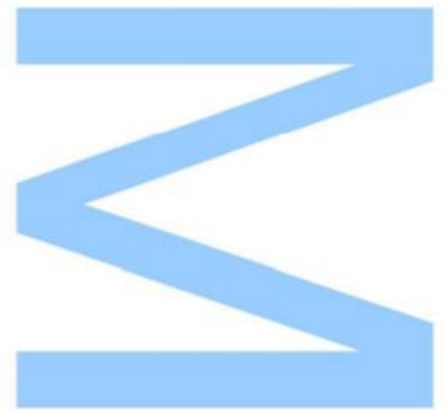


FOODSHED SELF- RELIANCE AND WATER FOOTPRINT: the influence of relocalization and dietary scenarios on food systems in Entre Douro e Minho region



Maysa Hernandez Ricardo Toledo

Mestrado em Ecologia e Ambiente

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Orientadora:

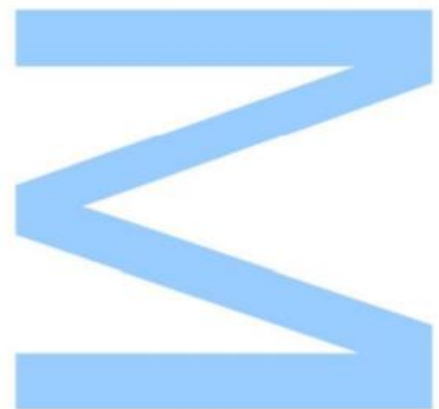
Andreia Saavedra Cardoso, Centro de Investigação em Biodiversidade e Recursos Genéticos (CIBIO/InBIO) - Universidade do Porto

Co-orientadores:

Claudia Maria Carvalho dos Santos, Centro de Biologia Molecular e Ambiental (CBMA) - Universidade do Minho

João Pradinho Honrado, Faculdade de Ciências e Centro de Investigação em Biodiversidade e Recursos Genéticos (CIBIO/InBIO) - Universidade do Porto





*À construção de um mundo sem fome e com
soberania alimentar*

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Porto, 2 de novembro de 2022

RESUMO

O crescimento populacional global e a atual crise alimentar exigem novas abordagens de planeamento territorial/alimentar de base ecológica, pretendendo fornecer alimentos saudáveis e nutritivos, ao mesmo tempo que promovem sistemas alimentares sustentáveis. Os sistemas alimentares regionalizados que visam responder a estes desafios e avaliar o papel do fornecimento de alimentos de uma região, detém o conceito de bacia alimentar, que é uma área geográfica que rodeia uma cidade e tem um certo potencial para satisfazer as necessidades alimentares de uma população. A pegada hídrica deve ser considerada para uma reavaliação dos sistemas alimentares de uma forma sustentável, uma vez que é na agricultura que o consumo de água se destaca.

Neste estudo, pretendeu-se avaliar a influência do cenário de realocação do Entre Douro e Minho (EDM) na autossuficiência alimentar e na PH, nomeadamente através de alterações no uso e ocupação do solo e tendo em conta cinco dietas (*Reference (REF)*, *Meat based (MB)*, *EAT- lancet (EAT)*, *Mediterranean (MED)* e *Strict Vegetarian (SV)*). Uma caracterização da actual bacia alimentar, e uma avaliação do uso agrícola regional e da potencial autossuficiência alimentar foi realizada, seguido de uma avaliação da PH da região EDM e do cenário de realocação.

Os resultados indicam que as dietas com menor ingestão de proteínas animais (EAT e SV) apresentaram uma menor pegada alimentar. A região EDM apresentou autossuficiência nos sistemas de culturas e animais que apresentavam um certo nível de especialização, como por exemplo nos produtos lácteos. No cenário de realocação, a maioria dos grupos alimentares apresentados aumentou a autossuficiência entre o EDM quando comparado com o cenário potencial. No entanto, grupos alimentares provenientes de sistemas especializados diminuem a autossuficiência entre cenários, o que evidencia a importância de considerar dietas e avaliação da autossuficiência quando é proposta uma realocação da bacia alimentar. Os produtos alimentares de origem animal apresentaram o nível mais elevado de pegada hídrica de produção no cenário actual, como lacticínios e carne de bovino. O cenário de realocação apresentou uma pegada hídrica total mais elevada em comparação com o cenário actual, mostrando a importância de diferenciar as culturas e o gadoa pecuária que já são autossuficientes antes de se propor uma potencial especialização.

Em conclusão, uma realocação que considere múltiplos aspectos relacionados com o ambiente e a produtividade é necessária para responder melhor aos motores da sustentabilidade e da resiliência de um sistema alimentar. Os resultados aqui apresentados poderiam também contribuir como ferramentas importantes para a gestão do território à escala local e regional e para o processo crescente de urbanização que diferentes regiões do mundo estão a viver, contribuindo para um planeamento alimentar que respeite tanto o ambiente como os aspectos socioeconómicos.

Palavras-chave: Bacia alimentar, autossuficiência, cenário de realocação, aprovisionamento alimentar, dietas, pegada ecológica, pegada hídrica, planeamento de base ecológica.

ABSTRACT

In the context of food crisis considering the global population growth, new urban food policies and new ecological based territorial/food planning are needed, intending to provide healthy and nutritious food at the same time as they promote sustainable food systems. Regionalized food systems that aim to respond to these challenges and assess the role of food provision of a region, holds the concept of foodshed, which is a geographic area that surrounds a city and has a certain potential to satisfy the food needs of a population. In parallel, water footprint (WF) must complement the analysis of food systems in a regionalized and sustainable way, since agriculture is the sector where water consumption stands out.

The main objective of this work is to assess the influence of relocalization scenarios on foodshed self-reliance and WF in Entre Douro and Minho (EDM) region, namely through changes in land-use and occupation and taking into account five diets (Reference (REF), Meat based (MB), EAT- *lancet* (EAT), Mediterranean (MED) and Strict Vegetarian (SV)). The first step was a characterization of current foodshed using agrarian statistics, and an assessment of regional current (actual land cover) and potential foodshed self-reliance (relocalization scenario). The second step was a WF assessment of current EDM foodshed and of the relocalization scenario.

The results showed that diets with less intake of animal protein (EAT and SV) presented the lower food footprint. EDM region presented higher values of self-reliability in current scenario in the crops and animals' systems that presented certain level of specialization, as dairy products. Considering the relocalization scenario, mostly all food groups expanded between the current and potential scenarios. However, food groups sourced from specialized systems presented decreases in self-reliance between scenarios, which stands out the fact of the importance to consider diets and self-reliance assessment when a relocalization of the foodshed is proposed. The WF assessment showed that the animal-based food products presented the highest level of WF of production in the current scenario, namely dairy and beef. The relocalization scenario presented a higher total WF in comparison to the current scenario, showing the importance of differentiating between crops and livestock that already are self-reliable, before proposing a potential specialization.

In conclusion, a relocalization that considers multiple aspects related to the environment and productivity is needed to better respond to the drivers of sustainability and resilience of a food system. The results presented here could also contribute as important tools to land management on a local and regional scales and for the growing process of urbanization that different regions in the world are experiencing, contributing for a food planning that respect both environment and socioeconomic aspects.

Keywords: Foodshed, self-reliance, relocalization scenario, food provision, diets, ecological footprint, water footprint, ecologically-based landscape planning.

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Abbreviations

EDM	ENTRE DOURO E MINHO
BAP	PORTUGUESE FOOD BALANCE
ES	ECOLOGICAL FOOTPRINT
GFN	GLOBAL FOOTPRINT NETWORK
WF	WATER FOOTPRINT
CRFS	CITY-REGION FOOD SYSTEM
INE	INSTITUTO NACIONAL DE ESTATÍSTICA
IPMA	INSTITUTO PORTUGUÊS DO MAR E DA ATMOSFERA
EFA	ECOLOGICAL FOOTPRINT ANALYSIS
UAA	UTILISED AGRICULTURAL AREA
CFSR	CURRENT FOODSHED SELF-RELIANCE
PFSR	POTENCIAL FOODSHED SELF-RELIANCE
BAP	PORTUGUESE FOOD BALANCE
REF	REFERENCE DIET
MED	MEDITERRANEAN DIET
EAT	EAT-LANCET DIET
MB	MEAT-BASED DIET
SV	STRICT-VEGETARIAN DIET
FF	FOOD FOOTPRINT
RO	RIBATEJO-OESTE
EFR	ENVIROMENTAL FLOW REQUIREMENT
ES	ECOSYSTEM SERVICE
FEW	FOOD, ENERGY AND WATER

1. Introduction

Population growth linked to the expanding urbanization process, brings an increasingly urban issue that is food security and self-sufficiency of cities and associated rural areas (Dubbeling 2015). So, how can a region respond to the challenges of food provision in a resilient and sustainable way? This question gains evidence among local, regional, national governments, civil society, the private sector and among researchers from different academic areas (Dubbeling 2015; Dubbeling et al. 2017; Zasada et al. 2017). For answering this challenge, researchers point to a systemic perspective of food provision, considering economic, social, political and environmental approaches (Dubbeling 2015; Wascher, et al. 2015; Dubbeling et al. 2017; Zasada et al. 2017).

In the view of this food self-sufficiency challenge, regionalized food system approaches stands out, and for this it is important to know the capacity of cities, regions and countries to obtain the necessary food within the limitations of their territory and associated natural resources (Donald et al. 2010; Cardoso et al. 2017; Zasada et al. 2017). The reformulation of current urban food systems, aimed at regionalization, brings multiple benefits such as greater social participation, ecological benefits, reduction of food miles, fresher products and regional agricultural competitiveness (Zasada et al. 2017).

Therefore, in order to re-evaluate the current food systems and promote sustainable food supply for cities and regions, it is necessary to characterize those systems, especially their current use and occupation of agricultural land, ecological footprints, as well as other human and economic components (Brand et al. 2017). Thus, one of the approaches to this characterization of food systems is based on the concept of foodsheds: which are a geographic area(s) from which a population withdraws its food sources, or the area that surrounds a city and has a certain potential to satisfy the food needs of a population (Schreiber et al. 2020). The characterization of a foodshed is pointed as essential for understanding the dynamics of food provision and an answer for cities food sufficiency (Schreiber et al. 2020).

Studies within the scope of agricultural territorial planning that propose the change of land use and occupation, due to specific trade-offs and synergies, are relevant in order to achieve these parameters of ecosystem sustainability of food provision (Cardoso et al. 2017; Schreiber et al. 2020). In their review work on foodshed, Schreiber et al. 2020 highlights the importance of using approaches in studies with foodsheds that consider the production and consumption patterns of specific regions, as well as showing that projects focused on the regionalization of food provision, provide specific and necessary knowledge for scientific

production, which seeks to evaluate the social, economic and ecological limitations and potentials of this provision.

Urban food planning based on urban development and expansion considers the needs of the city-region chain for food. In this perspective, urbanization plans tend to be revised from the food point of view, as food is considered an essential element in the functioning of these territories (Brand et al. 2017). In this context, studies with relocalization of foodsheds are lined up with an interdisciplinary approach that has been gaining popularity within the scope of food planning research in cities and regions (Wascher, Zasada, and Sali 2015; Dubbeling 2015; Brand et al. 2017; Cardoso et al. 2017; Zasada et al. 2017; Kurtz et al. 2020; Schreiber et al. 2020).

In addition to the potential effect of relocalization on food provision, it is also possible to highlight the effect of diets practiced by each location and their consumption patterns on the reassessment of food systems (Willett et al. 2019; Vicente-Vicente and Piorr 2021; Mouël and Lattre-gasquet 2018; Zasada et al. 2017; Kurtz et al. 2020; Cardoso et al. 2017). In their work with foodsheds, Cardoso et al. (2017) and Kurtz et al. (2020) demonstrated that different diets, with different percentages of vegetal food, have significant effects on the productivity of plant biomass and the ecological footprint of land use. The regionalization and the diversification of diets together has been identified as a strategy for the resilience of food systems, facing the risks caused by climate change and agricultural intensification, which seeks to meet population growth and its respective need for food (Desjardins et al. 2010; Cardoso et al. 2017; Mouël and Lattre-gasquet 2018; Berner et al. 2019).

Therefore, a systemic perspective of food supply, which considers in an integrated way the interactions between food systems elements, allows a more robust view of the functional conditions of this system and possible challenges related to the environment that these systems may face (Brand et al. 2017). In the context of agriculture, it is impossible not to consider the limits of the environment and natural resources associated with this production (Foley et al. 2005). Several natural resources are currently exploited, until being taken to the extreme of their capacity, being water one of the most severely affected (European Environment Agency 2020). This resource can be used in domestic and industrial supply, in tourism, but it is in agricultural supply that water consumption stands out, a scenario that can be aggravated in the context of exponential population growth and climate change (European Environment Agency 2020; Dias and Correia 2020).

Local climatic characteristics are undergoing changes, and this climate change linked to unsustainable agriculture aggravates environmental water stress at different scales, for example, by changing regional precipitation patterns, which makes them less predictable and

can prolong periods of drought (World Resources Institute). This fact increases the pressure on agricultural production, influencing the need for irrigation water and therefore, harm the productivity of different types of food systems (Willett et al. 2019). Changing natural landscapes for different purposes has long-term impacts on ecosystems and the resources and services that they provides (Millenium Development Goals Report 2015). Therefore, it is expected that changes in land use for agriculture will bring changes in hydrological processes, especially when these are done with little or no planning (Kepner et al. 2012). It is important to notice that agroindustry inputs and food products need the water provided by the rains, but also the water stored and used for irrigation. So, to reassess these systems for being more hydrologically sustainable, it becomes necessary to investigate both blue (surface and groundwater) and green water (soil moisture, water vapor) used in food provision, which is considered in a water footprint assessment (Hoekstra et al. 2011; Ibidhi and Ben Salem 2020; Matušík and Kočí 2021).

Local food sufficiency potential of a foodshed may vary if the availability of natural resources is scarce and also if the biophysical factors of the environment undergo changes (Schreiber et al. 2020). This highlights the need for knowledge about a foodshed water consumption, in order to transition to practices more aligned with the sustainability of the ecosystem and its resources (European Enviroment Agency 2020; Willett et al. 2019). Thereunto, it is necessary to identify and map such systems in the foodshed in order to better understand their capacities, vulnerabilities and resource use concerning different landscape coverage and food consumption patterns (Cardoso et al. 2017; Schreiber et al. 2020).

In this context, studies on the relocalization of foodshed are promising, as they are able to point out possible scenarios of conditions for the provision of natural resources, considering different climatic and environmental factors, consumption and production patterns and also in view of the spatial modification of these systems (Donald et al. 2010; Cardoso et al. 2017). In order to promote an ecological approach to territorial planning decision-making, Kepner et al. 2012 point that researchers and scientists need to consider the hydrological responses resulting from such planning, in addition to socioeconomic and political factors. This reassures the importance of setting foodshed relocalization from a water footprint perspective, as the use of scenarios can provide support for long-term land use planning, in order to ensure the sustainability of the use of water resources in agriculture (Kepner et al. 2012). Furthermore, the use of this scenarios allows comparing different uses of the landscape, which consider the interactions within and between natural and human systems and also explore the trajectories of change that result in differences between the present conditions and the possible future conditions (Flörke et al. 2011; Carvalho-Santos et al. 2016; Sali et al. 2016; Kepner et al. 2012).

1.2. Aims

This work has a main objective to assess the foodshed self-reliance and the influence of relocalization of foodshed and dietary scenarios on the water footprint, with two specific aims:

- 1) Evaluate how the food system relocalization of the Entre-Douro and Minho foodshed influences the food self-reliance and water footprint of these systems, namely through changes in land-use and occupation.
- 2) Evaluate the consequences of the relocalization of regional food system on the food self-reliance and water footprint, taking into account five diets (Reference, Meat based, EAT- *lancet*, Mediterranean and Strict Vegetarian).

1.3. Dissertation structure

- Introduction: in this chapter, a framework, points that highlight the importance of the main subject and the aims of this work are presented.
 - Subject review: Gather a definition of food provision, types of diets, water footprint concepts, review of relocalization studies and influence of diets on ecological footprints and methodological approaches.
- Methodology: describes the study area, main steps and methodological approach in the present work.
- Results: brings the results of the different steps described on methodology chapter.
- Discussion: analysis of results, corroboration from previous results present in the literature, possible limitations and future perspectives.
- Conclusion: final comments and description of the work's relevance for the scientific knowledge of the area.

2. Subject review

2.1. Framework and definition of food provision concepts

In this chapter, important concepts and approaches that support the relevance of this research are presented. Globalized food systems can provide to a population a lot of options of diversified food, however, the supply chains linked to this are complex and impactful (Schreiber et al. 2020). Concurrently with this, current patterns of food production and consumption force cities to import food sources from outside local producer's regions (Zasada et al. 2017). With this global interdependence population lost the connection between food and the land where it was sourced, losing also its sense of place. In addition to this, rural to urban migration withdraws people needed to produce food and young entrepreneurs from rural areas, which causes pressures as land use change (Kurtz et al. 2020), peri-urbanization (Joseph, Peters, and Friedrich 2019; Benedek, Ferto, and Szente 2020), decreasing of availability of resource (European Environment Agency 2020), in both rural and urban areas by difficult food access in the cities (Blay-palmer et al. 2018).

Towards food sustainability, new urban food policies and territorial/food planning intend to decrease the distance between producers and consumers, also search the vulnerabilities and import dependence presented in a city or a country, considering a regionalized approach (Dubbeling 2015). The main food provision concept of this study was the foodshed perspective, it is a geographic area(s) from which a population withdraws its food sources, or the area that surrounds a city and has a certain potential to satisfy the food needs of a population (Hedden, 1929).

Analogous to a watershed, the term “foodshed” was first used by Walter Hedden in New York City in 1929 in his book “*How Great Cities are Fed*”. Nonetheless, the planner and conservationist Benton MacKaye used before the general concept in 1920, when he developed a study on supply chains of cities and associated rural areas in Washington D.C. Both studies assess food flows throughout production chains and respective logistical efficiencies, promoting local and regionalized food networks (Schreiber et al. 2020). The concept comes to light again in 1991, with the permaculture activist Arthur Getz, who used the concept to explain how local and regional food systems work and its benefits to local self-sufficiency (Kloppenburg et al. 1996; Schreiber et al. 2020). Later, Kloppenburg et al (1996) embraced foodshed as a normative concept, supporting the idea that mapping local food systems and their linkages with the consumers enhance an understanding of sustainability as it reconnects people with the biophysical environment and the place in which they are placed. Kloppenburg et al (1996)

also point that the replace of the word “water” for “food” connects the cultural (‘food’) to the natural (‘...shed’), connecting nature and society. Besides, foodshed do not have hard and fixed boundaries but place-based indicators to delimitate them: population size and attributes, farmland and farmers, climate and soil, food infrastructure and food outlets, transportation, water resources, economic activities, cultural traditions and ethnicities (Kloppenburger et al. 1996). As a regionalized way to geographically limit the area of the food systems of a region, foodshed perspective is a set of methodologies to analyze and quantify food provision, so food systems and food chains begin to be considered from an ecological point of view considering regional food self-sufficiency in a sustainable way (Horst and Gaolach 2015; Brand et al. 2017; Schreiber et al. 2020).

Local food self-reliance of a city or a region is the capacity to provide the necessary foods present in main diet of its population (Schreiber et al. 2020). It is expressed as the ratio between domestic agricultural production and consumption, meeting the standard nutritional values, through the respective internal production and/or the importation of food products financed by the corresponding exports (Schreiber et al. 2020). In an integrated perspective of production and consumption, food self-reliance studies could determine the agricultural surface needed for certain location to achieve a balanced food provision (Horst and Gaolach 2015).

At the same time, food policies also search for a context where all people have physical, social and economic access to safe, nutritious food, in enough quantity to meet their nutritional preferences and needs, a concept that is called food security (Baer-Nawrocka and Sadowski 2019). According to Brand et al. (2017), there are urban food policies that intend to connect economic and social aspects with ecological aspects, by relocalising food systems in order to achieve food self-sufficiency and food security in the cities and regions. In his work is also pointed that sustainable city thinkers recognize that a change to more sustainable and planned way to produce food for the cities and regions are the answer to achieve a resilient urban system. The authors describes resilience as “a precursor to food security as it ensures that the food system can withstand macro-level threats, be they economic, sociopolitical or environmental” (Brand et al. 2017). Although this type of perspective raises counter-arguments, as by focusing on self-reliance, the country’s economy and import-export relations would be threatened by neglecting advantages from international trade, this type of assessment became a fundamental pillar of food security and a key indicator for food availability (Kaufmann et al. 2022).

The need for approximate producers to consumers and improve food systems dynamics, also influence the emergence of another food planning approach, the city-region

food systems (CRFS)(Blay-palmer et al. 2018). In 2015, The City Region Food System Alliance defined the CRFS as a systematization with an integrative focus in the relationships between different actors in urban and rural regions, which considers all the steps and processes involved along the food value chain, from production to the consumption, through the processing and commercialization of food resources in this a specific region. This is a territorial view of food systems, which consists in maximizing the integration of different agricultural sectors and food supply chains in geographical spaces with a regional dimension, rather than promoting long and impactful global scale chains (Brand et al. 2017).

However, the intention is not limited to shorten food supply chains, the perspective of CRFS intends to maximize the ecological and socioeconomic links, in a way that both urban and rural actors can co-governate the food provision process in the region they are located, creating participatory governance structures (Brand et al. 2017). Accordingly to Blay-palmer et al. (2018), the CRFS perspective needs to present linkages between three dimensions ecological, socioeconomic and governance, at different scales, to enhance the sustainability of food systems. Blay-palmer et al. (2018) add that this perspective develops food systems sustainability by:

- 1) Increasing access to food for both urban and rural residents, improving food security and food sovereignty;
- 2) Generating decent jobs and incomes, improving the local food economy;
- 3) Increasing the region's resilience, preventing local systems from becoming by and large dependent on the external provision of global food supply chains;
- 4) Fostering urban-rural-linkages; promoting a connection of food and resources of a food chain, also promoting the inclusiveness of Smallholders and family farmers and small food producers;
- 5) Promoting ecosystems and natural resource management, reducing ecological footprints from production to consumption;
- 6) Supporting participatory governance by fostering transparency and ownership across food systems activities.

This is a perspective that does not rely only on the “local trap”, which assumes that consuming local food products is inherently a good economic and environmental practice, avoiding understanding the food system in other geographic scales (Dubbeling 2015; Brand et al. 2017). While, the CRFS approach is gaining space in food planning decision-making, despite being a recent perspective, a categorization, assessment and validation of its benefits

is needed, in order to prove its impact (Dubbeling 2015). The main difference between the concept of Foodshed and CRFS is the ecological dimension that is implicit in the former, by assuming that the land and what it can cultivate defines the area of the food region, while the latter explores other kind of linkages and scales besides these to limit the food provisioning region (socioeconomic, environmental and governance) (Preiss and Schneider 2020).

There are an urgency to making food systems more ecologically sustainable and it reflects in the increase of studies involving urban FS and CRFS, food provision networks/food supply chains and methodologies to quantify and characterize these systems (Peters et al. 2009; Zasada et al. 2019; Schreiber et al. 2020). Schreiber et al. (2020) conducted a review of 42 publications on foodshed studies, from 1979 to 2019, showing that the knowledge about urban food provision boundaries, local self-reliance has long been discussed and presents many opportunities for further studies.

Studies on the characterization of foodsheds can present different approaches, which aim to quantify the productive potential and reassess characteristics of this region (Schreiber et al. 2020). According to Schreiber (2020), two approaches are adopted in these studies, – capacity and flow studies. Capacity studies seek to assess and estimate the potential for regional food self-sufficiency, by comparing food production and consumption patterns within a delimited geographic area. These include the estimation of the necessary size of a given foodshed to meet the food needs of a region, as well as the evaluation of any changes in agricultural land use that help meet this potential (Schreiber et al. 2020). Flow studies, on the other hand, consist of mapping the food supply networks for a given city-region, showing the demand for resources versus emissions that are incorporated into these flows, as well as the relationships between producers and consumers (Schreiber et al. 2020).

Schreiber et al (2020) grouped the foodshed capacity studies in self-sufficiency threshold and foodshed size. The first represent an assessment of local self-sufficiency, mainly throughout a comparison of production and consumption to calculate a ratio, which represents the share of food demand that could be satisfied through local production (Schreiber et al. 2020). The second was an determination of the local land needed to met food demands and also the size of the area where the population has to travel do meet the consumption (Schreiber et al. 2020). These approaches are combined in many of the foodshed self-sufficiency and relocalization studies reviewed (Peters, Bills, Lembo, et al. 2009; Desjardins, MacRae, and Schumilas 2010; Cardoso et al. 2017; Maia 2019; Schreiber et al. 2020; Vicente-Vicente et al. 2021).

2.2. Ecological footprints and water footprints

In the scope of flow studies, that consider the resource use embedded in food supply networks, various agendas, international conferences, decrees and reports point to the need to reconsider the way in which various sectors of industry, especially the agroindustry, tend to produce, towards sustainability (European Commission 2020; EEA 2020). The relevance of the sustainability concept emerged in the 70's, when researchers for the first time developed scenarios of how the environment would respond to infinite economic growth with finite resources. In the late 80's the concept of sustainable development was used to inform about the consequences of this growth, respective impacts on the environment, on terrestrial and aquatic ecosystems, and how these impacts would generate consequences in the life of the next generations, whether due to cultural, economic or social aspects (Cerutti et al. 2012). Nowadays, although this concept and perspective are much debated and controversial, the more accepted definition of a sustainable agriculture is: "To be sustainable, a farm must produce adequate yields of high quality, be profitable, protect the environment, conserve resources and be socially responsible in the long term" (Reganold et al. 2001). However, is highly difficult to delimit what a sustainable yield is, as it is influenced by a number of parameters, such as agroedaphic conditions, agricultural techniques and the growth characteristics of a plant or animal in a particular production system (Cerutti et al. 2012).

With the intention to better understand which parameters to measure to assess food system sustainability, over the last decades of the 20th century the method of the Ecological Footprint Analysis (EFA) was first introduced by Mathis Wackernagel and William Rees, basically is a tool to account for demand and supply, represented respectively by ecological footprint and biocapacity (Galli et al. 2007). Accordingly to Cerutti et al. (2012), EFA is an estimate of the total area required to supply the resources used and inherent greenhouse gas emissions that are necessary to sustain humanity, or for the production of a particular product. The development of different methodologies and approaches to assess the EF of several systems culminated in the development, in 2004, of the Global Footprint Network (GFN), a network of researchers and users of the EFA (Cerutti et al. 2012). Most approaches to assess EFA uses the concept of "biocapacity" to calculate the ecological footprint (Reganold et al. 2001; Banerjee et al. 2021; Grunewald and Gressot 2015; Cerutti et al. 2012; Billen et al. 2009; Goldstein et al. 2017; Candy et al. 2018; Alessandro Galli et al. 2016). According to the GFN, biocapacity is "the ecosystems' capacity to produce biological materials used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies" (Global Footprint Network Glossary). Therefore, in addition to considering biocapacity the EFA method also considers land components to calculate the

boundaries of the ecosystem, namely cropland, forest land, built-up land, energy land, grazing land and fishing grounds (Cerutti et al. 2012). It is also worth mentioning that within the ecosystem barriers to assess the ecological footprint, proposed by the GFN in the EFA method, those in which we can associate agricultural production and consumption patterns are cropland, grazing lands and also fishery grounds.

However, similarly with the concept of sustainability, the EFA method promotes discussions and some authors end up refuting the methods employed in these analyses (Alessandro Galli et al. 2016). Galli et al. (2016) published an article where conceptual and methodological aspects of the EFA method are discussed, with the intention to find the strengths and limitations of this approach. The main criticisms to this methodology are the simplification with which biocapacity values are assessed, currently reflected in policies and measures of impact by man, such as “Earth Overshoot Day, as the resources involved in the calculation are intrinsically related (Alessandro Galli et al. 2016). An example given by Giampietro and Saltelli, in Galli et al. (2016), is that in assessing the energy security of a system, the only biocapacity taken into account is the absorption of CO₂ by the earth. Although the questions posed by the GFN are extremely important, several authors state the answers provided so far should be reviewed, since we are living in a period of little scientific control of the methodologies before they gain media and academic acceptance. Rectifiers, on the other hand, point out that if the EFA does indeed result in an underestimate of the impacts of resource use, consistent economic development strategies are urgently needed, and rejecting these results would make these impacts even worse (Alessandro Galli et al. 2016).

It is now estimated that food systems account for 20-50% of all man-made environmental pressures (Goldstein et al. 2017). The “food footprint” or “foodprint” were the terms found to conceptualise the impacts on environmental resources caused by the food demand of cities and regions (REF). These are measured by several methods using biomass accounts, ecological footprint, nutrient flows and other indicators (Goldstein et al. 2017). Despite the strong link between food and environment, only recently policy and decision-making actions addressed these issues. In fact, according to Goldstein et al. (2017) the agri-food systems, and its impact on resource use and the environment, was the third least addressed issue in terms of the number of policy interventions. It is however important to highlight that foodshed studies, especially capacity studies (Peters, Bills, Lembo, et al. 2009; Desjardins, MacRae, and Schumilas 2010; Cardoso et al. 2017; Maia 2019; Schreiber et al. 2020; Vicente-Vicente et al. 2021), which also could use the relocalization approach, like the present study, do not use Wackernagel and Rees' EF methodology (A. Galli et al. 2007), as relocalization studies only consider bioproductive areas associated with crop production and those used for grazing (cropland and grazing land), this being a limitation of this approach.

In the scope of assessing the effects of food provision on ecological footprint, it is necessary to integrate water issues in this assessments, as it is in agriculture that water consumption stands out, up to 60 % of net water use at EU level (European Environment Agency 2020). Quantify the water use of food provision go in the direction of a sustainable development concept, which focuses on concerns related to the environment and the resources used in food production, especially water (Hoekstra et al. 2011). Therefore, solutions need to be elaborate in a way that answers concurrently the challenges of United Nations Sustainable Development Goal (SDG) 2 on food security and SDG 6 on water security (FAO et al. 2019).

There are certain indexes that allow to relate water availability and needs. The scarcity index (Water Exploitation Index – WEI) makes it possible to relate the supply and demand factors in a given watershed (Eurostat, 2017). The scarcity assessment carried out by WEI can be classified into four categories, no scarcity (countries that consume less than 10% of their renewable water resources); reduced scarcity (10% - 20%); moderate scarcity (20% - 40%); severe scarcity (>40%). According to the World Resources Institute, Portugal is among the 33 countries that will present a high risk of water stress by the year 2040, with demand equal to or greater than 80% of the country's average annual availability. This corroborates the fact that studies aimed at establishing the country's water security, taking into account the different economic sectors, are extremely important for the future.

Hoekstra (2002) has shown the importance of visualizing the hidden water use of products in order to quantify the effects of its consumption on fresh water availability. The “water footprint” (WF) concept was therefore introduced (Hoekstra, 2002; Hoekstra et al. 2011), as an indicator of freshwater use of different products that considers the direct and indirect water, i.e. the sum of blue and green water consumption measured over the full supply chain (Hoekstra et al. 2011). Water resources of rivers, lakes and aquifers represents *blue water*, while the water in the soil due to rain, available to plants and held in rhizosphere, is called *green water* (Mekonnen and Hoekstra 2011). The quantity of freshwater used in agroindustry is huge, as pointed before in EU 60% of freshwater use is for agroindustry, and due to this blue and green water resources that are being overexploited (Mekonnen and Hoekstra 2020; Mekonnen and Hoekstra 2011; Mekonnen and Hoekstra 2012). Water footprint assessments can provide information necessary for a better management of water resources (Hoekstra et al. 2011).

2.3. Influence of diets in ecological footprints and methodological approaches

Tackling agricultural water pressures requires changes in land use and farming practices, as well as the development of more sustainable and less impactful food systems (EEA 2020). This requires the assessment of water needs for food production chains and also the patterns of food consumption at regional scale (Kurtz et al. 2020; Foley et al. 2005; Vanham et al. 2021). Food patterns are cultural and an important part of identity, even so retrofitting diets is considered and a means to minimize the ecological impact of food provision (FAO et al. 2019). In short, relating food and water security is needed, and for that purpose FAO defined a healthy and sustainable diet as the “dietary patterns that promote all dimensions of individuals’ health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable” (FAO et al. 2019).

As part of the Portuguese National Programme for the Promotion of Healthy Eating (PNPAS), in December 2017 the law of the Integrated Strategy for the Promotion of Healthy Eating (EIPAS) was published (DGS, 2012). The intention of the PNPAS program is to promote adequate food consumption and the consequent improvement of the nutritional status of citizens, with a direct impact on the prevention and control of the most prevalent diseases at national level. According to data from this programme 14% of deaths in Portugal are directly or indirectly related to inadequate eating habits, such as low intake of fruit and vegetables, high intake of salt and sugar and low adherence to the Mediterranean diet (DGS, 2012). The PNPAS programme is issued by the Directorate General of Health (DGS) and targets the prevention of risk factors for chronic diseases, in particular childhood obesity, pointing out that in addition to environmental benefits, adequate consumption patterns also provide multiple benefits to human health. Adding to this, the National Food and Nutrition Security Council (CONSANTP) developed the National Food and Nutrition Security Strategy (ENSANTP), diagnosing the national state of food security and nutrition. The articulation of these national programs with the Farm to Fork Strategy and the Innovation Agenda for Agriculture 2020-2030 aims to promote the transition to sustainable, inclusive and resilient food systems.

The Mediterranean diet is recommended to achieve the targets of food and nutritional security, health and environmental sustainability, while it is based on the regional sociocultural lifestyle and current food consumption patterns (Bach-Faig et al. 2011). It is a culturally accepted diet, still largely practiced in Mediterranean countries, in particular in poorer rural areas, despite affluent food consumption patterns are being imposed by globalized food chains, urban development and economic growth (Bach-Faig et al. 2011). The macronutrients

present on this diet are mainly plant-based, with dominance of cereal grains, fruits, pulses and olive oil as the added fat, what makes it a healthy dietary pattern classified by UNESCO in 2010, as an intangible cultural heritage (Vanham et al. 2021). Grunewald and Gressot (2015) did a study to evaluate the ecological footprints of the Mediterranean diet, pointing out that Portugal has an overall high resources requirement, mainly because of its dietary habits, which are currently animal-protein based. Despite the dominant narrative, these authors refer that improvements on agricultural efficiencies are insufficient for achieving food security, since dietary patterns and food waste are critical (Grunewald and Gressot 2015).

The Lancet commission, represented by researchers from different areas (human health, environmental sciences and social science), used the planetary boundaries framework (Rockström et al. 2009) to propose a diet that is adequate for sustainable food systems and promotes healthy patterns of food consumption, called the EAT- Lancet diet (Willett et al. 2019). The planetary boundaries considered were land-use change and deforestation caused by the increase of cropland area, biodiversity loss, freshwater use, GHG emissions and soil pollution by nitrogen and phosphorus (Willett et al. 2019). To develop the EAT diet, the Lancet Commission focused on the environmental degradation caused by food production, including freshwater use, by considering the Environmental Flow Requirement (EFR) of the main agricultural and livestock systems (Willett et al. 2019). The Lancet Commission defines EFR as the “allowable upstream withdrawals and consumption that sets basin-scale boundaries for water use that ensures adequate environmental flows in watersheds”. Considering, in advance, the limitations of the river basins where a particular population is located, it is possible to guide changes in their consumption patterns, promoting a less impacting food consumption in relation to water resources (Willett et al. 2019). This diet proposes a 50% reduction of red meat and sugar consumption, and also an increase of plant foods consumption, such as cereals, nuts, fruits, vegetables and pulses, in order to achieve globally the target of a healthy and sustainable diet by 2050 (Willett et al. 2019).

There are several studies correlating this diet with its impact on hydrological resources (Vanham, et al 2013; Vanham and Bidoglio 2014; Harris et al. 2020; Vanham et al. 2021; Petersson et al. 2021). More recently, Vanham et al. (2021) carried out a study for several Mediterranean countries, comparing their current dietary patterns with both, Mediterranean and EAT- Lancet diets. The results showed that the blue and green water footprint varied in the different countries due to local climate conditions and the differences in crop irrigation needs. This study, as well as other that seek to evaluate the water footprint of certain diets are relevant for public policy making, as they show trade-offs and opportunities in food production scenarios that promote specific socioeconomic and environmental objectives (Vanham and Leip 2020; Vanham et al. 2021b).

2.4. Food system relocalization and respective approaches

Providing healthy food to a growing global population from sustainable food systems is a challenge that needs to be faced with urgency (Willett et al. 2019). Studies in urban food planning are gaining in importance in different parts of the globe, in order to rethink sustainable urban and peri-urban food provisioning (Peters et al. 2009; Dubbeling 2015; Wascher et al. 2016; Brand et al. 2017; Cardoso et al. 2017; Zasada et al. 2017; Preiss and Schneider 2020; Schreiber et al. 2020).

The relocalization is an approach that promotes local and regional food systems, that are based on short food supply chains, finding pathways to ensure sustainable resource use, and promoting the local economy, by bringing closer consumers and local producers (Hendrickson and Heffernan 2002; Hein, Ilbery, and Kneafsey 2006; Benedek, Ferto, and Szente 2020). The prefix 're' refers to the fact that cities may redevelop a local or regional urban food provisioning, continuing or getting back to its historical development trends; while 'local' represents an identifiable origin of the products that is limited to a local/regional scale (Hein, Ilbery, and Kneafsey 2006).

Reconnecting products, people and places in the food supply chain, augmenting regional food provisioning calls for a structural transformation of the current food system that involves its actors, including those responsible for food planning (Brand et al. 2017). Garnett (2014) points out that food-related problems are also socioeconomic problems, that do not result uniquely from a lack of technical knowledge or ill-suited individual decisions. In other words, the structural transformation that food system relocalization implies relies on producer-consumer relationships and on understanding their socio-economic context. Benedek, Ferto, and Szente (2020), in their review on food system relocalization, refer that consumers already prefer food products sourced by regionalized systems, mainly because these are perceived as fresh and high quality. Shortening the food supply chains, by relocalization, is documented in the literature by having multiple effects, such as change in productivity, resource uses, improves in food security, or is documented that this multiples effects are greater on the relocalization scenario when comparing with the current landuse (Kneafsey et al. 2013; Benedek, Ferto, and Szente 2020).

According to Garnett (2014), the authors that support the Life Cycle Analysis perspective criticize food systems relocalization by referring that shortening food supply chains does not contribute to reduce significantly the overall food supply chains impacts. Although, several authors affirm that food systems relocalization is a means to build strong

Foodshed and City-Region Food Systems linkages between the provision of nutritious food while promoting local economies and sustainable practices in food production (Levidow and Psarikidou 2014; D Wascher, Zasada, and Sali 2015; Brand et al. 2017; Cardoso et al. 2017). Benedek, Ferto, and Szente (2020) found in their systematic literature review that relocalizing food systems is a process that is increasingly gaining popularity, that could foster rural development in parallel with sustainable urban development, same as the concept of urban food planning, taking account food point of view to foster urbanization (Brand et al. 2017). Furthermore, the proponents of the relocalization perspective argue that local/regional food systems can be more resilient to face climate challenges and supply chain ruptures, due to anthropogenic impacts and price volatility, by promoting food and nutrients security, the sustainable use of natural resources, and the local and economy (Hendrickson and Heffernan 2002; Levidow and Psarikidou 2014; Cardoso et al. 2017; Benedek, Ferto, and Szente 2020).

Although Portugal presents good food policies, food planning still needs further investigation. For instance, Maia (2019) sought to assess the potential of urban agriculture in the city of Porto, as well as in the Greater Metropolitan Area of Porto, using the Metropolitan Foodshed and Self- Sufficiency methodology, finding out that most municipalities present a low index of food self-sufficiency, which implicates a need for outside inputs for food supply. He also concludes that urban food planning is essential to promote sustainable and resilient food systems, as the information given through land mapping of a foodshed helps decision-making actions (Maia 2019). Filipe (2021) developed in a master thesis, a potential relocalization scenario to the Entre Douro and Minho region, based on agroedaphic suitability and also in ecological based planning, pointing for a huge land occupation by temporary and permanent crops on the region and concluding that the mapping and integration of ecological properties of the landscape in CRFS planning is a line of research that can contribute to the implementation of land uses compatible with environmental sustainability, supporting landscape planning and management. However, the approach of this work did not analyze the effects on capacity and flows of the food systems on the region (Filipe, 2021). This type of work was done previously on Ribatejo-Oeste agrarian region, Cardoso et al. (2017) proposed a food system relocalization approach to achieve sustainability, by evaluating the agro-ecological potential to increase the regional food self-reliance in the region. The authors used three diets, also 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, showing that the local production could improve the self-reliance in more than 70% in the three diets analyzed.

The systemic approach to Foodshed, Water footprint and diets is widely promoted by studies that emphasize the benefits of local/regional urban food provisioning on the economic

and environmental performance of urban regions (Zasada et al. 2019; Schreiber et al. 2020). However, studies that propose quantitative assessments of the effects of relocalization and dietary scenarios on aspects of foodshed, such as food supply and use of natural resources, although existing in the literature (Schreiber et al. 2020), are of extreme importance to point out benefits and limitations of this methodology (Cardoso et al. 2017; Joseph, Peters, and Friedrich 2019).

Several authors explore how the changes in land use affects hydrological resources at different spatial and temporal scales (Kepner et al. 2012; Levidow and Psarikidou 2014; Carvalho-Santos et al. 2016; Kurtz et al. 2020; Vanham et al. 2021). However, studies that analyse the effects of relocalization on food provision, water footprint, proposing this assessment taking into account different diet patterns are absent in the main literature reviewed (Vanham, Mekonnen, and Hoekstra 2013; Cardoso et al. 2017; Harris et al. 2020; Schreiber et al. 2020; Vanham, Mekonnen, and Hoekstra 2020; Vanham et al. 2021).

3. Methodology

3.1. Overview of the methodology

The first step of this study consisted in a characterization of Entre Douro and Minho Foodshed (based on statistics), and an assessment of regional current (actual land cover) and potential food self-reliance (relocalization scenario). The second step consisted in a water footprint assessment of current EDM foodshed and relocalization scenario (Figure 1).

The Step 1 was to collect data and characterize the territory, occupation, and agricultural land use, using national statistics database (INE), (Vid. 1.1 and 1.2). Assessment of current foodshed self-reliance (CFSR) using regional agricultural production data (crops and animal), and the Portuguese Food Balance (BAP) data, as proxy of food consumption patterns per capita, considering the resident population in EDM. The secondary data used for this assessment was obtained from several agricultural statistics, regional agricultural productivity data included on the agricultural census (INE 2021) (Vid. 1.3).

Also in Step 1, diets were designed for meeting the average caloric and nutritional needs of the population. Such diets have different characteristics, but the mainly difference is the percentage of animal protein. Diets used were: Reference diet (REF), Meat based (MB), EAT- *lancet* (EAT), Mediterranean (MED) and Strict Vegetarian (SV) (Vid. 1.4). Assessment of the potential foodshed self-reliance (PFSR), using the relocalization scenario obtained from the master thesis of Filipe (2021)(Vid. 1.5). This relocalization scenario was developed based on soil ecological and other data to define ecologically suitable areas for agriculture and land cover types (temporary and permanent crops, pastures) (Filipe, 2021). The PFSR assessment was obtained for each of the diets considered. The amount of food per food group needed to reach the established nutrition parameters, was used to calculate the PFSR.

In the second step of this study, the foodshed relocalization scenario was used in comparison with the current agricultural land use to assess the water footprint (WF) associated with the potential foodshed for the relocalization scenario and dietary scenarios described above (Vid. 2.1). At this step, an assessment of WF per food group was evaluated, in order to produce the food items consumed in the diets to asses, considering the current occupation scenario (Vid 2.2). Assessment of WF of the diets considering the relocalization scenario was also performed in this step (Vid. 2.3). This made possible to assess the impacts of relocalization on the foodshed self-reliance and water footprint under different diets analyzed (Vid 2.4).

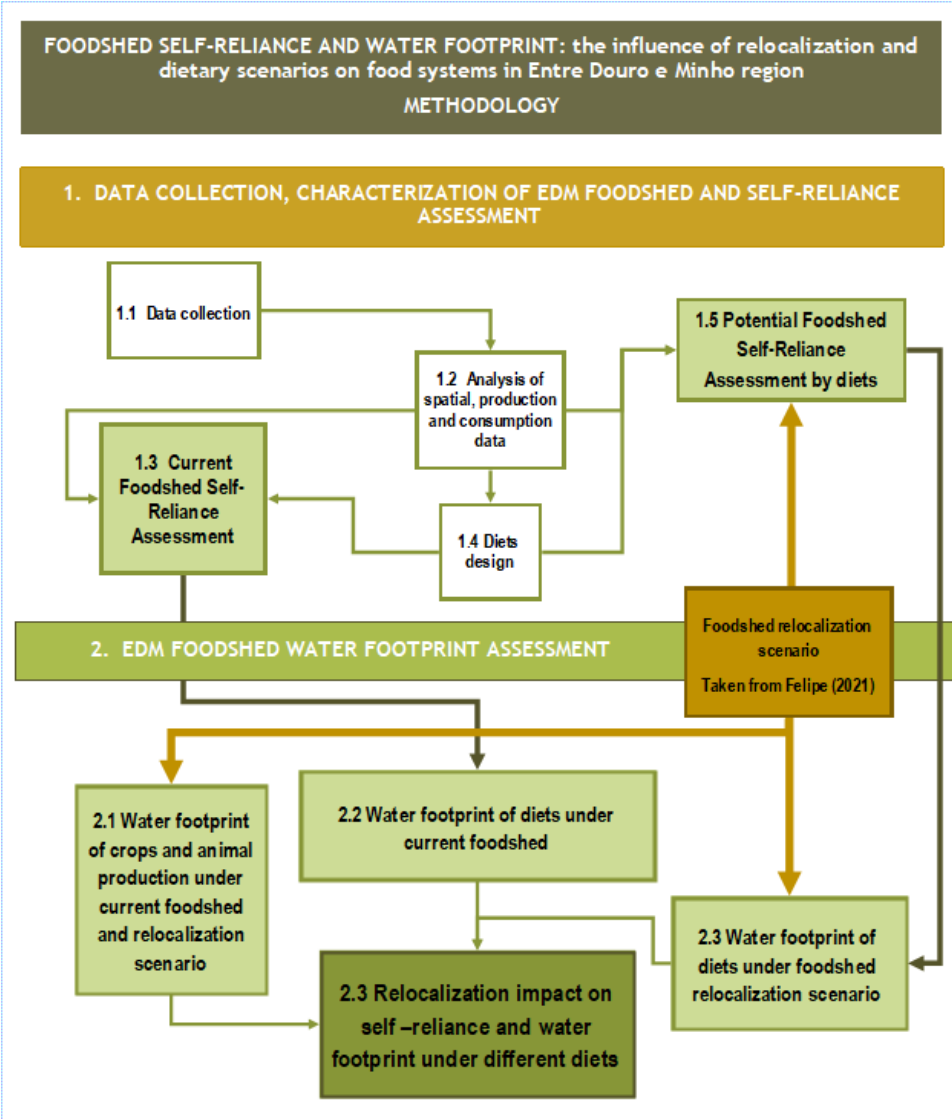


Figure 1 General methodology of the characterization of EDM foodshed and water footprint assessment.

3.2. Study area

The Entre-Douro and Minho (EDM) region was chosen as the study area for this project, mainly because the feasibility of our analysis, considering the region already has a proposition of a relocalization scenario made by Felipe (2021), but also because the region presents a great diversity of crops and also certain level of specialization in some sectors of agroindustry as will be justified below. Located in the northwest of continental Portugal, the region covers the districts of Viana do Castelo, Porto, Braga, and some municipalities of Aveiro, Vila Real and Viseu districts, corresponding to an area of ~ 877,236.5 ha, including 5 sub-regions accordingly to NUTS III 2013, Porto Metropolitan Area (AMP), Cávado, Ave, Tâmega and Sousa and Alto-Minho, totalizing 52 municipalities (Direcção Regional de Agricultura do Entre Douro e Minho, Geometral, and Agroconsultores 1999; INE 2019)(Figure 2).

Map of Entre-Douro and Minho Agrarian Region

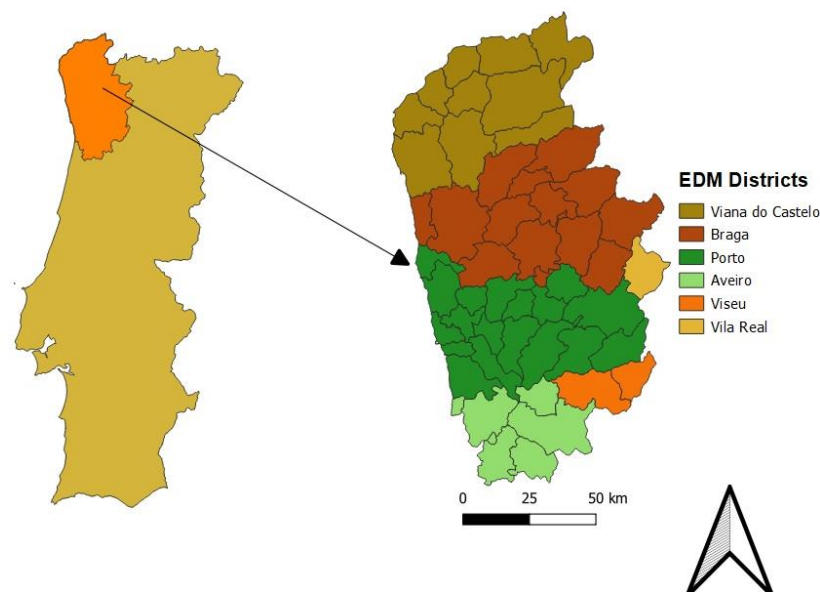
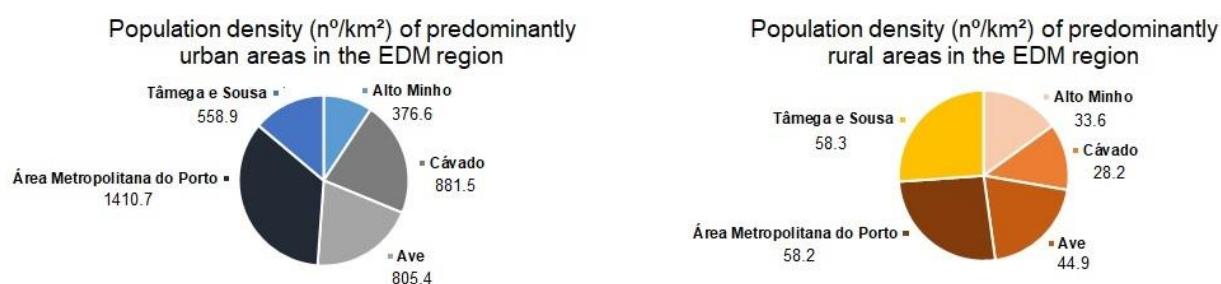


Figure 2 Map of districts presents in Entre Douro and Minho agrarian region.

The EDM region ground elevation has both plains/low altitude regions as well as mountainous regions that can reach more than 1,500 m of altitude above sea level. The climate is considered Mediterranean type with Atlantic influence with wet and mild winters and fresh summers with little or no rain. Precipitation values vary between low lands and mountains, generally they are between 700 mm annually and can go up to 3,000 mm in wet years in mountains (Instituto Português do Mar e da Atmosfera - IPMA), being the region of the country

with the higher levels of precipitation. Nonetheless, there is a dry season with almost no rain, mainly during July and August, which may continue until September (IPMA). Average annual temperatures in this region ranges between 18°C and 22°C. Temperature and precipitation values in the region will vary according to the proximity to the Atlantic Ocean and elevation. Portugal is not homogeneous in terms of scarcity index, for example, the Mediterranean bioclimatic domains, due to prolonged periods of drought and high temperatures, have a higher scarcity index than in the northern region of the country.

Population density of the EDM region is above the national average, according to INE (2021) there are 3 184 533 millions of inhabitants divided between urban and rural areas, being the second most populated region in the country, which represents 1/3 of Portugal's population. Population density is higher in urban areas than in rural areas, with Porto Metropolitan Area having the higheest density for urban areas, while Tâmega and Sousa has the highest density for rural areas, representing 1,410.7 and 58.2 habitants per km² respectively (Graphic 1).

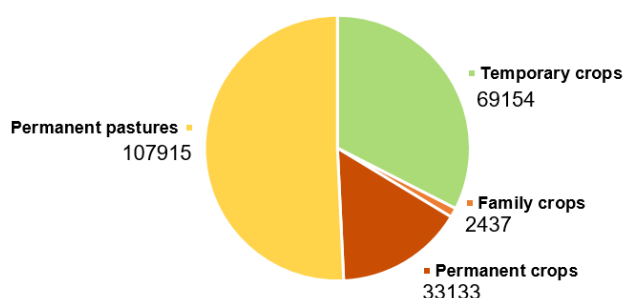


Graphic 1 Population density (nº/km²) of urban and rural areas of the EDM region (INE, 2021).

The region has 212,639 ha of Utilised agricultural area (UAA), what represents 5% of all UAA in the continental Portugal. EDM is characterized by different agriculture land types: the highest percentage is of permanent pastures, followed by temporary crops, permanent crops and, to a lesser extent, family crops (Graphic 2 and Figure 3) (INE 2019). The properties are characterized by their small size, an average of 4.3 ha per property. 94.4% of the systems has a singular producer as legal entity and only 19.3% of the workforce present in the production system is hired from outside of the family nucleus. The Entre Douro and Minho region has both rainfed farming systems (green water) and irrigated farming systems (green + blue water), in addition to presents different types of arable and animal systems, which makes it a great place to study these food system assesment methods (INE 2019). The majority of crops that provide the food products included in the Mediterranean diet are currently produced by irrigated faming systems (Vanham et al. 2016; INE - Instituto Nacional de Estatística, 2021).

Crops that are under irrigated conditions can achieve higher yields and biomass production than crops that grow under rainfed conditions (European Environment Agency 2020). Entre Douro e Minho region between 2018 and 2019 reached 84,3 % of its Utilised agricultural area (UAA) with some kind of irrigation system, presenting 80,004 ha of potential irrigated surface, representing almost half of UAA in the region (42%) (INE 2019). Evidencing the importance of carrying out studies correlating this diet with its consumption of water resources.

Utilised agricultural area (UAA) (ha) of Entre-Douro and Minho region



Graphic 2 Share of main land types of Entre-Douro and Minho region by classes of SAU (INE 2019).

Utilised agricultural area (UAA) of Entre-Douro and Minho region

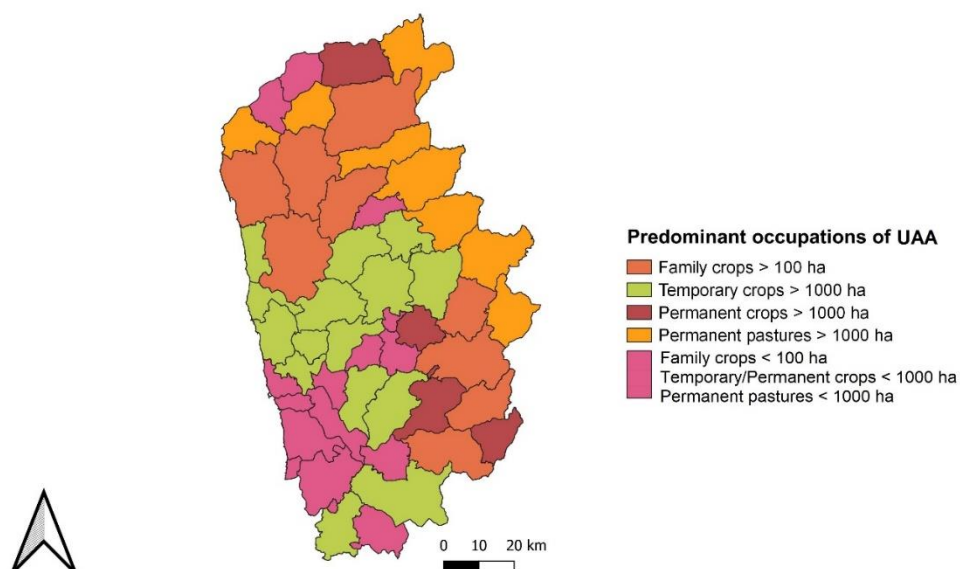


Figure 3 Map of Utilised agricultural area (UAA) of Entre-Douro and Minho region of predominant occupations by municipality (INE 2019).

Arable systems

The arable systems are represented by temporary crops and permanent crops, the first being represented by cereals and grains crops, and the permanent crops mostly represented by the vineyards and orchards. EDM region has almost 50% of its arable land composed by a rotated system of temporary crops (two different crops in the same year and in the same land), which is common in a region of smaller size agricultural patches, with the aim of making the land profitable.

Horticulture systems are evident in Póvoa de Varzim and Esposende coast municipalities and family type of agriculture is present in the area of influence of Porto, from the coast towards the North to the river Lima. The last agricultural census was carried out in 2019 an by INE (National Institute for Statistics), showing a decrease of arable land, around 37.9 thousand hectares, compared to 2009, although the fallow and horticultural areas have increased. Nonetheless, temporary crops continue to be expressive in this agrarian region, arable land as forage crops, as corn plantations used to feed dairy cattle, and cereals for grain, as wheat and rye, planted in higher altitudes, represent more than 85% of the regional total.

The permanent crops in this region are mainly represented by the vines, as EDM carried out 13.4% of national production of wine. In the EDM region, vines represent 70.3% of permanent crops, occupying 23,193 ha, presenting an increase between 2009-2019 of area under vines (+ 1.5 thousand ha). It is also important to highlight that the region has an important kind of wine, the Vinho Verde ("green wine"), characteristic from this zone, which represent a significant share of wine production.

Besides, there is the diversified land cover types in hilly land regions, which can also be evidenced. Due to the conditions of slope, precipitation and varied sun exposure in these environments, is possible to find a presence of several permanent crops, especially fruit trees. Small berry fruits are representative in the regions of EDM and Alentejo, together making up 48.9% of the national area used for these crops. Another representative crop of fruit trees in the EDM region are the citrus fruit, as lemons and oranges, which represent 13.6% of the national production (INE 2019).

Livestock systems

In livestock systems, it is important to consider the agricultural production by rotation of forage corn and grassland, this type of feed crops and land cover stands out, in order to supply the “Dairyshed”, this is a national denomination that refers to the specialization of dairy production in the EDM region. This zone consists of a set of 11 municipalities, namely: Viana do Castelo, Barcelos, Esposende, Póvoa de Varzim, Vila Nova de Famalicão, Vila do Conde, Santo Tirso, Trofa, Maia, Matosinhos and Oliveira de Azeméis, comprising an area approximately 158,000 ha (Direcção Regional de Agricultura do Entre Douro e Minho, 2007) (Figure 4).

The EDM region has the highest average of bovine effectives per holding (62.6 heads/holding), representing together with Açores 72.3% of the national dairy production (INE 2019). This type of production is held by family businesses and small farmers, being the main suppliers of national milk and with a great representativeness in the European market (Direcção Regional de Agricultura do Entre Douro e Minho, 2007). In addition to milk, these dairy production municipalities also supply other types of products, such as slurry, which have free or secured housing systems (67.0% of the dairy effective). The EDM region represents 80.4% of the slurry production, which can be used for different purposes, such as fertilizers for example.

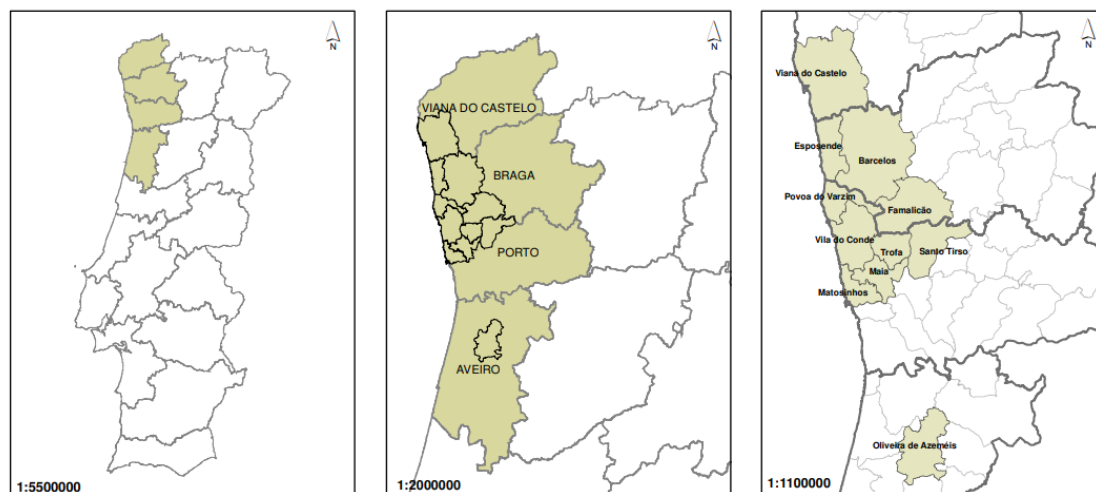


Figure 4 Map of Dairyshed present in Entre Douro and Minho region (sourced from Direcção Regional de Agricultura do Entre Douro e Minho et al. 2007).

It is worth noting that traditional agroforestry systems are present in areas from 700 to 800m, with chestnut groves (soutos) and chestnut woodlands (castinçais). These type of systems are more expressive in the municipalities of Ponte de Lima and Resende, aiming respectively to the production of edible fruits and timber. According to the agricultural census,

the greatest expression of permanent pastures is covered by woods and forests, which benefits both forestry and animal production sectors (INE 2019).

3.3. Data collection and processing

Spatial data were collected mainly from the database of National Institute of Statistics (INE), which provided data of utilised agricultural area (UAA) and its cropping patterns or trends in the share of the UAA under the main agricultural land cover types, also it was considered data from agricultural census (INE 2019) (Table 1).

Table 1 Indicators used for analysis of agricultural land use (INE database).

Indicator	Source
1. Utilised agricultural area of permanent crops (fruits, nuts and vegetable oils)	Area of permanent crops (ha) by Geographic localization (NUTS -2013) and Type (permanent crops) (2020).
2. Utilised agricultural area of temporary crops (cereals, tubers and starchy vegetables, pulses and vegetables)	Area of temporary crops (ha) by Geographic localization (Agrarian Region/Ilha), Type (temporary crops) (2020).
3. Livestock and granivores (cattle, pork, poultry)	- Livestock (No.) of agricultural holding by Geographic localisation and Animal species (2019). - Poultry (No.) by Geographic localization (Agrarian region/ Island) and Category (poultry) (2019);
4. Productivity of agricultural crops	Productivity of main agricultural crops (kg/ha) by Geographic localization (Agrarian region) (2020).

Indicator	Source
	Olive production (t) by Place of origin of olive (NUTS - 2013) (2020).
5. Olive production	Olive oil produced per quintal of olives (hl/ q) by Geographic localization (Agrarian region), Type of oil mill and Extraction system used (2020).
6. Egg production	- Poultry (No.) by Geographic localization (Agrarian region/ Island) and Category (egg production) (2019); - Egg production (t) by Geographic localization (NUTS - 2013) and Type of eggs (2020).
7. Milk Production	Milk collected (t) by place of origin (NUTS - 2013) and Type of milk (Collected) (2020).
8. Wine production	Declared wine production (hl) by producers by place of vinification (NUTS - 2013)
9. Daily Edible Capitation of Food	Portuguese food balance 2016-2020 – Daily Edible Capitation of Food Products Available for Supply by type of food product.
10. Wine consumption per capita	Human consumption of wine per capita (l/ inhab.); Portugal/Annual
11. Resident Population per city	Resident population by place of residence. Annual Statistical Survey (2019).

With the collection of this information, it was possible to analyse the current foodshed, cropping patterns, and the productivity values of crops and animal productions.

3.4. Current Foodshed Self Reliance Assessment

In order to describe the EDM foodshed, regional food production and consumption were analysed, enabling to evaluate the CFSR. This methodology was based on Cardoso et al. (2017) and Cardoso et al. (2021).

To estimate the annual crop production of temporary and permanent crops, the areas allocated to each type of crop and their respective productivity values per hectare were considered. For vegetable oils, land use and production indicators were considered based on data from the crops of their respective raw materials (olive and sunflower hull). As, according to INE, there is no production of sunflower in the EDM region, for the category of vegetable oils only olive oil was considered. For the EDM region, the olive oil indicator for the year 2020 gives the production value of 0.13 hl/q (yard) of olives or 1.3 hl/t of olives. Therefore, the assessment of the production of olive oil was done considering the olive production for the EDM region. The conversion of oil volume (hl) to mass (ton) was obtained through the oil density, multiplying the volume value obtained by 0.0913. Due to the expressive wine production in the region with regional, national and global importance, in this step of the study the production and consumption indicators for wine, given in hectolitres (hl), were also considered for the assessment of the self-reliance of wine production in the current foodshed.

For the livestock and granivores meat production, the livestock population (indicator 3, table 1), were considered the values of meat production per animal estimated in Table 2. To evaluate eggs production in the EDM region, an average of eggs production (t) per laying chicken were estimated, using the indicator number of laying chickens present in the North region (NUTS 2013) and the eggs production (t) values for the North region. With this average number and the indicator of the number of laying chickens per council was possible to estimate the municipal egg production (t) of the EDM region. For dairy production, the values of production were founded on indicator 7: Milk collected (t) by place of origin (NUTS - 2013) and Type of milk (Collected) (2020) (Instituto Nacional de Estatística (INE) 2019).

Table 2 Yield of meat per animal.

Food product	Yield per animal (t)	Study
Beef	0.36	(Cowell and Parkinson 2003)
Pork	0.072	
Chicken and other poultry	0.0017	

National data on *per capita* food consumption was used, considering regional consumption patterns based on Portuguese Food Balance Sheet (BAP) 2016-2020 (INE 2020) and using Daily Edible Intake of Food Products available on INE database (“Capitacao_gramas”). Thus, taking into account the total population of the region, found in INE database available on population census (INE 2021), the values of consumption of each food group were estimated, after it was multiplied by the days of the year to find the annual regional consumption for each food group. To calculate CFSR in the EDM region, the production and consumption values of each municipality present in the region were compared. After this, the CFSR or quotient between production by municipality and total regional consumption was obtained by food group. Thus, the municipal contribution to regional self-reliance was obtained and was estimated the CRFSR status by the food supply of the foodshed.

$$CFSR = \frac{\text{foodgroupproductionbymunicipality}}{\text{foodgroupregionalconsumption}}$$

From these values, charts were developed using geographic information system QGis 3.10.10 with the selected food groups: Cereal grains, tubers, vegetables and pulses (temporary crops); Fruits, vegetables oils and nuts (permanent crops); and Animal products. These charts were based on the Carta Administrativa Oficial de Portugal (CAOP) available on the website of the Direcção Geral de Território de Portugal (DGT, 2020).

3.5. Diets design

Based on the BAP, a Reference diet (REF) was designed, considering the regional consumption pattern found in the previous step. To design other diets, was performed a review and gathering of 16 studies that analyzed the influence of changes in dietary pattern on ecological footprints, with the keywords “diets”, “footprint”, “water footprint”. From this studies,

eight evaluated the influence of diets on the water footprint (Vanham, Mekonnen, and Hoekstra 2013; Vanham et al. 2016; Vanham et al. 2018; Kurtz et al. 2020; Vanham et al. 2021a; Zucchinelli et al. 2021).

Then, considering this review, isocaloric diets with adaptations of animal sources of proteins and vegetables were designed. The Mediterranean diet (MED) (Bach-Faig et al. 2011; U.S. Department of Health and Human Services and U.S. Department of Agriculture 2015) is considered in the majority of studies from European Union because of its health benefits and cultural acceptability. It was also considered EAT-Lancet diet (EAT), developed based on “the total global amount of cropland use, biodiversity loss, water use, greenhouse-gas emissions, and nitrogen and phosphorus pollution that can be due to food production”, considering the nine planetary boundaries which safeguard Earth’s natural cycles and maintain a ‘safe-operating space’ for the continued existence of life (Willett et al. 2019). MED and EAT diets have less than 50% of animal source of protein in their composition, being considered both plant-based diets in this study. Thus, a Strict Vegetarian diet (SV) with no source of animal protein and a Meat-based diet (MB), with more than 50% of animal source of protein were also considered. In the SV diet it was considered that all soya products would be considered in the pulses total. Despite fish-meat consumption per capita in Portugal has been above the average in Europe, in 2020 it represented only 20% of daily intake of total animal meat and 9% of daily consumption of animal products (INE, 2020). Because of that, in this study fish meat intake was not considered for diets design. Beverages were not considered also to allow the isocaloric comparison between diets sourced from the literature.

MB, MED and SV diets were design using the dietary guidelines of the United States Department of Agriculture (U.S. Department of Agriculture and U.S. Department of Health and Human Services 2010), as these guidelines offers the necessary nutrients and calories adjustments for the plant based alternatives diets scenarios. Also, was tried to avoid using different sources of dietary guidelines, however, this U.S. guideline presented different proposals based on the daily amount of calories, allowing it to be compared with the EAT-lancet diet. EAT diet was considered based on Willett et al. (2019), which has the same (Table 3). All diets were chosen and adjusted to be isocaloric. This adjustment was based on average calories consumed by Planetary Health EAT-lancet – 2,500 kcal in order to allow comparison with other diets found in the literature (Strict Vegetarian and Mediterranean diets).

Table 3 General description of diets design.

Diet	Description	Characteristics
Reference diet (REF)	Portuguese Food Balance Sheets (INE, 2021)	Diet is based on daily food consumption by Portuguese population
Meat – based (MB)	Based on USDA guidelines (USDA, 2015)	Diet based on animal source of protein (>50%).
EAT – <i>lancet</i> (EAT)	Based on Willet, et al 2019	Diet based on vegetal source of protein (<50%). Include animal flesh and dairy consumption.
Mediterranic / (MED)	Based on USDA guidelines (USDA, 2015)	Diet is based on vegetal source of protein (<50%) with a representative consumption of nuts. Include animal flesh and dairy consumption.
Strict – Vegetarian (SV)	Based on USDA guidelines (USDA, 2010)	Diet is only based on vegetal source of protein (100%). Includes great amount of beans, nuts and seeds.

Based on the INE database and the Portuguese Food Balance Sheet, the Reference diet showed that the population of Entre-Douro e Minho has a higher annual intake of cereals, dairy products and meat respectively than other food groups (Table 4).

Table 4 Reference diet (REF) (currently practiced) according to Portuguese Food Balance (Instituto Nacional de Estatística 2021).

Food group	Quant. g/day	t/pop/year
Cereal grains (with rice)	347.6	407,732.9
Tubers	213.1	15,743.8
Pulses	13.4	249,973.4
Vegetables	266.3	312,306.1
All fruits	269.1	864,625.3
Nuts	14.2	64,260.5
Vegetable oils	50.1	16,707.7
Meat	228.4	269,572.9
Eggs	26.3	30,843.4
Dairy	322.6	378173.2

Considering the references used in the development of diet scenarios, the Meat-based and Mediterranean diets have a higher consumption of dairy sources, while the EAT-*lancet* diet has a higher consumption of vegetables and the Strict Vegetarian has a higher consumption of fruits. It is also worth mentioning that the latter has more than twice the consumption of pulses than the other diets analyzed (Table 5).

Table 5 Daily food intake by diet scenario. (1) Quantity (g/day), (2) Quantity for total regional population for a year (t/pop/year).

Diet scenario	Meat based (MB)		EAT – <i>lancet</i> (EAT)		Mediterranean (MED)		Strict Vegetarian (SV)	
Food group	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)
Cereal grains (with rice)	224	260,367.4	232	269,666.3	224	260,367.4	224	260,367.4
Tubers or strachy vegetables	155.94	181,257.6	50	58,117.73	155.94	181,257.6	155.94	181,257.6
Pulses	53.76	62,488.2	100	116,235.5	53.76	62,488.2	172	199,925
Vegetables	104	483,539.5	300	348,706.4	104	120,884.9	104	120,884.9
All fruits	450	523,059.5	200	232,470.9	562	653,243	450	523,059.5
Nuts	21.9	25,455.5	25	29,058.86	21.9	25,455.5	79.09	91,930.62

Diet scenario	Meat based (MB)		EAT – <i>lancet</i> (EAT)		Mediterranean (MED)		Strict Vegetarian (SV)	
Food group	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)	Quantity (g/day)	(t/pop/year)
Vegetable oils	31	36,032.9	46.8	54,398.2	31	36,032.9	21	24,409.4
Meat	95.48	110,981.6	43	49,981.25	95.48	110,981.61 2	-	
Eggs	28.52	33,150.3	13	15,110.6	28.52	33,150.3	-	
Dairy	732	850,843.5	250	290,588.6	560	650,919	-	

3.6. The foodshed land-use relocation scenario

Due to the methodology employed in the present study, where the source of information on regional production is accessed from estimates using land cover and productivity data taken from the INE database, the present study does not follow the ecological footprint methodology proposed by Wackernagel and Rees, but only considers bioproductive areas associated with crop production and those used for grazing. To assess PFSR by diets, the areas needed to produce the amount of food present in each of the diets were estimated, which represents the food footprint (FF) (Table 6). The amount of food intake by diet was calculated by considering crop productivity for plant production (t/ha) (section 3.2.1), that uses the database from INE (2021), and animal productivity per area (Table 6). As beef production uses semi-extensive systems, we considered half of the footprint area as pastures and the other half as fodder crops, mainly silage and grain cereals, included in total temporary crops (Cowell and Parkinson 2003). Because o

Table 6 Land footprint values for animal food products.

Food product	Type of system	Area per tonne of food product (ha/t)	Productivity (t/ha)	Study
Beef	Semi-extensive	4.7	0.212	(Cowell and Parkinson 2003)
Pork	Intensive	1.2	0.83	(Cowell and Parkinson 2003)
Chicken and other poultry	Intensive	0.5	2	(Cowell and Parkinson 2003)
Eggs	Battery cage	0.45	2.22	(Mollenhorst and De Boer 2006)
Dairy	Intensive	0.22	4.54	(Cowell and Parkinson 2003)

The proportion of each food group produced by category of agricultural land use (temporary and permanent cropland, permanent pastures, multiple uses) is estimated considering the proportion of each food group in the diets chosen, maximizing the diversity of the supply of food products in the potential FS. This proportion was represented by partial and total percentages, as follows:

a) partial – is the percentage of the area of the food group in the total area needed for temporary or permanent crops separately;

b) total – is the percentage of the food group in the total agricultural land uses or land cover types necessary for the diet, considering arable land (temporary and permanent cropland), and pastureland.

Thus, it was possible to access the total area of the current foodshed needed to provide food in the diet scenarios, separately evaluating the area for temporary, permanent and pasture crops. Along with this, information about the land use defined in the relocalization scenario was taken from Filipe (2021) (Appendix 8). This relocalization scenario was built considering ecological and agroedaphic suitability, according to four main characteristics: soil agroedaphic suitability, soil ecological value, slope and terrain morphology. After that, it was possible to obtain the matrix that defines the suitability for agricultural uses, specifying the ecological conditions for temporary crops, permanent crops and pastures. From the relocalization scenario, it was also necessary to obtain the area occupied by temporary and permanent crops and pastures in each of the municipalities of the EDM region to evaluate the potential foodshed self-reliance (PFSR).

3.7. Self-reliance assessment and simulations

To calculate Potential Foodshed Self-Reliance (PFSR), considering the relocalization scenario, the following formula was used for each food group at the municipal level, based Cardoso et al. (2017) and Cardoso et al. (2021):

$$P(\text{foodgroupself}_{\text{reliance}}) = \frac{\text{agricultural land use area} \times \% \text{area}(\text{foodgroup})}{\text{food footprint for self}_{\text{reliance}} \text{ by food group}}$$

agricultural land use area: Agricultural land use area: the sum of the present and proposed areas on the relocalization scenario of permanent crops, temporary crops and pastures separately.

food footprint for self-reliance by food groups: the areas needed to produce the amount of food present in each of the food groups by diets.

To evaluate the PFSR of permanent crops, as the diets analyzed did not include wine intake, the percentage of the area occupied by vines in current land occupation was taken from total area of permanent crops in the relocalization scenario, although occupying 70% in the region. This was based on vineyards production data from INE (section 3.2.1.). As beef production occupies half area from temporary crops (fodder) and half from pastures, an average of beef production potential self-reliance was calculated, using the following formula:

$$P(Beefself_{reliance}) = \frac{(beefPFSRT \times 0,5) + (beefPFSRPas \times 0,5)}{2}$$

All data resulting from PFSR assessments were represented on maps developed in the geographic information system QGis 3.10.10.

3.8. Water footprint assessment and simulations

3.8.1. Water footprint of crops and animal production under current foodshed and relocalization scenarios

This work considered blue, green and gray (total) water footprint present on Mekonnen and Hoekstra (2012). This is a methodology widely used in studies that relate changes in dietary patterns and its influence on water footprint of crop and animal production (Vanham, Mekonnen, and Hoekstra 2013; Vanham and Bidoglio 2014; Vanham et al. 2016b; Vanham et al. 2018; Noya et al. 2019; Zucchinelli et al. 2021; Vanham et al. 2021a).

The steps of water footprint assessment are presented in Figure 5. First, considering the indicators of regional crop and animal production used in section 3.2.1. (Table 7), the total water footprint of current agricultural crops was assessed for each municipality by multiplying the production values (t) by WF units (m³/t)(Vid. 1.1). For each food group a respective unit of WF amount was used as listed in the global database provided by Mekonnen and Hoekstra (2011) and Mekonnen and Hoekstra (2012) (Table 8).

Secondly, to analyze the total WF of crop production under relocalization scenario the percentage of area occupied by each permanent and temporary types of crops on current agricultural occupation scenario was considered. Then this proportion was considered to

calculate how much area each food group occupies on the relocation scenario (Vid 1.2). The indicator of productivity (Table 7) was used to calculate how much vegetable biomass would be produced on the relocation scenario. To assess the WF of animal products in this scenario, since it was only possible to obtain information about the area occupied by main agriculture land uses in the relocation scenario (e.g., temporary), the grazing livestock index (number of cattle heads per fodder area) was calculated, considering the proportion of area occupied by fodder and pastures crops in the current foodshed, excluding the proportion area dedicated to temporary crops such as vegetables. By having this ratio, it was possible to estimate the potential number of animals present in the relocation scenario. The indicator of productivity (Table 7) was used to estimate the animal production on the relocation scenario. After this, the total WF of animal production of the relocation scenario was assessed using WF units (m^3/t) present on Table 8 (Vid. 1.3). Here, we assume a business-as-usual scenario considering that crop and animal production stays in the same proportion in the potential areas for relocation as it is now in EDM region.

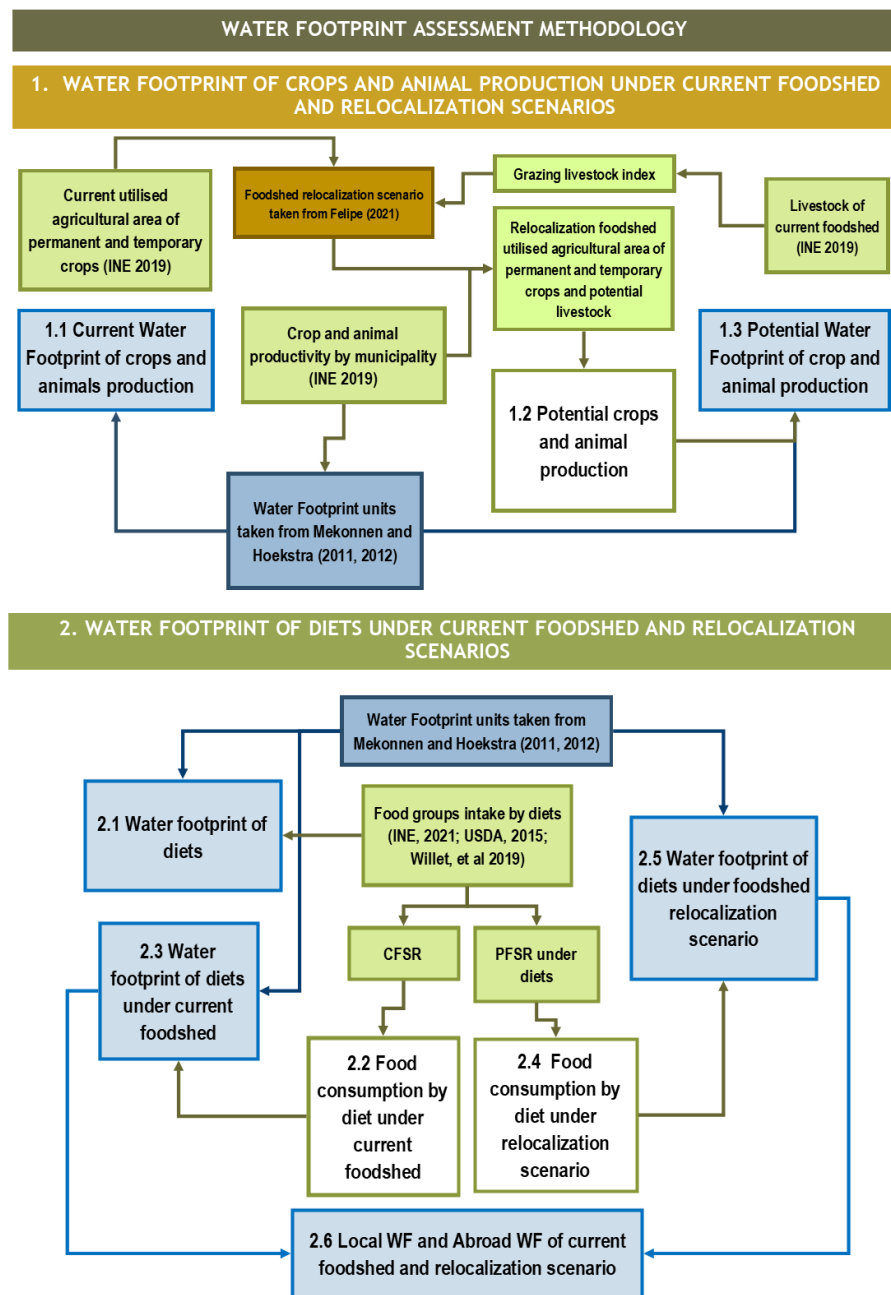


Figure 5 Methodology of the water footprint assessment (CFSR – Current Foodshed Self-Reliance; PFSR – Potential Foodshed Self-Reliance).

Table 7 Indicators of EDM foodshed production

Indicator	Source
1. Production of agricultural crops	• Productivity of main agricultural crops (INE, 2019) • Utilised agricultural area of permanent and temporary crops (INE, 2019)
2. Animal production	• Livestock (No.) of agricultural holding (INE, 2019) • Eggs production (INE, 2019) • Milk production (INE, 2019) • Yield per animal (beef, pork and poultry) (Cowell and Parkinson 2003) • Yield per animal (eggs) (INE, 2019) • Yield per animal (milk) (INE, 2019)

Table 8 The water footprint of some selected food products from vegetable and animal origin (1996–2005) (adapted from Mekonnen and Hoekstra, 2011 and 2012).

Food item	Total water footprint per ton (m ³ /ton)
Cereal grains	1,644
Tubers	387
Pulses	4,055
Vegetables	322
All fruits	962
Nuts	9,063
Vegetable oils	2,364
Wine	869
Beef	15,415
Poultry	4,325
Pork	5,988
Eggs	3,265
Dairy	1,020

3.8.2. Water footprint of diets

To calculate WF for the different diets under a consumption perspective (regardless from whether the products are produced on EDM region or not), the annual amount of food intake by regional population (t) of each food group in the five diets was multiplied by the WF units (m^3/t) (Vid. 2.1) assessing the WF of consumption.

Water footprint of diets under current foodshed

To calculate the WF of diets under current foodshed, the annual amount of food intake by regional population (t_1) in the different diets was multiplied by the CFSR of each food group (food production as a percentage of consumption), to assess how much biomass of food product (t) would be produced to attend the specific food intake by diet (Vid. 2.2). Then this value was multiplied with the WF units (m^3/t) to assess the water use by each diet analyzed (Vid. 2.3). The WF of diets under current foodshed was assessed based on the following formula:

$$WF_{dietscurrent} = (t_1 \times currentFSR_{foodgroup}) \times WF_{foodgroup}$$

Water footprint of diets under foodshed relocalization scenario

Here the annual amount of food intake by regional population in the different diets was also considered. But now, it was multiplied by PRFSR of each diet to assess how much food product (t) would be produced to attend food consumption of each diet (Vid. 2.4). Then this value was multiplied with the WF units (m^3/t) to assess the water use by each diet under the relocalization scenario (Vid. 2.5). The WF of diets under the relocalization foodshed was assessed based on the following formula:

$$WF_{dietspotential} = (t_1 \times potentialFSR_{foodgroup}) \times WF_{foodgroup}$$

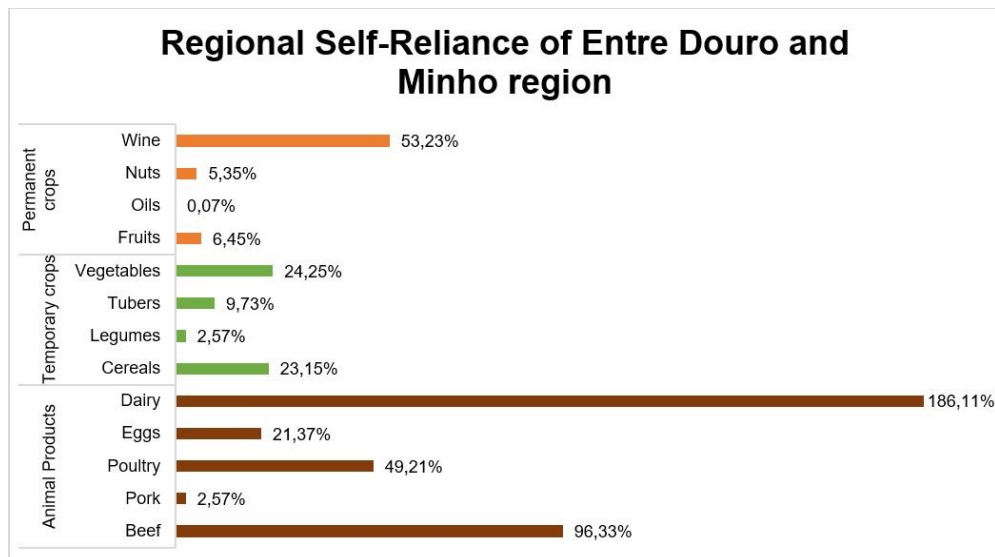
To understand the water flow of food systems on the EDM region, the WF of production and the WF of consumption were compared. This gives an idea on the amount of WF by food group, meaning that these products are produced locally (positive values), and the abroad WF, meaning the amount of food groups produced outside EDM region and therefore using water somewhere else (negative values) (Vid. 2.6). Here, the virtual water footprint (the water used in the production process of food, e.g., rice packaging, bread production) was not considered, because only primary products were assessed as an indicator of food intake by diet.

4. Results

4.1. Current and Potential Foodshed Self-Reliance Assessment

4.1.1. Current Foodshed Self Reliance (CFSR) Assessment

Overall, in 2020, the EDM region is not meeting self-reliance in the major food groups, especially for oils (0.07%), legumes (2.57%), fruits (6.45) and nuts (5.35%) (Graphic 3). Exception is for animal production, where the region exceeds self-reliance regarding dairy production that met 186.1%, followed by beef that met 96.33% (Graphic 3; Table 9), especially in the municipalities of the so called “Dairy basin from EDM region”: Vila do Conde, Póvoa de Varzim, Barcelos and V.N. Famalicão (Figure 6). The other types of animal production met less than half of self-reliance, namely 49.2% for poultry, 21.4% for eggs and of only 2.6% for pork. When analysing self-reliance by major agricultural systems, permanent crops appear with lower self-reliance compared to temporary crops and animal production, although wine met 53.23%, especially in the municipalities in the transition to the Douro wine region such as Amarante, and municipalities from the wine sub-region of the “Alvarinho” green wine (Figure 7). The temporary crops show low self-reliances, even for vegetables (24.25%), especially in the municipalities from the inland/mountainous areas (Figure 8). However, municipalities close to the sea, in particular Póvoa de Varzim show higher self-reliances, even though never reaching 100%, meaning that consumption is higher than production. Ponte de Lima presented the highest cereals CFSR, the council met 1.4% and also highest pulses CFSR, with 0.2% of the annual requirement on the EDM region. Resende was the municipality with higher representation in most of arable crops production, it met 0.06% of tubers in the region, 0.5% of fruits, 0.01% of olive oils and 0.7% of nuts consumed on the EDM region. Póvoa do Varzim met 6.7% of vegetables consumed. Felgueiras met 8.82% of wine consumed (Figure 7 and 8). In animal production, Vila do Conde has the higher contribution to region’s beef consumption, where beef production met 27.82% of the total consumed, and contributed to 48% of dairy consumed on the EDM region. Vila Nova de Famalicão met 0.81% of pork consumed. Amares met 12.71% of poultry and 6.3% of eggs consumed (Figure 6). Porto and São João da Madeira presented the lower CFSR for meat, eggs, dairy and vegetables oils, with less than 0.001%, of cereals, pulses, vegetables, fruits with no production and consequently no CFSR. Porto, the major city in EDM without an agriculture production system presented one of the lowest CFSR for all the food groups, especially for nuts, with 0.002% (Appendix I).



Graphic 3 Current Foodshed Self-Reliance of Entre Douro and Minho region by type of crops and animal products.

Table 9 Production of main agricultural crops and animal products in Entre Douro and Minho region (EDM) (t); Consumption of EDM region (t/population/year); Current Food Self-Reliance of the region (production as a percentage of consumption).

Food group	Production EDM region (t)	Consumption EDM region (t/pop/year)	Self-Reliance (%)
Cereals	94,403.4	407,732.9	23.1
Pulses	407.8	15,743.8	2.5
Tubers	24,321.9	249,973.4	9.7
Vegetables	75,736.4	312,306.1	24.2
Fruits	55,738.6	864,625.3	6.4
Vegetables oils	44.9	64,260.5	0.06
Nuts	894.6	16,707.7	5.3
Wine	891,174 ¹	1,673,986.5 ¹	53.2
Beef	63,149.04	66,188.33	96.33
Pork	3,395.3	132,055.3	2.5
Poultry	2,878.6	5,850.1	49.2
Eggs	6,591.9	30,843.4	21.4
Dairy	703,836	378,173.2	186.1

¹ value in hectolitres

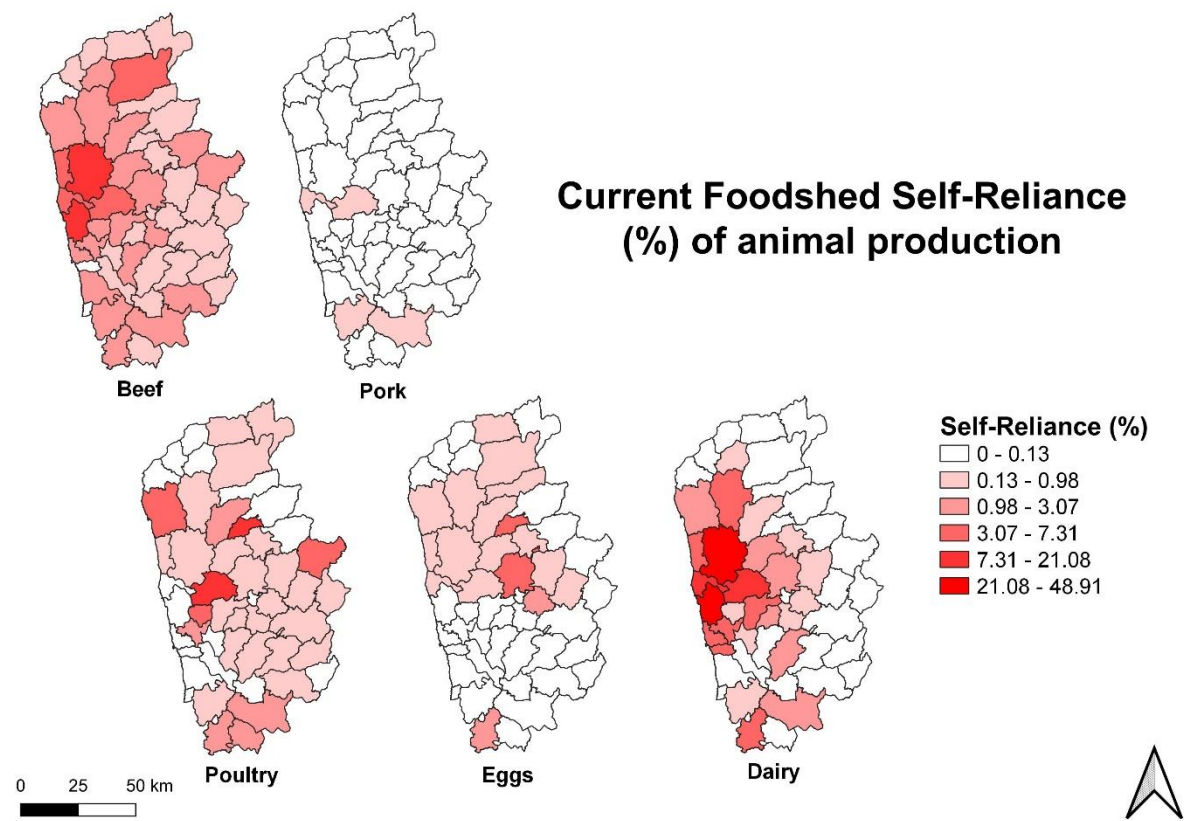


Figure 6 Entre Douro and Minho animal products current self-reliance.

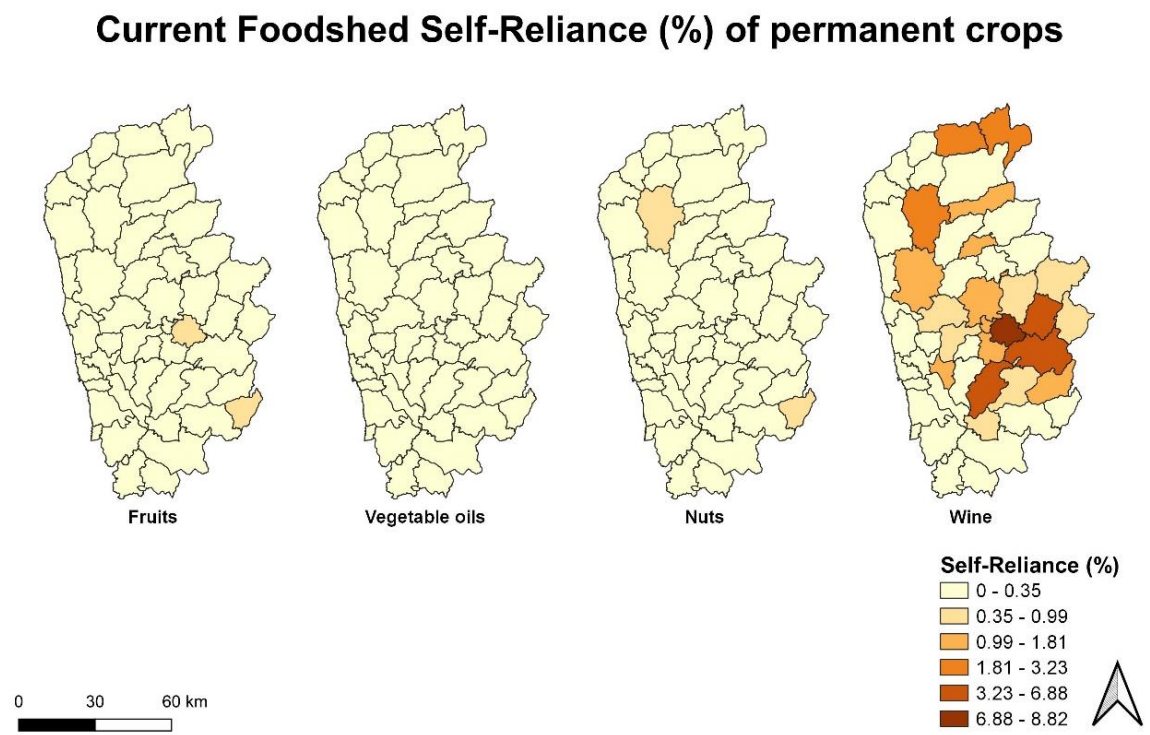


Figure 7 Entre Douro and Minho permanent crops current regional food self-reliance.

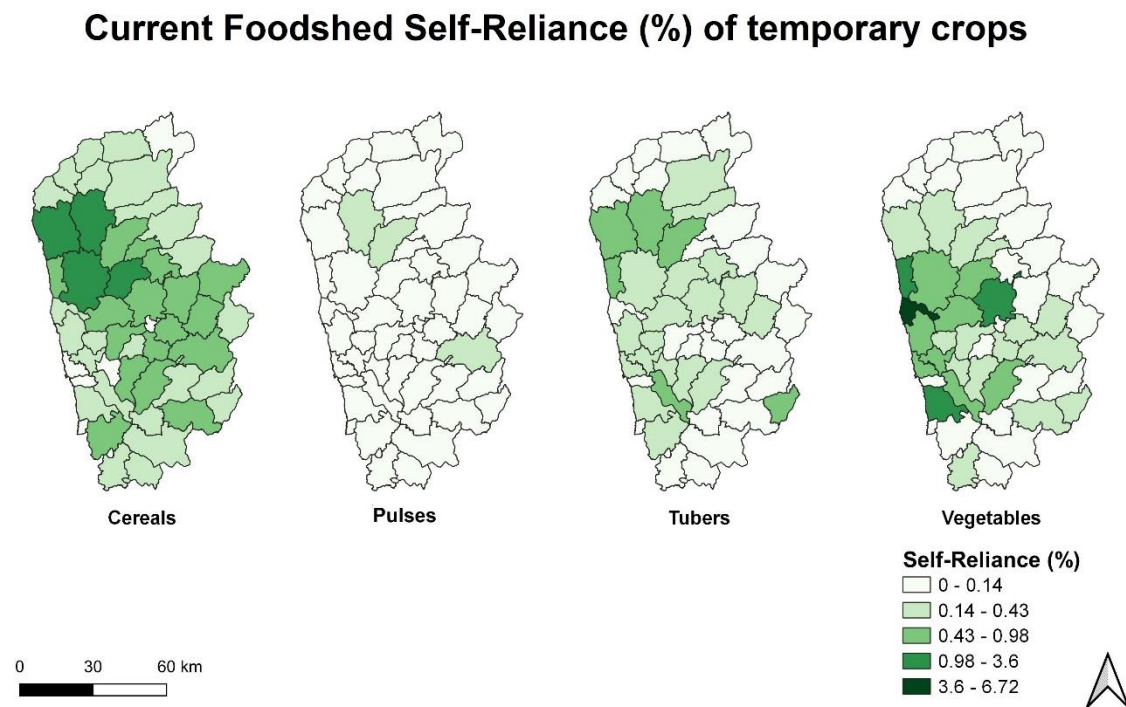


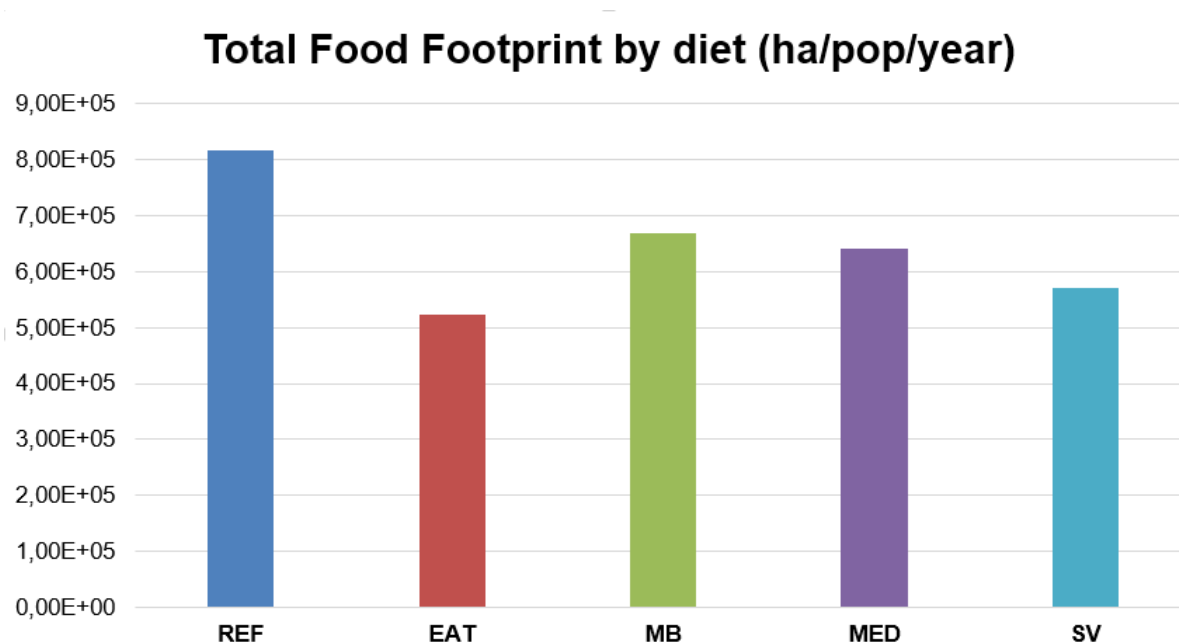
Figure 8 Entre Douro and Minho temporary crops current self-reliance.

4.1.3. Potential Foodshed Self-Reliance (PFSR) Assessment by diets

The first step of the assessment of PRFSR showed how much area was necessary to suit the required quantity of each food group included for each diet scenario to feed EDM population during a year. The REF diet presented the higher food footprint with 816,178.8 ha needed to produce the regional food needs, the detailed values of area needed by crop and animal production is on Table 10. It was followed by MB diet scenario with 668,168.7 ha, then MED diet with 641,464.8 ha, SV diet with 570,950.4 and the diet that has the lowest food footprint was EAT diet with 523,553.4 ha (Graphic 4).

Table 10 Area needed of crop and animal food groups for regional self-reliance considering Reference Diet (REF) (ha/population/year).

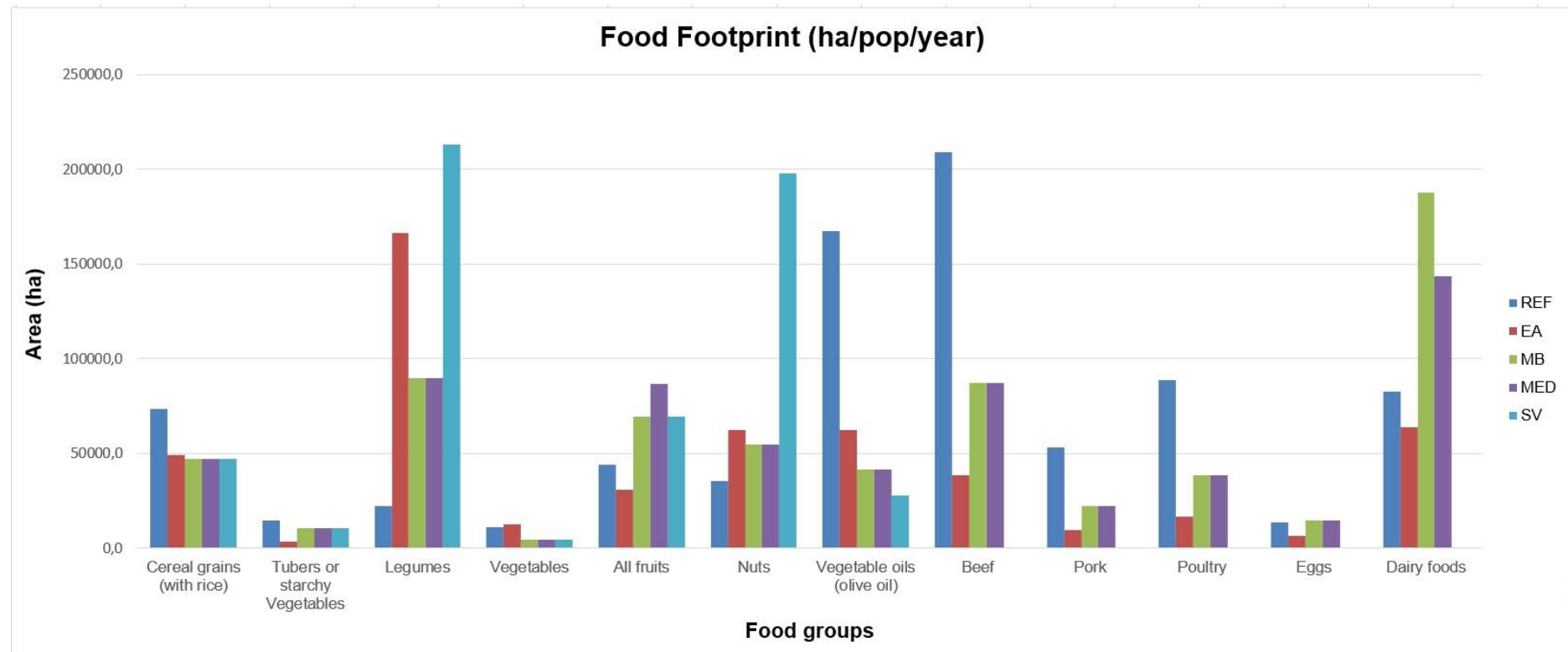
Food groups	Productivity EDM (t/ha)	Consumption Quantities (t/pop/year)	Food Footprint (ha/pop/year)	(%) in total area
Cereal grains (with rice)	5.494	404,034.4	73,541.03	9.01
Tubers	17.104	247,697.8	14,481.86	1.77
Pulses	0.698	15,575.6	22,314.61	2.73
Vegetables	27.401	309,535	11,296.49	1.38
All fruits	7.511	329,643.7	43,888.12	5.38
Nuts	0.465	16,505.4	35,495.48	4.35
Vegetable oils	0.348	58,234	167,339.08	20.50
Beef	0.212	44,332.20	209,114.16	25.62
Pork	0.83	44,332.20	53,412.29	6.54
Poultry	2	177,863.49	88,931.75	10.90
Eggs	2.22	30,569.9	13,770.23	1.69
Dairy foods	4.54	374,975.6	82,593.74	10.12



Graphic 4 Total Food Footprint (ha/population/year) by diets scenarios.

Considering other diets, the EAT and SV have the highest values of pulses food footprint, with 166,526.4 ha and 213,153.8 ha respectively. The EAT diet had the highest vegetables food footprint with 12,726 ha. The MED diet showed a fruits food footprint of 86,971.5 ha. The SV diet also showed the highest value of nuts food footprint with 197,700.3 ha. Dairy food footprint highest value are represented by the MB diet with 187,410.5 ha (Graphic 5).

Considering temporary crops, SV diet presented the highest PFSR, with 67.20%, followed by EAT diet, with 53.14%. The other diets scenarios presented a PFSR lower than 50%. In permanent crops, EAT diet presented the highest PFSR, with 50.82%, followed by MB diet, with 48.05% (Figure 9). The other diets presented PFSR lower than 50%, however, all diets scenarios presented PFSR higher than CFSR for permanent crops (Figure 10). Besides SV diet, the other diets presents PFSR for beef production, being the EAT diet the most self-reliable, with 31.39% of PFSR (Figure 11). Beef production PFSR was lower than CFSR in all diet scenarios that presented beef intake. The values of PFSR by municipality are represented on Appendix II. PFSR by all diets are represented on Graphic 6.



Graphic 5 Food footprint (ha/population/year) by food groups and diets scenarios

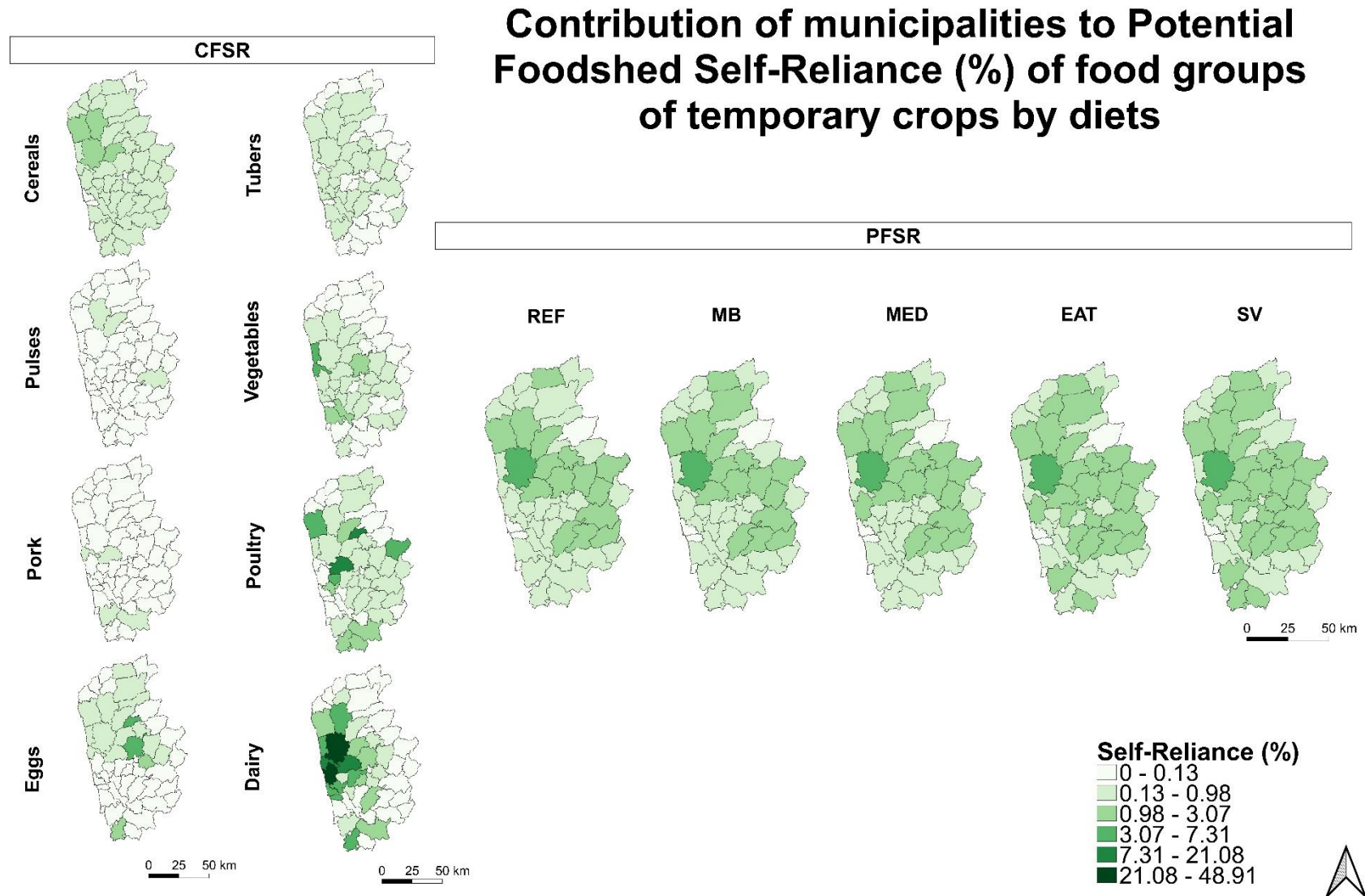


Figure 9 Contribution of municipalities to PFSR of temporary crops in EDM region under diets. (CFSR) Current Foodshed Self-Reliance; (PFSR) Potential Foodshed Self-Reliance.

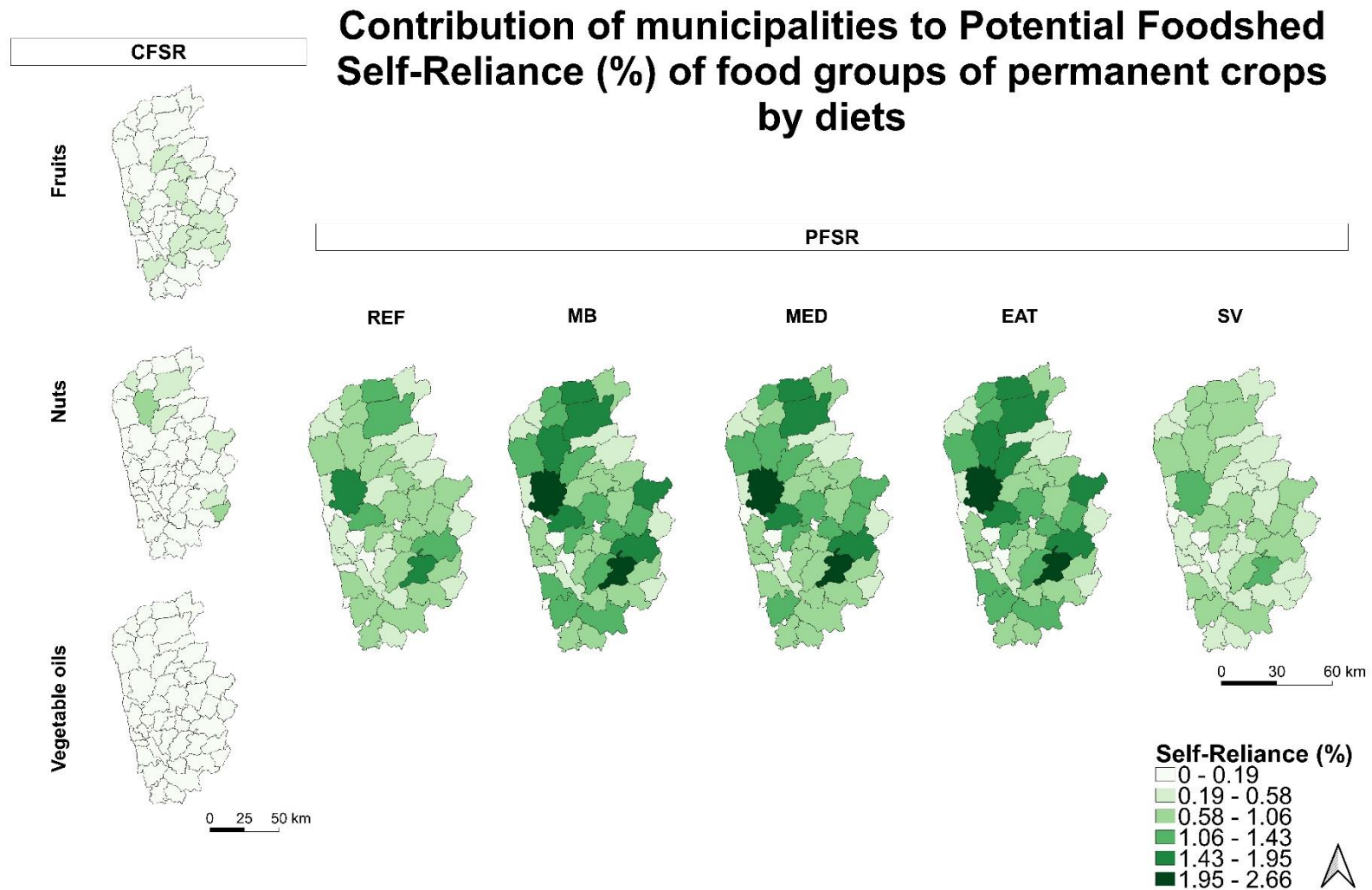


Figure 10 Contribution of municipalities to PFSR of permanent crops in EDM region under diets. (CFSR) Current Foodshed Self-Reliance; (PFSR) Potential Foodshed Self-Reliance.

Contribution of municipalities to Potential Foodshed Self-Reliance (%) of beef by diets

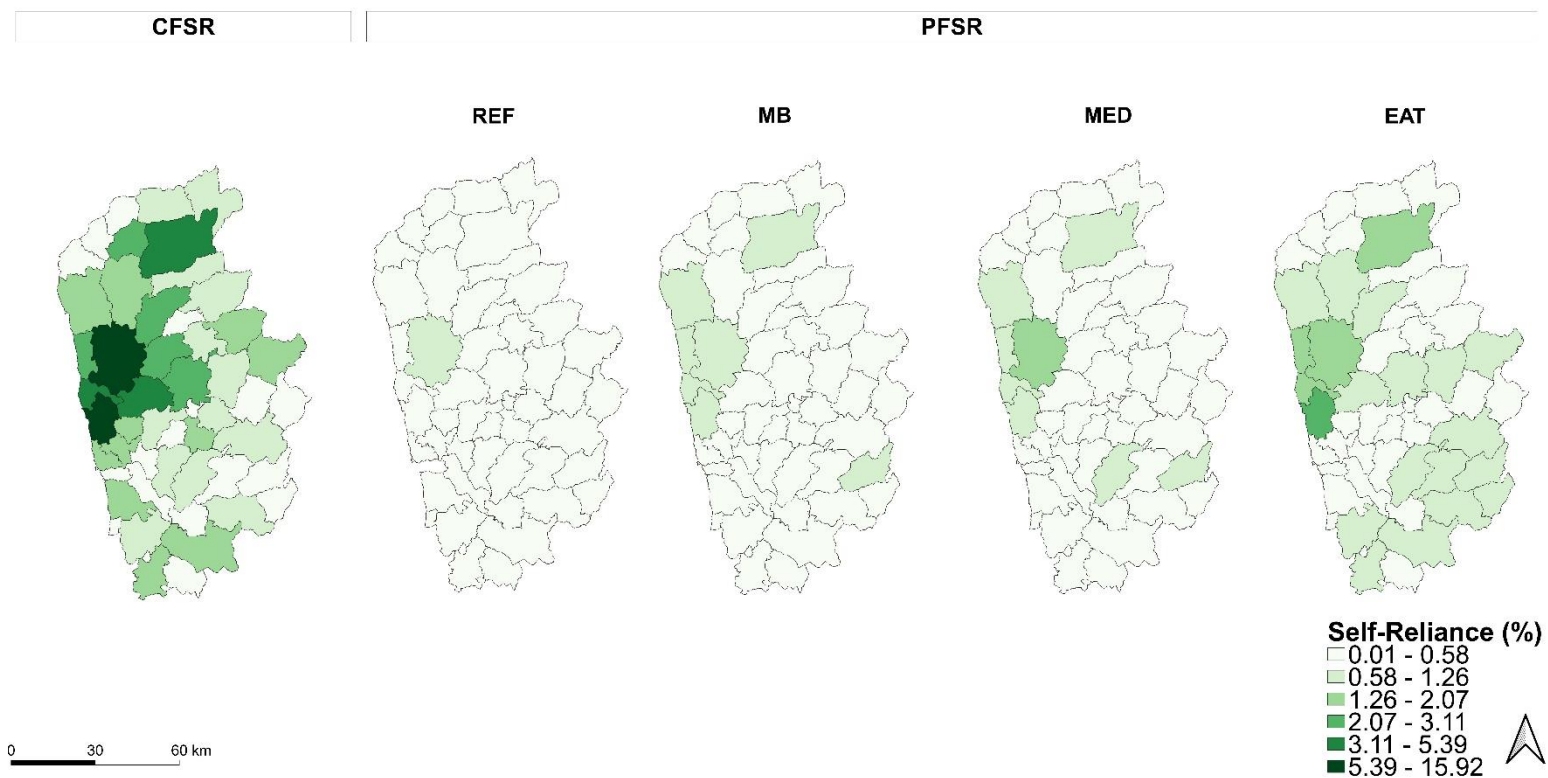
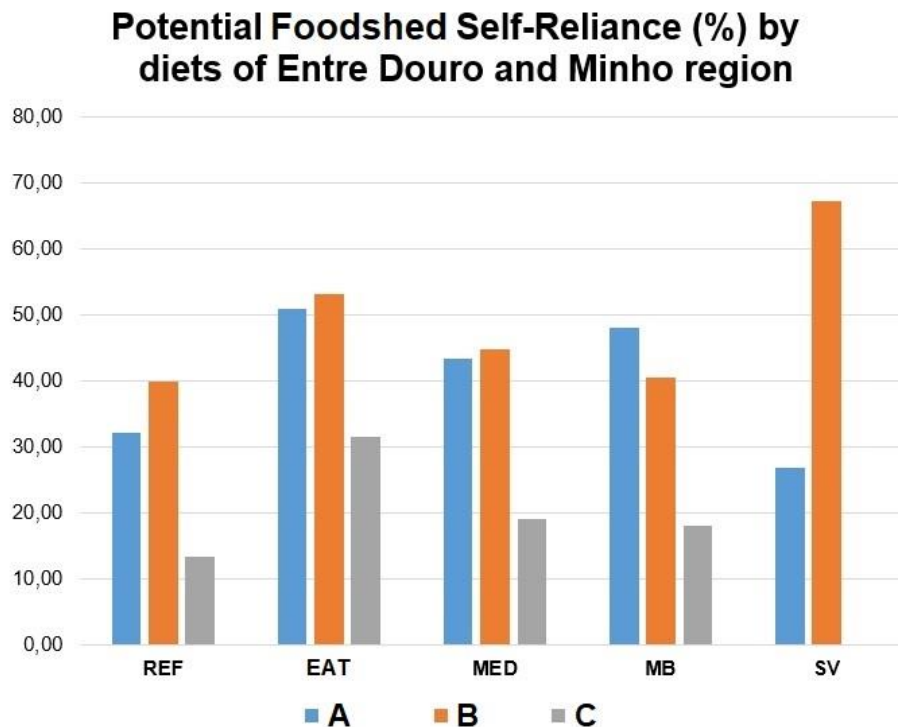


Figure 11 Contribution of municipalities to Potential Self-Reliance of beef production in EDM region under diets. (CFSR) Current Foodshed Self-Reliance; (PFSR) Potential Foodshed Self-Reliance.



Graphic 6 Potential Total Regional Self-Reliance of EDM region under diets analyzed. (A) Fruits, Nuts and Vegetables Oils; (B) Cereals, Tubers, Pulses, Vegetables, Pork¹, Poultry¹, Eggs¹ and Dairy¹; (C) Beef. 1 - SV diet does not include consumption of animal products.

4.2. Current and Potential Foodshed Water Footprint Assessment

4.2.1. Water footprint of crops and animal production under current foodshed and relocalization scenarios

Regarding the Water Footprint (WF) of current foodshed, results showed that EDM region had a total WF in the production of $2,095.81 \times 10^6$. Beef production presents the highest WF in the region, a total of 973.44×10^6 m³, followed by dairy production with 717.91×10^6 m³, cereals grains production with 155×10^6 m³ and wine production, with 97.57×10^6 m³. The lowest WF was represented by vegetables and oils production with 0.106×10^6 m³ (Table 11).

Considering crops production, (temporary crops in 2020) by municipality, Ponte de Lima had the highest cereals WF, with 9.73×10^6 m³ and the highest for pulses WF, with 0.150×10^6 m³. Resende had the highest tubers WF, with 0.609×10^6 m³. Póvoa de Varzim had the highest WF for vegetables, with 6.76×10^6 m³ (Figure 12). Considering permanent crops, Resende showed in 2020, the highest fruits WF, with 4.49×10^6 m³, the highest nuts WF, with

$1.19 \times 10^6 \text{ m}^3$ and the highest vegetable oils WF, with $0.024 \times 10^6 \text{ m}^3$. Amarante had the highest wine production WF, with $7.54 \times 10^6 \text{ m}^3$ (Figure 13).

Considering animal production, Barcelos had the highest meat WF, with $284 \times 10^6 \text{ m}^3$. Amares had the highest egg WF, with $6.37 \times 10^6 \text{ m}^3$. Vila do Conde had the highest dairy WF, with $188.68 \times 10^6 \text{ m}^3$ (Figure 14). Barcelos was the municipality with the highest total WF production, considering all food groups, with $360.16 \times 10^6 \text{ m}^3$ (Figure 15). The results of the WF assessment of food production by municipality under current foodshed are presented in Appendix III.

Table 11 Water footprint (10^6 m^3) of crop and animal food production under current EDM foodshed.

Food group	Production EDM region (t)	WF EDM region (10^6 m^3)
Cereals	94,403.4	155.20
Pulses	407,8	9.41
Tubers	24,321.9	1.64
Vegetables	75,736.4	24.39
Fruits	55,738.6	53.62
Vegetables oils	44.9	0.11
Nuts	894.6	8.11
Wine	112,283.16	97.57
Beef	87,099.12	973.44
Pork	3,395.3	20.33
Poultry	2,878.64	12.45
Eggs	6,591.9	21.52
Dairy	703,836	717.91
Total	-	2,095.81

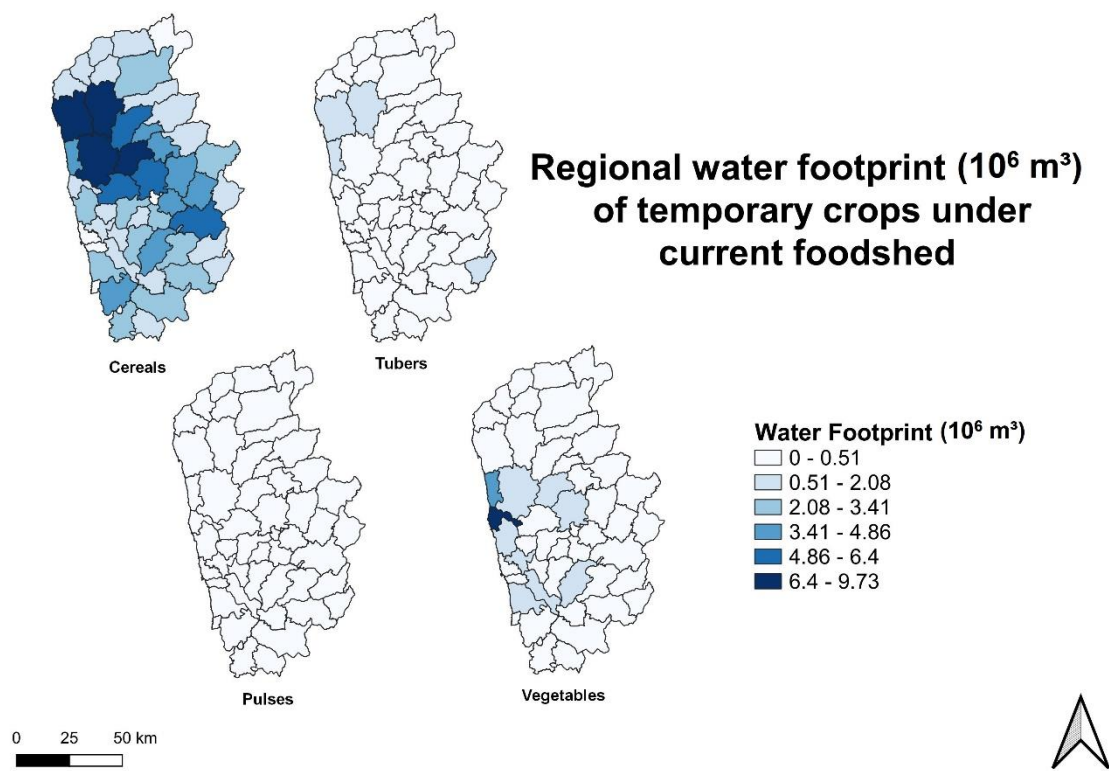


Figure 12 Water footprint (10^6 m^3) of temporary crops, in current foodshed, by municipality.

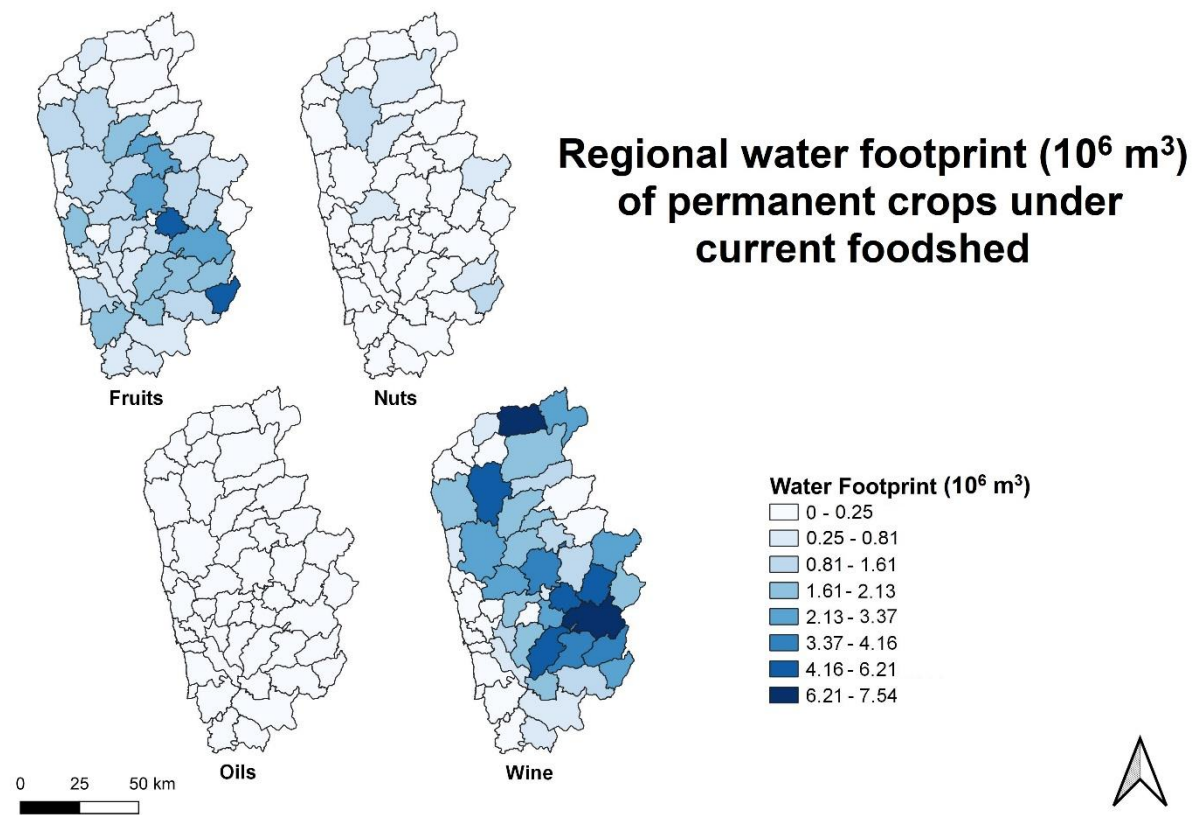


Figure 13 Water footprint (10^6 m^3) of permanent crops, in current foodshed, by municipality.

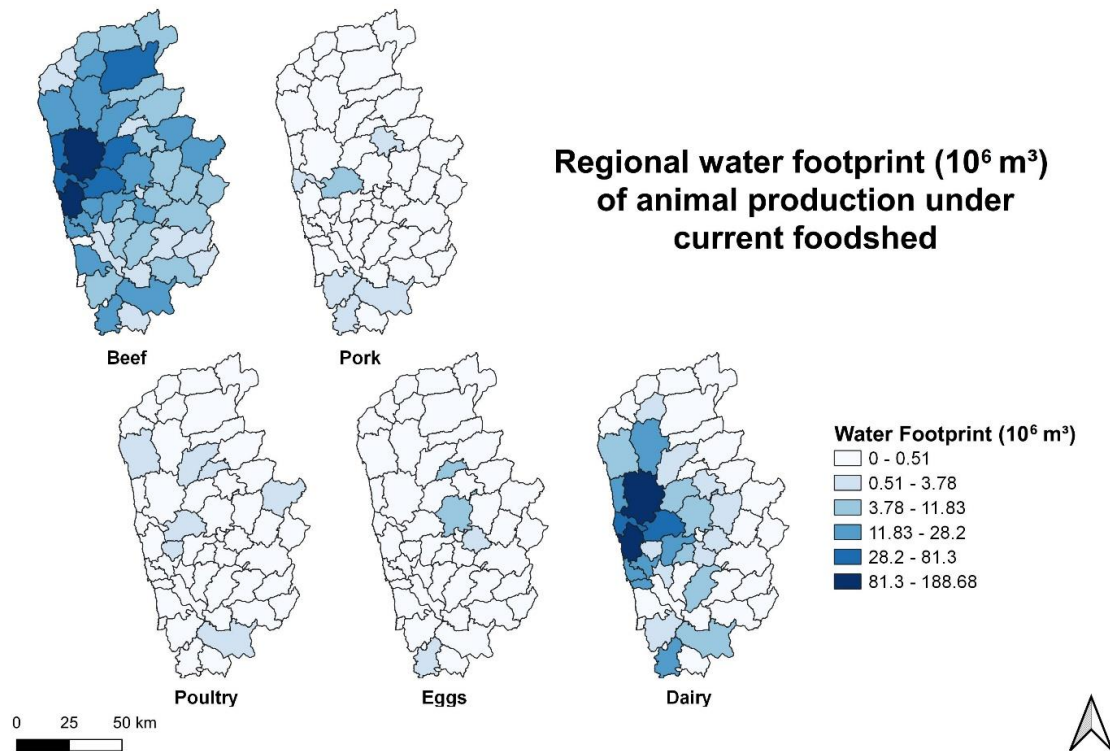


Figure 14 Water footprint (10^6 m^3) of animal production, in current foodshed, by municipality.

Total crops and animal production water footprint (10^6 m^3) under current foodshed

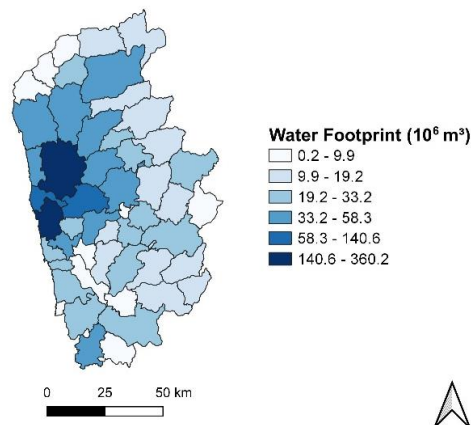


Figure 15 Total water footprint (10^6 m^3) of crops and animal production, in current foodshed, by municipality.

The WF assessment of the relocalization scenario showed that the EDM region would present a WF production of $5,297 \times 10^6 \text{ m}^3$. The highest WF of production is for dairy products, with $2,588.52 \times 10^6 \text{ m}^3$, followed by beef production, with $2,564.79 \times 10^6 \text{ m}^3$ and finally eggs

production, with $50.84 \times 10^6 \text{ m}^3$. The lowest production WF was represented by vegetable oils, with $0.053 \times 10^6 \text{ m}^3$ (Table 12). Considering temporary crops, Barcelos had the highest WF of production for cereal grains, with $1.44 \times 10^6 \text{ m}^3$ and the highest tubers WF, with $0.049 \times 10^6 \text{ m}^3$. Ponte de Lima had the highest pulses WF, with $0.01 \times 10^6 \text{ m}^3$. Guimarães showed the highest vegetable WF, with $0.135 \times 10^6 \text{ m}^3$ (Figure 16). Considering permanent crops, Marco de Canavezes had the highest fruits WF, with $0.189 \times 10^6 \text{ m}^3$. Ponte de Lima had the highest nuts WF, $0.083 \times 10^6 \text{ m}^3$, the highest oils WF, $0.008 \times 10^6 \text{ m}^3$. Amarante had the highest wine WF, with $0.735 \times 10^6 \text{ m}^3$ (Figure 17).

Considering animal production, Barcelos had the highest beef production WF, with $1,312.97 \times 10^6 \text{ m}^3$ and the highest dairy production WF, with $1,466.62 \times 10^6 \text{ m}^3$. Vila Nova de Famalicão presented the highest pork production WF, with $21.10 \times 10^6 \text{ m}^3$ and the highest poultry production WF, with $6.67 \times 10^6 \text{ m}^3$. Guimarães presented the highest eggs production WF, with $23.87 \times 10^6 \text{ m}^3$. Barcelos had the highest production WF under relocalization scenario, $10,771.19 \times 10^6 \text{ m}^3$ (Figure 18). The comparison of WF between current and potential EDM foodshed are presented in Figure 19. The results of the WF of Production under the foodshed relocalization scenario are presented in Appendix III.

Table 12 Water footprint (10^6 m^3) of crop and animal food production under EDM foodshed relocalization scenario.

Food group	Production EDM region (t)	WF EDM region (10^6 m^3)
Cereals	5,060.07	8.32
Pulses	21.61	0.41
Tubers	1,069.05	0.09
Vegetables	2,691.22	0.87
Fruits	2,676.15	2.57
Vegetables oils	22.82	0.45
Nuts	49.19	0.05
Wine	7,354.13	6.40
Beef	166,382.69	2,564.79
Pork	7,981.08	47.79
Poultry	5,988.45	25.90
Eggs	15,569.86	50.84
Dairy	2,537,772.39	2,588.52
Total	-	5,297

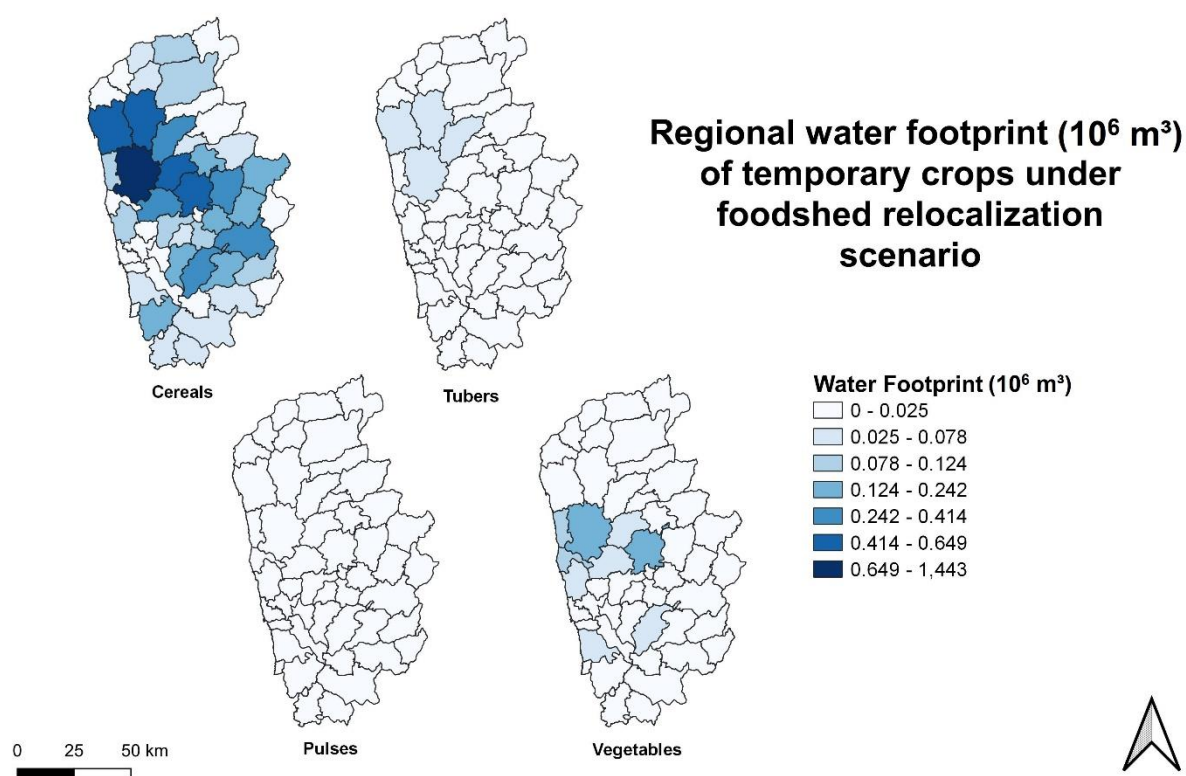


Figure 16 Water footprint (10^6 m^3) of temporary crops production, under foodshed relocalization scenario by municipality.

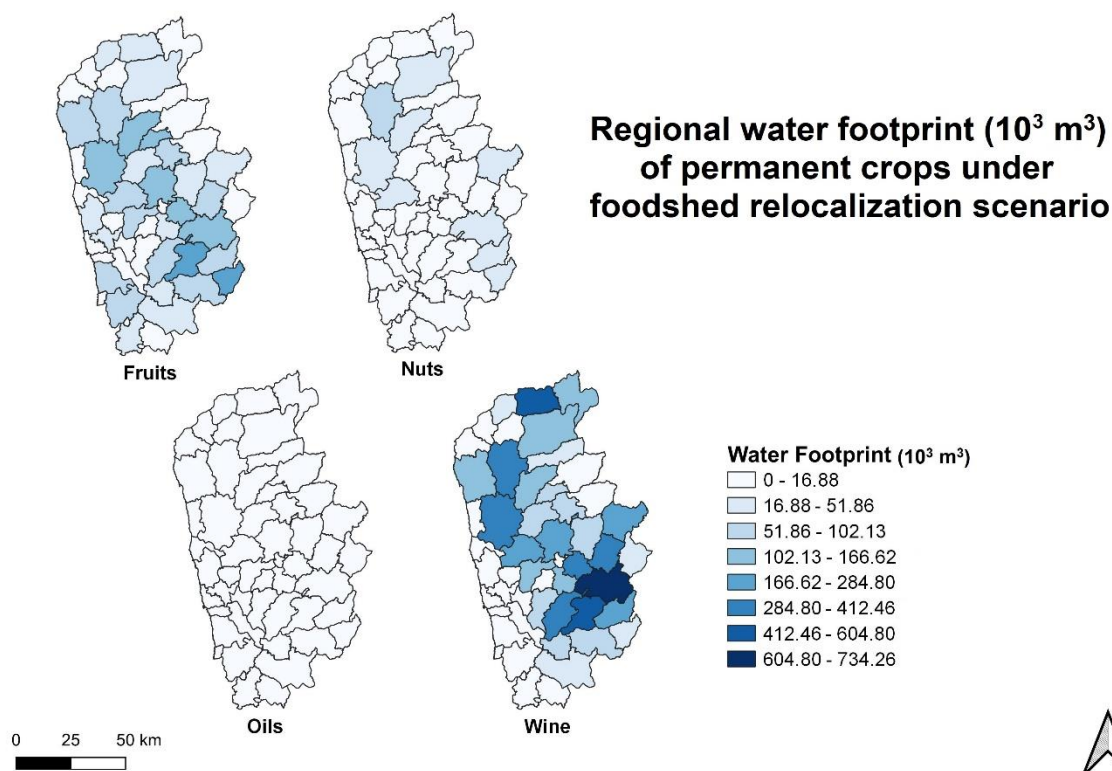


Figure 17 Water footprint (10^6 m^3) of permanent crops production, under foodshed relocalization scenario by municipality.

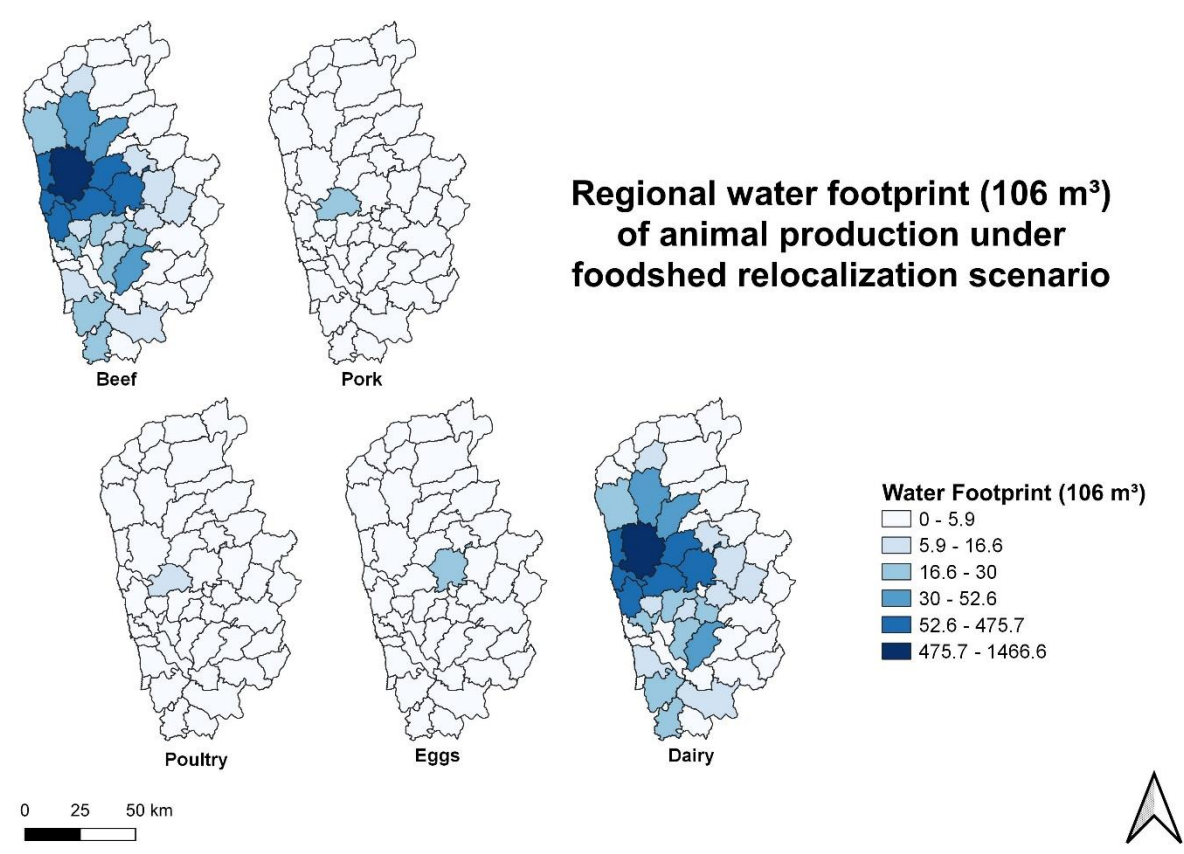


Figure 18 Water footprint (10^6 m^3) of animal production, under foodshed relocalization scenario by municipality.

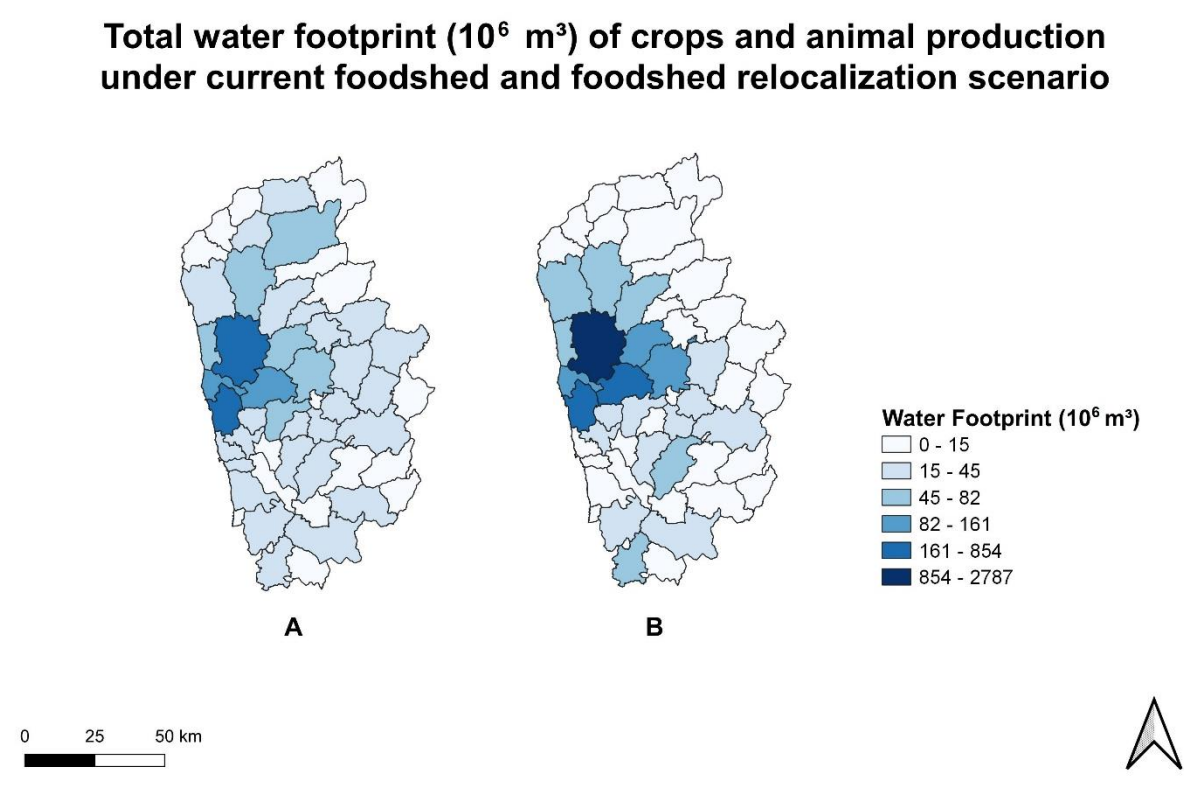


Figure 19 Total water footprint (10^6 m^3) of crops and animal production by municipality under current foodshed (A) and foodshed relocalization scenario (B).

4.2.2. *Water footprint of diets*

The assessment of the WF of diets showed that the REF diet had the highest WF of consumption, with $3,727.68 \times 10^6$ m³/pop/year, followed by MB diet, with $3,314.04 \times 10^6$ m³/pop/year. The lowest values of WF of consumption are for the SV diet with $2,554.3 \times 10^6$ m³/pop/year and EAT diet with $2,330.70 \times 10^6$ m³/pop/year, while the MED diet presents intermediary values with $3,235.36 \times 10^6$ m³/pop/year. Dairy products presented the highest consumption WF in the MB and MED diet. In the REF diet poultry consumption WF was higher. Cereals consumption WF was higher in the EAT diet. Nuts presented the highest consumption WF in the SV diet. The WF of each food group are presented on Table 13 (Graphic 7).

Table 13 Water footprint (10^6 m³) of diets, by food groups.

Food group	REF	EAT	MB	MED	SV
Cereal grains (with rice)	664.23	443.33	428.04	428.04	428.04
Tubers	95.86	22.49	70.15	70.15	89.94
Pulses	63.16	471.33	253.39	253.39	603.31
Vegetables	99.67	112.28	38.92	38.92	38.92
All fruits	317.12	223.64	503.18	628.42	503.18
Nuts	149.59	263.36	230.70	230.70	833.17
Vegetable oils	137.67	128.60	85.18	85.18	57.70
Beef	683.38	125.42	285.70	285.70	
Pork	265.46	48.72	110.98	110.98	
Poultry	769.26	145.79	331.70	331.70	
Eggs	99.81	49.34	108.24	108.24	
Dairy	382.48	296.40	867.86	663.94	
Total	3,727.68	2,330.70	3,314.04	3,235.36	2,554.27

4.2.3. Water footprint of diets under current foodshed

The assessment of the WF of diets under current foodshed showed that the REF diet had the highest WF of consumption, with $1,664.23 \times 10^6$ m³/pop/year, followed by MB diet, with $1,498.20 \times 10^6$ m³/pop/year. The lowest values of WF of consumption are for the EA diet with 672.62×10^6 m³/pop/year and SV diet with 206.5×10^6 m³/pop/year, while the MED diet presents intermediary values with $1,302.29 \times 10^6$ m³/pop/year (Graphic 8). Dairy products presented the highest consumption WF, in all diets analyzed with the exception of the REF diet, where beef consumption had a higher WF, and the SV diet, with no dairy food intake sourced by animals. The WF of each food group are presented on Table 14 (Graphic 7).

Table 14 Water footprint (10^6 m³/pop/year) of diets (consumption), under current foodshed, by food group.

Food group	REF	EAT	MB	MED	SV
Cereal grains (with rice)	153.44	102.41	98.88	98.88	98.88
Tubers	9.30	2.18	6.80	6.80	6.80
Pulses	1.58	11.78	6.33	6.33	15.08
Vegetables	24.12	27.17	9.42	9.42	9.42
All fruits	20.30	14.31	32.20	40.22	32.20
Nuts	7.93	13.96	12.23	12.23	44.16
Vegetable oils	0.10	0.04	0.02	0.02	
Beef	658.28	120.82	275.21	275.21	
Pork	6.83	1.25	2.85	2.85	
Poultry	378.53	71.74	163.22	163.22	
Eggs	21.36	10.56	23.16	23.16	
Dairy	382.48	296.40	867.86	663.94	
Total	1,664.23	672.62	1,498.20	1,302.29	206.56

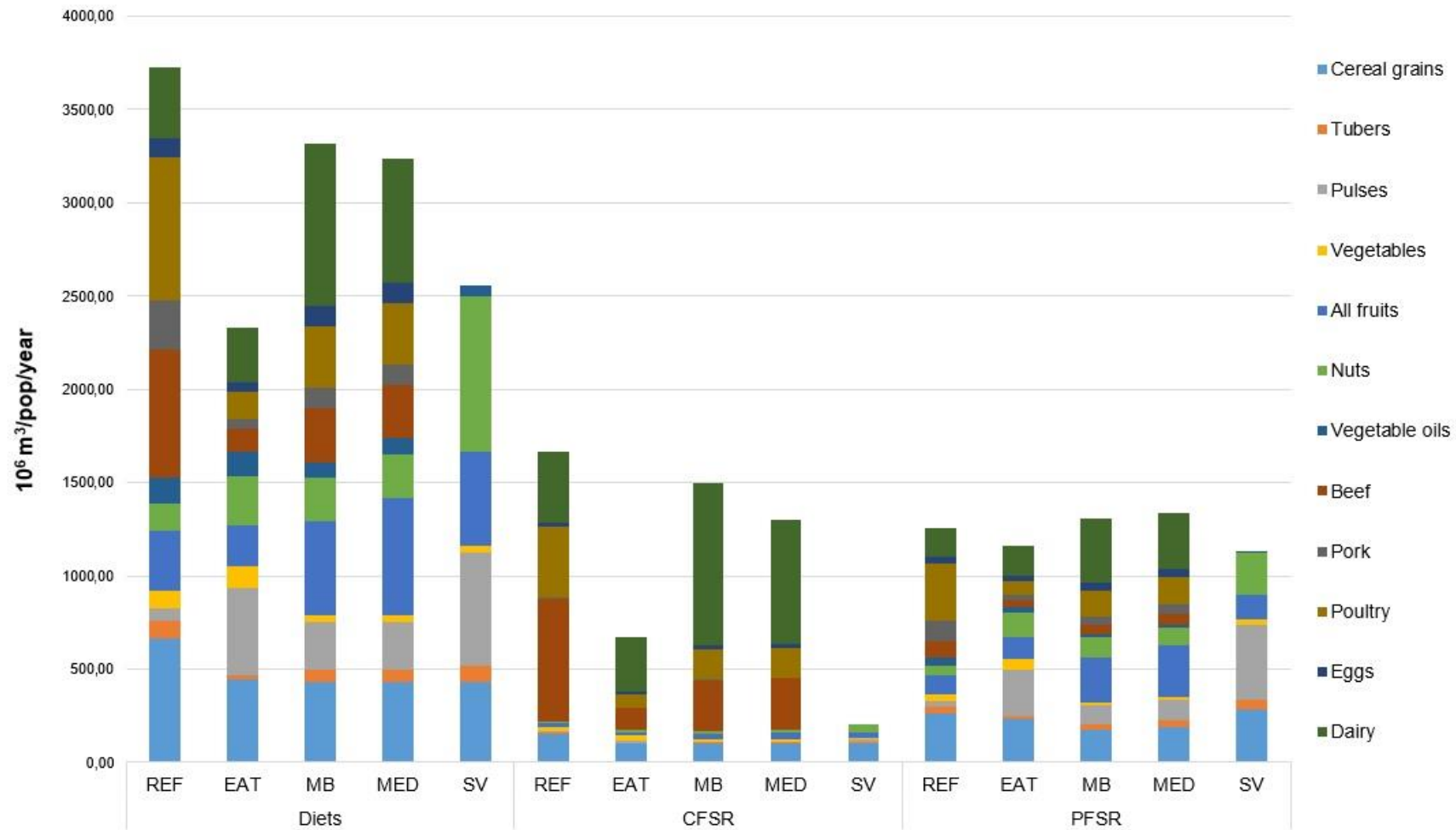
4.2.4. Water footprint of diets under foodshed relocalization scenario

The WF assessment of diets under the foodshed relocalization scenario showed that the MED diet had the highest consumption WF, with $1,336.83 \times 10^6$ m³/pop/year, followed by MB diet, with $1,310.65 \times 10^6$ m³/pop/year. The lowest WF of consumption was represented by the SV diet with $1,131.15 \times 10^6$ m³/pop/year, followed by the EAT diet with $1,157.94 \times 10^6$ m³/pop/year. The REF diet presented an intermediary WF of consumption, with $1,256.75 \times 10^6$ m³/pop/year (Graphic 10). Dairy products presented the highest consumption WF, with the exception of the REF diet, where poultry WF was higher, the EAT diet, where pulses WF was higher and for the SV diet, which has no dairy food intake or any product of animal origin. The WF of each food group are presented on Table 15 (Graphic 7).

Table 15 Water footprint (10^6 m³/pop/year) of diets (consumption) by food groups EDM foodshed relocalization scenario.

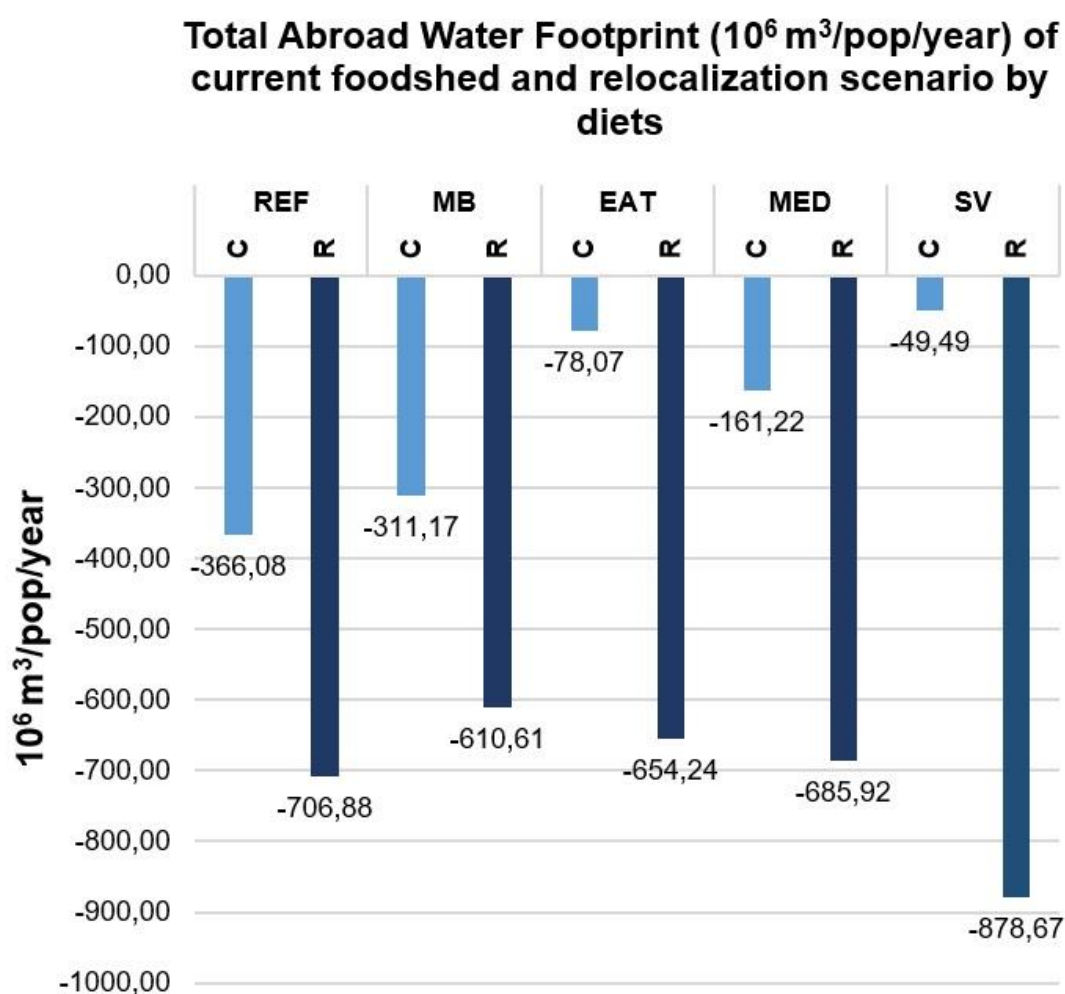
Food group	REF	EAT	MB	MED	SV
Cereal grains (with rice)	264.56	235.63	172.81	191.16	287.64
Tubers	38.18	11.95	28.32	31.33	47.14
Pulses	25.16	250.51	102.30	113.16	405.42
Vegetables	39.70	59.68	15.71	17.38	26.16
All fruits	101.88	113.66	240.57	272.01	135.03
Nuts	48.06	133.85	110.30	99.86	223.58
Vegetable oils	44.23	26.14	16.29	14.75	6.19
Beef	90.75	39.38	51.55	54.62	
Pork	105.73	25.90	44.81	49.56	
Poultry	306.40	77.49	133.91	148.14	
Eggs	39.75	26.22	43.70	48.34	
Dairy	152.34	157.53	350.37	296.51	
Total	1,256.75	1,157.9₄	1,310.65	1,336.8₃	1,131.15

Water footprint (10⁶ m³/pop/year) of diets by food groups



Graphic 7 Water footprint (m³/population/year) of diets by food groups. CFSR – under current foodshed; PFSR – under foodshed relocalization scenario.

When assessing water requirements, comparing the WF of production with the WF of consumption in the current foodshed, the REF diet presented the highest need for abroad WF to reach the consumption parameters of the EDM population, with $366.08 \times 10^6 \text{ m}^3$ represented by poultry. Followed by the MB diet, with total abroad WF of $311.17 \times 10^6 \text{ m}^3$, represented by poultry and dairy production. The lowest abroad WF was represented by SV diet with $49.49 \times 10^6 \text{ m}^3$. When assessing abroad WF on the relocalization scenario, the SV diet presented the highest need for imported water to reach the consumption parameters of the EDM population, with $878.67 \times 10^6 \text{ m}^3$, with the highest expression in tubers with $403.77 \times 10^6 \text{ m}^3$. Followed by the REF diet, with $706.88 \times 10^6 \text{ m}^3$, with the highest expression of poultry with $293.94 \times 10^6 \text{ m}^3$. The MB diet presented the lowest abroad WF, besides its expressiveness, with $610.61 \times 10^6 \text{ m}^3$. All the values referring to abroad WF are presented in Table 16 (Graphic 8).



Graphic 8 Total abroad water footprint (10^6 m^3) of diets under current foodshed and relocalization scenario (C – Current foodshed; R – Foodshed relocalization scenario).

Table 16 Relation of Water footprint of production and consumption (10^6 m^3) of diets under current foodshed and relocalization scenario (¹sum of negative values, which represented abroad water footprint; C – Current foodshed; R – Foodshed relocalization scenario).

Diet	REF		MB		EAT		MED		SV	
Food group	C	R	C	R	C	R	C	R	C	R
Cereal grains (with rice)	1.761	-109.365	56.321	-17.611	52.790	-80.429	56.321	-35.965	56.321	-132.442
Tubers	0.114	-28.768	2.608	-18.907	7.231	-2.542	2.608	-21.915	2.608	-37.725
Pulses	0.063	-23.515	-4.693	-100.657	-10.142	-248.870	-4.693	-111.522	-13.441	-403.775
Vegetables	0.267	-15.312	14.967	8.672	-2.785	-35.291	14.967	7.003	14.967	-1.770
All fruits	33.325	-48.264	21.417	-186.950	39.308	-60.038	13.402	-218.390	21.417	-81.406
Nuts	0.180	-39.952	-4.119	-102.190	-5.850	-125.739	-4.119	-91.751	-36.050	-215.468
Vegetable oils	0.010	-44.124	0.082	-16.184	0.070	-26.037	0.082	-14.642	0.090	-6.088
Beef	684.351	1,251.88 ₀	1,067.425	1,291.080	1,221.816	1,303.25 ₁	1,067.425	1,288.018		
Pork	13.506	-85.402	17.478	-24.474	19.078	-5.564	17.478	-29.233		
Poultry	-366.080	-293.946	-150.771	-121.465	-59.288	-65.036	-150.771	-135.688		
Eggs	0.163	-18.232	-1.640	-22.175	10.965	-4.699	-1.640	-26.816		
Dairy	335.43	2,436.19	-149.95	2,238.15	421.51	2,430.99	53.97	2,292.01		
Total¹	-366.08	-706.88	-311.17	-610.61	-78.07	-654.24	-161.22	-685.92	-49.49	-878.67

5. Discussion

5.1. Current Foodshed Self-Reliance and Water Footprint

5.1.1. Current Foodshed Self-Reliance

When compared the regional production with the regional population consumption, the last one, sourced from Portuguese food Balance (BAP), the EDM region presented CFSR values that were lower than 50% for almost all the food groups, except for dairy, beef and wine production that achieved around or more than 100% of CFSR. Considering dairy production, these results are corroborated by the fact that the region is, after the Azores, the largest producer of milk and dairy products, corresponding to 25% of national production and more than half of the country's mainland production (INE, 2021). This shows the regional agricultural specialization on this food product.

The results for CFSR in beef are sustained by the extensive production of native cattle of the Minhota breed, mainly in the Viana do Castelo region, from which meat can be taken. Moreover, there is also a characteristic production in the region of Peneda-Gerês, with the Cachena breed, which meat production is of protected designation of origin (DOP), because it defines a territory, an own and unique way of production and cultural potential. Also in the same regions with higher CFSR in dairy production, the number of cattle head was also high, promoting high production and consequent greater self-reliance (INE, 2021). The EDM region is responsible for about 35% of the slaughtering of all beef cattle in Portugal, but the beef production in the present study was assessed by the number of cattle present in the region, which correspond to 17% of national production. The extensive systems are rare in the region, because of topography and occupation by urban areas, which are not so favorable to this type of production, although almost half of the UAA is represented by pastures, extensive beef production is usually better adapted to regions with lower slope conditions.

The self-reliance of wine production also stands out in the EDM region, specially in the zone of Amarante municipality and the transition to Douro river, which has a characteristics production of green wine ("vinho verde"). The EDM region supply more than half of the wine consumed by the regional population, this also reflects the degree of specialisation, since EDM is the second largest wine producer in the country (INE, 2021). Besides standing out in the agricultural sector, wine also contributes to wine tourism, being a sector referred to as strategic for Portugal, a target for the development of territorial management policies due to its high heritage, landscape and cultural capital (Comunidade Intermunicipal do Douro 2015).

Considering the other food groups, the agricultural census pointed out that tuber crops had a reduction of its agricultural surface area, due to the lower competitiveness and edaphoclimatic suitability on the EDM region, which can explain the lowest value of CFSR (INE, 2021). Thus, the Ribatejo-Oeste (RO) region has the major representativeness of production and exports of tubers and vegetables in the country, in particular tomatoes. Which increase the specialization of the RO region and EDM import dependency on a sub-national scale, by providing the remaining food products to other regions in the country (Cardoso et al. 2017; INE, 2021).

Besides being lower than 50% of CFSR, cereals and vegetables production met $\frac{1}{4}$ of what was consumed by the population, considering BAP. The first one due to its representativeness in EDM region, 85% of arable land in the region are represented by cereals crops (INE, 2021). The second one due to the increase in protected cultivation and the investment made in the sector in the last 10 years, especially in Póvoa do Varzim and Esposende, therefore with higher CFSR in these municipalities (INE, 2021).

Vegetables oils, as olive oils and sunflower seeds oils, pulses and nuts, had the lowest value of CFSR. These types of food groups are not a speciality of the study region, due to the environmental conditions necessary for their production. As opposed to what occurs in the Alentejo agricultural region, for example, which is already highly specialised in these types of crops, as it presents more suitable conditions of climate and land use, and is responsible for a large part of national production (INE, 2021). Despite having the highest percentage of land use in subtropical fruit production, and the second largest in the production of berries, the EDM region still depends on the provision of fresh fruits and citrus fruits from other regions, accordingly to agricultural census, in Portugal the major responsible for fresh fruit provision is the Algarve agrarian region (INE, 2021).

The EDM region, considering other sectors of animal production, showed higher values of CFSR than for crops production. It met 20% of eggs consumed, Kaufmann et al. (2022) pointed that these types of production are not related to regions with large occupation of urban areas characteristic of the EDM region, which have the second highest population density in AMP.

According to INE and Direção Geral do Território (DGT), in recent years in Portugal there have been changes in land use, with an increase of more than 60% of artificialized territories, and loss of about 12% of agricultural territories. According to Filipe (2021), when preliminarily analysed the flows between land occupations in the EDM region, the author observed that the notorious agricultural losses in 2018 were mainly due to the increase in the process of artificialization, the rapid expansion of the AMP region being the largest responsible

for this fact. Followed by afforestation and abandonment of land in agricultural and semi-natural spaces which presented an agricultural potential. The gains in occupied areas were more representative in the municipalities of Vila do Conde and Póvoa do Varzim, mainly by temporary crops. This condition of urbanisation may have contributed to the lower productivity of some types of crops, while the increase in area of temporary crops, consequent of the systems with specialisation in the region, may be related to the higher values of self-reliance.

Griffin et al. (2015) did a research of self-reliance in the Northeast region of US, National data of food intake and compared it with the food provided by current regional foodshed. Their self-reliance assessment demonstrate that a disproportionately low share of food per capita would be produced locally, the authors suggest some solutions to change this situation, such as changes in land use and cropping patterns to more suitable areas and environment conditions, raising crop and animal productivity and shifting on dietary preferences (Griffin et al. 2015). Zasada et al. (2017) also did a self-sufficiency assessment with four metropolitan areas in Europe. The authors estimated the foodshed area, considering local conditions, as food consumption in different dietary patterns, size of regional population, used agricultural land and biophysical conditions. They also analyze different scenarios of food production and how it can influence the foodshed and its self-sufficiency, such as conventional and organic farming scenario. The authors also support the idea that food planning with sustainable agriculture and food supply chains innovations, as the Metropolitan Foodshed and Self-Sufficiency Model used by them in the study, could be a solution to reduce the vulnerability of food systems and promote sustainability of food provision.

5.1.2. Water footprint of crops and animal production under current foodshed

The results found on production WF assessment demonstrate that the higher values of water use are linked to higher production of animal-based food products, dairy production and beef production presented the higher water use in current EDM foodshed. It is well documented in several studies that relate water consumption to food production, as the supply chain of an animal product starts with feed from crop cultivation and ends with the consumer, this type of product is without exception linked to higher consumption of water directly and indirectly (Mekonnen and Hoekstra 2012; Vanham and Bidoglio 2014; Ercin and Hoekstra 2016; Noya et al. 2019; Ibidhi and Ben Salem 2020). Livestock WF is reported to represent one third of total WF of agriculture (Mekonnen and Hoekstra 2012; Hoekstra 2012).

Firstly, considering crops, cereals grains presented the highest WF of production, Mekonnen and Hoekstra (2011) also analyze the WF of main crops in global scale and also find that cereals crops presented the highest WF production. This fact could be explained by the level of production (t) of the region, the highest value of the temporary crop production, which consequently correspond to a higher production WF. However, Mekonnen and Hoekstra (2011) also affirms that exist a relationship between the WF and yield in cereals production in different countries, suggesting that the WF, in most cases, is less influenced by the agroclimate of the region and more by the farm management of the crop in question. This shows that, the opportunity for better water management lies in improving water productivity, increasing production per unit of water consumed (Mekonnen and Hoekstra 2011).

Considering the animal products studied here, dairy products WF is explained, not only by the regional specialization in dairy farming, which is proven by the dairy WF presented in the municipalities (e.g. Barcelos and Vila do Conde), but also by the type of production, which is intensive in the most part of the year in the EDM region (Cerqueira et al. n.d.; INE, 2021). Ibidhi and Salem (2020) explains in their review about livestock WF that more intensive systems contribute to higher values of WF, because of the inclusion of high quality feed, which are mostly produced by irrigated systems that increase blue water consumption. Beef production WF was also higher than other type of meat WF, this happens because ruminants animals require eight times more feed per kilogram of meat produced than monogastric animals, as pigs, sheeps and goats, what contributes to higher water consumption (Ibidhi and Ben Salem 2020). Another possible explanation for this result, in addition to diet composition and type of production system, is based on the fact that WF is also associated with animal characteristics such as animal weight, age at slaughter, animal breed, animal productivity and reproductive efficiency (Ibidhi and Ben Salem 2020). That could also explain the high values of WF production of cereals and grains present in the same area, as dairy products in the EDM region need corn silage as main type of feed, in addition to compound feeds (Cerqueira et al. n.d.). Accordingly to Hoekstra (2012), fodder crops is by far the largest contributor to the increase of total WF in the agriculture.

5.2. Effects of diets and foodshed relocalization on self-reliance and water footprint

5.2.1. *Potential Foodshed Self-Reliance Assessment by diets*

The PFSR assessment by diets showed that the REF diet presented the higher food footprint. This result can be explained by the fact that this dietary pattern presented the higher intake of animal products, specially the higher intake of meat, which is well documented to have higher land use to be produced (Cardoso et al. 2017; Joseph, Peters, and Friedrich 2019; Kurtz et al. 2020). This dietary pattern is based on INE data on current food consumption, according to the Portuguese Food Balance (BAP) for the years 2016 to 2020. The excess intake of these food groups is noticeable, which is closely linked to the higher incidence of cardiovascular diseases, especially when compared to the standards proposed as healthy by the Directorate-General for Health (DGS) in the Integrated Strategy for the Promotion of Healthy Eating (EIPAS) (Graça et al. 2018).

A number of studies have already assessed the self-sufficiency capacity of regions, based on different dietary patterns, with the intention of meeting the food needs of the population in that region through regionalized production. Cardoso et al (2017) evaluated the potential foodshed for several diets for Ribatejo-Oeste agrarian region, where the meat-based diet, needed twice the area that was necessary for food self-sufficiency in comparison to the strict-vegetarian diet. This difference in land footprint was caused by the groups cereals grains, silage and also grazing land needed for meat, eggs and dairy production (Cardoso et al. 2017). Cassidy et al. (2013), propose a new perspective to look at production yields, considering how many people can be fed by a given crop, by comparing agricultural production from different food chains, provided by tones of food, with actual food delivery, provided on the basis of calories of food consumed by humans per hectare. The results showed several inefficiencies, for example in Brazil, where although the production of pulses is high, the use of these crops to feed people is very low, due to the fact that 79% of the soybean produced in the country is destined for animal feed (Cassidy et al. 2013). Joseph, Peters, and Friedrich (2019) also did an assessment of food self-sufficiency, the authors evaluated the effects of individual choices, with the main focus on meat consumption, in the metropolitan region of Hamburg, proving that this food group has the greatest influence on the amount of agricultural land for production. Kurtz et al. (2020) evaluated the impact of diet scenarios on U.S. Foodshed. Using the Foodprint Model (Peters et al. 2016), the authors analyzed the area needs for different patterns of food consumption, showing that a Vegan diet needs 20% of the needed by the Omnivorous diet with 80% of animal products intake (Kurtz et al. 2020). The range of food footprint (land)

in those scenarios comes from changes in animal products consumption, as they depend on temporary cropland and grazing lands (Kurtz et al. 2020). Zasada et al (2017) and Kurtz et al (2020) also pointed that, by reducing the consumption of animal-based food components, the area needed in a supply chain would be reduced as well, and the levels of self-sufficiency could be achieved also.

This is why changing consumption patterns, in essence reducing the consumption of animal products, has been documented and discussed as beneficial for both the environment and human health. Changing consumption patterns is also pointed out as a strategy to regulate the use of resources such as energy, land and water by productive systems (Joseph, Peters, and Friedrich 2019). For example, the EU does not domestically produce enough food for livestock systems, but depends on land outside its territory, such as Brazil and Argentina, for example, which reaffirms the importance of individual consumption actions aimed at reducing the use of these resources (European Commission 2013).

The influence of high consumption of animal-based food products on land use is a widely studied topic. In the present study, however, the EAT diet scenario presented a smaller food footprint than the SV diet scenario, mostly because of the higher intake of pulses in the last one. This could be explained by the low productivity of this type of culture in the region, 0.698 t/ha accordingly to INE (2019), this value is below the national and global average yield for chickpeas and beans (0.824 and 0.956 t/ha), the main pulses crops of Portugal (Rawal and Navarro 2019). Considering this fact, the productivity of this type of crop could be related to the high land use occupation of cities and urban centers. Because of that, to attend the intake of pulses required for the SV diet, to achieve healthy food patterns of protein intake, more area is needed.

Also in the present study, when total self-reliance in each diet scenario was analyzed, the strict-vegetarian diet presented a higher self-reliance than the omnivorous diets, meat and plant-based, showing that a reduction in feed crops has a significant impact on the regional self-reliance (RSR) (Cardoso et al. 2017). Studies that promote the assessment of RSR through relocalization and diet scenarios can provide important data to develop new food policies and food planning, as they can demonstrate theoretically how much area is necessary to achieve these patterns (Brand et al. 2017; Cardoso et al. 2017; Maia, 2019; Zasada et al. 2017).

When compared, the EDM current foodshed, presented 11.76% of permanent crops Current Foodshed Self-Reliance (CFSR) based on BAP, while on the relocalization scenario, REF diet presented 32.12% of permanent crops Potential Foodshed Self-Reliance (PFSR), EAT diet presented 50.82%, MED diet 43.28%, MB diet 48.05% and SV diet 26.83%.

Temporary crops on EDM current foodshed showed a CFSR of 366.9%, while on the relocation scenario, REF diet presented 39.83% of PFSR, EAT diet presented 53.14%, MED diet 44.65%, MB diet 40.47% and SV diet 67.20%. The comparison of beef production self-reliance showed that EDM foodshed had 48.1% of beef CFSR, while REF diet had 13.28% of PFSR, EAT diet 31.39%, MED diet 19.11% and MB diet 18.07%. Filipe (2021), in the work that resulted on the EDM relocation scenario used in the present work, carried out a potential planning and ecological adequation of agricultural land use based mainly on agroedaphic characteristics of the soil. The increase of self-reliance of permanent crops between scenarios reflects the relocation scenario proposed by Filipe (2021), that is an ecologically based land use plan that used ecological suitability and landscape planning methods, following previous studies by Magalhães, Cunha, and Pena (2011) and Cardoso et al. (2017). Filipe (2021) showed that permanent crops had an increase of 7.3% in their areas, from 2.1% (18,343.9 ha) to 9.4% (82,400.3 ha), which resulted in an increase of production and consequently in self-reliance, as area and productivity were variables used in the analysis of RSR.

However, the results relocation proposal by Filipe (2021) also achieved an increase of 9.9% in the total area of temporary crops, from 11.4% (100, 189.4 ha) to 21.3% (186,982.8 ha) of the total EDM area between EDM current foodshed and relocation scenario, which would positively influence the PFSR of these crops. To produce the relocation scenario, Filipe (2021) optimised the allocation of land cover types according to ecological suitability and types of agricultural uses, then assessed the impact of the scenario, which reconciles all agricultural uses, on the ecological value of the landscape. The methodology not considered the needs of plant and animal production, in order to obtain a degree of self-reliance of the relocation scenario according to the food needs of the resident population. Considering the results in the present study, animal production were considered partially in the total temporary crops areas of relocation without being considered the fact of the specific origin of livestock feed (fodder/corn), the relocation scenario only provides information about agricultural land use area, which can explain the decrease in PFSR.

It is also worth mentioning that, considering only the PFSR, the EA diet presented the higher permanent crops and beef RSR, and the SV diet presented higher temporary crops RSR. The first result could be addressed, in addition to the increase in permanent crop areas, to the less intake of vegetable oils in comparison to other healthy diet patterns and less beef meat intake, among other animal-based foods, which could promote higher self-reliance (production as a proportion of consumption) as the consumption pattern changes. The SV diet temporary crops PFSR could be explained by the fact that all biomass produced by these crops resulted in plant-based food to meet the diet requirements, so the production factor was

changed in self-reliance assessment. This is corroborated by Willett et al. (2019), when EAT diet was proposed it considered the planetary boundaries, pointing that by reducing the consumption of animal products, parameters of food security and sustainability would be benefited. However, it is important to note that, besides the relocalization scenario has all land cover types, nowadays on global scale, most of agricultural land are suitable for pastures and unsuitable for crop production, affirming the need for an analysis of the effects of self-reliance with multiple perspectives and not only from shifts in diets (Filipe 2021; Cardoso et al. 2017; Rüschoff et al. 2022). That is why it is important to make studies that consider the different regions and to have a national scale study, which should integrate biodiversity and other ecosystem services, in addition to food supply.

5.2.2. Water footprint of crops and animal production under foodshed relocalization scenario

The comparison between EDM current foodshed and the relocalization scenario WF showed that the proposed relocalization could result in higher water consumption, precisely when animal production, which is already self-reliable, is boosted. Considering the methodology applied in this study, business as usual for animal production, it could be observed that when relocalizing food systems, without differentiating between crops and livestock systems that already present self-sufficiency, the consequent scenario is as impactful as the current scenario when considering water consumption in production. The direct water consumption of livestock is one good indicator of water use, but to better understand this resource flow in the supply chain is necessary to estimate how much water is used before livestock growth, e.g. in the production of forage and fodder crops, so it is possible to predict the consequences of potential spatialisation under these production systems (Doreau, Corson, and Wiedemann 2012). As explained before the relocalization scenario used here was built based on ecological suitability, and an ecological based landscape planning methodology, which according to Saavedra Cardoso et al. (2017) should be prior to a self-reliance assessment, to ensure that foodshed relocalization studies integrate land use sustainability criteria and are more than land footprint calculations to meet the food needs for a specific population. When considering the development of more resilient food systems, animal feed is a crucial factor to include in studies of water footprint (Doreau, Corson, and Wiedemann 2012; Hoekstra 2012), which also applies to self-reliance and foodshed relocalization studies. However, the present study contributes to ensure that a more integrated perspective is necessary to assess the environmental effects of foodshed relocalization. This research can

provide tools to understand the relationship of self-reliance and various factors (e.g. land-use, water use, waste and loss, energy, etc) (Cardoso 2018; Schreiber et al. 2020).

5.2.3. Water footprint of diets under current foodshed and relocalization scenario

Food consumption represents the largest proportion of an individual total WF, exceeding by far the amount of other water uses at home (Vanham et al. 2021). In the present study, in both current and relocalization scenario of EDM foodshed, Meat-based diet presented the highest value of WF, which are strictly linked to higher animal products intake. Beef production also had a high production WF, most municipalities that presented this condition are related to areas of greater urban density, such as the Porto Metropolitan Area (AMP), the second area with the highest population density in the country. These areas are related to better living standards, many authors discuss the fact that greater purchasing power of the population leads to a greater consumption of animal-based food, as meat and dairy products (Brand et al. 2017; Noya et al. 2019). Vanham et al. (2021) realized an assessment of diets WF of nine countries in the Mediterranean zones, comparing Mediterranean diet and Eat-lancet diet with the reference diet in each country, showing that the higher levels of WF are accountable to higher meat intake.

The REF diet presented the highest WF of consumption, mainly because of the high intake of beef meat and dairy products, animal products which present high values of WF units. The MED diet, besides not presenting the highest WF of consumption presented higher total WF in comparison to the EAT diet, this factor can be explained by the higher intake of dairy products and nuts, food products with high value in the unit of WF also. Dairy products, as beef production, represent one third of total animal production WF, thus, dairy cattle consumes per year 4 times units of WF by animal, diets with higher intake of this type of product, are pointed to be more water consumptive (Mekonnen and Hoekstra 2012). Also, nuts are produced under specialized systems located in dryer regions, which make it mostly connected to irrigated systems, rising the blue WF consumption (Mekonnen and Hoekstra 2011; Vanham et al. 2021). Accordingly to Vanham, Mekonnen, and Hoekstra (2020) 74% of global nuts production are located in regions with blue water stress.

In the present study, the food consumption proposed in the EAT diet was effective in controlling the water use, similarly to other studies relating this diet scenario to the WF (Vanham, Mekonnen, and Hoekstra 2020; Vanham et al. 2021; Cambeses-Franco et al. 2022).

To develop the EAT diet, the Lancet Commission focus on freshwater use, considering the Environmental Flow Requirement (EFR) of main agricultural and livestock systems (Willett et al. 2019), which consequently enhance the use sustainability of this resource to attend a regional population consumption. The Lancet Commission also consider the limitations of the basins where a particular population is located to guide changes in their consumption patterns through EAT diet, aiming to promote a less impacting consumption in relation to water resources (Willett et al. 2019).

SV diet presented the lowest values of WF in both, current and relocalization scenarios, diets based strictly on plant-based foods usually have low WF values, due to the reduction or no intake of animal-based products (Vanham, Mekonnen, and Hoekstra 2013; Zucchinelli et al. 2021). However when compared the SV diet between scenarios, the potential spacialization resulted on higher value of WF. This can be explained by the high intake of nuts, as permanent crops presented an increase of its area on the relocalization scenario, also higher values of self-reliance of nuts, the potential productiveness of this food product base on SV diet consumption pattern were higher than in current foodshed, so also the WF related to this diet was higher. Even so, in the present study was assumed that total area of temporary and permanent crops on the relocalization scenario under SV diet would be used for crop production, excepting fodder crops. The agricultural land used to livestock production, eventually in a shift to vegetarian pattern of food consumption, could be used for other functions than food supply, Cardoso et al. (2017) in their study mapping the potential foodshed in RO pointed that 50% to 70% of land uses can be assigned to other specific ecosystem services (ES) than food provisioning services. The authors give examples of regulation, support, habitat and cultural ES. So is important to notice that, this diet context could contribute to promotion of less regional WF the region, however could increase the needs to water use abroad of the EDM region, which may impact other regions that produce this food group and present some water deficit condition.

When comparing the other food groups between the diets and between the current scenario and the relocalization scenario, both permanent and temporary crops showed a reduction in WF values. Considering other ecological resources, the relocalization prove to optimize the food supply while ensuring sustainable land-use (Cardoso et al. 2017). The relocalization scenario used in the present study also considered a proposition of silvopastures uses and multiple uses that contribute to the conservation of soil and water, in order to get the maximum potential of agricultural land use only where the ecological suitability allowed it (Filipe 2021). Brinkley, Raj, and Raja (2022) in their review about food planning that integrates food, energy and water (FEW) pointed that by relocalizing food supply an integration of those three

aspects would be possible, contributing to urban food planning in view of resources sustainability and food systems resilience.

The assessment of abroad WF, which compared the WF of production with the WF of consumption in the current foodshed and relocalization scenario, showed that REF diet and MB diet presented the highest consumption of water from poultry systems allocated abroad from EDM region. This is explained by the high intake of these food groups in each diet, combined with high WF units and considering the low production of this item on the EDM region, which allows the WF of consumption to overlap with that of production, indicating that the water use occurred in other food systems out from EDM region. When assessing abroad WF in relocalization scenario, it was interesting to find that SV diet presented the highest abroad WF, with greater expression in pulses and nuts, but the others food groups also presented a significant increase of abroad WF. This resulted mainly because the increase of self-reliance in these food groups, which promote a possibility to meet the food intake of these diets on the relocalization scenario. However, the important thing to notice here is, even the relocalization promoting the self-reliability of these food groups, the abroad WF assessment indicates that a healthy and plant-based diet will not always be the more sustainable choice, considering water use, because this WF could happen in places that experience water deficit and water stress scenarios. Hoekstra (2012) indicates that the management of water resources must consider this flows between regions. Nowadays the management of water resources is based on the premise that they are local or regional resources, considering only the watershed that provides the resource, obscuring the fact that the problems are related to remote consumption and virtual water, coming from other regions (Hoekstra 2012). Animal source food also needs special attention, since the food supplied to livestock is composed of a number of ingredients, which makes it difficult to trace its origins in the production chain, reflected in the lack of detailed information on resource uses by livestock systems (Hoekstra 2012).

5.3. Implications for spatial planning and land management

The present study was based on a relocalization scenario developed by Filipe (2021), which used ecological suitability and ecologically-based landscape planning methods in order to understand the limits of the bioproductive area of the EDM region or the extent of its regional foodshed. As discussed in Cardoso et al. (2017), the growing urbanization brought with it the need for government entities to address the sustainability of urban and peri-urban food provisioning. Relocalization studies such as the proposed by Filipe (2021), for the EDM region,

and by Cardoso et al. (2017), for the Ribatejo-Oeste, are examples of methodologies that intend to understand the extent and the land-use spatialization of a regional foodshed. Despite considering land use suitability criteria by using the methods referred, these are insufficient to determine that relocalization is *per se* environmentally sustainable.

In the present study, the results of the relocalization scenario on self-reliance and water footprint are globally satisfactory when considering food provisioning targets. However, if maintaining the current agricultural regional specialization profile, e.g. in dairy products, and the proportion of livestock population per area, the relocalization scenario aggravates the already unsustainable use of natural resources. Therefore, to ameliorate the environmental consequences of relocalization scenarios in future studies the scenarios should be developed with the prior consideration of diets, and with regional alternative development pathways that correct current unsustainable agricultural specialization trends. By maintaining these trends in the assumptions of the relocalization scenario, the current study proved that food system relocalization scenarios should integrate further criteria besides the described above. Therefore, it is possible to increase the self-reliance of food groups according to the needs of each diet and also to optimise crops of interest for which there is currently the need for greater self-reliance. This was the approach adopted in Cardoso et al. (2017), to optimise land use according to ecological suitability and landscape planning methods, and considering for each diet a relocalization scenario or "foodshed landscape plan" (Cardoso et al. 2017).

With the intention of promoting the environmental sustainability of food systems relocalisation, future studies should consider other criteria as described by González De Molina and Lopez-Garcia (2021) and Padró and Tello (2022). Among these are the biophysical cycling of soil's nutrients and biodiversity levels, which are essential for the agroecological transition to occur in a way that benefits both social and environmental aspects. Such factors, among others, can contribute to better guide a potential transition to localized food systems.

The results of relocalization studies that integrate these criteria are generally in line with the European Green Deal and with particular targets of the Farm to Fork strategy, can provide information for spatial planning programmes, at regional and local level, and be included in specific regional and local food strategies.

5.4. Limitations and future work

The present study assessed for the first time how the relocalization would influence the WF of food products under different diets, showing that by reviewing the current land spacialization under suitable environmental conditions the effects could contribute to the sustainability of diverse resources, as land and water use. It is important to notice that considering temporary crops, specially fodder crops, and animals production, the data provided by the relocalization scenario, although essential to carry out the other analyses, do not provide enough information, in addition to land occupation, to carry out detailed potential self-reliance and WF assessments of the effect of this methodology on the crops mentioned above. The relocalization scenario could be more specific, as made in Cardoso et al. (2017), in which representative crops of the main food groups and model crops are used, including fodder crops, which would allow more direct access to potential productivity values of these crops. This can be considered a limitation of the data used in the present study, since these types of methodologies do not exist in relocalization studies for this agrarian region and for Portugal, such a study exists only for Ribatejo and Oeste (Cardoso et al. 2017).

Futhermore, there are some gaps present in the statistical databases, such as the lack of detailed information on a regional and municipal scale. It was necessary to perform approximations for almost all production data, since statistical indicators of production with municipal geographical disaggregation were only data related to milk and wine production. In addition, there is no information about the type of livestock feeding, pasture intensification, grazing livestock index, average number of animals per livestock, meat consumption per capita in municipal level, information that would help to understand more detailed what the potential productivity, self-reliance and WF of animal production would be. Without this disaggregation and accessing the results in an approximate way, although such approximation is described by authors as very close to the real values of the main production indicators (Schreiber et al. 2020; Vicente-Vicente et al. 2021), the presence of more specific data in these types of studies are fundamental for an evaluation that reflects the reality and that will serve as a basis for the development of land management strategies aimed at the sustainability of food systems.

Griffin et al. (2015), in their assessment of U.S Northeast self-reliance, demonstrate that four main factors influence regional self-reliance: land used for agriculture, crop (or animal) productivity, population and dietary preferences. Those factors shifts can be influence by different set of drivers. Because of that, it is recommended that in future studies with proposals of relocalization in food systems, an analysis of self-reliance should be considered also. For example, when in the current foodshed there are food groups that already presented self-reliance and specialization condition, as dairy products, create a relocalization scenario without

considering representative types of land cover, could reduce the self-reliability of the system. Also is necessary to considered more specifically, the crops and crop productivity that provide the feed for the livestock simultaneously with the assessment of potential animal productivity on these scenarios, besides the dietary preferences of population.

Kaufmann et al. (2022) pointed in their meta-analysis of RSR in European Union (UE), that self-sufficiency assessment without been considered the feed requirements of livestock production, could obscure potential import dependencies. The authors give an example about pork meat production in Europe, which depends on imports of protein feed from South and North America, when analyzed only pork meat production, which presented 106% of self-reliance in 2019, the fact that oils seed meals had a self-reliance of only 24% is missed (Kaufmann et al. 2022). Livestock system has a double role, being an intermediate consumer of primary biomass as the same time is a producer of animal-sourced products, this example suggest the need to assess the import and feed dependency of the systems, a challenge, considering the lack of census information about grazing and animal feed in different agricultural databases (Kaufmann et al. 2022).

Schreiber et al. (2020) and Kaufmann et al. (2022) suggest that by integrating animal feed in self-sufficiency assessment, an indicator framework, which promote the feasibility of local self-sufficiency, could allow food systems sustainability and short supply chains, reducing the dependence on external inputs. The capacity are complex, since foodsheds have a number of possible factors to be evaluated and quantified, such as the need to import resources from outside the region's boundaries, either to achieve self-sufficiency parameters or to meet the region's livestock production. The methodology used in the present study to evaluate the PFSR, considering animal production, is based on the information of land occupation by type of crop (temporary and pastures), not considering the potential animal production of relocalization scenario. This could mask the real values of potential self-reliance of the livestock systems, underestimating systems that in the current scenario present a certain level of specialisation. However, the information gathered here are important to build knowledge about foodshed analysis, taking this debate to academic and institutional levels, in order to promote valuable insights into the sustainability and resilience of the region's food systems (Peters, Bills, Wilkins, et al. 2009; Cardoso et al. 2017; Schreiber et al. 2020). Thus, it is important to carry out future studies aiming to develop more detailed solutions, improving the scenario of food supply with potential to provide information for evidence-based policy making (Cardoso et al. 2017; Kaufmann et al. 2022).

Flow analysis of the foodshed is essential to provide knowledge of resource use related to food supply, such as water embodied to diferent food products, nonetheless, short supply

chains, as considered on foodshed studies and implied on the relocalization scenario do not always result in better resource use (Schreiber et al. 2020). Besides specialization present negative aspect from a social and environmental point of view considering other natural resources, such as promoting land holdings in the hands of a few producers and also further impacting land use for example, it could enhance the efficiency of the food systems (Schreiber et al. 2020), promoting the local economy. In their study of virtual water flows, Akoto-Danso et al. (2019) pointed that the specialization also is linked to the environmental conditions where the farming systems are placed and by decrease the productive specialisation profile of a region, it could cause resource shortages what can threaten the food security of a CRFS. Besides, this decrease also can make food systems vulnerable to climate change, as well as geopolitical crises (Schreiber et al. 2020).

Thus, to rethink current food systems, especially the use of water resources linked to animal production, there are alternatives approaches such as choosing feed with higher water content, choosing livestock that use less water, choose faster growing animals and promoting more extensive livestock food systems (Doreau, Corson, and Wiedemann 2012). In their review, considering the water footprint to food supply management, Aivazidou et al. (2016) also brings together a series of propositions for the mitigation of the WF including crops and livestock production, like choosing rainfed crops to cultivate animal feed, organic crops that could reduce consumptive WF. Hoekstra et al. (2011) suggest the adoption of irrigation schedules based on climatic characteristics and mulching to reduce water loss from the soil by evaporation. Agrifood supply chains WF need to be reduced imperatively, and this process needs a well-structured decision-making, pointing the trade-offs of this process, something that can organize the corporate management of this environmental and economic resource, specially in environmental sensitive markets (Aivazidou et al. 2016). To overcome this challenge, international collaboration is more than welcome, in the cases of industrialized countries that import feed from developing countries, where the first one could support the latter in development of cooperation policies to reduce impacts on local water systems (Hoekstra 2012).

As showed before the influence of dietary patterns shifts of meat-based to plant-based on the ecological footprints is well studied field (Vanham, Mekonnen, and Hoekstra 2013; Vanham et al. 2016; Cardoso et al. 2017; Vanham et al. 2018; Campos and Madureira 2019; Kurtz et al. 2020; Vanham, Mekonnen, and Hoekstra 2020; Vanham et al. 2021; Zucchini et al. 2021), however foodshed case studies linked to that are rare, as the same as self-reliance assessment (Cardoso et al. 2017). The present study showed that, same as Cardoso et al (2017), foodshed assessment that are based on advanced mapping techniques and very efficient correlation models to identify potential self-reliance, may be more inaccurate in terms

of results, as it uses only representative crops, than considering yields and areas with agricultural suitability for the main land cover types. Despite the methodology applied in the present study is simple, the use of statistical information of yields and available agricultural land instead of crop simulation models can rise results close to the reality.

However, incomplete diets, with no comprise of all food groups and agricultural commodities, and incomplete data about food intake, as happens with meat in municipal scale, is common and could give some uncertainty about the results (Cardoso et al. 2017). But, as in the present study it was necessary to design diets with a level of comparison, so as not to make adaptations that would interfere with the macronutrient uptake in each diet, some food groups were no longer considered. These intervals of information can harm the promotion of these regionalized methodologies for the development of public policies, and new land planning under urbanization conditions by the main drivers. Moreover, to access the ecological footprint, specifically in this work the WF, it would be interesting in future work these evaluations to be carried out at the level of final product, to raise important information about the degree of use of this natural resource in the region and in other regions. Furthermore, to better understand the water consumption related to food consumption in a given region, it would be interesting to perform a more detailed water footprint assessment taking into account the main agricultural crops of interest in the region. For example, in the present study we consider the general water footprint of cereals, being that in the agricultural region of the EDM the main cereal grown is fodder maize, with these types of adjustments the assessment of water consumption can be more focused on the productive reality and bring more baseline information for decision-making. Also, it would still be interesting to add to the WF analysis of diets the consumption of wine, as this is a crop of importance in the region and also has high WF unit values.

6. Conclusion

There are many studies corroborating the fact that regionalizing food systems and changing consumption patterns could be some of the solutions for diverse food provision environmental issues, as well as promoting other socioeconomic aspects. Considering this fact, the present study aimed to evaluate, in the first step, the influence of relocalization on food self-reliance in the Entre Douro and Minho region, under several dietary scenarios. In the second step, a water footprint assessment was conducted to perceive the influence of the relocalization scenario on water use, under several dietary scenarios. This allowed to evaluate the municipalities contribution to food self-reliance within the current regional land use and under the relocalization scenario, as well as which diet presented higher potential food self-reliance by food group. It was also possible to evaluate how much water was consumed by food group in each municipality under the current and the relocalization scenario, and which diet/food group presents higher water consumption.

Although the relocalization scenario from Filipe (2021), presented an optimization of agricultural land use, based on ecological suitability and landscape planning methods, the present study showed that to fully comprehend the effects and potential benefits of this methodology, it is necessary to evaluate the capacities and also the resource flows of the foodshed. The results presented here confirm the improvements in self-reliance that the relocalization of the foodshed could promote on the main agricultural crop types and food groups. Permanent crops, due to the increase in land occupation, showed in the relocalization scenario higher values of potential food self-reliance (PFSR). The temporary crops, with the exception of animal food groups included in this land cover, also presented higher values of PFSR. Animal production, represented by specialised production systems, that depends largely on fodder included in temporary crops presented lower PFSR in comparison to current foodshed scenario. A potential relocalization could decrease these productions in order to augment other food groups self-reliance. This is the case of the decrease in self-reliance for dairy production in the EDM region, which may be in line with environmental sustainability targets, although could compromise sub-national trade and international exports and have other socioeconomic impacts for the region.

Considering the analyzed diets, the results of the present study showed that diets with lower consumption of animal food products have greater potential self-reliance. However, depending on the type of food group, the low productivity when related with high consumption values can reduce the self-reliance values, as it is the case with pulses and nuts in the Strict Vegetarian diet. Accordingly, it is important to consider that proposals for changes in

consumption patterns should consider crop productivity values, land use, level of agricultural specialization, in addition to the environmental characteristics of foodsheds. This entails that relocalisation studies should use ecologically-based landscape planning methods and consider previously diets on the relocalisation scenarios.

In what concerns the assessment of water footprint (WF), similarly to other studies relating ecological footprints with animal production, the animal-based products presented the highest values of freshwater consumption. It was confirmed that animal-based products, sourced from intensive production systems, due to their dependence on feed crops for livestock, also have higher WF values, as it is the case between dairy products and beef. Considering the methodology business as usual for animal production, it could be observed in relocalization, the importance to differentiate crops and livestock that already present self-reliability, because the water consumption would be higher than current scenario. It was noticed that the relocalization of the foodshed, despite bringing benefits and promoting other ES, did not decrease the total WF of production.

In the context of diets, the results followed what has been well documented in the literature, diets with lower consumption of foods of animal origin had the lowest WF values. After all, as evaluated in production, these systems have double the consumption of water in the production chain, especially in animal husbandry. However, it was also observed that depending on the food group, WF units linked to a high consumption rate may increase the total WF of the diet, as we observed on SV diet and its high consumption of legumes and nuts. Therefore, it is important to consider these aspects in a supposed change in consumption patterns, also considering the location where these systems are located and the resource imports needed to achieve the food needs of a diet. When comparing the diets in the current foodshed and the relocalization scenario, it was observed that the potential spatialization caused a decrease in WF values in animal-based diets, thus proving that this approach together with changes in the dietary pattern can bring multiple benefits when directed to the sustainability of food systems.

In conclusion, the present study considers regionalization, here based on the concepts of Foodshed and City-Region Food Systems, as essential approaches for the development of a resilient and sustainable food supply. It also proposes a more comprehensive view of the methodology that considers multiple aspects related to the environment and productivity of the systems. Rethink the food supply chain in a sustainable perspective demands a set of assessments in order to better understand the possible trade-offs and priorities for new proposals for planning, production and logistics. The results presented here could also contribute as important tools to land management on a local and regional scale and for the

growing process of urbanization that different regions in the world are experiencing, contributing for a food planning that respect both environment a socioeconomic aspects. As demonstrated, sustainable food provision that includes food security and sovereignty is one of the greatest challenges faced by governmental entities today, requiring many approaches to overcome. The questions proposed in the present study serve as a principle for the reassessment of current food supply chains, especially in the context of intensive agriculture under the effect of climate change. It was intended to validate that there are other paths to be followed with new proposals for the land use that includes, in parallel, the carrying capacity of the food systems allocated therein and the flow of resources necessary for its maintenance.

7. References

- Aivazidou, Eirini, Naoum Tsolakis, Eleftherios Iakovou, and Dimitrios Vlachos. 2016. "The Emerging Role of Water Footprint in Supply Chain Management: A Critical Literature Synthesis and a Hierarchical Decision-Making Framework." *Journal of Cleaner Production* 137: 1018–37. <https://doi.org/10.1016/j.jclepro.2016.07.210>.
- Akoto-Danso, Edmund Kyei, Hanna Karg, Pay Drechsel, George Nyarko, and Andreas Buerkert. 2019. "Virtual Water Flow in Food Trade Systems of Two West African Cities." *Agricultural Water Management* 213 (March): 760–72. <https://doi.org/10.1016/J.AGWAT.2018.11.012>.
- Bach-Faig, Anna, Elliot M. Berry, Denis Lairon, Joan Reguant, Antonia Trichopoulou, Sandro Dernini, F. Xavier Medina, et al. 2011. "Mediterranean Diet Pyramid Today. Science and Cultural Updates." *Public Health Nutrition* 14 (12A): 2274–84. <https://doi.org/10.1017/S1368980011002515>.
- Baer-Nawrocka, Agnieszka, and Arkadiusz Sadowski. 2019. "Food Security and Food Self-Sufficiency around the World: A Typology of Countries." *PLoS ONE* 14 (3): 1–15. <https://doi.org/10.1371/journal.pone.0213448>.
- Banerjee, Arnab, Ram Swaroop, Meena Manoj, Kumar Jhariya, and Dhiraj Kumar. 2021. *Agroecological Footprints Management for Sustainable Food System*. <https://doi.org/10.1007/978-981-15-9496-0>.
- Base de dados do Instituto Nacional de Estatística (INE). 2022. "Capitação Edível Diária de Produtos Alimentares Disponível Para Abastecimento." INE database.
- Benedek, Zsófia, Imre Ferto, and Viktória Szente. 2020. "The Multiplier Effects of Food Relocalization: A Systematic Review." *Sustainability (Switzerland)* 12 (9): 3524. <https://doi.org/10.3390/SU12093524>.
- Berner, Simon, Hartmut Derler, René Rehorska, Stephan Pabst, and Ulrike Seebacher. 2019. "Roadmapping to Enhance Local Food Supply: Case Study of a City-Region in Austria." *Sustainability (Switzerland)* 11 (14): 1–16. <https://doi.org/10.3390/su11143876>.
- Billen, Gilles, Sabine Barles, Josette Garnier, Joséphine Rouillard, and Paul Benoit. 2009. "The Food-Print of Paris: Long-Term Reconstruction of the Nitrogen Flows Imported into the City from Its Rural Hinterland." *Regional Environmental Change* 9 (1): 13–24. <https://doi.org/10.1007/s10113-008-0051-y>.
- Blay-palmer, Alison, Guido Santini, Marielle Dubbeling, Henk Renting, Makiko Taguchi Id, and Thierry Giordano. 2018. "Validating the City Region Food System Approach : Enacting Inclusive , Transformational City Region Food Systems." *Sustainability (Switzerland)* 10 (1680). <https://doi.org/10.3390/su10051680>.
- Brand, Caroline, Nicolas Bricas, Damien Conaré, Benoit Daviron, Julie Debru, Laura Michel, and Christophe-Toussaint Soulard. 2017. *Designing Urban Food Policies*. Edited by Caroline Brand, Nicolas Bricas, Damien Conaré, Benoit Daviron, Julie Debru, Laura Michel, and Christophe-Toussaint Soulard. 1st ed. Versailles: Springer, Cham. <https://doi.org/https://doi.org/10.1007/978-3-030-13958-2>.
- Brinkley, Catherine, Subhashni Raj, and Samina Raja. 2022. "Planning for FEWsheds: The Role of Planning in Integrating and Strengthening Food, Energy and Water Systems." <https://doi.org/10.1177/08854122221093387>, April.

<https://doi.org/10.1177/08854122221093387>.

- Cambeses-Franco, Cristina, Gumersindo Feijoo, María Teresa Moreira, and Sara González-García. 2022. "Co-Benefits of the EAT-Lancet Diet for Environmental Protection in the Framework of the Spanish Dietary Pattern." *Science of The Total Environment* 836 (August): 155683. <https://doi.org/10.1016/J.SCITOTENV.2022.155683>.
- Campos, Susana, and Livia Madureira. 2019. "Can Healthier Food Demand Be Linked to Farming Systems' Sustainability? The Case of the Mediterranean Diet Can Healthier Food Demand Be Linked to Farming Systems' Sustainability? The Case of the Mediterranean Diet," no. June. <https://doi.org/10.18461/ijfsd.v10i2.17>.
- Candy, Seona, Graham Mark Turner, Jennifer Sheridan, and Rachel Carey. 2018. "Quantifying Melbourne's 'Foodprint': A Scenario Modelling Methodology to Determine the Environmental Impact of Feeding a City." *Economia Agro-Alimentare* 20 (3): 371–99. <https://doi.org/10.3280/ECAG2018-003007>.
- Cardoso, Andreia Saavedra. 2018. "Ecological Based Landscape Planning for City Region Food Systems Environmental Sustainability." *Excertos Da Candidatura Ao Concurso Estímulo Ao Emprego Científico Individual*, no. 2.
- Cardoso, Andreia Saavedra, Tiago Domingos, Manuela Raposo de Magalhães, José de Melo-Abreu, and Jorge Palma. 2017. "Mapping the Lisbon Potential Foodshed in Ribatejo e Oeste: A Suitability and Yield Model for Assessing the Potential for Localized Food Production." *Sustainability (Switzerland)* 9 (11). <https://doi.org/10.3390/su9112003>.
- Cardoso, Andreia Saavedra, Manuela Raposo Magalhães, Tiago Domingos, and João Pradinho Honrado. 2021. "Agroecological Network Planning as an Approach for Food System Localisation . The Lisbon City-Region Case Study Agroecological Network Planning as an Approach for Food System Localisation . The Lisbon City-Region Case Study," no. June: 3–4. <https://doi.org/10.13140/RG.2.2.32634.21447>.
- Carvalho-Santos, Claudia, João Pedro Nunes, António T. Monteiro, Lars Hein, and João Pradinho Honrado. 2016. "Assessing the Effects of Land Cover and Future Climate Conditions on the Provision of Hydrological Services in a Medium-Sized Watershed of Portugal." *Hydrological Processes* 30 (5): 720–38. <https://doi.org/10.1002/hyp.10621>.
- Cassidy, Emily S., Paul C. West, James S. Gerber, and Jonathan A. Foley. 2013. "Redefining Agricultural Yields: From Tonnes to People Nourished per Hectare." *Environmental Research Letters* 8 (3). <https://doi.org/10.1088/1748-9326/8/3/034015>.
- Cerqueira, Joaquim Lima, Rui Belchior Cruz, Manuel Diogo Salgueiro, and José Pedro Araújo. n.d. "Alimentação e Produtividade Em Vacas Leiteiras Na Região Norte - Ucanorte XXI." Accessed August 19, 2022. <https://www.ucanorte.pt/destaques/artigos-tecnicos/alimentacao-e-produtividade-em-vacas-leiteiras-na-regiao-norte/>.
- Cerutti, Alessandro K., Gabriele L. Beccaro, Marco Bagliani, Simone Contu, Dario Donno, and Giancarlo Bounous. 2012. "Ecological Footprint Applied in Agro-Ecosystems: Methods and Case Studies." *The Functioning of Ecosystems*. <https://doi.org/10.5772/35966>.
- Comunidade Intermunicipal do Douro. 2015. "Estratégia Integrada de Desenvolvimento Territorial Da Região de Coimbra 2014-2020." *Comunidade Intermunicipal Do Douro*. Vol. 1. https://www.cim-regiaodecoimbra.pt/wp-content/uploads/2018/06/RCoimbra_EIDT_v2.pdf.
- Cowell, S J, and S Parkinson. 2003. "Localisation of UK Food Production: An Analysis Using Land Area and Energy as Indicators." *Agriculture, Ecosystems & Environment* 94 (2):

221–36.

- Cowell, Sarah J., and Stuart Parkinson. 2003. "Localisation of UK Food Production: An Analysis Using Land Area and Energy as Indicators." *Agriculture, Ecosystems and Environment* 94 (2): 221–36. [https://doi.org/10.1016/S0167-8809\(02\)00024-5](https://doi.org/10.1016/S0167-8809(02)00024-5).
- Daniel Boris Silva Maia. 2019. "Integrating Food into Urban Planning." Tese (Mestrado) Departamento de Engenharia Civil, Faculdade de Engenharia da Universidade do Porto.
- Desjardins, Ellen, Rod MacRae, and Theresa Schumilas. 2010. "Linking Future Population Food Requirements for Health with Local Production in Waterloo Region, Canada." *Agriculture and Human Values* 27 (2): 129–40. <https://doi.org/10.1007/s10460-009-9204-y>.
- DGS. n.d. "Programa Nacional de Promoção Da Alimentação Saudável : DGS." Accessed September 19, 2022. <https://alimentacaosaudavel.dgs.pt/>.
- Dias, Filipa, and Catarina Correia. 2020. *O Uso Da Água Em Portugal*. Edited by Fundação Calouste Gulbenkian e Return On Ideas.
- Direcção Geral de Território (DGT). 2020. "Carta Administrativa Oficial de Portugal -- CAOP 2020." 2020. http://mapas.dgterritorio.pt/ATOM-download/CAOP-Cont/Cont_AAD_CAOP2020.zip.
- Direcção Regional de Agricultura do Entre Douro e Minho, Geometral, and Agroconsultores. 1999. "Carta de Solos e Aptidão Da Terra Para a Agriculturura (1:25.000) Em Entre Douro e Minho - Memórias." Lisboa.
- Direcção Regional de Agricultura do Entre Douro e Minho, Instituto para o Desenvolvimento Agrário da Região Norte, Escola Superior Agrária do Instituto Politécnico de Viana do Castelo, and Universidade do Porto - CIBIO. 2007. "Plano de Ordenamento Da Bacia Leiteira Primária Do Entre Douro e Minho." Viana do Castelo.
- Donald, Betsy, Meric Gertler, Mia Gray, and Linda Lobao. 2010. "Re-Regionalizing the Food System?" *Cambridge Journal of Regions, Economy and Society* 3 (2): 171–75. <https://doi.org/10.1093/cjres/rsq020>.
- Doreau, Michel, Michael S Corson, and Stephen G Wiedemann. 2012. "Water Use by Livestock : A Global Perspective for a Regional Issue ?" 2 (2): 9–16.
- Dubbeling, Marielle. 2015. "City Region Food Systems," no. July 2016.
- Dubbeling, Marielle, Guido Santini, Henk Renting, Makiko Taguchi, Louison Lançon, Juan Zuluaga, Luca de Paoli, Alexandra Rodriguez, and Verónica Andino. 2017. "Assessing and Planning Sustainable City Region Food Systems : Insights from Two Latin American Cities." *Sustainability (Switzerland)* 9: 1455. <https://doi.org/10.3390/su9081455>.
- EEA. 2020. *Water and Agriculture: Towards Sustainable Solutions. Report: EEA 17*.
- Ercin, A. Ertug, and Arjen Y. Hoekstra. 2016. "European Water Footprint Scenarios for 2050." *Water (Switzerland)* 8 (6). <https://doi.org/10.3390/w8060226>.
- European Comission. 2020. "Farm to Fork Strategy."
- European Commission. 2013. "The Impact of EU Consumption on Deforestation: Comprehensive Analysis of the Impact of EU Consumption on Deforestation Final Report." <https://doi.org/10.2779/822269>.
- European Enviroment Agency. 2020. *Water and Agriculture: Towards Sustainable Solutions*.

- Copenhagen K Denmark. <https://doi.org/10.2800/73735>.
- FAO, IFAD, UNICEF, WFP, and WHO. 2019. "The State of Food Security and Nutrition in the World 2019." *Food and Agriculture Organization of the United Nations*. Rome.
- Flörke, Martina, Florian Wimmer Cesr, Cornelius Laaser, Rodrigo Vidaurre, Jenny Tröltzsch, Thomas Dworak, Ulf Stein Ecologic, et al. 2011. "Final Report for the Project Climate Adaptation – Modelling Water Scenarios and Sectoral Impacts Authors :"
- Foley, Jonathan A., Ruth DeFries, Gregory P. Asner, Carol Barford, Gordon Bonan, Stephen R. Carpenter, F. Stuart Chapin, et al. 2005. "Global Consequences of Land Use." *Science* 309 (5734): 570–74. <https://doi.org/10.1126/science.1111772>.
- Galli, A., J. Kitzes, P. Wermer, M. Wackernagel, V. Niccolucci, and E. Tiezzi. 2007. "An Exploration of the Mathematics behind the Ecological Footprint." *International Journal of Ecodynamics* 2 (4): 250–57. <https://doi.org/10.2495/ECO-V2-N4-250-257>.
- Galli, Alessandro, Mario Giampietro, Steve Goldfinger, Elias Lazarus, David Lin, Andrea Saltelli, Mathis Wackernagel, and Felix Müller. 2016. "Questioning the Ecological Footprint." *Ecological Indicators* 69: 224–32. <https://doi.org/10.1016/j.ecolind.2016.04.014>.
- Garnett, Tara. 2014. "Three Perspectives on Sustainable Food Security : Ef Fi Ciency , Demand Restraint , Food System Transformation . What Role for Life Cycle Assessment ?" *Journal of Cleaner Production* 73: 10–18. <https://doi.org/10.1016/j.jclepro.2013.07.045>.
- Global Footprint Network. n.d. "Glossary - Global Footprint Network." Accessed September 28, 2022. <https://www.footprintnetwork.org/resources/glossary/>.
- Goldstein, Benjamin, Morten Birkved, John Fernández, and Michael Hauschild. 2017. "Surveying the Environmental Footprint of Urban Food Consumption." *Journal of Industrial Ecology* 21 (1): 151–65. <https://doi.org/10.1111/jiec.12384>.
- González De Molina, Manuel, and Daniel Lopez-Garcia. 2021. "Principles for Designing Agroecology-Based Local (Territorial) Agri-Food Systems: A Critical Revision." *Agroecology and Sustainable Food Systems* 45 (7): 1050–82. <https://doi.org/10.1080/21683565.2021.1913690>.
- Graça, Pedro, Maria João Gregório, Sofia Mendes De Sousa, Sónia Brás, Tatiana Penedo, Telmo Carvalho, Narcisa M. Bandarra, et al. 2018. "A New Interministerial Strategy for the Promotion of Healthy Eating in Portugal: Implementation and Initial Results." *Health Research Policy and Systems*. <https://doi.org/10.1186/s12961-018-0380-3>.
- Griffin, Timothy, Zach Conrad, Christian Peters, Ronit Ridberg, and Ellen Parry Tyler. 2015. "Regional Self-Reliance of the Northeast Food System." *Renewable Agriculture and Food Systems* 30 (4): 349–63. <https://doi.org/10.1017/S1742170514000027>.
- Grunewald, Nicole, and Michel Gressot. 2015. "The Ecological Footprint of Mediterranean Diets," no. April.
- Harris, Francesca, Cami Moss, Edward J.M. Joy, Ruth Quinn, Pauline F.D. Scheelbeek, Alan D. Dangour, and Rosemary Green. 2020. "The Water Footprint of Diets: A Global Systematic Review and Meta-Analysis." *Advances in Nutrition*. Oxford University Press. <https://doi.org/10.1093/advances/nmz091>.
- Hein, Jane Ricketts, Brian Ilbery, and Moya Kneafsey. 2006. "Distribution of Local Food Activity in England and Wales: An Index of Food Relocalization." *Regional Studies* 40 (3): 289–301. <https://doi.org/10.1080/00343400600631533>.

- Hendrickson, Mary K., and William D. Heffernan. 2002. "Opening Spaces through Relocalization: Locating Potential Resistance in the Weaknesses of the Global Food System." *Sociologia Ruralis* 42 (4): 347–69. <https://doi.org/10.1111/1467-9523.00221>.
- Hoekstra, Arjen Y. 2012. "The Hidden Water Resource Use behind Meat and Dairy." *Animal Frontiers* 2 (2): 3–8. <https://doi.org/10.2527/af.2012-0038>.
- Hoekstra, Arjen Y., Ashok K. Chapagain, Maite M. Aldaya, and Mesfin M. Mekonnen. 2011. *The Water Footprint Assessment Manual. Setting the Global Standard*. Earthscan. 1st ed. Vol. 31. London. <https://doi.org/10.1080/0969160x.2011.593864>.
- Horst, M., and B. Gaolach. 2015. "The Potential of Local Food Systems in North America: A Review of Foodshed Analyses." *Renewable Agriculture and Food Systems* 30 (5): 399–407. <https://doi.org/10.1017/S1742170514000271>.
- Ibidhi, R., and H. Ben Salem. 2020. "Water Footprint of Livestock Products and Production Systems: A Review." *Animal Production Science*. CSIRO. <https://doi.org/10.1071/AN17705>.
- INE, Instituto nacional de Estatística. 2019. "RECENSEAMENTO AGRÍCOLA 2019." 2021. <https://www.acos.pt/files/20210401145737753recenseamento-agricola-2019-2021.pdf>.
- Instituto Nacional de Estatística. 2020. *Balança Alimentar Portuguesa:2020*. <https://www.ine.pt/xurl/pub/437140067>.
- Instituto Nacional de Estatística (INE). 2021. "RECENSEAMENTO AGRÍCOLA 2019." 2021. <https://www.acos.pt/files/20210401145737753recenseamento-agricola-2019-2021.pdf>.
- Joseph, Sarah, Irene Peters, and Hanno Friedrich. 2019. "Can Regional Organic Agriculture Feed the Regional Community? A Case Study for Hamburg and North Germany." *Ecological Economics* 164 (October): 106342. <https://doi.org/10.1016/J.ECOLECON.2019.05.022>.
- Kaufmann, Lisa, Andreas Mayer, Sarah Matej, Gerald Kalt, Christian Lauk, Michaela Theurl, and Karl-Heinz Erb. 2022. "Regional Self-Sufficiency: A Multi-Dimensional Analysis Relating Agricultural Production and Consumption in the European Union." *Sustainable Production and Consumption*, 100310. <https://doi.org/10.1016/j.spc.2022.08.014>.
- Kepner, William G., Molly M. Ramsey, Elizabeth S. Brown, Meghann E. Jarchow, Katharine J. M. Dickinson, and Alan F. Mark. 2012. "Hydrologic Futures: Using Scenario Analysis to Evaluate Impacts of Forecasted Land Use Change on Hydrologic Services." *Ecosphere* 3 (7): art69. <https://doi.org/10.1890/es11-00367.1>.
- Kloppenburg, Jack, John Hendrickson, and G. W. Stevenson. 1996. "Coming in to the Foodshed." *Agriculture and Human Values* 13 (3): 33–42. <https://doi.org/10.1007/BF01538225>.
- Kneafsey, Moya, Laura Venn, Ulrich Schmutz, Bálint Balázs, Shakirat Oluwatosin Haroon-sulyman, Abdulfatah Aishat Tolulope, Lori Stahlbrand, et al. 2013. "Short Food Supply Chains and Local Food Systems in the EU. A State of Play of Their Socio-Economic Characteristics. Citizen Science to Promote Creativity, Scientific Literacy, and Innovation throughout Europe View Project Agroecology and Organic Horticult." *Jrc Scientific and Policy Reports* 24 (1): 77–95. <https://doi.org/10.2791/88784>.
- Kurtz, Julie E., Peter B. Woodbury, Zia U. Ahmed, and Christian J. Peters. 2020. "Mapping U.S. Food System Localization Potential: The Impact of Diet on Foodsheds." *Environmental Science and Technology* 54 (19): 12434–46. <https://doi.org/10.1021/acs.est.9b07582>.
- Levidow, Les, and Katerina Psarikidou. 2014. "Food Relocalization for Environmental

- Sustainability in Cumbria,” no. August. <https://doi.org/10.3390/su3040692>.
- Magalhães, Manuela, Natália Cunha, and Selma Pena. 2011. “The Ecological Land Suitability in the Land-Use Plan: Sintra’s Municipality Case Study.” In *7th Virtual Cities and Territories*, 307–12. Lisbon: Iniciativa Digital Politecnica. <https://doi.org/10.5821/CTV.7705>.
- Mariana Cardoso Filipe. 2021. “Sistemas Alimentares Cidade-Região e a Conservação Da Biodiversidade: O Caso de Estudo Da Região Agrária Do Entre-Douro-e-Minho.” Universidade do Porto.
- Matušítk, Jan, and Vladimír Kočí. 2021. “What Is a Footprint? A Conceptual Analysis of Environmental Footprint Indicators.” *Journal of Cleaner Production*. Elsevier Ltd. <https://doi.org/10.1016/j.jclepro.2020.124833>.
- Mekonnen, M. M., and A. Y. Hoekstra. 2011. “The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products.” *Hydrology and Earth System Sciences* 15 (5): 1577–1600. <https://doi.org/10.5194/hess-15-1577-2011>.
- Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2012. “A Global Assessment of the Water Footprint of Farm Animal Products.” *Ecosystems* 15 (3): 401–15. <https://doi.org/10.1007/s10021-011-9517-8>.
- . 2020. “Blue Water Footprint Linked to National Consumption and International Trade Is Unsustainable.” *Nature Food* 1 (12): 792–800. <https://doi.org/10.1038/s43016-020-00198-1>.
- Mollenhorst, H., P. B.M. Berentsen, and I. J.M. De Boer. 2006. “On-Farm Quantification of Sustainability Indicators: An Application to Egg Production Systems.” *British Poultry Science* 47 (4): 405–17. <https://doi.org/10.1080/00071660600829282>.
- Mouël, Chantal Le, and Marie De Lattre-gasquet. 2018. *Land Use and Food Security in 2050: A Narrow Road. Land Use and Food Security in 2050: A Narrow Road*. <https://doi.org/10.35690/978-2-7592-2880-5>.
- Noya, I., L. Lijo, O. Piñeiro, R. Lopez-Carracelas, B. Omil, M. T. Barral, A. Merino, G. Feijoo, and M. T. Moreira. 2019. “Water Footprint of Livestock Farming.” In *Environmental Footprints and Eco-Design of Products and Processes*, 21–54. Springer. https://doi.org/10.1007/978-981-13-2508-3_2.
- Padró, Roc, and Enric Tello. 2022. “Exploring Agroecology Transition Scenarios: A Pfaundler’s Spectrum Assessment on the Relocation of Agri-Food Flows.” *Land* 2022, Vol. 11, Page 824 11 (6): 824. <https://doi.org/10.3390/LAND11060824>.
- Peters, Christian J., Nelson L. Bills, Arthur J. Lembo, Jennifer L. Wilkins, and Gary W. Fick. 2009. “Mapping Potential Foodsheds in New York State: A Spatial Model for Evaluating the Capacity to Localize Food Production.” *Renewable Agriculture and Food Systems* 24 (1): 72–84. <https://doi.org/10.1017/S1742170508002457>.
- Peters, Christian J., Nelson L. Bills, Jennifer L. Wilkins, and Gary W. Fick. 2009. “Foodshed Analysis and Its Relevance to Sustainability.” *Renewable Agriculture and Food Systems* 24 (1): 1–7. <https://doi.org/10.1017/S1742170508002433>.
- Petersson, Tashina, Luca Secondi, Andrea Magnani, Marta Antonelli, Katarzyna Dembska, Riccardo Valentini, Alessandra Varotto, and Simona Castaldi. 2021. “A Multilevel Carbon and Water Footprint Dataset of Food Commodities.” *Scientific Data* 8 (1). <https://doi.org/10.1038/s41597-021-00909-8>.
- Preiss, Potira Viegas, and Sergio Schneider. 2020. *Sistemas Alimentares No Século XXI: Debates Contemporâneos*.

- Reganold, John P., Jerry D. Glover, Preston K. Andrews, and Herbert R. Hinman. 2001. "Sustainability of Three Apple Production Systems." *Nature* 410 (6831): 926–30. <https://doi.org/10.1038/35073574>.
- Rockström, Johan, W. Steffen, K. Noone, Å. Persson, F.S. Chapin, E. F. Lambin, T. M. Lenton, et al. 2009. "A Safe Operation Space for Humanity." *Nature* 461 (September): 472–75.
- Rüschhoff, Judith, Carl Hubatsch, Jörg Priess, Thomas Scholten, and Lukas Egli. 2022. "Potentials and Perspectives of Foodself-Sufficiency in Urban Areas—a Casestudy from Leipzig." *Renewable Agriculture AndFood Systems* 37: 227–36. <https://doi.org/https://doi.org/10.1017/S174217052100048X>.
- Sali, Guido, Federica Monaco, Chiara Mazzocchi, and Stefano Corsi. 2016. "Exploring Land Use Scenarios in Metropolitan Areas: Food Balance in a Local Agricultural System by Using a Multi-Objective Optimization Model." *Agriculture and Agricultural Science Procedia* 8: 211–21. <https://doi.org/10.1016/j.aaspro.2016.02.095>.
- Schreiber, Kerstin, Gordon M. Hickey, Geneviève S. Metson, Brian E. Robinson, and Graham K. MacDonald. 2020. *Quantifying the Foodsheed: A Systematic Review of Urban Food Flow and Local Food Self-Sufficiency Research*. J. Phys. Energy. Vol. 2.
- U.S. Department of Agriculture and U.S. Department of Health and Human Services. 2010. "Dietary Guidelines for Americans, 2010." DC: U.S. Government Printing Offic. 7th ed. Washington. <https://doi.org/10.1001/jama.2016.0077>.
- U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015. "2015–2020 Dietary Guidelines for Americans." U.S.D.A. Washington. <https://doi.org/10.1097/NT.0b013e31826c50af>.
- United Nations. 2015. "The Millennium Development Goals Report," no. June: 1.
- Vanham, D., and G. Bidoglio. 2014. "The Water Footprint of Agricultural Products in European River Basins." *Environmental Research Letters* 9 (6). <https://doi.org/10.1088/1748-9326/9/6/064007>.
- Vanham, D., M. M. Mekonnen, and A. Y. Hoekstra. 2013. "The Water Footprint of the EU for Different Diets." *Ecological Indicators* 32: 1–8. <https://doi.org/10.1016/j.ecolind.2013.02.020>.
- Vanham, D., S. del Pozo, A. G. Pekcan, L. Keinan-Boker, A. Trichopoulou, and B. M. Gawlik. 2016a. "Water Consumption Related to Different Diets in Mediterranean Cities." *Science of The Total Environment* 573 (December): 96–105. <https://doi.org/10.1016/J.SCITOTENV.2016.08.111>.
- . 2016b. "Water Consumption Related to Different Diets in Mediterranean Cities." *Science of the Total Environment* 573 (December): 96–105. <https://doi.org/10.1016/j.scitotenv.2016.08.111>.
- Vanham, Davy, Sara Comero, Bernd Manfred Gawlik, and Giovanni Bidoglio. 2018. "The Water Footprint of Different Diets within European Sub-National Geographical Entities." *Nature Sustainability* 1 (9): 518–25. <https://doi.org/10.1038/s41893-018-0133-x>.
- Vanham, Davy, Susann Guenther, Marta Ros-Baró, and Anna Bach-Faig. 2021a. "Which Diet Has the Lower Water Footprint in Mediterranean Countries?" *Resources, Conservation and Recycling* 171 (December 2020). <https://doi.org/10.1016/j.resconrec.2021.105631>.
- . 2021b. "Which Diet Has the Lower Water Footprint in Mediterranean Countries?" *Resources, Conservation and Recycling* 171 (August).

<https://doi.org/10.1016/j.resconrec.2021.105631>.

- Vanham, Davy, and Adrian Leip. 2020. "Sustainable Food System Policies Need to Address Environmental Pressures and Impacts: The Example of Water Use and Water Stress." *Science of the Total Environment* 730 (August). <https://doi.org/10.1016/j.scitotenv.2020.139151>.
- Vanham, Davy, Mesfin M. Mekonnen, and Arjen Y. Hoekstra. 2020. "Treenuts and Groundnuts in the EAT-Lancet Reference Diet: Concerns Regarding Sustainable Water Use." *Global Food Security* 24 (March). <https://doi.org/10.1016/J.GFS.2020.100357>.
- Vicente-Vicente, José Luis, and Annette Piorr. 2021. "Can a Shift to Regional and Organic Diets Reduce Greenhouse Gas Emissions from the Food System? A Case Study from Qatar." *Carbon Balance and Management* 16 (1). <https://doi.org/10.1186/s13021-020-00167-y>.
- Vicente-Vicente, José Luis, Esther Sanz-Sanz, Claude Napoléone, Michel Moulery, and Annette Piorr. 2021. "Foodshed, Agricultural Diversification and Self-Sufficiency Assessment: Beyond the Isotropic Circle Foodshed—A Case Study from Avignon (France)." *Agriculture* 11 (2): 143. <https://doi.org/10.3390/agriculture11020143>.
- Vikas Rawal, and Dorian Kalamvrezos Navarro. 2019. "The Global Economy of Pulses." *FAO*. <https://doi.org/10.4324/9781351263207-4>.
- Wascher, D, I. Zasada, and G. Sali. 2015. "Tools for Metropolitan Food Planning - A New View on the Food Security of Cities." *The Governance of City Food Systems*, no. December: 68–97.
- Wascher, Dirk, Michiel Van Eupen, Stefano Corsi, Guido Sali, and Ingo Zasada. 2016. *Metropolitan Foodsheds as Spatial References for a Landscape-Based Assessment of Regional Food Supply. Agriculture in an Urbanizing Society Volume One: Proceedings of the Sixth AESOP Conference on Sustainable Food Planning "Finding Spaces for Productive Cities."*
- Willett, Walter, Johan Rockström, Brent Loken, Marco Springmann, Tim Lang, Sonja Vermeulen, Tara Garnett, et al. 2019. "Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems." *The Lancet* 393 (10170): 447–92. [https://doi.org/10.1016/S0140-6736\(18\)31788-4](https://doi.org/10.1016/S0140-6736(18)31788-4).
- Zasada, Ingo, Ulrich Schmutz, Dirk Wascher, Moya Kneafsey, Stefano Corsi, Chiara Mazzocchi, Federica Monaco, et al. 2017. "Food beyond the City – Analysing Foodsheds and Self-Sufficiency for Different Food System Scenarios in European Metropolitan Regions." *City, Culture and Society* 16 (March 2017): 25–35. <https://doi.org/10.1016/j.ccs.2017.06.002>.
- Zucchinelli, Maria, Rosangela Spinelli, Sara Corrado, and Lucrezia Lamastra. 2021. "Evaluation of the Influence on Water Consumption and Water Scarcity of Different Healthy Diet Scenarios." *Journal of Environmental Management* 291 (August). <https://doi.org/10.1016/j.jenvman.2021.112687>.

8. Appendix

Appendix 1 Current Foodshed Self-Reliance by municipalities and food groups (%).

Municipality	Beef	Pork	Poultry	Eggs	Dairy	Cereals	Pulses	Tubers	Vegetables	Fruits	Vegetable oils	Nuts	Wine
Amarante	8.53E-03	3.60E-02	2.74E-01	1.29E-03	1.67E-04	8.41E-03	1.51E-03	1.37E-03	3.77E-03	3.04E-03	2.22E-05	1.36E-03	4.74E-02
Amares	3.63E-03	1.74E-02	1.27E+01	6.32E-02	0.00E+00	5.86E-03	7.98E-04	8.21E-04	4.04E-03	3.41E-03	3.69E-06	3.34E-04	1.20E-02
Arcos de Valdevez	4.52E-02	1.46E-02	2.64E-01	2.60E-03	1.24E-03	4.06E-03	5.32E-04	1.51E-03	7.02E-04	2.05E-04	0.00E+00	2.50E-03	1.48E-03
Arouca	1.65E-02	3.13E-01	2.25E+00	1.06E-03	1.81E-02	4.19E-03	2.66E-04	4.79E-04	2.63E-04	8.62E-04	9.24E-06	9.18E-04	2.62E-04
Baiao	3.62E-03	3.33E-02	1.69E-01	1.03E-03	0.00E+00	3.10E-03	1.20E-03	1.16E-03	7.90E-04	2.08E-03	1.46E-04	3.09E-03	1.18E-02
Barcelos	1.57E-01	2.00E-02	5.98E-01	3.80E-03	4.80E-01	1.34E-02	8.87E-04	3.22E-03	8.07E-03	1.40E-03	3.69E-06	1.06E-03	1.55E-02
Braga	2.90E-02	1.88E-02	3.93E-01	2.78E-03	3.07E-02	1.34E-02	1.77E-04	2.05E-03	5.35E-03	1.86E-03	7.39E-06	1.22E-03	2.76E-03
Cabeceiras de Basto	1.52E-02	5.74E-02	3.31E+00	1.13E-03	0.00E+00	4.59E-03	2.22E-04	1.03E-03	1.75E-04	8.83E-04	2.77E-05	2.53E-03	5.27E-03
Caminha	1.15E-03	7.03E-03	1.14E-01	8.35E-04	0.00E+00	1.59E-03	1.77E-04	7.53E-04	2.63E-04	4.30E-05	0.00E+00	7.51E-04	4.84E-05
Castelo de Paiva	2.13E-03	1.21E-02	1.04E-01	4.99E-04	0.00E+00	2.88E-03	3.55E-04	4.11E-04	7.90E-04	2.16E-03	0.00E+00	4.73E-04	8.55E-03
Celorico de Basto	5.81E-03	2.48E-02	3.86E-01	1.47E-03	0.00E+00	5.83E-03	1.20E-03	2.74E-03	1.58E-03	1.49E-03	8.13E-05	8.07E-04	4.92E-02
Cinfaes	1.09E-02	2.89E-02	7.86E-01	1.25E-03	0.00E+00	4.97E-03	4.88E-04	2.74E-04	1.84E-03	1.15E-03	9.42E-05	1.31E-03	1.21E-03
Espinho	1.09E-04	3.26E-04	3.08E-03	3.92E-05	0.00E+00	5.39E-05	0.00E+00	0.00E+00	1.75E-04	9.10E-05	1.85E-06	0.00E+00	0.00E+00
Esposende	3.11E-02	5.94E-03	2.03E-01	1.90E-03	4.52E-02	6.10E-03	1.20E-03	5.54E-03	3.60E-02	1.48E-04	0.00E+00	8.63E-04	1.52E-03
Fafe	7.36E-03	1.64E-02	1.62E-01	1.66E-03	3.35E-03	5.42E-03	9.31E-04	2.74E-03	1.40E-03	1.14E-03	1.85E-06	1.14E-03	9.40E-03
Felgueiras	9.06E-03	6.41E-02	2.03E-01	1.96E-02	4.64E-03	6.95E-03	2.66E-04	1.09E-03	2.63E-03	5.05E-03	0.00E+00	4.73E-04	8.82E-02

Municipality	Beef	Pork	Poultry	Eggs	Dairy	Cereals	Pulses	Tubers	Vegetables	Fruits	Vegetable oils	Nuts	Wine
Gondomar	2.51E-03	1.76E-02	7.08E-02	6.22E-04	4.44E-04	2.91E-03	2.22E-04	4.79E-03	9.83E-03	8.93E-04	0.00E+00	2.78E-04	5.78E-04
Guimaraes	2.31E-02	3.36E-02	2.92E-01	5.69E-02	2.58E-02	9.35E-03	6.65E-04	1.85E-03	1.66E-02	3.32E-03	5.54E-06	1.42E-03	1.14E-02
Lousada	1.66E-02	1.14E-02	2.78E-01	6.55E-04	7.70E-03	4.90E-03	3.10E-04	1.37E-03	2.19E-03	1.20E-03	9.24E-06	1.09E-03	1.53E-02
Maia	2.03E-02	3.32E-03	1.21E+00	5.60E-04	4.62E-02	2.34E-03	4.43E-05	2.39E-03	7.11E-03	1.43E-03	0.00E+00	5.57E-05	2.00E-04
Marco de Canaveses	2.52E-03	1.58E-02	4.15E-01	1.01E-03	0.00E+00	3.96E-03	1.24E-03	1.03E-03	1.14E-03	2.02E-03	2.22E-05	5.29E-04	6.12E-03
Matosinhos	1.56E-02	6.49E-03	2.84E-02	4.55E-04	4.07E-02	7.55E-04	4.43E-05	2.33E-03	4.91E-03	1.85E-04	0.00E+00	1.39E-04	2.99E-06
Melgaco	9.17E-03	6.98E-03	1.58E-01	8.33E-04	1.90E-04	5.79E-04	4.43E-05	7.53E-04	8.77E-05	3.70E-05	0.00E+00	1.67E-04	3.23E-02
Moncao	9.16E-03	1.24E-02	3.33E-01	2.09E-03	0.00E+00	2.65E-03	2.22E-04	1.03E-03	7.90E-04	2.15E-04	0.00E+00	1.39E-04	3.23E-02
Mondim de Basto	5.46E-03	1.36E-02	3.04E-01	6.81E-04	0.00E+00	2.72E-03	2.66E-04	4.11E-04	8.77E-05	2.86E-04	3.51E-05	2.50E-04	5.00E-03
Oliveira de Azemeis	1.89E-02	1.15E-01	1.85E+00	1.30E-02	4.61E-02	4.11E-03	5.32E-04	8.21E-04	2.54E-03	4.37E-04	0.00E+00	3.06E-04	2.75E-05
Pacos de Ferreira	5.12E-03	3.52E-02	3.85E-01	5.16E-04	2.29E-02	2.20E-03	1.33E-04	7.53E-04	7.02E-04	4.68E-04	0.00E+00	5.57E-05	3.15E-04
Paredes	9.82E-03	2.32E-02	1.90E-01	1.14E-03	0.00E+00	5.09E-03	4.43E-04	3.01E-03	4.30E-03	5.75E-04	0.00E+00	3.62E-04	1.20E-03
Paredes de Coura	2.41E-02	9.76E-03	7.74E-02	9.26E-04	4.76E-03	1.97E-03	1.77E-04	1.37E-03	8.77E-05	9.81E-05	0.00E+00	2.78E-04	0.00E+00
Penafiel	8.91E-03	3.03E-02	1.72E-01	1.25E-03	1.94E-02	6.45E-03	9.75E-04	2.87E-03	6.67E-03	2.42E-03	1.11E-05	7.51E-04	6.88E-02
Ponte da Barca	7.83E-03	6.76E-03	1.01E-01	1.34E-03	0.00E+00	1.89E-03	4.88E-04	2.05E-03	8.77E-04	2.34E-04	0.00E+00	1.42E-03	1.81E-02
Ponte de Lima	2.06E-02	3.29E-02	5.92E-01	4.33E-03	4.52E-02	1.45E-02	2.35E-03	5.47E-03	2.11E-03	1.16E-03	1.85E-05	7.35E-03	2.47E-02
Porto	6.53E-05	2.20E-04	3.08E-03	2.50E-05	5.55E-02	0.00E+00	0.00E+00	1.37E-04	2.63E-04	0.00E+00	1.85E-06	2.78E-05	8.72E-05
Povoa de Lanhoso	8.08E-03	9.79E-02	3.31E-01	1.61E-03	6.36E-03	7.25E-03	5.76E-04	2.12E-03	9.65E-04	3.44E-03	0.00E+00	5.84E-04	2.63E-03
Povoa de Varzim	4.78E-02	2.14E-01	5.93E-02	4.91E-03	2.11E-01	1.82E-03	1.77E-04	5.47E-04	6.72E-02	2.37E-04	0.00E+00	0.00E+00	5.68E-05

Resende	3.57E-03	1.09E-02	6.00E-02	5.46E-04	0.00E+00	1.74E-03	3.55E-04	6.29E-03	1.67E-03	5.39E-03	1.63E-04	7.85E-03	1.26E-03
Santa Maria da Feira	1.26E-02	1.69E-01	2.10E-01	9.89E-04	9.79E-03	6.10E-03	1.11E-03	2.81E-03	1.32E-03	2.38E-03	0.00E+00	7.24E-04	4.18E-06
Municipality	Beef	Pork	Poultry	Eggs	Dairy	Cereals	Pulses	Tubers	Vegetables	Fruits	Vegetable oils	Nuts	Wine
Santo Tirso	1.26E-02	3.63E-02	8.14E-01	8.97E-04	7.31E-02	4.46E-03	0.00E+00	1.03E-03	3.51E-03	1.09E-03	0.00E+00	1.67E-04	5.93E-03
Sao Joao da Madeira	9.25E-05	2.20E-04	2.05E-03	6.16E-06	0.00E+00	6.74E-05	0.00E+00	6.84E-05	0.00E+00	0.00E+00	0.00E+00	8.35E-05	0.00E+00
Terras de Bouro	8.73E-03	1.49E-02	1.11E-01	4.45E-04	0.00E+00	2.40E-03	1.77E-04	5.47E-04	8.77E-04	2.51E-04	0.00E+00	2.23E-04	8.60E-05
Trofa	2.07E-02	6.32E-03	3.41E+00	4.34E-04	5.61E-03	2.38E-03	0.00E+00	2.87E-03	2.19E-03	2.63E-04	0.00E+00	5.57E-05	2.07E-04
Vale de Cambra	3.32E-03	1.53E-02	1.98E+00	3.75E-04	9.97E-04	2.03E-03	3.55E-04	3.42E-04	1.75E-04	5.34E-04	0.00E+00	4.45E-04	2.58E-03
Valenca	3.88E-03	6.60E-03	8.19E-02	7.42E-04	0.00E+00	2.38E-03	8.87E-05	8.90E-04	1.14E-03	7.16E-04	0.00E+00	3.62E-04	1.01E-03
Valongo	3.63E-03	1.69E-03	3.30E-02	2.55E-04	6.22E-03	1.37E-03	1.33E-04	2.39E-03	2.02E-03	7.56E-04	0.00E+00	2.78E-04	1.73E-02
Viana do Castelo	1.86E-02	3.89E-02	3.10E+00	4.22E-03	1.97E-02	1.15E-02	1.29E-03	5.27E-03	2.98E-03	1.06E-03	1.85E-06	1.09E-03	3.52E-03
Vieira do Minho	1.60E-02	4.37E-02	1.27E-01	1.30E-03	0.00E+00	2.28E-03	7.09E-04	9.58E-04	1.23E-03	3.48E-04	2.40E-05	3.06E-04	3.41E-05
Vila do Conde	1.59E-01	8.89E-03	1.08E-01	1.13E-03	4.89E-01	3.46E-03	4.43E-05	2.87E-03	5.97E-03	2.43E-03	0.00E+00	5.57E-05	1.56E-04
Vila Nova de Cerveira	2.10E-03	5.07E-03	6.77E-02	3.72E-04	0.00E+00	1.46E-03	4.43E-05	6.16E-04	8.77E-05	1.10E-04	0.00E+00	2.45E-03	1.43E-04
Vila Nova de Famalicao	5.39E-02	8.12E-01	8.02E+00	1.43E-03	1.31E-01	9.36E-03	4.88E-04	2.05E-03	4.83E-03	1.38E-03	0.00E+00	1.86E-03	9.89E-03
Vila Nova de Gaia	1.59E-02	7.47E-03	6.60E-02	5.95E-04	1.32E-03	3.91E-03	2.66E-04	3.08E-03	1.58E-02	1.46E-03	7.39E-06	7.51E-04	1.02E-05
Vila Verde	2.45E-02	3.67E-02	2.21E+00	2.86E-03	8.79E-03	9.55E-03	1.55E-03	4.79E-03	1.84E-03	2.43E-03	0.00E+00	2.81E-03	2.19E-03
Vizela	2.36E-03	1.14E-03	3.15E-02	2.04E-04	0.00E+00	7.55E-04	0.00E+00	1.37E-04	6.14E-04	2.09E-04	0.00E+00	0.00E+00	1.42E-02
Total (%)	96.33	2.57	49.21	21.4	186	23.15	2.5	9.7	24.2	6.4	0.06	5.3	53.23

Appendix 2 Potential Self-Reliance (%) by municipalities and diets. (A) Fruits, Nuts and Vegetables Oils; (B) Cereals, Tubers, Pulses, Vegetables, Pork, Poultry, Eggs and Dairy; (C) Beef.

Diets	REF			EA			MED			MB			SV	
Municipality	A	B	C	A	B	C	A	B	C	A	B	C	A	B
Amarante	1.232	1.419	0.399	1.948	1.894	0.712	1.659	1.591	0.503	1.833	1.438	0.464	1.029	2.394
Amares	0.643	0.347	0.091	1.016	0.463	0.140	0.866	0.389	0.108	0.956	0.352	0.099	0.537	0.586
Arcos de Valdevez	1.089	0.978	0.452	1.722	1.305	1.459	1.467	1.097	0.772	1.620	0.991	0.745	0.909	1.650
Arouca	0.770	0.474	0.196	1.218	0.632	0.582	1.037	0.531	0.319	1.146	0.480	0.306	0.643	0.799
Baião	0.626	1.090	0.407	0.990	1.455	1.097	0.843	1.222	0.628	0.931	1.105	0.598	0.522	1.839
Barcelos	1.682	3.438	0.994	2.661	4.588	1.881	2.266	3.855	1.286	2.503	3.485	1.194	1.405	5.800
Braga	0.538	1.211	0.307	0.851	1.615	0.427	0.725	1.357	0.350	0.801	1.227	0.317	0.449	2.042
Cabeceiras de Basto	1.044	1.296	0.390	1.652	1.730	0.794	1.407	1.453	0.522	1.554	1.314	0.487	0.872	2.187
Caminha	0.234	0.197	0.067	0.370	0.263	0.163	0.315	0.221	0.098	0.348	0.200	0.093	0.196	0.332
Castelo de Paiva	0.449	0.158	0.094	0.710	0.211	0.348	0.605	0.177	0.174	0.668	0.160	0.170	0.375	0.266
Celorico de Basto	0.804	1.138	0.317	1.271	1.519	0.555	1.083	1.276	0.396	1.196	1.154	0.365	0.671	1.920
Cinfães	0.628	0.504	0.302	0.993	0.672	1.130	0.845	0.565	0.563	0.934	0.510	0.550	0.524	0.850
Espinho	0.064	0.015	0.042	0.101	0.020	0.214	0.086	0.017	0.096	0.095	0.016	0.095	0.053	0.026
Esposende	0.268	0.523	0.440	0.425	0.698	1.858	0.362	0.587	0.886	0.400	0.531	0.872	0.224	0.883
Fafe	0.646	1.803	0.471	1.022	2.405	0.712	0.871	2.021	0.554	0.962	1.827	0.505	0.540	3.041
Felgueiras	0.876	0.708	0.187	1.385	0.945	0.289	1.180	0.794	0.222	1.303	0.718	0.202	0.731	1.195
Gondomar	0.370	0.244	0.078	0.585	0.326	0.172	0.498	0.274	0.108	0.550	0.248	0.101	0.309	0.412
Guimarães	0.833	1.732	0.454	1.317	2.312	0.692	1.122	1.942	0.536	1.239	1.756	0.489	0.695	2.923
Lousada	0.593	0.787	0.202	0.938	1.050	0.290	0.799	0.882	0.232	0.882	0.797	0.211	0.495	1.327

Diets	REF			EA			MED			MB			SV	
Municipality	A	B	C	A	B	C	A	B	C	A	B	C	A	B
Maia	0.495	0.345	0.124	0.784	0.461	0.320	0.667	0.387	0.187	0.737	0.350	0.177	0.414	0.583
Marco de Canaveses	1.573	1.250	0.378	2.488	1.669	0.775	2.119	1.402	0.508	2.340	1.267	0.474	1.314	2.110
Matosinhos	0.456	0.030	0.083	0.721	0.040	0.419	0.614	0.034	0.188	0.678	0.030	0.187	0.381	0.051
Melgaço	0.526	0.326	0.127	0.832	0.435	0.357	0.708	0.365	0.200	0.782	0.330	0.192	0.439	0.550
Monção	1.077	1.169	0.325	1.704	1.560	0.567	1.451	1.311	0.405	1.603	1.185	0.374	0.900	1.973
Mondim de Basto	0.293	0.277	0.121	0.463	0.370	0.374	0.394	0.311	0.202	0.436	0.281	0.194	0.244	0.468
Oliveira de Azeméis	0.629	0.583	0.250	0.995	0.778	0.762	0.847	0.653	0.412	0.936	0.591	0.397	0.525	0.983
Paços de Ferreira	0.469	0.572	0.147	0.741	0.764	0.212	0.631	0.642	0.170	0.697	0.580	0.154	0.391	0.965
Paredes	0.523	0.873	0.224	0.827	1.165	0.323	0.704	0.979	0.259	0.778	0.885	0.235	0.437	1.473
Paredes de Coura	0.769	0.787	0.218	1.216	1.050	0.379	1.036	0.882	0.272	1.144	0.798	0.251	0.642	1.328
Penafiel	0.786	1.815	0.486	1.243	2.423	0.780	1.058	2.036	0.586	1.169	1.840	0.537	0.656	3.063
Ponte da Barca	0.369	0.373	0.116	0.583	0.498	0.248	0.497	0.419	0.159	0.549	0.378	0.149	0.308	0.630
Ponte de Lima	0.964	1.429	0.387	1.525	1.907	0.638	1.299	1.603	0.471	1.435	1.449	0.433	0.805	2.412
Porto	0.004	0.001	0.000	0.006	0.002	0.000	0.006	0.001	0.000	0.006	0.001	0.000	0.003	0.002
Póvoa de Lanhoso	0.670	1.066	0.277	1.060	1.422	0.411	0.903	1.195	0.323	0.997	1.080	0.295	0.560	1.798
Póvoa de Varzim	0.121	0.340	0.441	0.191	0.454	2.052	0.163	0.381	0.946	0.180	0.345	0.937	0.101	0.574
Resende	0.260	0.145	0.162	0.411	0.194	0.733	0.350	0.163	0.341	0.386	0.147	0.337	0.217	0.245
Santa Maria da Feira	0.845	0.749	0.313	1.337	0.999	0.936	1.139	0.840	0.511	1.258	0.759	0.491	0.706	1.263
Santo Tirso	0.901	0.797	0.205	1.425	1.063	0.297	1.214	0.893	0.237	1.341	0.807	0.216	0.752	1.344
São João da Madeira	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.001

Diets	REF			EA			MED			MB			SV	
Municipality	A	B	C	A	B	C	A	B	C	A	B	C	A	B
Trofa	0.096	0.272	0.140	0.151	0.363	0.483	0.129	0.305	0.249	0.142	0.276	0.241	0.080	0.459
Vale de Cambra	0.491	0.743	0.228	0.776	0.991	0.480	0.661	0.833	0.310	0.730	0.753	0.290	0.410	1.253
Valença	0.793	0.563	0.146	1.255	0.752	0.217	1.069	0.631	0.170	1.181	0.571	0.155	0.663	0.950
Valongo	0.112	0.145	0.037	0.178	0.194	0.051	0.152	0.163	0.042	0.167	0.147	0.038	0.094	0.245
Viana do Castelo	0.905	1.649	0.541	1.431	2.200	1.252	1.219	1.848	0.770	1.346	1.671	0.726	0.756	2.781
Vieira do Minho	0.548	0.960	0.258	0.867	1.281	0.419	0.739	1.077	0.312	0.816	0.973	0.286	0.458	1.620
Vila do Conde	0.552	0.926	0.566	0.873	1.236	2.130	0.743	1.038	1.059	0.821	0.939	1.034	0.461	1.562
Vila Nova de Cerveira	0.262	0.227	0.066	0.415	0.303	0.128	0.354	0.255	0.086	0.391	0.230	0.080	0.219	0.383
Vila Nova de Famalicão	1.101	1.366	0.405	1.741	1.823	0.802	1.483	1.531	0.535	1.638	1.384	0.498	0.919	2.304
Vila Nova de Gaia	0.769	0.376	0.133	1.217	0.501	0.337	1.036	0.421	0.198	1.145	0.381	0.188	0.643	0.634
Vila Verde	0.937	1.387	0.382	1.482	1.851	0.654	1.262	1.555	0.473	1.394	1.406	0.435	0.782	2.340
Vizela	0.101	0.142	0.037	0.159	0.190	0.055	0.136	0.159	0.043	0.150	0.144	0.039	0.084	0.240
Total	32.128	39.830	13.282	50.823	53.149	31.399	43.285	44.660	19.116	47.810	40.372	18.044	26.835	67.199

Appendix 3 Food Footprint (ha/population/year) by Reference diet (% partial: the percentage of the area of the food group in the total area needed for temporary or permanent crops separately; % total: the percentage of the food group in the total agricultural uses necessary for the diet. considering arable land. temporary and permanent cropland. and pastureland.

Food groups	Quantities g/day	Consumption Quantities t/pop/year	Productivity t/ha	Food Footprint ha/pop/year	% area in diet (partial)	% area in diet (total)
Cereals	347.6	404,034.4	5.494	73,541.03	15.82	9.01
Tubers	213.1	247,697.8	17.104	14,481.86	3.12	1.77
Pulses	13.4	15,575.6	0.698	22,314.61	4.80	2.73
Vegetables	266.3	309,535	27.401	11,296.49	2.43	1.38
All fruits	269.1	329,643.7	7.511	43,888.12	17.79	5.38
Nuts	14.2	16,505.4	0.465	35,495.48	14.39	4.35
Vegetable oils	50.1	58,234	0.348	167,339.08	67.82	20.50
Meat-beef	38.14	44,332.20	0.212	209,114.16	22.49 ¹	25.62
Meat-pork	38.14	44,332.20	0.83	53,412.29	11.49	6.54
Meat-chicken	153.02	177,863.49	2	88,931.75	19.13	10.90
Eggs	26.3	30,569.9	2.22	13,770.23	2.96	1.69
Dairy foods	322.6	374,975.6	4.54	82,593.74	17.77	10.12

¹ Percentage of area in temporary crops

Appendix 4 Food Footprint (ha/population/year) by Eat-Lancet diet (% partial: the percentage of the area of the food group in the total area needed for temporary or permanent crops separately; % total: the percentage of the food group in the total agricultural uses necessary for the diet. considering arable land. temporary and permanent cropland. and pastureland.

Food groups	Quantities g/day	Consumption Quantities t/pop/year	Productivity t/ha	Food Footprint ha/pop/year	% area in diet (partial)	% area in diet (total)
Cereals	232	269,666.25	5.494	49,083.77	14.09	9.38
Tubers	50	58,117.73	17.104	3,397.90	0.98	0.65
Pulses	100	116,235.45	0.698	166,526.44	47.80	31.81
Vegetables	300	348,706.36	27.401	12,726.05	3.65	2.43
All fruits	200	232,470.91	7.511	30,950.73	19.84	5.91
Nuts	25	29,058.86	0.465	62,492.18	40.07	11.94
Vegetable oils	18.72	21,759.28	0.348	62,526.66	40.09	11.94
Vegetable oils (sunflower)	28.08	32,638.92	0	0.00	0.00	0.00
Meat-beef	7	8,136.48	0.212	38,379.63	5.51 ¹	7.33
Meat-pork	7	8,136.48	0.83	9,802.99	2.81	1.87
Meat-chicken	29	33,708.28	2	16,854.14	4.84	3.22
Eggs	13	15,110.61	2.22	6,806.58	1.95	1.30
Dairy foods	250	290,588.64	4.54	64,006.31	18.37	12.23

¹ Percentage of area in temporary crops

Appendix 5 Food Footprint (ha/population/year) by Meat-based diet (% partial: the percentage of the area of the food group in the total area needed for temporary or permanent crops separately; % total: the percentage of the food group in the total agricultural uses necessary for the diet. considering arable land. temporary and permanent cropland. and pastureland.

Food groups	Quantities g/day	Consumption Quantities t/pop/year	Productivity t/ha	Food Footprint ha/pop/year	% area in diet (partial)	% area in diet (total)
Cereals	224	260,367.42	5.494	47,391.23	10.33	7.09
Tubers	155.94	181,257.57	17.104	10,597.38	2.31	1.59
Pulses	53.76	62,488.18	0.698	89,524.61	19.52	13.40
Vegetables	104	120,884.87	27.401	4,411.70	0.96	0.66
All fruits	450	523,059.55	7.511	69,639.14	42.00	10.42
Nuts	21.9	25,455.56	0.465	54,743.15	33.02	8.19
Vegetable oils	12.4	14,413.20	0.348	41,417.23	24.98	6.20
Vegetable oils (sunflower)	18.6	21,619.79	0	0.00	0.00	0.00
Meat-beef	15.95	18,533.93	0.212	87,424.19	9.53 ¹	13.08
Meat-pork	15.95	18,533.93	0.83	22,330.04	4.87	3.34
Meat-chicken	65.98	76,694.01	2	38,347.01	8.36	5.74
Eggs	28.52	33,150.35	2.22	14,932.59	3.26	2.23
Dairy foods	732	850,843.53	4.54	187,410.47	40.86	28.05

¹ Percentage of area in temporary crops

Appendix 6 Food Footprint (ha/population/year) by Mediterranean diet (% partial: the percentage of the area of the food group in the total area needed for temporary or permanent crops separately; % total: the percentage of the food group in the total agricultural uses necessary for the diet. considering arable land. temporary and permanent cropland. and pastureland.

Food groups	Quantities g/day	Consumption Quantities t/pop/year	Productivity t/ha	Food Footprint ha/pop/year	% area in diet (partial)	% area in diet (total)
Cereals	224	260,367.42	5.494	47,391.23	11.43	7.39
Tubers	155.94	181,257.57	17.104	10,597.38	2.56	1.65
Pulses	53.76	62,488.18	0.698	89,524.61	21.59	13.96
Vegetables	104	120,884.87	27.401	4,411.70	1.06	0.69
All fruits	562	653,243.25	7.511	8,6971.54	47.49	13.56
Nuts	21.9	25,455.56	0.465	54,743.15	29.89	8.53
Vegetable oils	12.4	14,413.20	0.348	41,417.23	22.62	6.46
Vegetable oils (sunflower)	18.6	21,619.79	0	0.00	0.00	0.00
Meat-beef	15.95	18,533.93	0.212	87,424.19	10.54 ¹	13.63
Meat-pork	15.95	18,533.93	0.83	22,330.04	5.39	3.48
Meat-chicken	65.98	76,694.01	2	38,347.01	9.25	5.98
Eggs	28.52	33,150.35	2.22	14,932.59	3.60	2.33
Dairy foods	560	650,918.55	4.54	143,374.13	34.58	22.35

¹ Percentage of area in temporary crops

Appendix 7 Food Footprint (ha/population/year) by Strict Vegetarian diet (% partial: the percentage of the area of the food group in the total area needed for temporary or permanent crops separately; % total: the percentage of the food group in the total agricultural uses necessary for the diet. considering arable land. temporary and permanent cropland. and pastureland.

Food groups	Quantities g/day	Consumption Quantities t/pop/year	Productivity t/ha	Food Footprint ha/pop/year	% area in diet (partial)	% area in diet (total)
Cereals	224	260,367.42	5.494	47,391.23	17.20	8.30
Tubers	155.94	181,257.57	17.104	10,597.38	3.85	1.86
Pulses (soy)	44	51,143.60	0	0.00	0.00	0.00
Pulses	128	148,781.38	0.698	213,153.84	77.35	37.33
Vegetables	104	120,884.87	27.401	4,411.70	1.60	0.77
All fruits	450	523,059.55	7.511	69,639.14	23.57	12.20
Nuts	79.09	91,930.62	0.465	197,700.26	66.93	34.63
Vegetable oils	8.4	9,763.78	0.348	28,056.83	9.50	4.91
Vegetable oils (sunflower)	12.6	14,645.67	0	0.00	0.00	0.00

Appendix 8 Area of main types of land cover on the foodshed relocalization scenario.

Municipality	Temporary crops	Permanent crops	Pastures
Amarante	6597.77	3211.59	183.13
Amares	1613.76	1609.25	18.66
Arcos de Valdevez	4546.74	2724.92	869.66
Arouca	2201.91	1908.41	325.27
Baião	5068.15	1588.66	563.04
Barcelos	15982.61	4237.16	563.62
Braga	5628.09	1346.74	17.83
Cabeceiras de Basto	6025.61	2625.65	277.58
Caminha	915.54	578.06	74.59
Castelo de Paiva	734.13	1122.27	226.59
Celorico de Basto	5291.2	2066.74	134.67
Cinfães	2340.85	1564.72	738.13
Espinho	71.19	157.96	160.13
Esposende	2433.51	663.9	1292.32
Fafe	8380.5	1612.36	84.92
Felgueiras	3293.21	2247.84	40.17
Gondomar	1136.51	915.17	69.06
Guimarães	8053.35	2114.92	87.79
Lousada	3656.59	1496.88	20.95
Maia	1605.21	1223.9	157.37
Marco de Canaveses	5813.15	3998.85	274.78
Matosinhos	139.79	1125.25	314.24
Melgaço	1514.71	1325.26	190.77
Monção	5435.99	2799.84	135.83
Mondim de Basto	1289.6	732.38	216.41
Oliveira de Azeméis	2708.89	1552.09	435.41
Paços de Ferreira	2660.26	1157.84	16.56
Paredes	4057.62	1309.76	24.33
Paredes de Coura	3658.31	1897.39	89.4
Penafiel	8439.85	2027.94	134.19
Ponte da Barca	1735.28	919.11	94.68
Ponte de Lima	6645.01	2476.05	123.82
Porto	5.38	10.13	0
Póvoa de Lanhoso	4954.3	1672.63	42.85
Póvoa de Varzim	1581.6	298.79	1487.72
Resende	674.18	652.95	525.81
Santa Maria da Feira	3481.45	2086.93	526.85
Santo Tirso	3703.53	2251.34	24.05
São João da Madeira	2.24	0.84	0
Terras de Bouro	387	858.84	202.34
Trofa	1265.22	236.28	301.27
Vale de Cambra	3453.85	1214.45	178.42
Valença	2618.29	1968.77	22.01
Valongo	674.18	280.24	1.87
Viana do Castelo	7664.09	2261.9	538.85

Municipality	Temporary crops	Permanent crops	Pastures
Vieira do Minho	4464.07	1355.15	75.39
Vila do Conde	4305.04	1363.03	1398.15
Vila Nova de Cerveira	1055.31	647.98	39.87
Vila Nova de Famalicão	6349.84	2782.86	266.09
Vila Nova de Gaia	1746.59	1900.39	162.46
Vila Verde	6447.81	2342.61	146.77
Vizela	660.59	249.01	5.92

Appendix 9 Water footprint (10^6 m³/year) of crops and animal production under current EDM foodshed.

Municipality	Cereals	Tubers	Pulses	Vegetables	Fruits	Nuts	Oils	Beef	Pork	Poultry	Eggs	Dairy	Wine
Amarante	5.6361	0.1324	0.0962	0.3794	2.5319	0.2065	0.0034	8.0910	0.2850	0.0692	0.1298	0.4141	7.5377
Amares	3.9290	0.0794	0.0509	0.4059	2.8368	0.0506	0.0006	3.7514	0.1380	3.2163	6.3671	0.0000	2.0924
Arcos de Valdevez	2.7187	0.1456	0.0340	0.0706	0.1704	0.3793	0.0000	49.2898	0.1156	0.0669	0.2619	3.0827	2.0160
Arouca	2.8090	0.0463	0.0170	0.0265	0.7173	0.1391	0.0014	23.4518	2.4726	0.5686	0.1068	45.0908	0.6706
Baiao	2.0774	0.1125	0.0764	0.0794	1.7261	0.4678	0.0222	3.9123	0.2630	0.0429	0.1038	0.0000	3.9980
Barcelos	8.9960	0.3111	0.0566	0.8117	1.1665	0.1601	0.0006	283.9129	0.1578	0.1512	0.3826	1192.940	2.8818
Braga	8.9779	0.1986	0.0113	0.5382	1.5493	0.1854	0.0011	37.9357	0.1483	0.0994	0.2795	76.2205	1.9863
Cabeceiras de Basto	3.0800	0.0993	0.0142	0.0176	0.7343	0.3835	0.0042	16.9645	0.4535	0.8381	0.1136	0.0000	2.6526
Caminha	1.0658	0.0728	0.0113	0.0265	0.0357	0.1138	0.0000	1.1654	0.0556	0.0288	0.0841	0.0000	0.1316
Castelo de Paiva	1.9329	0.0397	0.0226	0.0794	1.7942	0.0716	0.0000	2.2531	0.0957	0.0264	0.0502	0.0000	1.8972
Celorico de Basto	3.9109	0.2648	0.0764	0.1588	1.2366	0.1222	0.0123	8.4739	0.1957	0.0978	0.1480	0.0000	5.6745
Cinfães	3.3329	0.0265	0.0311	0.1853	0.9546	0.1981	0.0143	12.5028	0.2289	0.1990	0.1258	0.0000	1.4642
Espinho	0.0361	0.0000	0.0000	0.0176	0.0757	0.0000	0.0003	0.1110	0.0026	0.0008	0.0040	0.0000	0.0000
Esposende	4.0916	0.5362	0.0764	3.6175	0.1230	0.1306	0.0000	30.9989	0.0470	0.0513	0.1915	112.3852	0.3226
Fafe	3.6309	0.2648	0.0594	0.1412	0.9492	0.1728	0.0003	8.8735	0.1298	0.0411	0.1671	8.3346	1.5534
Felgueiras	4.6606	0.1059	0.0170	0.2647	4.1971	0.0716	0.0000	10.0777	0.5070	0.0513	1.9714	11.5225	5.4326
Gondomar	1.9509	0.4633	0.0142	0.9882	0.7428	0.0421	0.0000	2.6193	0.1388	0.0179	0.0627	1.1043	0.4796
Guimaraes	6.2683	0.1787	0.0425	1.6676	2.7601	0.2149	0.0008	31.7426	0.2660	0.0740	5.7252	64.2051	4.0108
Lousada	3.2877	0.1324	0.0198	0.2206	1.0011	0.1644	0.0014	18.0966	0.0901	0.0703	0.0660	19.1340	3.1831
Maia	1.5716	0.2317	0.0028	0.7147	1.1886	0.0084	0.0000	30.1554	0.0263	0.3062	0.0564	114.9158	0.1740
Marco de Canaveses	2.6554	0.0993	0.0793	0.1147	1.6790	0.0801	0.0034	2.9079	0.1250	0.1051	0.1016	0.0000	4.1593
Matosinhos	0.5058	0.2251	0.0028	0.4941	0.1535	0.0211	0.0000	25.2831	0.0513	0.0072	0.0458	101.1453	0.0891
Melgaco	0.3884	0.0728	0.0028	0.0088	0.0308	0.0253	0.0000	10.0389	0.0552	0.0400	0.0839	0.4733	2.9922
Moncao	1.7793	0.0993	0.0142	0.0794	0.1790	0.0211	0.0000	9.7336	0.0983	0.0843	0.2100	0.0000	7.1218
Mondim de Basto	1.8245	0.0397	0.0170	0.0088	0.2375	0.0379	0.0053	6.4373	0.1078	0.0769	0.0686	0.0000	1.9523
Oliveira de Azemeis	2.7548	0.0794	0.0340	0.2559	0.3637	0.0464	0.0000	30.7714	0.9093	0.4681	1.3074	114.5740	0.0679
Pacos de Ferreira	1.4722	0.0728	0.0085	0.0706	0.3890	0.0084	0.0000	9.8335	0.2785	0.0974	0.0520	57.0076	0.2334
Paredes	3.4141	0.2912	0.0283	0.4323	0.4784	0.0548	0.0000	11.2708	0.1832	0.0481	0.1150	0.0000	2.1306

Municipality	Cereals	Tubers	Pulses	Vegetables	Fruits	Nuts	Oils	Beef	Pork	Poultry	Eggs	Dairy	Wine
Paredes de Coura	1.3187	0.1324	0.0113	0.0088	0.0816	0.0421	0.0000	14.2065	0.0772	0.0196	0.0932	11.8314	0.0637
Penafiel	4.3264	0.2780	0.0623	0.6706	2.0114	0.1138	0.0017	9.6893	0.2393	0.0436	0.1258	48.1472	6.2093
Ponte da Barca	1.2645	0.1986	0.0311	0.0882	0.1947	0.2149	0.0000	9.4673	0.0535	0.0255	0.1351	0.0000	1.4473
Ponte de Lima	9.7276	0.5295	0.1500	0.2118	0.9655	1.1126	0.0028	29.9224	0.2604	0.1498	0.4362	112.3983	5.4920
Porto	0.0000	0.0132	0.0000	0.0265	0.0000	0.0042	0.0003	0.0444	0.0017	0.0008	0.0025	137.8884	0.0340
Povoa de Lanhoso	4.8593	0.2052	0.0368	0.0971	2.8633	0.0885	0.0000	9.0011	0.7743	0.0838	0.1617	15.8212	1.6086
Povoa de Varzim	1.2193	0.0530	0.0113	6.7585	0.1973	0.0000	0.0000	96.4042	1.6939	0.0150	0.4944	523.9010	0.0764
Resende	1.1651	0.6090	0.0226	0.1676	4.4865	1.1884	0.0247	3.7791	0.0858	0.0152	0.0550	0.0000	2.6187
Santa Maria da Feira	4.0916	0.2714	0.0708	0.1323	1.9758	0.1096	0.0000	10.6105	1.3352	0.0531	0.0995	24.3267	0.0934
Santo Tirso	2.9896	0.0993	0.0000	0.3529	0.9042	0.0253	0.0000	19.1954	0.2871	0.2059	0.0903	181.7500	1.7868
Sao Joao da Madeira	0.0452	0.0066	0.0000	0.0000	0.0000	0.0126	0.0000	0.0832	0.0017	0.0005	0.0006	0.0000	0.0000
Terras de Bouro	1.6077	0.0530	0.0113	0.0882	0.2089	0.0337	0.0000	9.8058	0.1181	0.0280	0.0448	0.0000	0.2080
Trofa	1.5987	0.2780	0.0000	0.2206	0.2184	0.0084	0.0000	35.4607	0.0500	0.8624	0.0438	13.9413	0.1485
Vale de Cambra	1.3639	0.0331	0.0226	0.0176	0.4440	0.0674	0.0000	3.7181	0.1211	0.5012	0.0378	2.4780	0.4584
Valenca	1.5987	0.0861	0.0057	0.1147	0.5953	0.0548	0.0000	5.4162	0.0522	0.0207	0.0748	0.0000	0.8149
Valongo	0.9213	0.2317	0.0085	0.2029	0.6288	0.0421	0.0000	5.2164	0.0134	0.0083	0.0257	15.4531	1.3497
Viana do Castelo	7.7134	0.5097	0.0821	0.3000	0.8826	0.1644	0.0003	22.8746	0.3078	0.7834	0.4250	49.0609	1.8292
Vieira do Minho	1.5264	0.0927	0.0453	0.1235	0.2896	0.0464	0.0036	15.9101	0.3453	0.0322	0.1311	0.0000	0.2547
Vila do Conde	2.3213	0.2780	0.0028	0.6000	2.0217	0.0084	0.0000	230.8772	0.0703	0.0274	0.1136	1215.880	0.1570
Vila Nova de Cerveira	0.9755	0.0596	0.0028	0.0088	0.0913	0.3709	0.0000	2.8635	0.0401	0.0171	0.0374	0.0000	0.1103
Vila Nova de Famalicao	6.2773	0.1986	0.0311	0.4853	1.1499	0.2824	0.0000	85.4108	6.4183	2.0292	0.1441	325.7579	3.3741
Vila Nova de Gaia	2.6193	0.2979	0.0170	1.5882	1.2128	0.1138	0.0011	3.1021	0.0590	0.0167	0.0599	3.2799	0.1740
Vila Verde	6.4038	0.4633	0.0991	0.1853	2.0212	0.4256	0.0000	25.4884	0.2902	0.5582	0.2875	21.8487	1.9056
Vizela	0.5058	0.0132	0.0000	0.0618	0.1736	0.0000	0.0000	3.4295	0.0090	0.0080	0.0205	0.0000	0.4541
Total	155.1992	9.4126	1.6416	24.3871	53.6205	8.1083	0.1061	1342.632	20.3311	12.4501	21.5225	4626.314	97.5741

Appendix 10 Water footprint (10^6 m³/year) of crops and animal production under EDM foodshed relocalization scenario.

Municipality	Cereals	Tubers	Pulses	Vegetables	Fruits	Nuts	Oils	Wine	Beef	Pork	Poultry	Eggs	Dairy
Amarante	0.37328	0.00877	0.00637	0.02513	0.15678	0.02009	0.00688	0.73426	3.878	0.974	0.237	0.444	246.607
Amares	0.06365	0.00129	0.00083	0.00657	0.10850	0.00247	0.00112	0.10213	1.768	0.115	2.688	5.322	0.000
Arcos de Valdevez	0.12408	0.00665	0.00155	0.00322	0.02088	0.03131	0.00080	0.16662	4.354	0.272	0.157	0.617	15.576
Arouca	0.06209	0.00102	0.00038	0.00059	0.03843	0.00804	0.00491	0.03882	7.509	2.820	0.648	0.122	61.304
Baiao	0.10569	0.00572	0.00389	0.00404	0.09668	0.02252	0.00260	0.19265	1.950	0.690	0.113	0.272	0.259
Barcelos	1.44330	0.04991	0.00908	0.13023	0.13728	0.02056	0.00238	0.37037	1312.976	1.306	1.252	3.167	9451.134
Braga	0.50722	0.01122	0.00064	0.03041	0.04953	0.00757	0.00029	0.08114	77.501	0.432	0.290	0.815	225.327
Cabeceiras de Basto	0.18630	0.00601	0.00086	0.00107	0.04943	0.03051	0.00520	0.21125	2.036	1.415	2.616	0.355	0.000
Caminha	0.00980	0.00067	0.00010	0.00024	0.00101	0.00199	0.00011	0.00231	0.057	0.026	0.014	0.040	0.023
Castelo de Paiva	0.01424	0.00029	0.00017	0.00059	0.04103	0.00244	0.00093	0.06458	1.992	0.036	0.010	0.019	0.000
Celorico de Basto	0.20773	0.01406	0.00406	0.00844	0.06108	0.00765	0.00293	0.35572	5.890	0.536	0.268	0.406	37.741
Cinfaes	0.07832	0.00062	0.00073	0.00435	0.07467	0.00939	0.00264	0.06949	4.194	0.278	0.241	0.153	0.060
Espinho	0.00003	0.00000	0.00000	0.00001	0.00035	0.00000	0.00000	0.00000	1.619	0.000	0.000	0.000	0.000
Esposende	0.09995	0.01310	0.00187	0.08837	0.00247	0.00263	0.00057	0.00650	61.116	0.059	0.065	0.241	133.948
Fafe	0.30545	0.02227	0.00500	0.01188	0.03177	0.00844	0.00009	0.07597	15.811	0.563	0.178	0.725	27.639
Felgueiras	0.15407	0.00350	0.00056	0.00875	0.15746	0.00488	0.00024	0.37039	14.400	0.865	0.088	3.362	11.871
Gondomar	0.02226	0.00529	0.00016	0.01127	0.01342	0.00117	0.00020	0.01331	1.953	0.082	0.011	0.037	1.017
Guimaraes	0.50674	0.01445	0.00343	0.13481	0.13843	0.01377	0.00040	0.25729	86.402	1.110	0.309	23.879	308.013
Lousada	0.12068	0.00486	0.00073	0.00810	0.02687	0.00745	0.00036	0.14452	29.873	0.171	0.133	0.125	22.343
Maia	0.02532	0.00373	0.00005	0.01152	0.02786	0.00031	0.00066	0.00646	18.686	0.022	0.255	0.047	85.565
Marco de Canaveses	0.15496	0.00579	0.00462	0.00669	0.18908	0.00970	0.00289	0.50449	3.876	0.376	0.316	0.306	7.728
Matosinhos	0.00071	0.00032	0.00000	0.00069	0.00591	0.00072	0.00027	0.00304	4.644	0.004	0.001	0.003	7.444
Melgaco	0.00591	0.00111	0.00004	0.00013	0.00232	0.00102	0.00000	0.12028	0.207	0.043	0.031	0.066	0.000
Moncao	0.09709	0.00542	0.00077	0.00433	0.02513	0.00179	0.00007	0.60480	2.331	0.277	0.237	0.591	0.000
Mondim de Basto	0.02362	0.00051	0.00022	0.00011	0.00401	0.00084	0.00075	0.04337	0.413	0.072	0.051	0.046	0.528
Oliveira de Azemeis	0.07491	0.00216	0.00092	0.00696	0.01699	0.00218	0.00000	0.00320	29.859	1.276	0.657	1.834	169.329
Pacos de Ferreira	0.03932	0.00194	0.00023	0.00188	0.00887	0.00030	0.00006	0.00820	6.369	0.384	0.134	0.072	54.273

Municipality	Cereals	Tubers	Pulses	Vegetables	Fruits	Nuts	Oils	Beef	Pork	Poultry	Eggs	Dairy	Wine
Paredes	0.13906	0.01186	0.00115	0.01761	0.01577	0.00217	0.00018	0.08464	20.151	0.385	0.101	0.242	24.274
Paredes de Coura	0.04843	0.00486	0.00042	0.00032	0.00706	0.00242	0.00000	0.00366	8.451	0.146	0.037	0.177	29.087
Penafiel	0.36654	0.02355	0.00528	0.05681	0.08879	0.00699	0.00049	0.38193	35.886	1.046	0.190	0.550	193.548
Ponte da Barca	0.02203	0.00346	0.00054	0.00154	0.00684	0.00598	0.00025	0.04035	0.255	0.048	0.023	0.121	2.662
Ponte de Lima	0.64887	0.03532	0.01001	0.01412	0.08402	0.08346	0.00803	0.41246	31.094	0.896	0.516	1.501	261.114
Porto	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00001	0.000	0.000	0.000	0.000	0.000
Povoa de Lanhoso	0.24166	0.01020	0.00183	0.00483	0.09374	0.00448	0.00049	0.08161	9.321	1.987	0.215	0.415	18.366
Povoa de Varzim	0.01936	0.00084	0.00018	0.10730	0.00144	0.00000	0.00000	0.00069	56.539	1.388	0.012	0.405	339.249
Resende	0.01354	0.00707	0.00026	0.00195	0.18525	0.02351	0.00170	0.05186	2.159	0.051	0.009	0.033	0.000
Santa Maria da Feira	0.14299	0.00948	0.00247	0.00463	0.09777	0.00693	0.00017	0.00591	20.119	2.408	0.096	0.179	26.079
Santo Tirso	0.11115	0.00369	0.00000	0.01312	0.05520	0.00172	0.00006	0.12201	19.881	0.551	0.395	0.173	106.898
Sao Joao da Madeira	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.000	0.000	0.000	0.000	0.000
Terras de Bouro	0.00625	0.00021	0.00004	0.00034	0.00865	0.00088	0.00007	0.00542	0.385	0.024	0.006	0.009	0.000
Trofa	0.02030	0.00353	0.00000	0.00280	0.00140	0.00006	0.00000	0.00106	15.892	0.033	0.565	0.029	80.737
Vale de Cambra	0.04729	0.00115	0.00079	0.00061	0.01569	0.00248	0.00026	0.01688	3.188	0.217	0.897	0.068	10.066
Valenca	0.04202	0.00226	0.00015	0.00301	0.02026	0.00327	0.00005	0.04866	2.174	0.071	0.028	0.101	13.656
Valongo	0.00623	0.00157	0.00006	0.00137	0.00331	0.00036	0.00011	0.01147	1.203	0.005	0.003	0.009	6.498
Viana do Castelo	0.59343	0.03921	0.00631	0.02308	0.05397	0.01126	0.00212	0.12550	22.139	1.222	3.110	1.687	157.535
Vieira do Minho	0.06840	0.00415	0.00203	0.00554	0.01246	0.00190	0.00036	0.01047	2.946	0.798	0.074	0.303	0.000
Vila do Conde	0.10031	0.01201	0.00012	0.02593	0.04864	0.00035	0.00015	0.00649	377.745	0.157	0.061	0.253	3065.560
Vila Nova de Cerveira	0.01033	0.00063	0.00003	0.00009	0.00284	0.00728	0.00002	0.00217	0.393	0.022	0.009	0.020	3.723
Vila Nova de Famalicão	0.40013	0.01266	0.00198	0.03093	0.09077	0.02381	0.00045	0.28480	173.725	21.108	6.673	0.474	1362.513
Vila Nova de Gaia	0.04592	0.00522	0.00030	0.02784	0.06906	0.00655	0.00097	0.01003	13.501	0.053	0.015	0.054	2.545
Vila Verde	0.41448	0.02999	0.00641	0.01199	0.12410	0.03021	0.00069	0.13541	45.143	0.969	1.864	0.960	105.830
Vizela	0.00335	0.00009	0.00000	0.00041	0.00120	0.00000	0.00000	0.00343	0.833	0.003	0.003	0.007	3.107
Total	8.319	0.414	0.088	0.867	2.574	0.446	0.054	6.398	2564.789	47.791	25.900	50.836	16680.778