal welfare, fair trade, and other social movements for a more sustainable and ethical provision of food have established a common ground to question and bring about changes in the food regime [2].

As a response to these public concerns, North American and European planning opened a new research area for food planning. Local government authorities have developed specific strategies to account for how cities might change their food provision and have proposed policies to transform the food system [3–5]. Currently, these strategies focus on urban food provision as an opportunity to discuss the role of food systems in achieving urban sustainability objectives.

In fact, 20–30% of total anthropogenic environmental pressures that derive from private consumption are caused by the global food system [6]. Over half of the world's population (54%) live in urban areas [7] and wealth concentration determines higher per capita food demand and resource-intensive or affluent diets. The food system is therefore a major area of transition to urban sustainability. Several perspectives on how to achieve food system sustainability currently exist and reflect the stakeholders' different entry points from within the food industry, civil society, policy makers, or the research community. Two of these perspectives are particularly representative of civil society and local government authorities: demand restraint and food system transformation [8].

According to Garnett (2014) [8], the demand restraint perspective focuses on consumer dietary patterns. This perspective suggests that a dietary shift can be a more effective means of tackling the environmental impacts of the food system, as well as any food-related disease burden.

The food system transformation perspective calls for a structural change to food regime and a focus on the production and consumption relationships among the actors and their socio-economic context [8]. It strongly advocates food system relocalization as the basis to build new city region sustainable linkages for "food and nutrition security, environmental resilience and economic vitality" [9]. This perspective aims at food and nutrition security and the promotion of rural economic development [10,11]. With this purpose, specific public policies for the development of Territorial Food Systems (TFS) [12,13] have been pursued in Europe and in the global North. TFS were defined as a "consistent set of supply chains located in given geographic area of regional size" [14], under participative governance, contributing significantly to Regional Food Self-Reliance (RFSR), and promoting quality products, social and economic equity, small farming and agri-food businesses and sustainable management of natural resources [13].

Studies based on Life Cycle Analysis have criticized relocalization on the grounds that transport makes a relatively minor contribution to overall food chain impacts. For example, only about 10–15% of greenhouse gas (GHG) emissions from the food system are due to transportation [15], therefore, food miles are an insufficient indicator of food system sustainability [15,16].

However, when addressing food system sustainability and resilience, the role of relocalization has also been endorsed as a risk reduction strategy. Relocalization may build the capacity to endure and adjust to failures in the mainstream food system in the event of natural or man-made disruptions in food supply or price volatility [9,17,18].

The potential of TFS to build regional self-reliance has also been considered as a strategy to enhance resilience and promote sustainable land use and food and nutrition security [18–20]. The provision of agricultural ecosystem services is also considered as an advantage of TFS [17,21].

The relationship between the resilience of the food system and the geographic origin of food was established by the foodshed concept [22], which refers to the geographic areas that produce food for a specific population. According to Hedden (1929), the study of foodsheds should answer the problem of where food might come from when the food system is threatened. However, the scope of foodshed analysis is not restricted to the management of food supply failures, and can be used to envision food system change [23].

In fact, there are additional arguments to endorse food system relocalization, other than the reduction of risks and failures of long food supply chains. The environmental impacts related to food consumption in the European Union (EU) are a growing load on land and water resources in their places of production [24]. In particular, an increasing proportion of global meat and feed staple crops and by-products are traded as imports to the EU, where the environmental impacts of these products become disconnected to and invisible from their places of consumption [25,26]. The displacement of environmental pressures has also been related to losses to biodiversity and ecosystem services [26]. However, there are other dietary patterns costs that cannot be adequately described without considering food security and social and political conflicts relating to land and water in non-EU export countries. Therefore, relocalization is another way to take direct responsibility and internalize the negative outcomes of the current food regime, with regard to environmental, ethical, economic and political issues.

Wherefore, in recent years, foodshed analysis has emerged as an approach in food systems planning designed to measure the potential of a given region, city, or any other geographic scale to depend on its ecological productive capacity for food provision [27,28].

### 1.1. Background on Foodshed Analysis and Mapping

In their most developed version, foodshed analysis and mapping was used to assess the agro-ecological potential for food self-sufficiency or food self-reliance; one tool among others in food systems planning with special interest for policy analysis and planning [27,28].

Since the 1970s, agricultural studies on food security have tried to relate the global food production potential of the world with the associated natural resources requirements [29]. Thereafter, the effort was addressed by De Vries et al. (1995) [30] in a 2040 prospective study encompassing 15 world regions that considered the different diets and consumption needs for the projected population, and two alternative types of farming. These studies were based on the perspective that greater regional food self-reliance was fundamental to providing food security. As to what constitutes the land footprint of diets, Gerbens-Leenes et al. (2002) [31] further developed these approaches through a comparison of the diets of several EU countries with that of the USA.

Contemporary foodshed assessments have advanced mapping methodologies to identify the regional potential for food self-reliance. However, agricultural productivity is often estimated by statistical information on yields and available agricultural land, and not crop simulation models [23,32–34]. Furthermore, this is seldom conducted on a complete diet, comprised of all food groups, and detailed in quantities of agricultural commodities (food and feed, and fodder crops and livestock).

As to what regards the agro-ecological data used or produced under these studies for mapping potential foodsheds, generally, when used, land suitability models were underdeveloped as they did not consider agro-ecological suitability with comprehensive agro-climatic and edaphic data [35]. Furthermore, most of these studies only assessed the average land requirements of the observed per capita meat-based diet and seldom considered alternative diets, such as those based on dietary guidelines, vegetarian, or regionalized diets [35–38].

The environmental sustainability of meat-based and plant-based diets has been addressed by several fields of research [39–41], although foodshed case studies have rarely faced the challenge of quantifying the land use change and impacts on regional self-reliance of diets based on plant protein sources. However, the study by Peters et al. (2016) on the carrying capacity [42], or the number of persons fed per unit land area of US agricultural land proved the exception to all these methodology gaps. It concluded, as De Vries et al. did 20 years ago (1995) [30], that a dietary change to plant-based and vegetarian diets could contribute substantially to meet future food needs and towards a sustainability transition.

Nevertheless, it has been emphasized that a dietary reduction in livestock products does not imply more cropland availability. In fact, some livestock products depend on permanent pastures and forages usually cultivated on less suitable agricultural lands than temporary or permanent crops [43,44]. This means that different ecological land suitability conditions, e.g., the proportion of suitable grazing lands and cropland, also influence the carrying capacity or land footprint.

### 1.2. Context

Food planning has not been addressed at any level of the Portuguese planning system, and until now, there has been no national or regional debate about Food Self-Reliance (FSR).

In what regards the organization of spatial and land-use planning in Portugal, it is regulated and framed by the state, national government and municipal government, according to the law in force (Decree-Law no. 80/2015) [45]. The regional programs for spatial or territorial planning, on the regional level, perform the identification of agricultural, forestry and livestock areas relevant to the regional strategy for rural development. However, the spatial plans that serve primarily to regulate specific land use, and are legally binding on individuals, are on the local level—the Municipal (or inter-municipal) Director Plans. These are the main instruments to guide local spatial development and integrate and articulate the established by the national and regional programs for spatial policy. At this level, rural land is classified accordingly to the dominant land use, for example, as agricultural and forestry areas, natural areas, etc., and land use parameters established.

Thereby, the programs and plans included in the planning system identify the areas attributed to agricultural, forestry and livestock uses, and the areas of the National Agricultural Reserve (NAR), which are under the protection of this legal regime. This regime of protection of soils with high biomass production capacity was considered in the National Planning System in 1989, and includes by definition the areas which, due to land characteristics in terms of agro-climatic, geomorphological and pedological conditions, are more suitable for agricultural activity. It is a public utility restriction of national scope constituted to protect a reserve of agricultural land. In the areas of NAR, non-agricultural uses are considered acceptable only exceptionally, if compatible with the objectives of protection of the agricultural activity, by prior binding opinion or notification to the NAR regional entity (Decree-Law no. 73/2009) [46].

Even if national planning instruments, at all levels of government, emphasize the necessity of protecting and adequately planning the areas that are the basis of the productive component of the food system, landscape planning in Portugal continues to lean strongly toward urban planning. In fact, despite the integration of agricultural spaces and resources in the National Planning System, it did not prevent either the urban development of areas essential for maintaining the ecological balance of the landscape, or sealing soils of high ecological value. These are soils with high biomass production capacity or relevant from the standpoint of nature conservation and traditional agro-silvo-pastoral systems [47].

In general, Municipal Director Plans limit urban development in NAR areas or under agricultural land use classification. However, land use regulation is discretionary and does not establish legal duties to use rural land in particular ways. Therefore, these planning instruments are alone insufficient to determine the active use of agricultural or forestry areas. This could be achieved through "active" land-use planning and governance where municipalities and civic organizations acquire land [48], or support collective farmland acquisition and management initiatives, and issue the land to support the emergence of ecologically and socially responsible farm projects. Apart from spatial/land-use planning and public policies aimed at steering land use, other policies not targeted at land use, like agricultural, rural development, and tax policies, can ensure the effectiveness of the land-use system by aligning individual and institutional preferences with land use objectives [49].

### *1.3. Aims and Roadmap*

The purpose of this paper was therefore to evaluate the agro-ecological potential of the Lisbon city region, Ribatejo e Oeste, to increase its Regional Food Self-reliance (RFSR) by adopting the demand restraint and food system relocalization approaches to food system sustainability. We use agro-ecological potential in the sense of land suitability to agrarian uses, and in particular to the land uses connected to food production. In considering methodological issues, the agro-ecological potential results from the integration of two types of land suitability: agro-edaphic and agro-climatic. Even though this methodology promotes the allocation of agricultural uses according to the Ecological Land Suitability, and can be considered an "application of ecological concepts and principles to the design and management of sustainable food systems"[50], it has no other relations to agroecology.

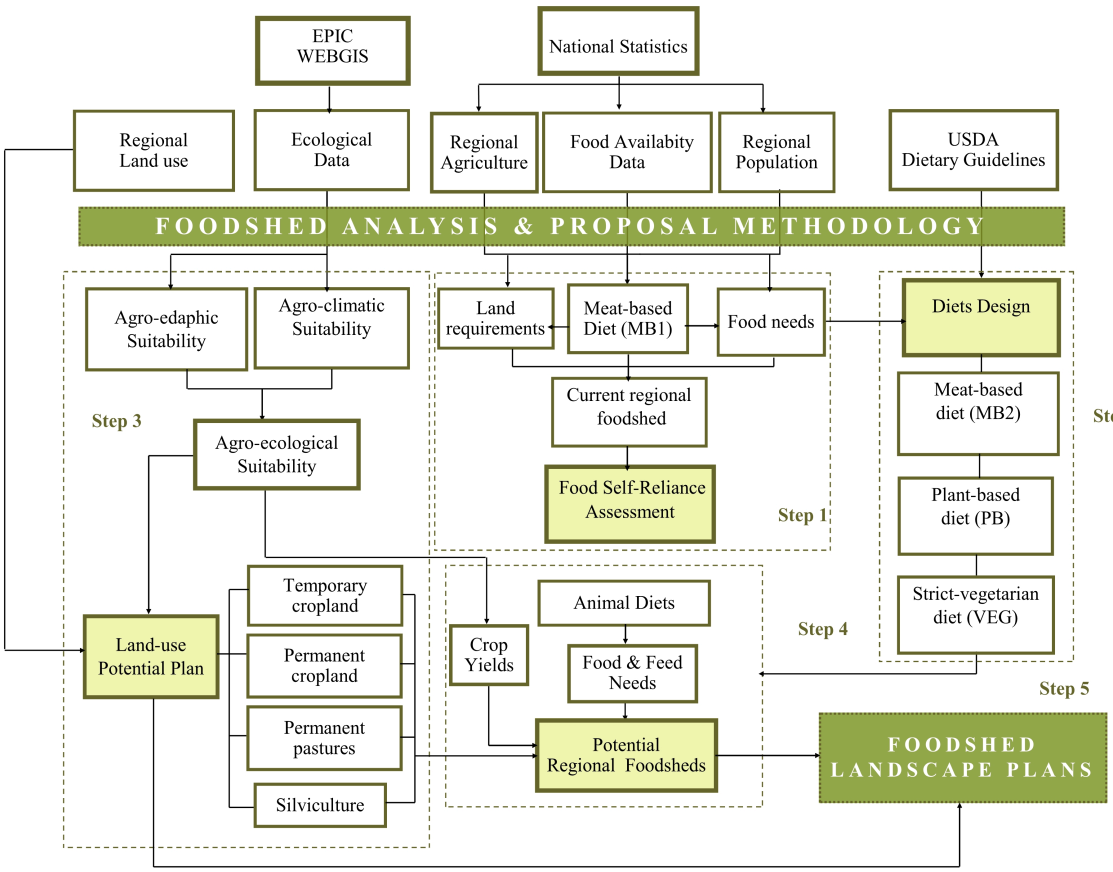
The methodology deployed addressed the problem of the land footprint of different diets through a landscape and food planning perspective. In this context, this study intends to present data that can be used to foster the debate about food system relocalization in the Lisbon region, and the strategic food reserve of natural resources that constitutes the basis of food security. This allowed us to address the current inability of spatial planning and management instruments to safeguard this strategic reserve, and to establish the necessary link to food security and other benefits that can arise from the development of Territorial Food Systems (TFS).

Furthermore, our study aimed to draw attention to the introduction of food system sustainability and resilience into the planning objectives of several European countries, the USA and Canada. Food plans and strategies frequently advance goals for RFSR, but as stated by Kneafsey (2010) [51], such proposals should take into account the regional agro-ecological capacity for food production, which varies based on natural resources such as soil fertility, climate, and available water resources.

## 2. Materials and Methods

### *2.1. Goals*

This study was undertaken with five main objectives and steps (Scheme 1). Step 1 was to conduct a food self-reliance assessment of the Ribatejo e Oeste current foodshed, by calculating the area required for plant and animal production for regional self-reliance. Here we considered the national data on food availability as a proxy of food needs per capita for a meat-based diet (MB1). Step 2 was to elaborate the diet design by considering a dietary shift to a rectified meat-based diet (MB2) and two possible alternative dietary scenarios, plant-based (PB) and strict vegetarian (VEG). For these diets, we estimated the quantity of locally grown food needed to meet the population's optimal food nutritional requirements. Step 3 was to obtain the agro-ecological suitability maps, for representative crops from the main food groups, with agro-edaphic and agro-climatic suitability models, and to propose a land-use potential plan with the definition of the areas allocated to the main agro-silvo-pastoral land uses. Step 4 was to evaluate the agro-ecological potential of Ribatejo e Oeste, to increase its Regional Food Self-Reliance (RFSR), with the proposal of potential regional foodsheds. To do so, we accounted for how much of these food requirements could be sustainably produced through local agriculture with an allocation model that used the agro-ecological suitability maps for representative crops from the main food groups. Finally, Step 5 was to assess and integrate the land-use potential plans (from Step 3) with the results from the potential regional foodsheds (from Step 4) in the foodshed landscape plans.




**Scheme 1.** General methodology for foodshed analysis and proposal.

### 2.2. Characterization of Ribatejo e Oeste Agriculture

The region selected as a case study was Ribatejo e Oeste, an important agricultural region in mainland Portugal (Figure 1). The region includes several agricultural areas: Lisbon, Setúbal Peninsula, Oeste (West), the Coast and hills of Ribatejo, Lezíria do Tejo (the Tagus river alluvial plain), and Charneca, the Ribatejo heathland.

The resident population in the region is about 3.5 million inhabitants [52]. Regarding rural typology, this region includes the following categories: urban rural (Lisbon and the Setúbal Peninsula), dense rural (West), rural transition to industry and services (Coast and hills of Ribatejo), and low density rural (Lezíria do Tejo and Charneca) [53].

Viticulture, fruticulture, and horticulture are present in Oeste, Lisbon, the Setúbal Peninsula, and Lezíria do Tejo. Intensive horticulture is mainly present in peri-urban areas and extensive horticulture and cereal production (rice and maize) in Lezíria do Tejo. In Charneca, the cork oak agro-silvo-pastoral systems stand out for their economic and ecological relevance [53].

However, despite the economic dimension of agriculture in the region and its importance in international trade, it appears that the dominant agricultural trajectory between 1999–2009 was a reduction in the use of primary factors of production (land and labor), or deactivation [54]. In fact, despite an increase in the productivity of the major crops [55] (except vineyards), there was a cultivated area contraction and a decrease in the agricultural population. From the point of view of the dynamics of agrarian systems, we are faced with a contradictory development as defined by Mazoyer and Roudart (1997) [56], where certain production units progress, while others regress and tend to disappear.

This region ranked second in the Portuguese agrarian regions with the highest decrease in family farming population between 1999–2009 [57,58]. The Ribatejo e Oeste was also the agrarian region of the mainland where there was (during the period of analysis) the largest increase in poor pastures or rough grazing associated with agricultural deactivation [59].

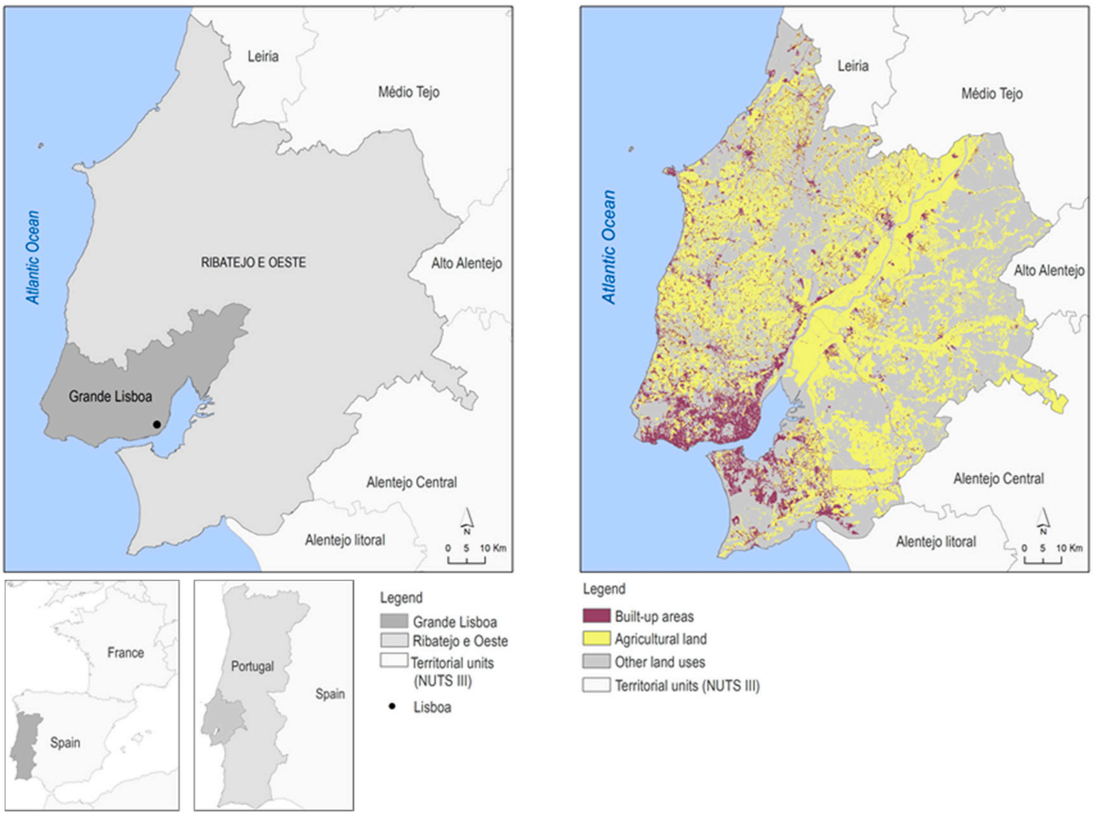



**Figure 1.** Location of the Ribatejo e Oeste Agrarian Region and Grande Lisboa (Greater Lisbon).

With regard to changes in agricultural land use, in the period 2000–2012, the decline of agricultural land was 57,050, around 12% of the total agricultural area (around 326,511 hectares) [60,61]. Prior research that addressed landscape change and the evolution of agriculture in Ribatejo e Oeste has shown that Land Use and Land Cover changes (LULCC) were fundamentally determined by global economic, technological, and institutional drivers (globalization, agricultural agreement and Common Agricultural Policy (CAP) that led to the structural adjustment of agriculture and agricultural abandonment. However, the region still contains relevant local socioeconomic and institutional drivers that allow urbanization (land policy, land use planning, and the role of the construction sector in the economy).

### *2.3. Food Self-Reliance Assessment*

To describe the current regional foodshed, we analyzed food consumption and regional production, i.e., a food self-reliance assessment. We used national data on food availability (the 2012 Portuguese Food Balance, BAP) [62] as a proxy for estimates of per capita food consumption. We considered these data to account for food consumption at a regional level, with reference to the total resident population, and compared the results with the regional production data [63] to estimate the RFSR. Our goal was to estimate the RFSR potential status by food agricultural products, i.e., the mass balance between the current production capacity and food consumption for the resident population (3,431,869 inhabitants).

Next, the area needs were estimated, and discriminated by type of crop and animal production to obtain RFSR. The area required for each plant product was estimated with the use of regional average crop yields [55], and animal products land footprint values were considered from life cycle analysis studies (LCA) [64].

### *2.4. Evaluation of the Agro-Ecological Potential for Regional Food Self-Reliance (RFSR)*

#### 2.4.1. Diet Design and Accounting

The meat-based diet (MB1) was corrected using the dietary guidelines of the United States Department of Agriculture [65], as these standards have the vegetarian food patterns adjustments necessary for the proposal of the alternative isocaloric dietary scenarios: plant-based and strict vegetarian (Tables 1–3).

Each main food group (meat and eggs, dairy, fresh fruit, vegetables, grains, tubers, vegetable oils, pulses and nuts and seeds) was analyzed considering specific representative food items: meat and eggs (25% bovine, 25% pork, 40% poultry, 10% eggs); dairy (100% milk); fresh fruit (15% apple, 30% pear, 5% citrus fruits, 50% other fresh fruits); vegetables (100% broccoli); grains (70% wheat, 10% maize, 20% rice); tubers (100% potato); vegetable oils (35% olive oil, 65% sunflower oil); pulses (100% beans); nuts and seeds (cork-oak acorns, 99.55%), and pine nut kernels (0.05%).

The choice for cork-oak acorns was due to the fact that the Ribatejo e Oeste has the lowest contribution to the national production of nuts (2%) [63] on the continent. This was justified by less favorable agro-climatic conditions for the production of the most commonly consumed nuts. Acorns, are edible fruits with a history of ancient use in the Mediterranean, in both human and animal nutrition and traditional medicine [66]. Recent scientific studies have validated their use in human nutrition as edible wild foods [67].

As animal feed, grain cereals and silage, pulses meal, and oilseeds meal were considered for intensive systems of meat production: pork, poultry, and dairy cattle (Table 4). The animal diets were taken from Portuguese LCA studies and, when necessary, experts were consulted [68–70]. Conversions from feed items to crop amounts were determined and complete animal diets were accounted for the requirements of edible meat and eggs sub-categories for each chosen diet (Figure 2).

**Table 1.** The general description of the diets.

| Name | Description | Code | Key Characteristics |
|---|---|---|---|
| Meat-based (1) | Based on national estimates of per capita food availability | MB1 | No adjustment to food availability data is made. |
| Meat-based (2) | Based on USDA dietary guidelines | MB2 | The percentage of protein from plant sources ranges from 30 to 41%. Includes animal flesh and dairy. |
| Plant-based | Based on USDA dietary guidelines | PB | Decreased amounts of meats and increased amounts of pulses and nuts, so that 50% of all protein is plant-based. Includes animal flesh and dairy. |
| Strict-vegetarian | Based on USDA dietary guidelines | VEG | Eliminates all animal products and increased amounts of cooked dry beans and peas, and nuts and seeds. Amounts of vegetable oils were reduced to maintain an isocaloric energy level. |

Source: Adapted from United States Department of Agriculture Dietary Guidelines [65] and from National Statistics of Food Availability [62].

**Table 2.** Macronutrient profile of the diet scenarios.

| Scenario Name | Scenario Symbol | Total Energy (kcal Day$^{-1}$) | Protein (g Day$^{-1}$) | Fat (g Day$^{-1}$) | Carbohydrate (g Day$^{-1}$) |
|---|---|---|---|---|---|
| Meat-based (1) | MB1 | 2757 | 96 | 105 | 350 |
| Meat-based (2) | MB2 | 2000 | 91 | 71 | 260 |
| Plant-based | PB | 2000 | 81 | 69 | 279 |
| Strict-vegetarian | VEG | 2000 | 67 | 75 | 286 |

Source: Adapted from United States Department of Agriculture Dietary Guidelines [65] and from National Statistics of Food Availability Data [62].

Beef and calf (bovine meat) production was considered on a grazing system on permanent pastures and in open woodland pastures (montado), and complemented with cereal silage [71]. The highly productive pasture system chosen was the Sown Biodiverse Permanent Pastures, Rich in Legumes (SBPPRL), which allows a high stocking rate capacity of 0.92 calves by hectare [72].

**Table 3.** Daily food intake by diet scenario: (1) Quantity (g/day), (2) Quantity for total regional population for a year ($10^4$ t/pop/year).

| Meat-Based (MB1) | | | Meat-Based (MB2) | | |
|---|---|---|---|---|---|
| **Food Group** | **Quant. g/day** | **$10^4$ t/pop/year** | **Food Group** | **Quant. g/day** | **$10^4$ t/pop/year** |
| Vegetables | 265 | 33.16 | Vegetables | 235 | 29.44 |
| Pulses | 10 | 1.23 | Pulses | 35 | 4.38 |
| Tubers | 206 | 25.78 | Tubers | 105 | 13.15 |
| Cereal grains | 347 | 43.48 | Cereal grains | 170 | 21.29 |
| Fresh Fruit | 202 | 25.35 | Fresh Fruit | 300 | 37.58 |
| Meat and eggs | 212 | 26.52 | Meat and eggs | 125 | 15.66 |
| Dairy | 346 | 43.34 | Dairy | 375 | 46.97 |
| Vegetable oils | 58 | 7.32 | Vegetable oils | 27 | 3.38 |
| Nuts/Seeds | 8.2 | 1.03 | Nuts/Seeds | 7 | 0.92 |
| | Total | 207.20 | | Total | 172.78 |
| **Plant-Based (PB)** | | | **Strict-Vegetarian (VEG)** | | |
| **Food Group** | **Quant. g/day** | **$10^4$ t/pop/year** | **Food Group** | **Quant. g/day** | **$10^4$ t/pop/year** |
| Vegetables | 235 | 29.44 | Vegetables | 235 | 29.44 |
| Pulses | 65 | 8.14 | Pulses | 190 | 23.80 |
| Tubers | 105 | 13.15 | Tubers | 105 | 13.15 |
| Cereal grains | 170 | 21.29 | Cereal grains | 170 | 21.29 |
| Fresh Fruit | 300 | 37.58 | Fresh Fruit | 300 | 37.58 |
| Meat and eggs | 40 | 5.01 | Vegetable oils | 18 | 2.25 |
| Dairy | 375 | 46.97 | Nuts/Seeds | 31 | 3.91 |
| Vegetable oils | 27 | 3.38 | | Total | 131.42 |
| Nuts/Seeds | 16 | 2.04 | | | |
| | Total | 167.01 | | | |

Source: Adapted from United States Department of Agriculture Dietary Guidelines [65] and from the National Statistics of Food Availability Data [62].

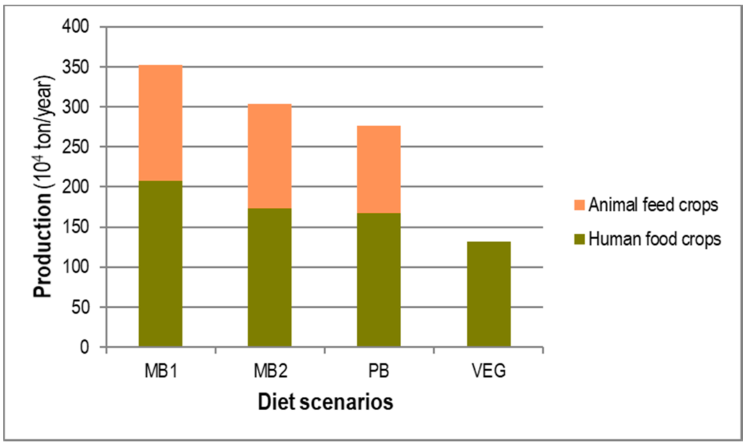



**Figure 2.** Plant production for human and animal consumption for the diet scenarios.

Regarding fish-meat, Portugal is the European country where per capita fish consumption has been, for several years, far above the European average [73]. However, in 2012 it only represented about 23% of the daily intake per capita of total animal meat, and 9% of the daily intake per capita of animal products [62]. Consequently, fish meat was neither considered on the meat-based diet, nor on the plant-based diet. For plant-based and strict-vegetarian diets, the category soy products was not included despite soy being considered as an animal feed and one of the representative crops for the group pulses. Therefore, for a complete diet design regarding proteins, these categories should be considered for all diets. The balance was made so that the protein deficit was the same in all three diets proposed at about 7 g per day.

**Table 4.** Annual staple feed requirements, by food crop, by diet ($10^4$ t/animals$^{-1}$year$^{-1}$).

| Animal Staple Feed ($10^4$ t/Animals/Year) | MB1 | MB2 | PB | VEG |
|---|---|---|---|---|
| Wheat (grain and silage) | 31.51 | 29.47 | 25.65 | 0.00 |
| Maize (grain and silage) | 81.56 | 78.71 | 70.83 | 0.00 |
| Barley (grain) | 10.20 | 8.20 | 5.87 | 0.00 |
| Sunflower Soy (meal and oil) | 1.59 | 0.94 | 0.30 | 0.00 |
| Soy (meal and oil) | 20.00 | 13.28 | 6.45 | 0.00 |
| Totals | 144.86 | 130.59 | 109.10 | 0.00 |

### 2.4.2. Agro-Ecological Land Suitability Model

To evaluate the agro-ecological potential of Ribatejo e Oeste to increase its Regional Food Self-Reliance (RFSR), we developed an agro-edaphic suitability model and an agro-climatic suitability and yield model for representative crops (Sections 2.4.3 and 2.4.4).

### 2.4.3. Agro-Edaphic Suitability Model: Land-Use Potential Plan

Our agro-edaphic suitability model and the Land-Use Potential Plan were built on the landscape-system methodology, an existing ecologically based planning methodology [74]. We also used the Food and Agriculture Organization agro-ecological suitability method [75] as a reference, which defined the principles for the assessment of land suitability and influenced most of the subsequent agro-ecological based methodologies.

The agro-edaphic suitability was developed with a Multiple Criteria Decision Analysis approach (MCDA), in a Geographic Information System (GIS). This method evaluated several ecological criteria simultaneously: soil ecological value [47], land morphology [76], and slope; and assigned weight factors to each criterion, and to each class in each criterion (Table 5).

The basis for the Land-Use Potential Plan was agro-edaphic suitability. This plan identified the areas ecologically suitable for agriculture, protection and production forestry and for agro-silvo-pastoral systems, which included the open woodland permanent pastures (montado).

To complement the Land Use Potential Plan, multiple and built-up uses were also considered in the proposal, with the addition of two ecological factors to the analysis: potential water permeability [77], and slope orientation (Aspect) (Figure 3). Concerning multiple uses, these were proposed for areas where the ecological value did not imply a preferable use and where land use planning could be more flexible.

**Table 5.** Factors, classes and weights assigned to the multi-criteria analysis of agro-edaphic suitability.

| **Factors** | | | | | | | **Weight (%)** |
|---|---|---|---|---|---|---|---|
| Soil ecological value | Very low | Low | Variable | High | Very high | | 65 |
| Class weight (1–5) | 1 | 2 | 3 | 4 | 5 | | |
| Land morphology | Hillcrests | | Wet System | Hillslopes | Wet areas | Coastal areas | Water bodies | 15 |
| Class weight (1-5) | 4 | | 5 | 3 | 0 | 0 | 0 | |
| Slope (%) | 0–5 | 5–8 | 8–16 | 16–25 | 25–45 | >45 | | 20 |
| Class weight (1–5) | 5 | 4 | 3 | 2 | 1 | 1 | | |

As nature conservation areas, we selected coastal conservation areas based on important coastal features from the coastline [78], and the natural constraints to the agro-edaphic suitability. Classified conservation areas were included as a land-use class, as land use in this category must be within the framework of several legal injunctions and protection values. As classified conservation areas, we considered: Natura 2000 Network, Important Bird Areas, European Network of Biogenetic Reserves, World Network of Biosphere Reserves, and Ramsar Sites. Natural and Semi-natural Vegetation with conservation value were also integrated to preserve vegetation biodiversity (species) and maintain the integrity of plant communities (phytocenoses) and vegetation mosaics [79]. At a regional and local level, classified conservation areas, such as natural reserves and protected landscapes, admit agrarian uses, even if the management priority is ecological sustainability. For this reason, they were analyzed and considered for the proposal of agricultural uses in the Potential Land-Use Plan.

Finally, we considered the current land use and occupation, always maintained when adequate from an ecological point of view.

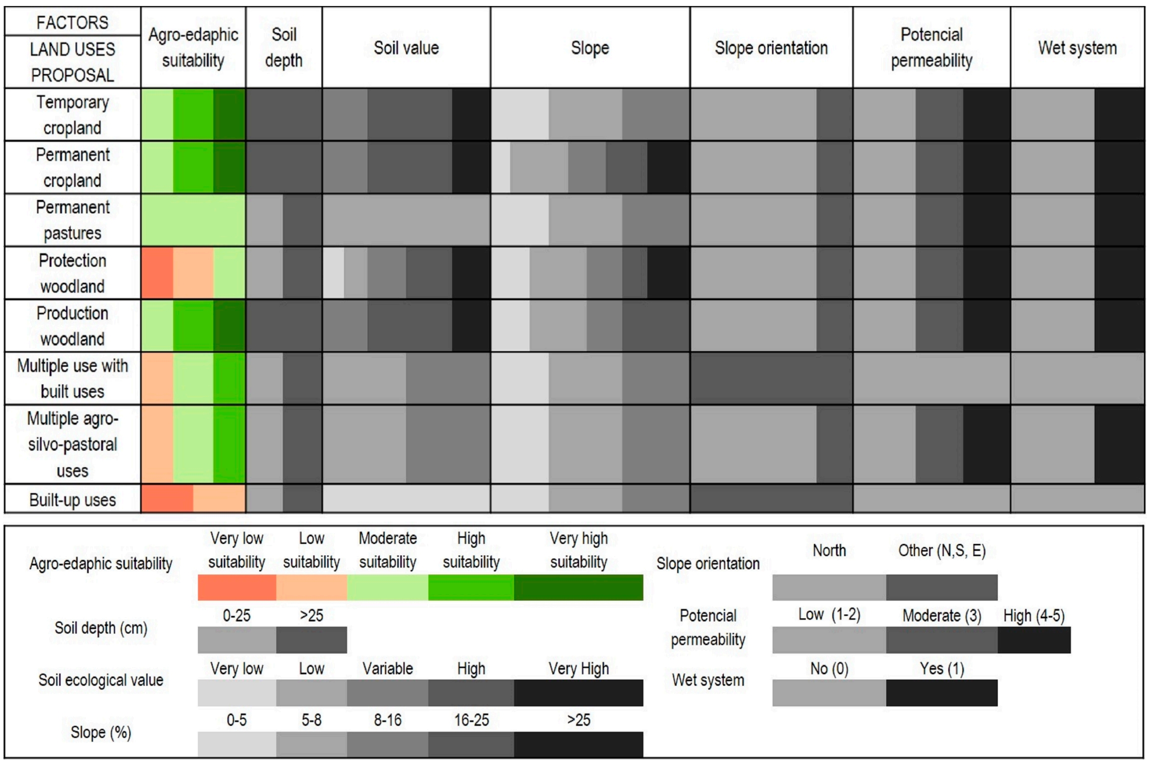



**Figure 3.** General outline of landscape planning based on agro-edaphic suitability.

#### 2.4.4. Agro-Climatic Suitability and Yield Model

For several years, the main system for land resource assessment with potential yield calculation was FAO's agro-ecological zoning (AEZ) methodology and supporting software packages for application at global, national and regional levels.

This methodology evolved to become the Global Agro-ecological Zones (GAEZ), a Multiple Criteria Decision Analysis (MCDA) model in a geographic information system (GIS), that combined methods of agro-ecological assessment of land suitability with socio-economic criteria. GAEZ generates detailed information that can be used for planning and decision support to promote food security and agricultural development, globally, as well as at national and regional levels [80]. GAEZ calculations are based on 10 or 30 arc-min latitude/longitude spatial climate datasets with no possibility of direct access to the code to perform modifications, thus no possibility of changing crop management. Furthermore, GAEZ assessments are at 5 arc-min resolution and in this study, we required greater resolution since the area of our study was a small and diverse regional area. Our spatial datasets of weather, terrain and soil had a greater resolution than those available for GAEZ and we aimed at 30 arc-s potential and actual yield assessments. Therefore, we were compelled to use a system that fully served our objectives, which has been validated for Portuguese conditions and that could evolve according to our needs.

We further developed the agro-climatic suitability and yield model, CSS_Zoner (see Supplementary Materials), a productive assessment and crop zoning model [81]. The model simulated the growth and production of any annual crop, biennial or perennial, with the main climate variables, texture and soil depth and the necessary plant requirements. The soil variables and monthly climate variables were used to generate the variables the model required, using submodels for estimation or interpolation.

The spatial climate database consisted of a 30 arc-s cell grid generated by using climate normals information from all stations of the national network (IPMA), for the period 1961–1990.

The spatial soil database consisted of a 30 arc-s cell grid of the following variables: soil texture (relative to the first 30 cm) and the effective soil depth [82]. With these variables, the model estimated the following soil physical characteristics: field capacity, wilting point, soil moisture, and soil bulk density.

Nutritional limitations, reductions of production by biotic or abiotic factors, and reductions due to management deficiencies were not considered. In addition to productivity, the model calculated other secondary variables that could be used to explain achieved production, or to document aspects related to crop performance. Among these were total dry matter production, maximum leaf area index, plant height, crop root depth, growth period, and the components of the water balance in the soil. The growth sub-models incorporated in the modeling system assumed that the type of agriculture as conventional, using current best practices.

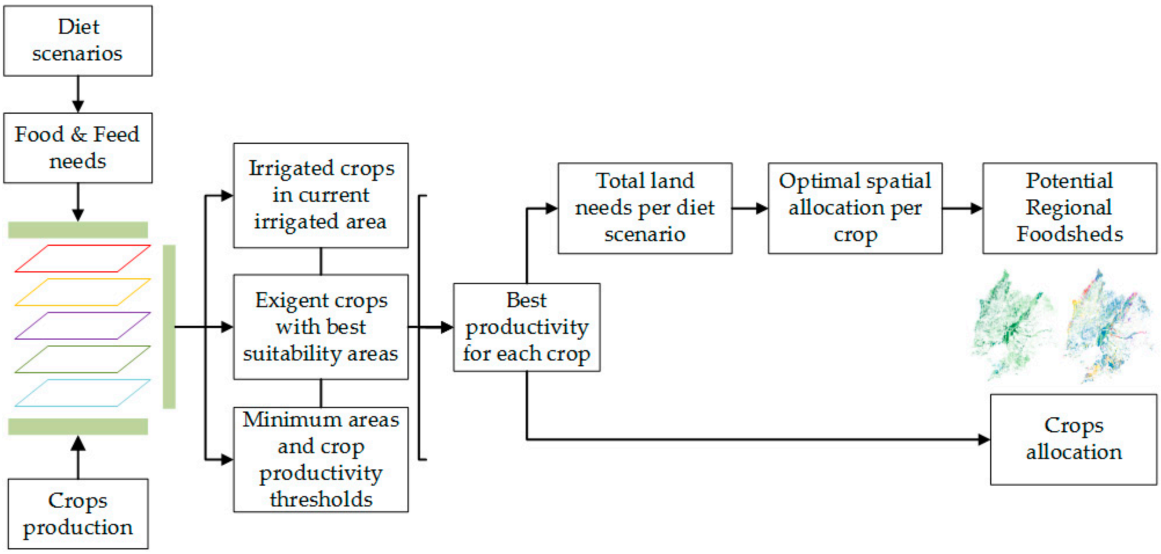
The generated results were integrated into a geographic information system (GIS) resulting in the mapping of production ("Cell Yield"), in tons per hectare for each crop. The areas classified with major biophysical constraints that affected land suitability to the analyzed crops were excluded from the mapping. Among the constraints, rock outcroppings, coastal cliffs, dune sands and dunes, beach sands, and water bodies, both inland and coastal [78] were considered. In our climate, there are unique characteristics associated with rice cultivation, namely the need for flooding the crop for much of its life cycle. Therefore, the distribution area of this crop was restricted to the areas classified as wet system in the National Ecological Network [76]. If the existing cultivars were incompatible with the soil depth and climatic conditions of the site, the program considered zero output.

### *2.5. Potential Regional Foodshed Model*

Using agro-edaphic suitability and other ecological factors, we developed a land-use plan where were identified the major agro-silvo-pastoral uses, multiple uses, and built-up uses. We considered the current land occupation, always maintained when adequate from an ecological point of view. In all these cases, the mean regional statistical productivities were taken to account for the contribution of these crops, and the available grazing, land for the agro-ecological potential for food self-reliance [55].

Regarding most food and feed crops, we used the results from the integration of the two types of suitability: agro-edaphic and agro-climatic. For this purpose, we assigned a Land Productivity Index [83] to the various classes of the agro-edaphic suitability. The representative crops for the nine food and feed groups were the following: maize (irrigated cereal grains and silage); barley and wheat (rainfed cereal grains and silage); potato (tubers); broccoli (vegetables); beans and soy (pulses grains and meal); olive and sunflower (vegetable oils and seeds meal); cork-oak acorns and pine nut kernels (nuts and seeds).

For land requirements and agro-ecological potential for food self-reliance, we developed a model in a geographic information system (GIS) (Scheme 2). This potential foodshed model optimized crop allocation to maximize food self-reliance. For this purpose, the model considered for each representative crop the best cell with the highest productivity, and therefore the best agro-ecological suitability. This method of allocation stopped when each crop reached its total amount requirements for the three different diet scenarios.




**Scheme 2.** Potential foodshed allocation model.

The model also considered an established order of the crops to be allocated (based on the crops' maximum productivity), which was tested among others, and gave the best productivity and self-reliance results. Furthermore, concerning economic viability, only cells with productivity above an economic threshold value for each specific crop were considered [84]. The outputs consisted of two maps: one with the best productivity values, and the other with the allocated crops. In addition, the model calculated the productivity statistics, total area allocated for crop, and the total production necessary to calculate the self-reliance.

Several constraints were imposed: (1) The irrigated crops should be allocated to the current irrigated area, and only if this area was not sufficient allocate irrigated crops to the current rainfed area; (2) concerning the crop allocation, fertility demanding crops were given the most agro-edaphic suitable areas; and (3) the minimum area allocated was 3.5 ha for crops and 0.5 for vegetables [85].

## 3. Results

### *3.1. Food Self-Reliance Assessment*

In 2014, the agricultural production of Ribatejo e Oeste met 109% of the annual required cereal grains, 2390% of vegetable needs, 193% of fresh fruits, 120% of pork meat, and 80% of tubers requirements. All the other food groups have self-reliance below 100% (Table 6), what evinces the regional profile of production specialization.

For example, the processed tomato industry is one of the most important sectors in the Portuguese agri-food industry, and the country ranked fourth in global exports in 2012 [86]. Portugal is the only country in the world which exports almost all of its processed tomato production (93%), with a prominent place in EU markets and Japan [86]. Consequently, some of these productions for which the region is self-reliant are exported, and do not currently contribute to meet local food needs. These results enable us to identify areas of current food demand where increased regional production is necessary to meet food consumption requirements.

The food needs of the population of the agrarian region of Ribatejo e Oeste imply that about 173,489 hectares of agricultural area are required, or per capita about 0.05 ha (Table 7), if we exclude animal products. With these, the food needs of the population of the agrarian region of Ribatejo e Oeste imply about 593,701 ha, or 0.17 ha per capita.

**Table 6.** Production of main agricultural crops (t), Portugal and Ribatejo e Oeste (2014), Consumption and Self-reliance (Ribatejo e Oeste): Production in Portugal (**1**) and in Ribatejo e Oeste (**2**); (**3**) Consumption and (**4**) Self-reliance (production as a percentage of consumption).

| Plant Crops and Animal Products | Production Portugal (t) or (kL) | Production Ribatejo e Oeste (t) or (kL) | Consumption Ribatejo e Oeste | Self-Reliance (%) |
|---|---|---|---|---|
| Cereal grains | 1,333,256 | 474,596 | 434,789 | 109% |
| Dried pulses | 2333 | 127 | 12,276 | 1% |
| Tubers | 539,872 | 203,193 | 255,036 | 80% |
| Vegetables | 988,650 | - | - | - |
| Tomato | 1,310,366 | 1,140,610 | 47,725 | 2390% |
| Fresh fruit | 574,936 | 368,415 | 191,026 | 193% |
| Citrus fruit | 304,016 | 16,065 | 62,506 | 26% |
| Nuts | 31,982 | 688 | 10,271 | 7% |
| Wine (kL) | 603,327 | 193,849 | 140,363 | 138% |
| Olive oil (kL) | 66,533 | 2870 | 29,859 | 10% |
| Beef meat | 79,842 | 9731 | 46,347 | 21% |
| Pork meat | 360,053 | 97,850 | 81,296 | 120% |
| Poultry meat | 295,261 | 51,544 | 83,425 | 62% |
| Eggs | 132,432 | - | 25,679 | - |
| Milk (t) | 1964 | 176 | 433,411 | 0% |

Source: Adapted from National Statistics of Food Availability and Agricultural Statistics [55,62].

**Table 7.** Surface needs by type of plant crop for regional self-reliance (ha/year). (**1**) Productivity of main agricultural crops (kg/ha); (**2**) Annual edible food requirements for the total population of Ribatejo e Oeste (ton/Pop. Total); and (**3**) Surface requirements by type of plant production for regional self-reliance (ha/year).

| Plant Production | Productivity Ribatejo e Oeste (kg/ ha) | Food Needs (ton or kL/pop. Total) | Area by Crop (ha) |
|---|---|---|---|
| Cereal grains | 9126 | 434,789 | 47,643 |
| Dried pulses | 790 | 12,276 | 15,539 |
| Tubers | 27,219 | 255,036 | 9370 |
| Vegetables | 26,963 [1] | 331,572 | 12,297 |
| Fresh fruits | 20,510 | 191,026 | 9314 |
| Citrus fruit | 10,504 | 62,506 | 5951 |
| Nuts and seeds | 1243 | 10,272 | 8264 |
| Grape (kg)/Wine (kL) [2] | 7459/5.33 | 140,363 | 26,335 |
| Olive fruit (kg)/Olive oil (kL) [3] | 541/0.07 | 29,859 | 38,778 |
| | Total | | 173,490 |

Source: Adapted from National Statistics of Food Availability and Agricultural Statistics [55,62]. [1] Productivity value for Portugal since the data does not exist for the agrarian region. [2] The volume of wine produced by 1400 kilogram of grapes equals 1 kL [87]. [3] The volume of oil produced per quintal of olives (hl/q) is in the Ribatejo e Oeste of 0.13 hl per quintal of olives [88].

The land footprint to produce animal food groups—meat, eggs and dairy products—implies tripling the required agricultural area per person, relative to the plant component of the diet (Table 8). The total area required by the meat-based diet (1) of 593,701 ha, was higher than the agricultural area of the region, which was about 326,511 ha in 2012 [61]. The contraction of the agricultural area in the period between 2000 and 2012 was 24,437 ha, which is the surface necessary to feed 143,750 people.

**Table 8.** Surface needs by type of animal production for regional self-reliance (ha): (**1**) Edible annual intake and (**2**) Area.

| Animal Production | Edible Annual Intake (Ton or kL/Pop. Total) | Area by Type of Production(ha) |
|---|---|---|
| Meat [1] | 211,069 | 356,647 |
| Bovine meat | 46,347 | 152,946 |
| Pork meat | 81,296 | 121,944 |
| Poultry | 83,425 | 81,757 |
| Eggs | 25,679 | 11,556 |
| Dairy | 433,411 | 52,009 |
| | Total | 420,212 |

Source: Adapted from National Statistics of Food Availability [62]; Life cycle analysis data for crop and pasture area necessary for the production of a weight unit of meat (bovine, pork, poultry), milk and eggs [64,89]. [1] Were excluded from the meat category the meat of goat and lamb, other meats and edible offal for the minor place they represent under this category

Considering the values obtained for the land footprint of the current meat-based diet (1), i.e., 0.17 ha per capita, the current agricultural area would be enough for a RFSR of 56%, or 1,920,653 people, if the food production was only allocated to regional food consumption.

### *3.2. Agro-Suitability Models and Land-Use Potential Plan*

Agro-edaphic suitability (Figure 4) and other ecological factors were the basis for the Land-Use Plan (Figure 5). We maintained the current land occupation when adequate from an ecological point of view. In the areas of conflict, other ecologically suitable land-uses were proposed, including nature conservation land-uses.

Thus, certain uses and occupations as rice fields, permanent crops—vineyards, fresh fruit orchards, olive groves; and agro-silvo-pastoral systems, a specific open woodland pasture (montado)—and part of the existing permanent pastures were kept. Following this, the dietary requirements for the Fresh Fruits group and for Rice, in the Cereal Grains Group, were met. Regarding most food and feed crops, we used the results from the integration of the two types of suitability: agro-edaphic and agro-climatic (Figures 6 and 7). These results were used in the potential regional foodshed model and the total self-reliances for the food and feed crop requirements, for the three diets, were obtained.

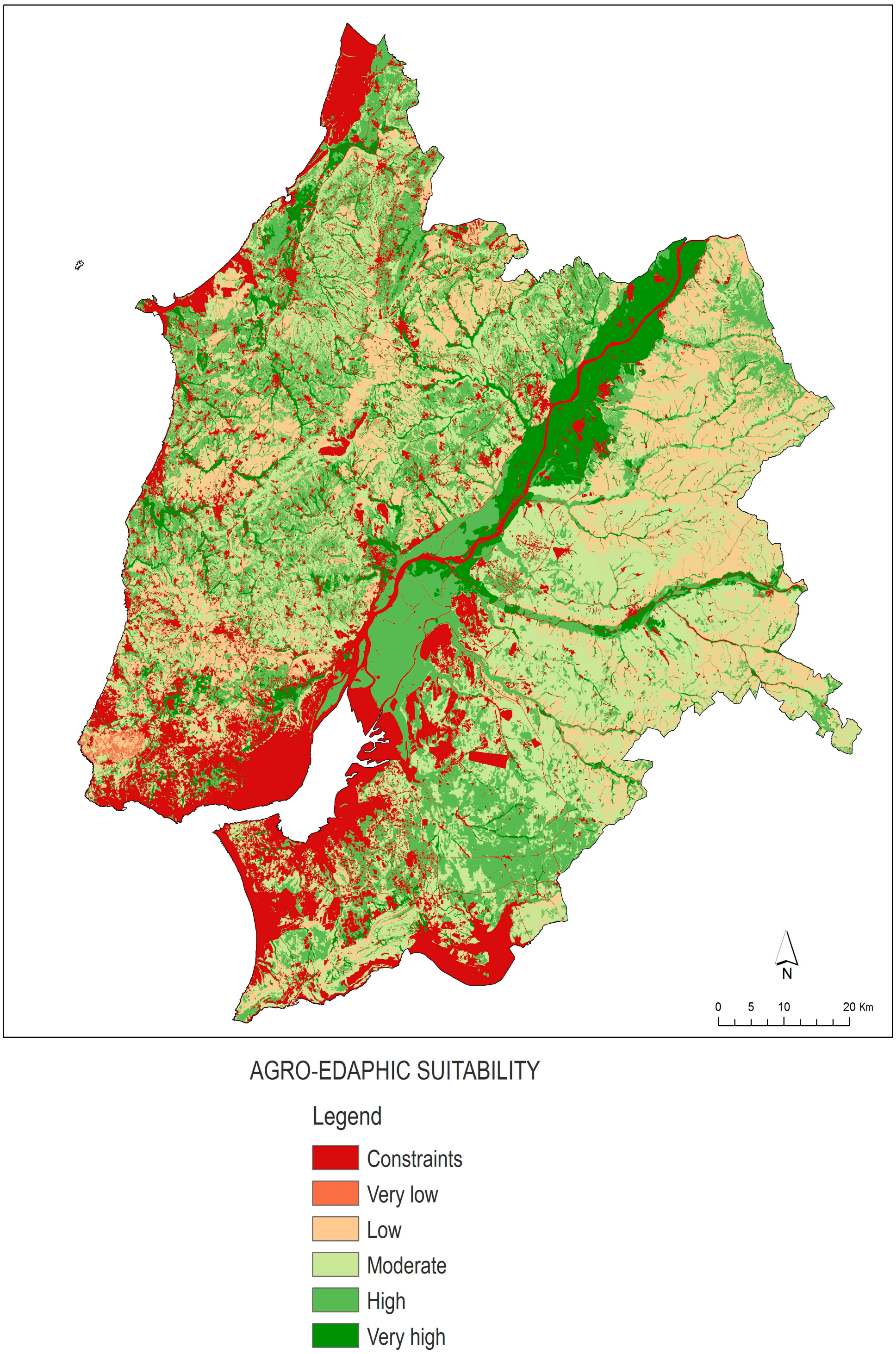



**Figure 4.** Agro-edaphic suitability, application to the Ribatejo e Oeste agrarian region.

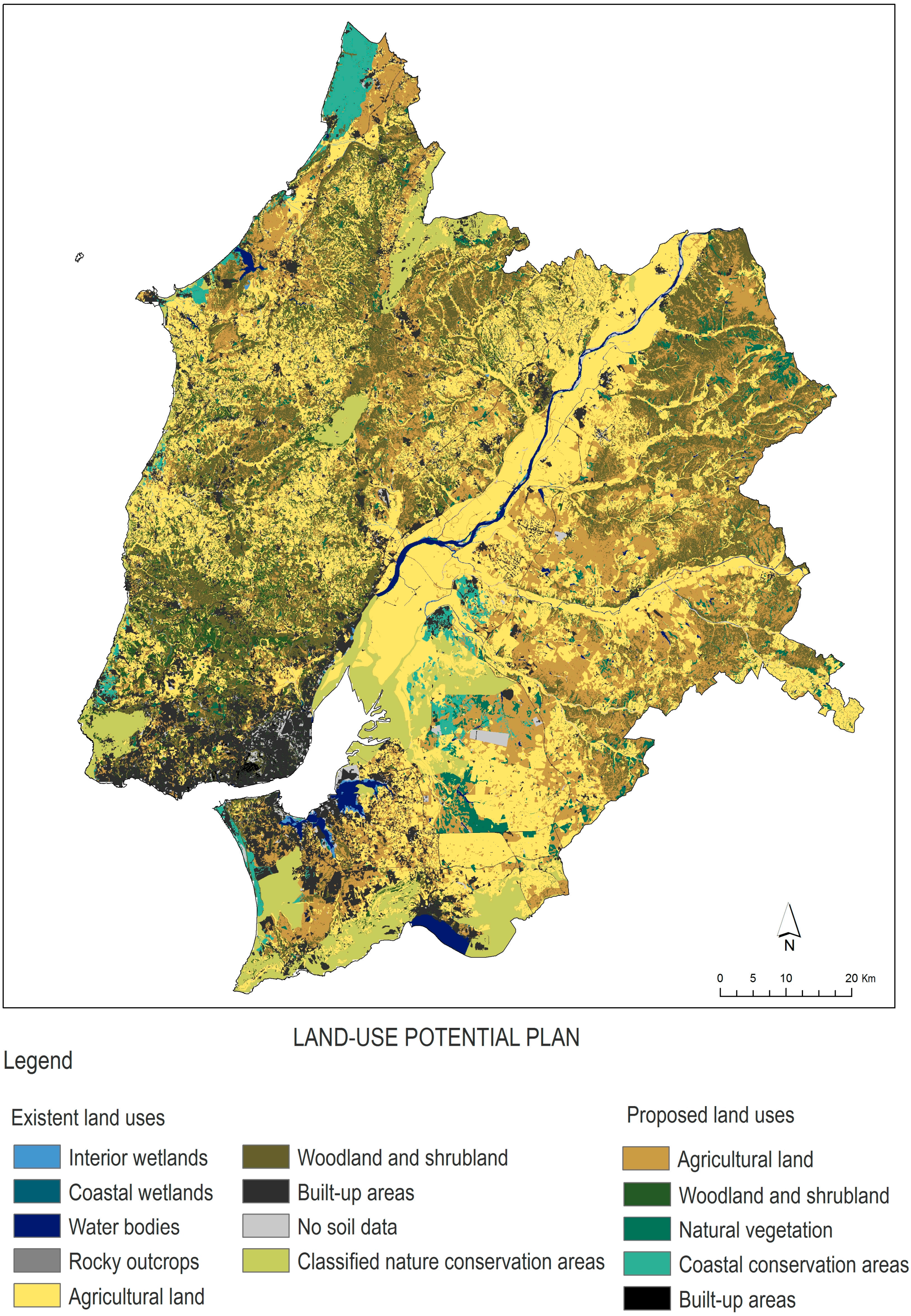



**Figure 5.** Land-use potential plan (distinguishing existing land uses which are maintained and new proposed land uses).

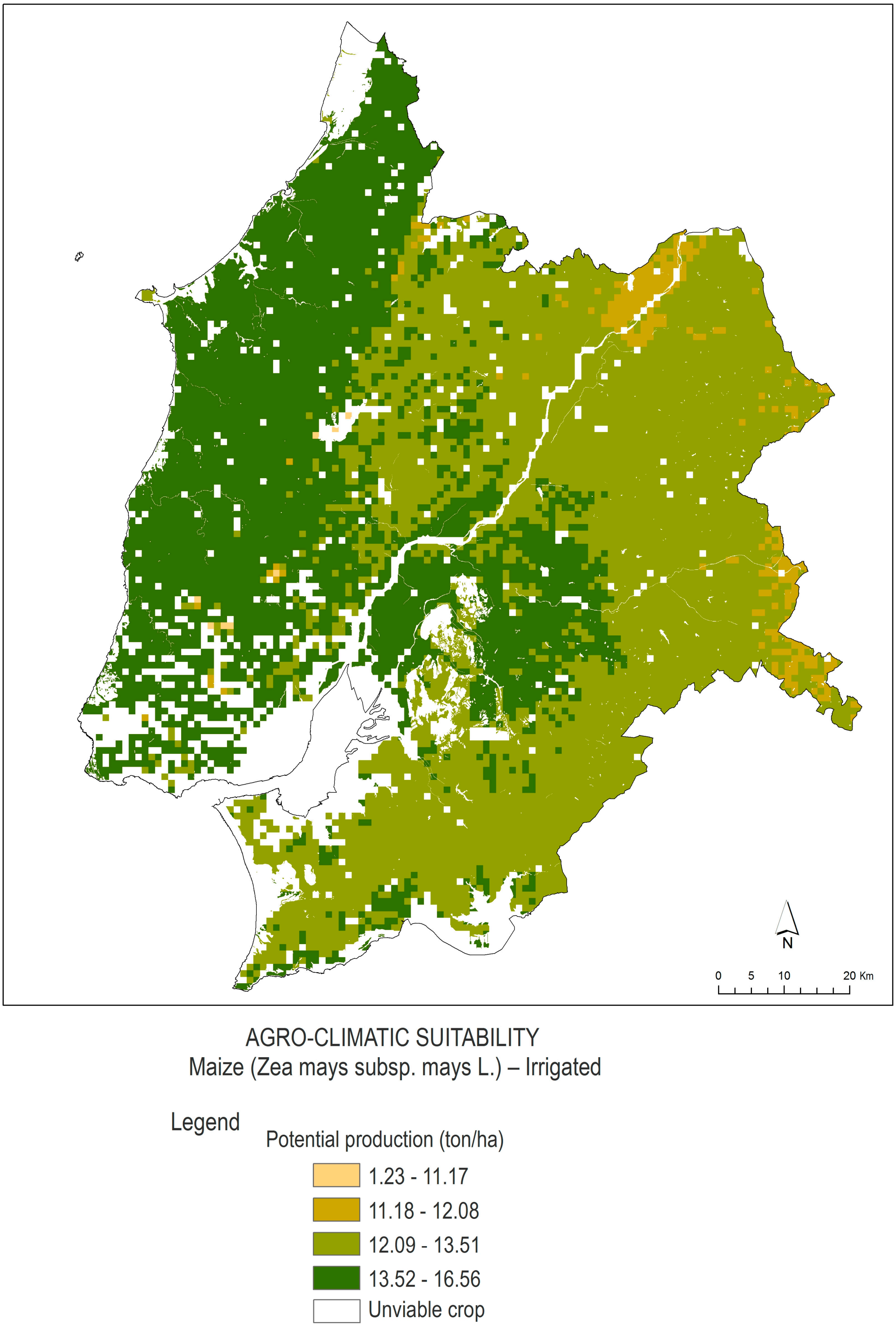



**Figure 6.** Agro-climatic suitability for irrigated maize

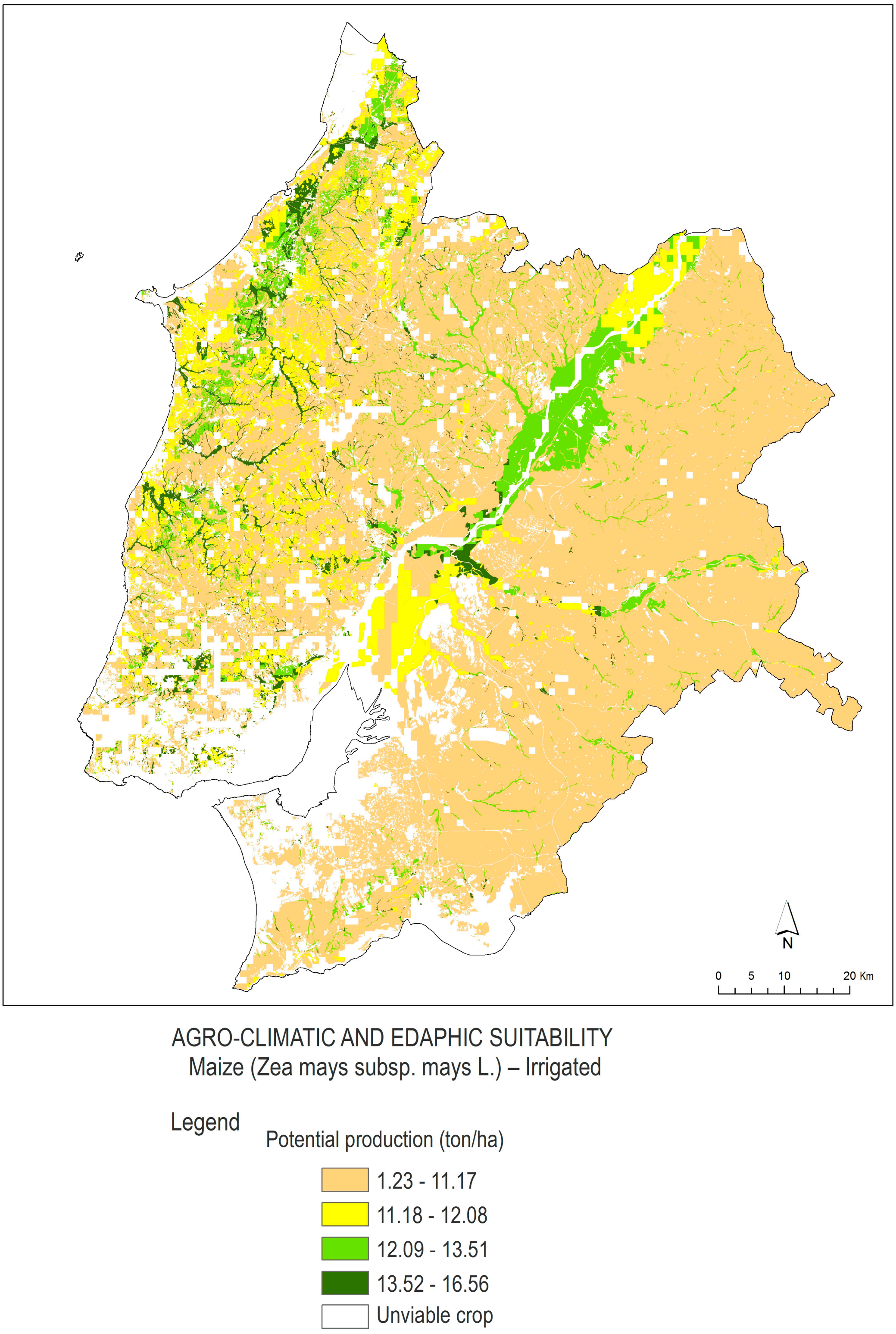



**Figure 7.** Agro-ecological suitability for irrigated maize (after integration of agro-climatic suitability with the agro-edaphic suitability).

### 3.3. Potential Regional Foodshed Model

The total self-reliances (%) obtained for the food and feed crop requirements for the three diets were: 71.64% (MB2), 76.06% (PB), and 84.11% (VEG) (Figure 8). The regional agro-ecological potential for food self-reliance was higher for the strict-vegetarian diet than for the omnivorous diet alternatives, meat- and plant-based. Even though there seem to be minor differences in total values, the reductions in feed crops impact significantly on the partial self-reliance for the sub-groups of meat and eggs and dairy products, if import substitution did not take place. This difference in potential self-reliance was based on the allocation model and was consistent with the life cycle analysis land area requirements to produce meat, eggs and milk as discussed previously (Tables 6 and 7) [64,89]. The area needed for the meat-based diet doubled the area needed for the strict-vegetarian diet, with a 12.5% decrease in the total self-reliance for the latter (Figures 9 and 10). These differences were fundamentally caused by the groups Cereal grains and silage and Grazing land, where the mass of animal feed and total land required was higher than other food and feed groups.

These data, concerning the land footprint of animal production and diets whose main protein source was animal, confirmed the results obtained in other studies. This is the case for both studies that investigated complete diets [40–42] and those that analyzed only the major protein-rich products [24,90,91].

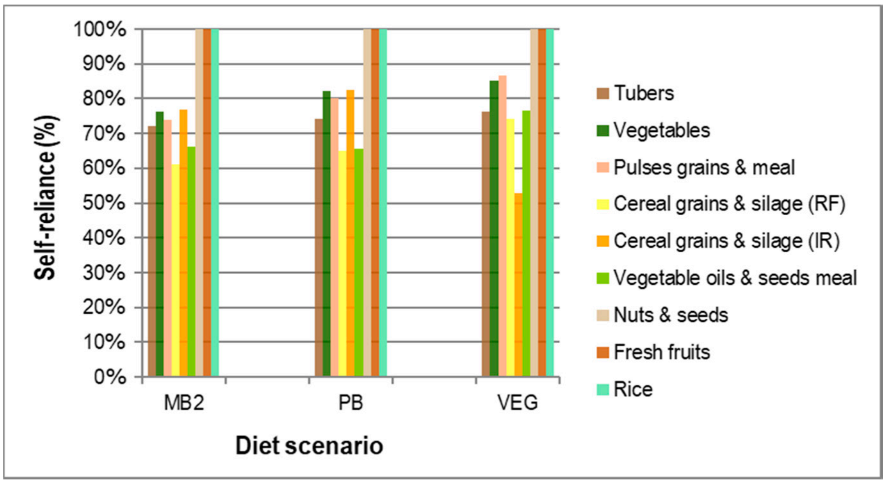



**Figure 8.** Self-reliance or potential percent of annual dietary requirements met by diet scenario, by food and feed group.

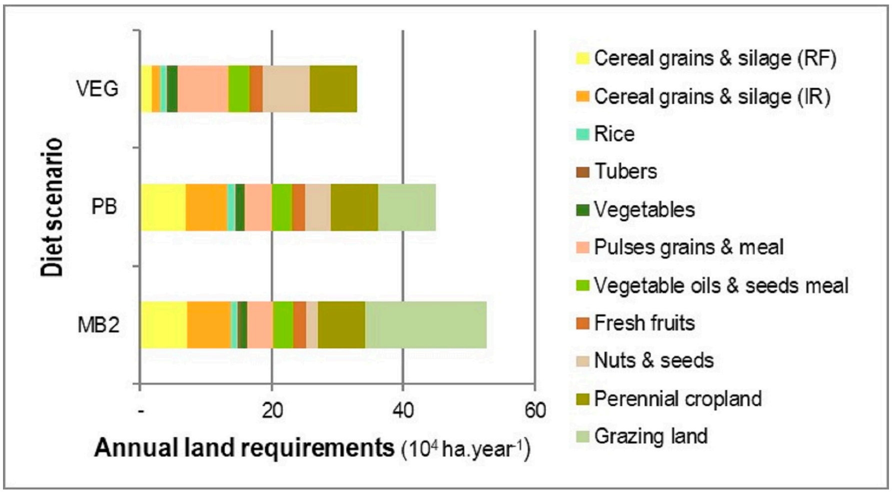



**Figure 9.** Total annual land requirements, by food and feed group and diet scenario.

For the plant-based scenario (PB), the reduction of land area on the potential regional foodshed, in comparison with the meat-based diet (MB2) was 95,032 ha (20% of MB2), and for the strict vegetarian scenario (VEG) was about 186,622 ha (40% of MB2). The reduction for the VEG scenario in comparison with the plant-based diet (PB) is, as expected lower, but still significant and at around 91,591 ha (25% of PB).

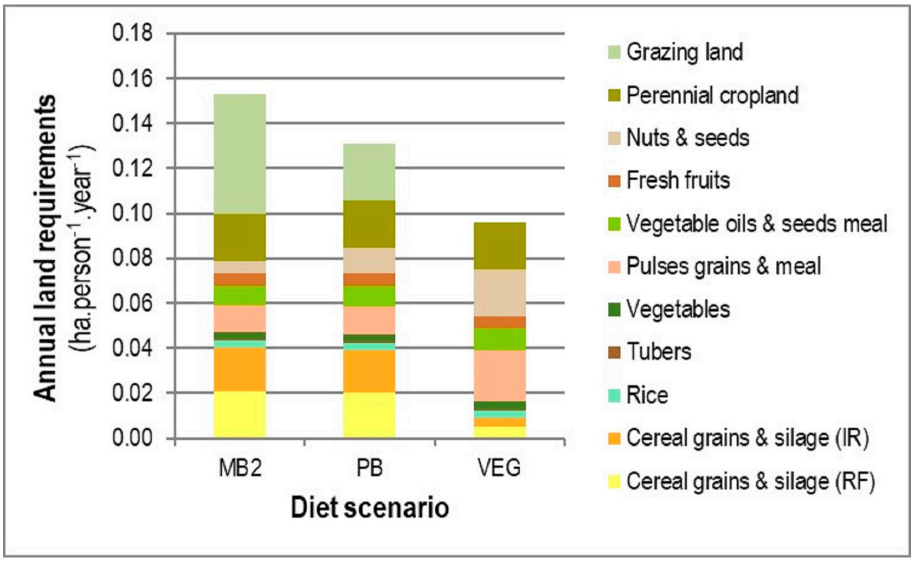



**Figure 10.** Annual land requirements by person, by food and feed group and diet scenario.

## 4. Discussion

Recent studies, that account for the number of persons fed per unit land area or "carrying capacity", with reference to different diets, have considered that meat-based diets are more efficient for they utilize land use for grazing and feed crops that are less suitable to other crops [42]. In fact, as was the case in the foodshed landscape plans for the plant-based and strict vegetarian diets, the results presented suggest that these areas are not necessary for food production (Figure 11). Therefore, they can be allocated to land uses other than agricultural. Nonetheless, to account for the unused land for grazing and feed crops in vegetarian diets (as other studies have done) is not a proper way to measure land use efficiency. Food provision is just one among other possible ecosystem services (ES), as such, to account for the environmental impact of food, it is necessary to consider the effects of dietary changes on the potential provisioning of other important ES [24].

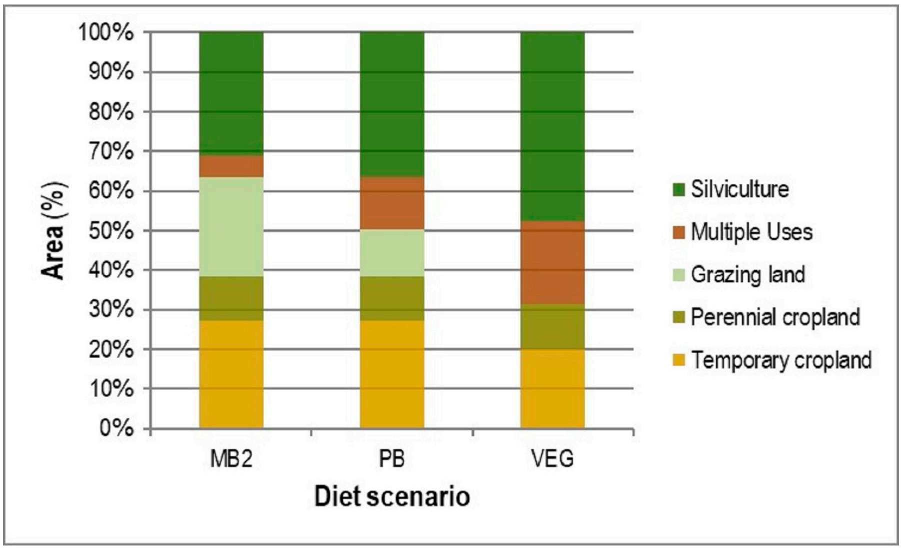



**Figure 11.** Allocation of the main categories of agro-silvo-pastoral land use (Area, %).

In fact, in the plant-based and the strict-vegetarian scenarios, 50% or 70% of land uses can be specifically assigned to ES other than food provisioning, respectively (Figures 11 and 12). These may include regulating, supporting and habitat, as well as cultural ES, that can be augmented aside from the provision value of silvicultural and agro-silvo-pastoral multiple land uses. However, grazing lands for the omnivorous diets were considered in cork oak montado, whose conservation value has been recognized by the European Habitats Directive, and are known by delivering important ES in other categories than provisioning [92]. The highly productive pastures system chosen was the Sown Biodiverse Permanent Pastures, Rich in Legumes (SBPPRL). This system also contributes to supporting ES like nutrient cycling, hydrological cycle regulation, soil protection, and global climate regulation through carbon sequestration [93]. The resulting foodshed landscape plans could be further used to assess the potential allocation of ES in each scenario and the trade-offs and synergies between the categories of ES [94] (Figures 13–15).

The dependence on imported animal feed was eliminated through relocalization, and the land footprint of animal production was therefore accounted. However, self-reliance in all the potential foodsheds still maintained a dependence on imported agricultural inputs, such as fossil fuels for fertilizers and energy.

Considering the values obtained for the land footprint of the current apparent food consumption (Meat-based 1, MB1) based on food supply data, the present agricultural area would be sufficient for a RFSR of 56% (Section 3.1), if food production was allocated only for regional food consumption. However, to properly compare RFSR degrees between MB1 and the other scenarios, the same potential regional foodshed model should be used.

In consideration of further improvements to the potential foodshed methodology, we singled out the following:

- Include the regional apparent food consumption (MB 1) as a scenario in the potential foodshed model;
- Introduction of other scenarios, for example, an ovo-lacto vegetarian diet and a Mediterranean diet;
- Include Seafood and Soy products categories for a complete diet design regarding proteins;
- Consider different systems of production (organic farming);
- Consider agricultural waste and by-products as feed, as changes in animal diets could enhance environmental performance of omnivorous diets;
- Consider other representative crops in some groups increasing, for example, the crops of the vegetables group;
- Develop agro-climatic suitability models for nut trees to diversify the food items in the nuts and seeds group with simulated productivity values;
- Integrate the water requirements into the model to expand the view of the resource-use pattern of the different diet scenarios;
- Consider nitrogen cycling in the agroecosystem to serve as a land cost proxy for the different scenarios, considering nutrient cycling in soil-crop-animal systems; and
- Assess the potential allocation of ecosystem services (ES) in each scenario and the trade-offs and synergies between the categories of ES.

The inclusion of different systems of production in the analysis, in particular organic farming is a major challenge due to the extreme difficulty in finding data to parameterize the models. Moreover, yields under organic farming are more variable than conventional ones in relation to the environment, and technical routes must be locally adapted to maximize crop performance. More research is needed before we are ready to model crop performance under organic farming in the region due to the site specificity of the problem and the lack of suitable data on organic production systems.

There were various levels of uncertainty in the methodology adopted, which are inherent in such complex approaches. However, a yield simulation was performed using standard modeling approaches that have been repeatedly validated under our conditions. Under Mediterranean conditions, the major yield uncertainty is derived from the soil input data due to spatial variability of soil properties, namely soil depth, and the limitations of soil surveys. The validity of the results, at other levels of aggregation, are subject to changes in unforeseeable political, economic and social external factors.

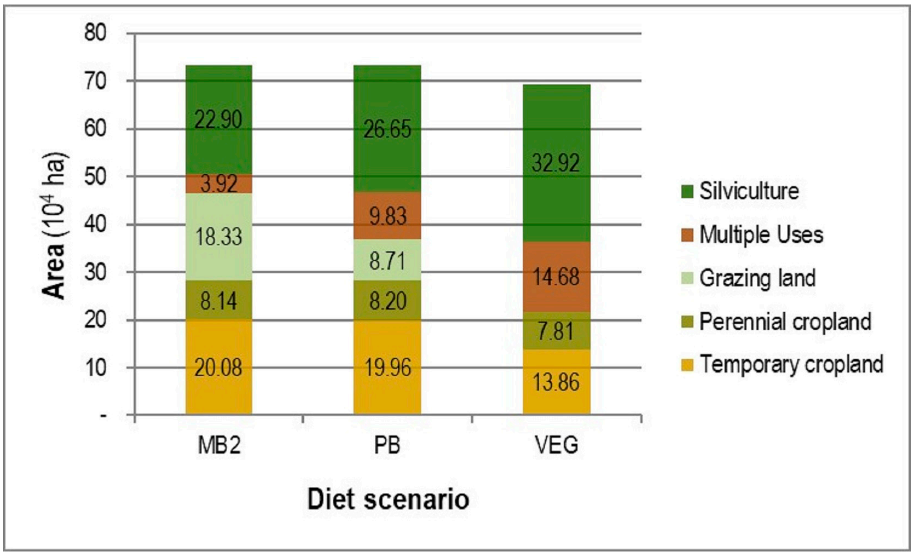



**Figure 12.** Allocation of the main categories of agro-silvo-pastoral land uses (Area, $10^4$ ha).

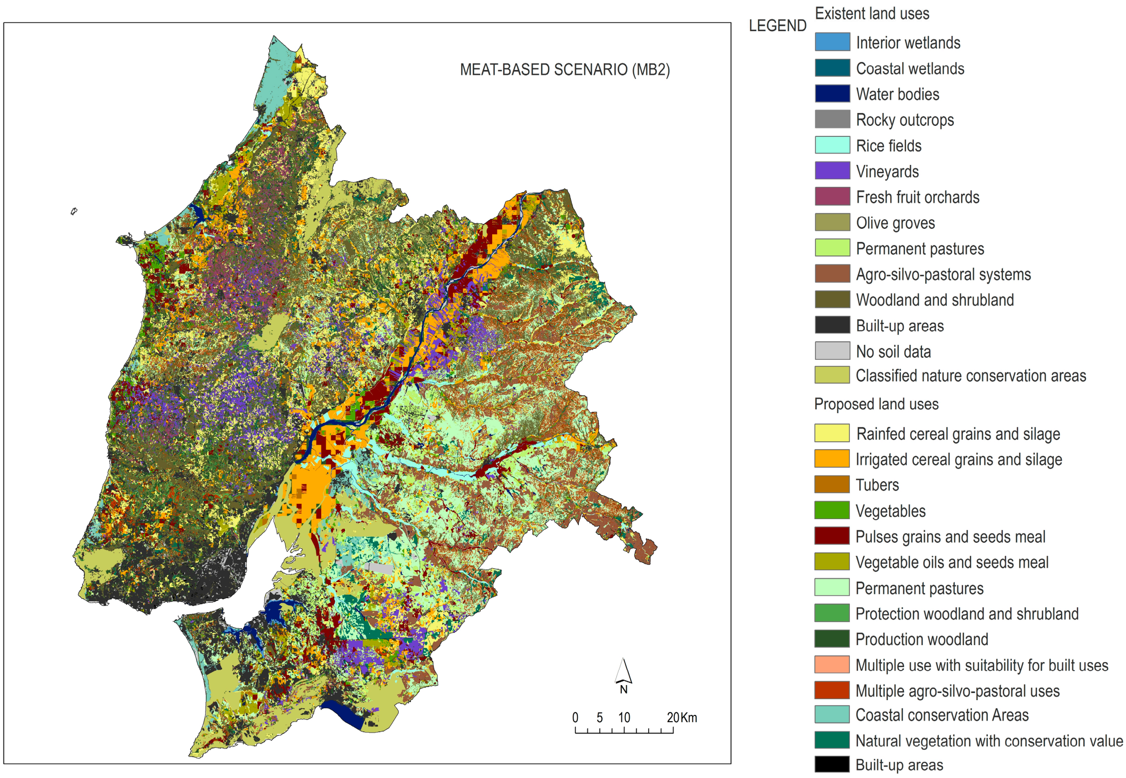



**Figure 13.** Landscape Foodshed Plan: Meat-based scenario (MB2).

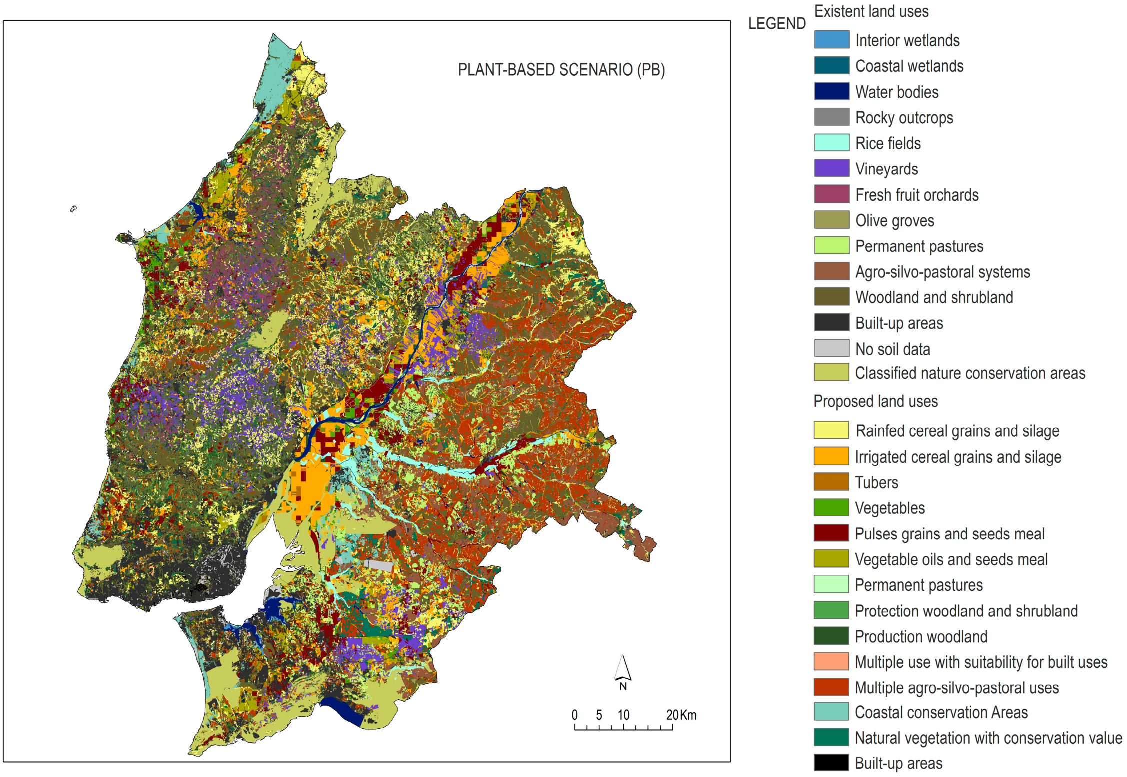



**Figure 14.** Landscape Foodshed Plan: Plant-based scenario (PB).

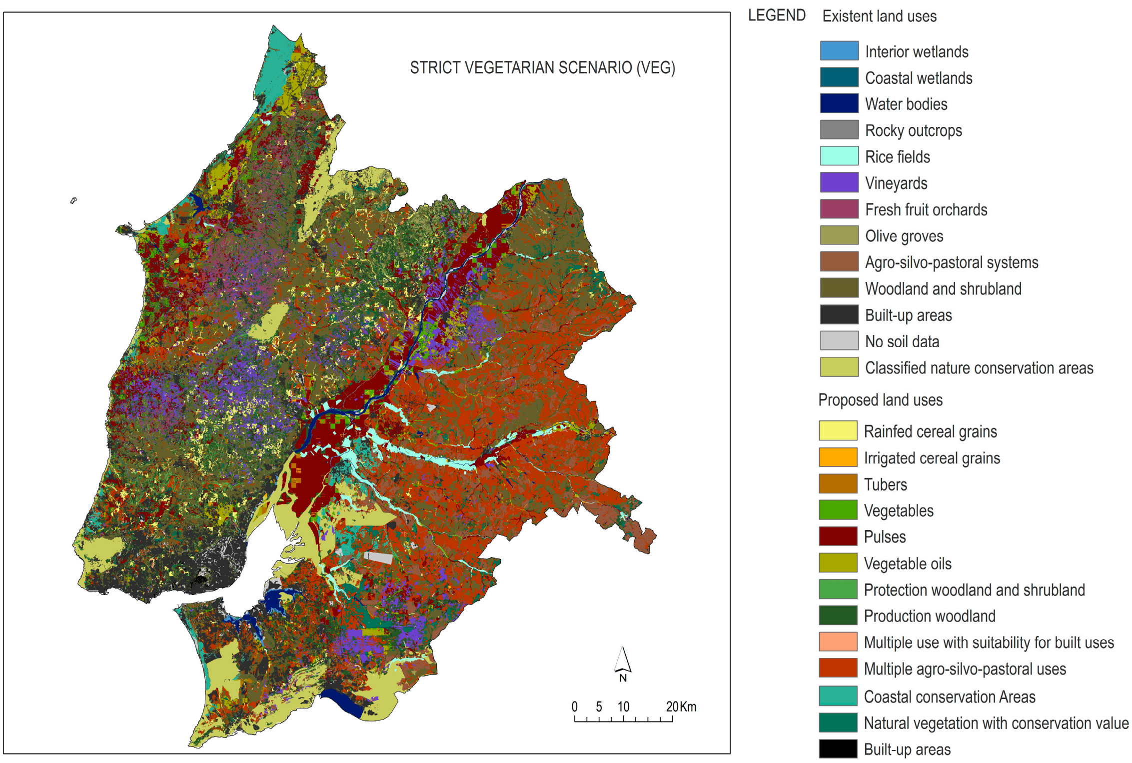



**Figure 15.** Landscape Foodshed Plan: Strict-vegetarian scenario (VEG).

The food system requires a form of integrated approach to planning, that links diverse policy objectives across multi-sectoral domains, and should entail the participation of a wide set of agents across vertical and horizontal levels of government/governance [49,95]. Two steps are necessary to ensure the effectiveness of the objectives of land-use and food system relocalization: (1) capacity for cooperation and development of consensus-building processes, and (2) incentives and public policies, either aimed at steering land use, or other policies not targeted at land use, like agricultural and food and rural development [49].

The first step to ensure the effectiveness of the land-use plans proposed, is to cooperate and develop consensus-building processes about the objectives of the land and the food system and the present and future needs for ecosystem services (ES). This can be achieved with participatory governance methods, that foster the alignment of individual and institutional preferences with land use and food policy objectives [49].

Although the methodology proposed for the landscape foodshed plans was not community-based, the final objective is to include them in the planning process at the municipal and regional level. This requires its integration in the scope of the Regional Programs for spatial planning and the Municipal Director Plans, the last of which are the local land-use plans that are legally binding on individuals. For this purpose, the proposal must be subjected to the scrutiny of political will, public discussion, and social preferences. The Potential Land-Use Plan is a key element in raising the awareness of professionals, policy-makers, territorial agents and citizens, and thus influences approaches to landscape planning and management.

Concerning the food system planning and relocalization part of the proposal, this study intended to present data that could be used to foster the debate about the strategic food reserve of natural resources or the regional basis of food security. We considered that this debate should take place at academic and institutional levels, as well as in civil society, so that food system sustainability and resilience may be considered as objectives of the current spatial planning policy framework.

The foodshed landscape plans can be used in future studies, with participatory methods of scenario development, e.g., backcasting [96,97], which was the case with the development of the Urban Food Strategy of Exeter, where this method was used to envision more sustainable food systems. This type of participatory method can serve as a basis for the construction of formal territorial food strategies or even food plans [98]. After participatory methods reach conclusions, it would be necessary to identify priority policies, planning actions and financial incentives to promote the land uses and other changes that connect that specified future to the present situation.

Currently there are important barriers to food system relocalization and the implementation of the proposed foodshed landscape plans. These are the current global drivers of land use and land cover changes (LULC)—economic, technological and institutional—that lead to agricultural structural adjustment and deactivation; and the local socioeconomic and institutional drivers that allow urbanization of agricultural areas. Therefore, we consider that policy measures are required to regulate these trends when they are detrimental for land use sustainability, and if there is public support for the relocalization of the food system.

The second step to ensure the effectiveness of the land-use plans proposed, is to consider appropriate incentives for land-use change where necessary, either through spatial/land-use planning and public policies aimed at steering land use, or other policies not targeted at land use, like agricultural and rural development [49]. Therefore, to include the foodshed plans as a reference in the spatial planning and management instruments, financial incentives should be accorded for actions and measures that lead to their implementation, in the scope of the Municipal Director Plans. The financial instruments that could be used to allocate funds to pursue these objectives exist partially under the second pillar of the Common Agricultural Policy, through the EU's rural development policy. These would be beneficial for territorial agents that are frequently constrained by the drivers mentioned and are not necessarily making land use and management decisions according to their free-will.

In Portugal, changes in the agri-food market have led to a huge concentration of supply in a small number of large distributors, responsible for three-quarters of sales [99]. The maintenance of small producers in face of the identified pressures requires measures that value these agents and territorial resources by facilitating market access. Thus, regarding relocalization objectives, specific public policies for the development of territorial or place-based supply chains should be pursued, taking advantage of the funds for this, available under the EU's rural development policy (Local development, e.g., LEADER).

Regarding consumer interest in territorial or place-based supply chains, there is strong evidence that certain consumers are willing to patron them, among other reasons, to support local agriculture and the rural economy [99]. However, a regional study should address specifically this demand and the recent development of these type of supply chains to understand their impact on the agricultural sector and rural economies, and their potential to counteract deactivation processes in regional agriculture.

In Portugal, considering the constraints of the dietary scenarios, it is fundamental to consider a dietary transition as suggested by the demand restraint perspective. There are significant apparent food consumption deviations from the recommended dietary requirements, and food-related disease incidence is the main factor responsible for the years of life prematurely lost [100,101]. In a recent study for the Mediterranean, Galli et al. (2017) [102] showed that Portugal had the highest per capita ecological footprint for apparent food consumption, mostly because of an animal protein-intensive diet.

The resolution for these problematic trends requires policies and actions to shift eating patterns, which need to target health and sustainability-relevant consumption practices [103]. Within this scope, we considered that the results should also provide a basis for discussion to be used in awareness actions about the differences in land footprint for several diets.

## 5. Conclusions

The results presented suggest the high potential for food system relocalization, while ensuring sustainable land use. Ribatejo e Oeste is the most populated agrarian region of Portugal, and even if it received all the available region's production potential, would in fact meet about 70–85% of its total food needs, in the rectified diet scenarios.

The food system relocalization perspective is therefore ecologically feasible in this case study area. The regional food system has great potential in supplying a large share of current food needs, even without a dietary change from the meat-based diet (MB2).

Specific public policies for the development of territorial or place-based supply chains could be pursued for the aim of relocalization. Nevertheless, a Territorial Food Systems (TFS) development program would be more effective, if possible, as part of a regional food policy. With that purpose, other complementary studies are necessary to understand the feasibility of TFS, for instance if the food processing and distribution sector could develop the capacity to meet regional food needs.

Although the methodology proposed for the landscape foodshed plans is not community-based, the final objective is to include these for consideration in the planning process. To achieve this, a public participation process and consultation with territorial and food system agents would have to take place, possibly in the scope of novel governance bodies to be established, such as a Food Policy Council. Furthermore, the national spatial planning and land-use framework should include food system objectives, at all levels, so that the development of these initiatives can be consequential, binding and deployed.

The developed methodology can also be used at supranational, national, regional and local levels and in other countries, with different spatial and land-use planning frameworks. This methodology informs future objectives for food self-reliance levels, for integration in spatial and land use planning. These objectives are frequently mentioned in food planning strategies and plans based on statistical data, without an assessment of the local agro-ecological potential.

As shown, a dietary transition would imply important land sparing, if the strict vegetarian scenario was adopted, which strengthens the "demand restraint" perspective for a transition to food system sustainability. Still, this perspective is relevant considering the national trends in food-related disease incidence, and public policies targeted at health and sustainability-relevant consumption practices should be envisioned.

Food provision is one of the most valued categories of ecosystem services (ES) to society, and food is a basic human need and a fundamental human right. Further studies must be done to assess the potential allocation of ES in each scenario and the trade-offs and synergies between the categories of ES. This would allow a more accurate analysis of the benefits of a dietary transition as an important win-win situation for human wellbeing and ecosystem health.

**Supplementary Materials:** The following are available online at www.mdpi.com/2071-1050/9/11/2003/s1, the Description and Parameterization of the Model CSS_Zoner with the following—Scheme S1: Flowchart of CSS_Zoner, Table S1: Approaches used in the subroutines present in object Canopy.

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