Chapter

The Evolution of Land-Use Changes in the Alto Tâmega Region, Portugal: From 1990 to 2018 - A Vision of Sustainable Planning

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Abstract

Considering the complex dynamics, patterns, and particularities that the Alto Tâmega region present—e.g., the fragility, shown to achieve sustainable development and growth—a study that analyzes the Land-Use of this region is seen as pivotal to identifying barriers and opportunities for long-term sustainable development, get a vision of sustainable planning. Using GIS (Geographic Information Systems), the present chapter enables us to identify the dynamics and patterns of the evolution of the Land-Use Changes in the Alto Tâmega Region from 1990 to 2018 (years 1990, 2000, 2012, and 2018 using CORINE (Coordination of Information on the Environment) data). Land-Use Changes studies are reliable tools to evaluate the human activities and footprint of proposed strategies and policies in a territory. This study permits us to reinforce that the Land-Use Changes in the Alto Tâmega Region have undergone multiple changes—marked by increasing and decreasing periods. Also, can be considered a surveying baseline for the comparative analysis of similar works for different Land-Use Changes trends in Europe or worldwide. This chapter also enables us to understand that the main actors should design development policies to protect, preserve and conserve these incomparable landscapes, environments, ecosystems, and the region as a whole.

Keywords: Alto Tâmega region, GIS tools, land-use changes, regional studies, sustainable planning, territorial planning and management

1. Introduction

1.1 Sustainable development

Institutions and citizens have been paying more attention to issues of sustainable development in the last few years [1, 2]. In 1987, Mrs. Brundtland – at the time, the Prime Minister of Norway – described in the United Nations World Commission on

Environment and Development's report "Our Common Future" the concept of sustainable development as "meeting the needs of the present without satisfying the needs of future generations". The required capacity constitutes the development of a hazard [3–5]. Thus, considering the concept of sustainable development, it's possible to adopt the scientific and technological spheres of progress in order to enhance and improve sustainable development management. That could be accomplished, for instance, by increasing mankind's knowledge regarding the laws of nature, by developing new ways to explore natural resources, and by improving the levels of efficiency in terms of resources' utilization [5].

The concept of sustainable development (SD) has been on the global agenda for fifty years and is now widely accepted among nations, organizations, and individuals alike [6–9]. According to the Brundtland Commission, SD is defined as a development that meets the needs of the present generation without compromising the ability of future generations to meet their needs [5, 9]. Theoretical perspectives of SD have been broadly discussed and applied, including several different requirements for what should constitute a sustainable organization [9, 10]. However, despite decades of research, there is a need for further studies on the integration of SD with core business measurements and processes [6, 9]. Moreover, SD's definition reflects a scenario where output is produced without generating a natural resources depletion of any kind [2, 8]. Additionally, one can mention the Sustainable Development Goals (SDGs), a blueprint with the aim to guide society into a more sustainable development [2].

SDGs can be characterized as a list of objectives, based on the long-term Outline Perspective Plan (OPP), that consider both development and sustainability. Indeed, SDGs were created in 2015 by the United Nations General Assembly, highlighting 17 interconnected main goals that would be applied to all nations. These goals will continue from 2016 to 2030. This series of goals has a total of 17 goals and 169 indicators attached to it [1–3, 8, 11].

Those 17 goals, basically, stand for: eradicating poverty and hunger; promoting health cares, well-being, education, access to potable water, to sanitation, and to an affordable and clean source of energy; fighting gender or other forms of inequality; providing dignified jobs to people; stimulating a sustainable economic growth; developing and promoting innovation within industry, while supporting the arise of infrastructure; reinforcing sustainability within cities and communities; promoting a responsible production process and conscious consumption; boosting climate action; protecting and preserving underwater and land life diversity; establishing strong institutions aiming to promote peace and justice; and establishing partnerships to enable the accomplishment of these goals by 2030, in a clear attempt to reach a higher level of human equality [2, 12, 13].

Current issues for urban studies are focused on implementing sustainable principles and addressing spatial demands related to the needs of modern society, maintaining environmental quality, protecting biodiversity, and managing the increasingly urgent issues of climate change adaptation and mitigation [14–16]. Urbanization is a process that creates and leaves an impact on the economic and social development of developing countries [2]. These issues globally depend on the unsolved conflict between anthropic systems and environmental components [17]. The need for tools to support policy-making oriented to sustainable planning arises at several levels of governance. In this regard, the fast progress of Geographic Information Systems (GIS) during the last few decades provided researchers with powerful tools with which to conduct spatial analyses and modelling [18, 19].

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Due to the need to examine the value of several urban indicators for each selected single field unit and find potential relationships between them, it was decided to conduct the research in the geographic information system (GIS) environment. Conducting urban research and analyses with the use of spatial information systems has been growing since the 1960s [20–24]. The use of GIS in urban and spatial planning is becoming more and more popular as they are undoubtedly tools that facilitate the work of urban planners and architects [21–24]. GIS systems enable the collection, processing, analysis, visualization and sharing of spatial data and their primary function is to support decision-making [25, 26]. No wonder that after 2000 they have been widely used in the work of town planners, planners and more and more often, also architects. GIS systems have become the basic tool in spatial research, the results of which may be helpful in the preparation of planning studies, i.e., local spatial development plans or studies of the conditions and directions of spatial development [24]. In the literature, we can find many examples of the use of GIS in such analyses, including determining the maximum allowable height of newly designed buildings, assessment of the city sprawl based on land use analysis using GIS and remote sensing, identification of areas for new investments, analysis of building layouts, land absorption analysis with the use of GIS, the study of the impact of building morphology on energy consumption, construction of a spatial database as a tool for participatory activities and many others [24, 27–29]. As a consequence of that, this article resorts to maps in order to geo-visualize the data, instead of simply exhibiting the obtained results in tables. GIS systems has also as one of its main advantages the fact that it provides spatial-based solutions [2, 20, 22, 26], meaning that these systems are able to detect variations through the integration of data from multiple sources. An example of that is the land use information that can be obtained for a specific region after combining hydrological data, soil, topographic maps, and GIS's images [30–33].

1.2 Land-use changes

The CORINE Land Cover (CLC) multi-temporal European datasets, delivered by the European Spatial Agency and Copernicus land monitoring services, were developed with a main purpose: to be a cognitive reference framework regarding the spread of land consumption, allowing comparisons to be established between different European nations [34–37].

In fact, Information on the Environment Coordination CORINE Land Cover (CLC), which is a combined effort of all European Community countries initiated in 1985, collects and interprets geospatial data aiming to: (a) obtain and coordinate interdisciplinary data regarding the environment's state; (b) establish a particular focus on EU countries' areas that are seen as priorities; (c) coordinate the organization and management of data, both locally and internationally; and (d) assure that data is compatible [34].

The CLC database is a tool for performing complex spatial analyses based on diverse land-use kinds. CORINE land cover classes (CLC) have three levels in their hierarchical organization. The first covers five main types of land-use and land cover: artificial areas, agricultural areas, forest and semi-natural areas, wetlands, and water bodies. The next level has fifteen departments. The third level includes forty-four departments that note that the methodological scope of the three individual-level three classes is strictly defined [38, 39].

In fact, the Geographic Information System (GIS) groups and makes available data on land changes. For that, it resorts to high-resolution land cover assessments and change evaluations, with a particular focus on urban areas [34, 40, 41]. In addition to that, these systems also allow an analysis on the variations of human activities and land cover [41, 42]. Moreover, Urban Atlas (UA) allows the differentiation of coverage classes by classifying high-resolution satellite pictures (SPOT 2.5 m, ALOS 2.5 m, RapidEye 5 m). Considering that the lowest mapping unit is 0.25 hectares, the development of land cover maps is limited to 305 European larger cities – where populations exceed 100,000 people – and they present an estimated accuracy of 5 meters. The fact is that the UA only has 20 classes, regarding land cover, a considerably lower number when compared to the CLC [34, 42].

Humans have made major modifications to the earth's surface over time in order to generate food via farming methods. Over half of the earth's surface has been transformed in the last few years, and over one-third of the earth's surface is believed to be agricultural [33, 43]. Humans are simultaneously confronting environmental problems on multiple fronts, such as climate change, loss of biodiversity, soil degradation, water pollution, and loss of ecosystem services, and each of these is caused either directly or indirectly by land-use changes [44–50]. It is estimated that approximately 60% of global land-use changes are directly associated with human land-use activities and 40% with indirect drivers, such as climate change [45]. The expansion of built-up land in urban and rural areas, agricultural intensification, energy, and material consumption are the primary drivers of land-use change [51].

Urbanization is a phenomenon that has followed mankind throughout History, being considered as a relevant feature in every society. One can classify urbanization as the transformation process of rural areas into urban areas, or, simply, as the agglomeration of built-up areas and different ways of life [36, 42]. Urbanization started to grow at exponential rates in the nineteenth century, as a consequence of the industrialization process, and, after that, has become a usual phenomenon within cities in expansion [42]. Moreover, urbanization directly affects approximately 80% of the European population since that's equivalent to the parcel of people currently living in urban areas [47, 52]. Additionally, multiple researchers point out that, by 2030, 75% of European landscapes will be urban in nature [45]. Nowadays, urban areas' continuous expansion can be observed mostly in large agglomerations' surrounding areas, which can be justified by multiple processes, such as suburbanization and urban sprawl [53]. The processes of landscape urbanization have a fundamental impact on its structure and physiognomy and depend on the intensity of changes and technological progress. The above processes change the structure of the landscape. In this paper, landscape is understood as a combination of different types of land cover [42].

Land use and land cover change (LULC) has become a fundamental and essential component in current strategies that concern monitoring environmental change and managing natural resources [54], is a global subject of study. Most studies have focused on metropolitan areas, and other environmental targets of interest, such as the tropics, karsts, coastal zones, ecosystem services, climate change [45, 51, 55], etc. The land surface is being considerably affected due mostly to the growth registered in terms of anthropogenic activities in the biosphere, which might ultimately end up affecting global systems' efficiency levels [54]. In fact, LULC and the resources associated to it have been utilized with the purpose of satisfying humans' social, material, cultural, and even spiritual necessities, which may be tracked down as the origin of significant changes [56, 57]. Quick changes regarding LULC in developing countries have created a depletion of important resources, such as water, soil, and vegetation [54, 58]. Furthermore, because of their quickness, extent, and intensity, global-scale implications – in terms of natural resources and greenhouse gas emissions, for instance – are also related with these land use changes [54, 59]. However, these implications might start to be observed on the local, regional, and national environments due to the massive and quick changes that have been taking place [54, 60].

In order to have a deeper knowledge on land dynamics, it becomes necessary to resort to LULC changes [54]. Researcher from different disciplines conducted multiple empirical studies that concluded that these changes in terms of LULC are important to numerous applications, like hydrology, forestry, agriculture, environmental studies, geology, and ecology [61]. Indeed, some researchers believe that LULC changes could end up playing a decisive role in terms of climate change and ecosystem's imbalance [61, 62]. As a result of that, mostly in developing countries, various resources – land, forest, water, among many others – are significantly declining [63]. Precise information regarding LULC changes, despite being difficult to get [54], is key to determine the root causes, as well as the consequences of these changes. Conducting an accurate analysis regarding the causes behind LULC changes is also fundamental to understand current changes and to produce realistic forecasts [54, 64].

Given the increasing number of disasters over recent years, one of the most efficient and accessible methods for reducing the pressure posed by natural or technological risks is reducing the vulnerability level of communities exposed to a particular hazard [65–68]. At all levels of government, there is a demand for instruments to enhance policy-making aimed at long-term planning [34]. Thus, territorial planning strategy can be considered as a key instrument to attribute wealth pre-conditions to inhabitants; consequently, this will enhance the levels of prosperity of a certain region's future generations by lowering social and spatial inequalities, ultimately leading to sustainable development of that same region [34].

The aim of current study is to map and explain the Land-Use Changes in the Alto Tâmega Region between 1990 and 2018. In this regard, we emphasize that the current study will contribute to science by enabling the collection of big data connected to Land-Use Changes, as well as an overview of how they have evolved in the Alto Tâmega Region over the last three decades.

Finally, we are able to discuss the spatial patterns observed, and to give some principles and recommendations for future regional planning and management strategies and policies to be developed and implemented throughout the Alto Tâmega Region.

2. The Alto Tâmega: a brief overview

The Alto Tâmega Region (NUTS III) (**Figure 1**), comprising the municipalities of Boticas, Chaves, Montalegre, Ribeira de Pena, Valpaços and Vila Pouca de Aguiar, covers an area of approximately 2922 km^2 and recorded, according to data from the 2021 Census of the National Institute of Statistics (INE), a resident population of 84,330 inhabitants, corresponding to roughly 2.5% of the population of the northern region of Portugal, with an average population density of 28.00 inhabitants per km^2 [69]. It is the 12th largest sub-region, the 24th most populous sub-region and the 19th densest sub-region in the country. It is made up of six municipalities and 118 parishes, with the city of Chaves being the administrative city and the main urban center of the sub-region. With 17,207 inhabitants in its urban area and 37,592 inhabitants in the

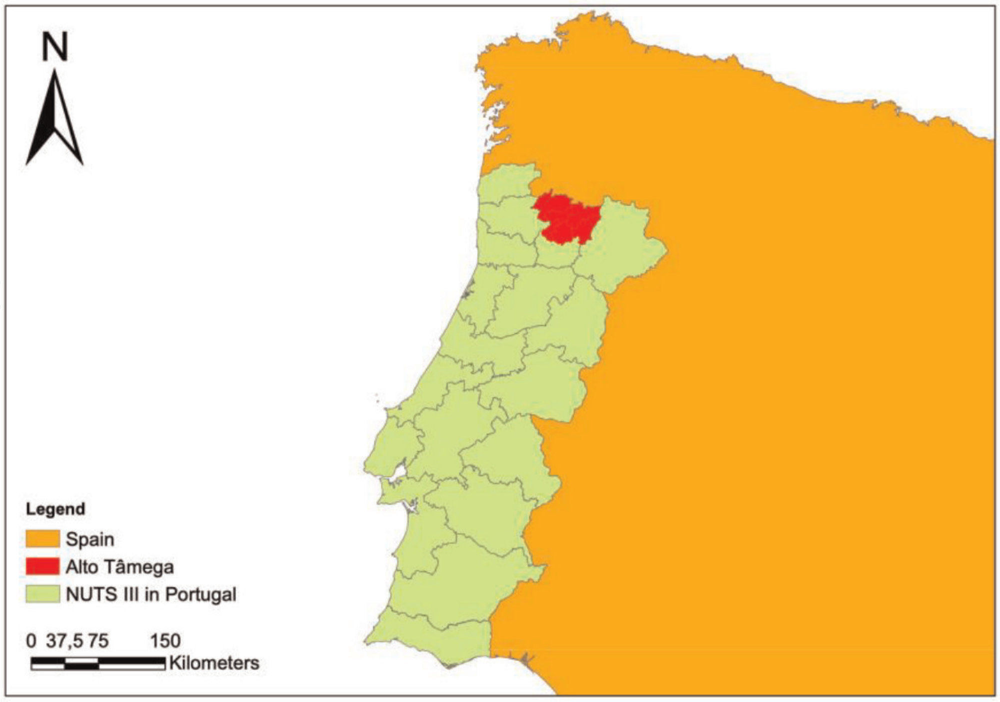

Figure 1.
Delimitation of the study area - Alto Tâmega Region (Source: Authors by ESRI ArcGIS, 2020).

entire municipality, it is the largest city and the largest municipality in Alto Tâmega Region, limited to the north by Galicia (Spain), to the east with the Terras de Trás-os-Montes, south with Douro and west with Cávado and Ave [70].

This territory is one of the twenty-three national Intermunicipal Communities (CIM), bordering four other CIMs – Cávado, Ave, Douro and Terras de Trás-os-Montes – and to the north with Spain, which places the region in a privileged position, in view of possibilities for promoting cross-border relations, especially with Orense [71].

The region under analysis corresponds to the territory covered by the Municipalities of Boticas, Chaves, Montalegre, Ribeira de Pena, Valpaços and Vila Pouca de Aguiar, according to data from the 2021 Census, Alto Tâmega Region registered 84,330 inhabitants, 9813 inhabitants less compared to the 2011 Census, where 94,143 inhabitants were registered. All six municipalities recorded a decrease in inhabitants by −10.4% (**Table 1**) [72, 73].

Municipalities	**Area (km^2)**	**Population (2021 census)**	**Population (2011 census)**	**Variation (%)**
Boticas	322.00	5.002	5.750	−13.0
Chaves	591.20	37.623	41.243	−8.8
Montalegre	805.50	9.279	10.537	−11.9
Ribeira de Pena	217.50	5.887	6.544	−10.0
Valpaços	548.70	14.714	16.882	−12.8
Vila Pouca de Aguiar	437.10	11.825	13.187	−10.3
Total	**2922.00**	**84.330**	**94.143**	**−10.4**

Table 1.
CORINE land cover nomenclature (Source: Authors).

Figure 2.
Alto Tâmega region - Municipality of Boticas (Source: Authors).

Next, a brief description of each of the municipalities is processed, starting with the municipality of Boticas. Founded on November 6, 1836, the municipality of Boticas is a land of unique historical, cultural and natural legacies, hills and mountains of indescribable natural beauty, secular mills, forts, dolmen ruins and Roman milestones (**Figure 2**). From here are the statues of the Calaico-Lusitano Warrior, ex-libris of portuguese archaeology. Barroso's "Enough of Oxen" are a legacy of communitarianism still present. Barrosã Meat, an autochthonous breed of this region and delicacy of kings in the past, stands out as a product of excellence, as well as Honey of Barroso and Honey Brandy. The gastronomic offer is completed with the famous Barroso-style stew, sausages, ham and "Wine of the Dead". The uniqueness of this territory and its inhabitants, constitute one of the most attractive posters in the region and led the United Nations Food and Agriculture Organization to distinguish it and declare it as a World Agricultural Heritage [70–73].

In relation to the Municipality of Chaves, the highlights are heritage, traditions, gastronomy, genuine flavors and ancestral knowledge that make Chaves a healthy land, with soul, which keeps its identity with extraordinary persistence (**Figure 3**). With its squares and spacious streets, parks and colorful gardens, imposing houses, buildings with facades that testify to ancient civilizations, but whose modernity enriches. Chaves offers multiple proposals for tours that allow you to discover impressive landscapes of the river and the mountains to discover a little more of the millenary history of the region. The thermal heritage, legacy of the Romans, is still a pole of attraction for Chaves and Vidago. The hotel and restaurant offer is vast and of excellent quality, a pretext for discovering this territory of well-being [70–73].

Montalegre is a border municipality, in the district of Vila Real, with approximately 800 km^2 of extension (**Figure 4**). Declared World Agricultural Heritage and

Figure 3.
Alto Tâmega Region - Municipality of Chaves (Source: Authors).

Figure 4.
Alto Tâmega region - Municipality of Montalegre (Source: Authors).

Biosphere Reserve, it has an unsurpassed tourist heritage. Ethnography, history, folklore, gastronomy and landscape are undoubtedly leftovers. Another of Barroso's great features is its natural formations, which, spared the action of generations, endow this territory with a majestic landscape and ethnic wealth, which this people preserve. The Peneda-Gerês National Park (PNPG), the secrets of Mourela, the fresh air of Larouco, the ham and smoked meat, the veal, the rye bread, the customs and customs, but above all the hospitality, honesty and human warmth that you experience, are strong reasons to visit the "Marvelous Kingdom" [70–73].

In the municipality of Ribeira de Pena you will find a rich and varied gastronomy, a cultural heritage enriched by the passage of the writer Camilo Castelo Branco and the Museum Network (**Figure 5**). The Tâmega, Póio, Louredo and Beça rivers invite you to take a dip and practice sports activities such as rafting or canyoning. The municipality stands out for its landscapes that mix between a majestic flora and so different between the green valleys and the altitudes, which extends from the Alvão mountain range to the Barroso region. Ribeira de Pena clearly assumes itself as a nature tourism destination, largely through the hotel and leisure facilities that were born in the county. It is here that we find one of the biggest Slides in the world, the "Fantasticable", which is the ex-libris of Pena Aventura Park. Also, in Ribeira de Pena you will be able to enjoy the environmental park and a network of walking paths that will guide you throughout the discovery of the territory [70–73].

The municipality of Valpaços is more than its 550 km^2 of beautiful landscapes, more than its cultivated land with excellent products, more than its 25 magnificent parishes full of heritage that are worth discovering, great stories that make us holders of a unique and wonderful gastronomy, rich and variety of fauna and flora, which enhances the practice of leisure activities, attracting different audiences, from various

Figure 5.
Alto Tâmega Region - Municipality of Ribeira de Pena (Source: Authors).

Figure 6.
Alto Tâmega Region - Municipality of Valpaços (Source: Authors).

parts of the country, at different times of the year (**Figure 6**). But it is also synonymous with modernity, with various facilities available to the visitor, as well as tourist projects of superior quality. Be sure to visit the Interactive Tourism Store, Wine House, Rabaçal Ecovia, the river beaches, among many other unique places that you can only find in Valpaços [70–73].

The municipality of Vila Pouca de Aguiar is located in Alto Tâmega, in Trás-os-Montes, in one of the highest relief regions in Northern Portugal, marked by mountains and plateaus with embedded valleys and rivers of excellent quality (**Figure 7**). Here, we find well-preserved ecosystems, coexisting with family farming and common forest management. Rare species persist in nature, such as the Iberian wolf, the blue peat butterfly, the "Veronica micrantha" and the bats (in Tresminas). Known for the abundance of megalithic monuments, and for the exploitation of gold in Roman times, Vila Pouca de Aguiar allows us to relate the human presence and the exploitation of natural resources, throughout history. Gold, Granite or Medicinal waters were (and are …) treasures that allowed the settlement of peoples and the development of society and local culture [70–73].

Briefly, the Alto Tâmega Region is characterized by the agricultural activity and agro-industry play an important role in the economic landscape of this low-density territory. The endogenous resources of outstanding quality are one of the differentiating factors of these municipalities, with emphasis on the endogenous products of recognized quality, many of which are guaranteed a Protected Designation of Origin (DOP) and Protected Geographical Indication (IGP), among which stand out the meat, honey, olive oil, chestnuts, potatoes, folar, smoked products and sausages, among others [70–73].

Figure 7.
Alto Tâmega Region - Municipality of Vila Pouca de Aguiar (Source: Authors).

The tourist activity constitutes another of the strategic bets of Alto Tâmega Region, based on an offer of thermal tourism and rural areas tourism (TER) that complements the natural beauty of the region, contextualized by large areas of natural interest and that provide a privileged framework in terms of biodiversity and landscape richness [70–73].

In addition, cultural heritage also plays an important role in the tourist, economic and social panorama of Alto Tâmega Region. In this case, the national monuments with great tourist interest, distributed throughout the six municipalities, as well as diverse cultural manifestations such as handicrafts and ethnographic traditions, should be highlighted [70–73].

The climate of the Alto Tâmega Region is generally considered to be comfortable and cool, however in winter the climate is cool, with frequent snowfall [74].

As for the soils, most of them have some aptitude for pastures and forestry, with fewer of those with good agricultural aptitude, these, in general, concentrated in the plains [74].

According to the 2021 Census, we can draw some conclusions regarding the Alto Tâmega Region [70–74]:

- The percentage of young residents stands at 9.2%, below the average for the North region with 12.5% and below the national average of 13.5%;

- The percentage of seniors residents is 30.7%, above the regional average in the North with 21.2% and above the national average with 22.3%;

- The percentage of foreign residents stands at 1.5%, below the regional average of the North with 2.5% and well below the national average with 6.4%;

- The sectors with the most workers are commerce, with 17.6% of all employed workers, followed by construction with 11.7%, manufacturing with 10.6% and accommodation and catering with 7.5%;

- The unemployment rate in 2020 was 6.0, 0.2% below the regional average in the North, which was 6.2 and 0.2% above the national average, which was in the 5.8%;

- Purchasing power stood at 70.4%, below the regional average of 93% in the North, with Portugal at 100%. Only the municipality of Chaves surpassed the average purchasing power of the Alto Tâmega Region with 79.1%;

- The average monthly salary in the region in 2019 was €954.20, below the average of €1100.40 recorded in the North region and below the national average of €1206.30.

3. Methodology

The data used was two layers of information. These can be utilized to duplicate this work in another work area because they are public and open. The analyzed area is the Alto Tâmega Region, in Portugal.

Data on land use were first gathered. The European Space Agency (EEA) provides a geodatabase employing polygonal graphic characteristics that suggest land uses throughout the European Union for the years 1990, 2000, 2006, 2012, and 2018 through the CORINE Land Cover (Coordination of Information-CLC) project [48, 75]. Regarding the use of remote sensing data, the information was supplied by means of shapefiles. So, these files were managed by using ArcGis 10.5. A project was generated and subsequentially the shapefiles were added as layers, that is to say, vectorial information.

The scale used is 1:100,000 in the Geodesic Reference System corresponding to the European Terrestrial Reference System 1989 (ETRS89) and the Mapping System is Universal Transverse Mercator (UTM), with the minimum cartographic unit (MCU) being equal to 25 hectares. The accuracy obtained has been increasing over the years, since in 1990 it was less than 50 meters, in 2000, 2006 and 2012 it was less than 25 meters, and finally, in 2018 it is less than 10 meters. Also, the information contained in these polygons is hierarchical in three levels of information (**Table 2**).

Level 1	**Level 2**	**Level 3**
1. Artificial surfaces	1.1. Urban fabric	1.1.1. Continous urban fabric
		1.1.2. Discontinuous urban fabric
	1.2. Industrial, commercial and transport	1.2.1.Industrial or commercial units
		1.2.2.Road and rail networks and associated land
		1.2.3.Port areas
		1.2.4.Airports
	1.3. Mine, dump and construction sites	1.3.1.Mineral extraction sites
		1.3.2.Dump sites
		1.3.3.Construction sites
	1.4. Artificial, non-agricultural vegetated areas	1.4.1.Green urban areas
		1.4.2.Sport and leisure facilities
2. Agricultural areas	2.1. Arable land	2.1.1. Non-irrigated arable land
		2.1.2. Permanently irrigated land
		2.1.3. Rice fields
	2.2. Permanent crops	2.2.1.Vineyards
		2.2.2.Fruit trees and berry plantations
		2.2.3.Olive groves
	2.3. Pastures	2.3.1.Pastures
	2.4. Heterogeneous agricultural areas	2.4.1.Annual crops associated with permanent crops
		2.4.2.Complex cultivation
		2.4.3.Land occupied by agriculture
3. Forests and semi-natural areas	3.1. Forests	3.1.1. Broad-leaved forest
		3.1.2.Coniferous forest
		3.1.3.Mixed forest

Level 1	Level 2	Level 3
	3.2.Shrub and/or herbaceous vegetation association	3.2.1. Natural grassland
		3.2.2.Moors and heathland
		3.2.3.Scierophyllous vegetation
		3.2.4.Transitional woodland shrub
	3.3. Open spaces with little or no vegetation	3.3.1.Beaches, dunes, and plains
		3.3.2.Bare rock
		3.3.3.Sparsely vegetated areas
		3.3.4.Burnt areas
		3.3.5.Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1.1.Inland marshes
		4.1.2.Peatbogs
	4.2. Coastal wetlands	4.2.1.Salt marshes
		4.2.2.Salines
		4.2.3.Intertidal flats
5. Water bodies	5.1. Inland waters	5.1.1.Water courses
		5.1.2.Water bodies
	5.2. Marine waters	5.2.1.Coastal lagoons
		5.2.2.Estuaries
		5.2.3.Sea and ocean

**For detailed information about the CLC Codes, the authors recommend the following source: www.eea.europa.eu/publications/COR0-landcover, accessed on 10 November 2022.*

Table 2.
CORINE Land Cover nomenclature (Source: [75]).*

The second layer of information corresponds to the administrative delimitation of the Alto Tâmega Region. From the National Geographic Information System of Portugal (SNIG), as shown in **Figure 8**.

ArcGIS 10.5 Geographic Information Systems (GIS) management software was then used to process both levels of data. When Lambert-2001's ETRS-LAEA was first adopted as the official coordinate reference system, all layers of information were converted to it by means of designation of projection in the project [75], due to the fact that they are the inputs, the projection of equivalent regions within the territory, on which ETRS-LAEA is based. In this way, it acts as a standard for homogeneous units across all of Europe. Thus, the representation of analytical and statistical data uses this coordinate system.

Subsequently, the layer relating to the administrative divisions of the country, Portugal has carried out a selection query through alphanumeric information and the Alto Tâmega Region was selected. Subsequently, this single region was kept in a single layer of information. This layer of information was the limit of the scope of action of this work. The clip tool was then used, with Alto Tâmega's boundary as the reference layer. This procedure was used for each of the years studied (1990, 2000, 2006, 2012 and 2018). In this way, land uses were obtained, but only those that were included in

Figure 8.
Delimitation of the study area - Alto Tâmega Region - Municipalities (Source: Authors by ESRI ArcGIS, 2020).

the region. Subsequently, geometric measurement of the area of each of the polygons was performed in hectares. This resulted in the number of hectares of each polygon representative of land uses according to the CLC nomenclature.

The alphanumeric data stored in each of the tables for the years under analysis was then exported by means of the command export and imported into a database that was maintained by the Microsoft Access database management program, a component of the Microsoft Office 365 suite of applications.

Using Structured Query Language (SQL), selection queries were created to the database to select in accordance with the CLC nomenclature, and then another grouping query was appended to the original query. Finally, for the years 1990, 2000, 2006, 2012, and 2018, the number of hectares for each land use was determined.

However, to take into account not only numerical but also geographical results, thematic maps were also obtained for each year in order to take into consideration both the numerical and geographic outcomes. This made it possible to pinpoint both the areas with the highest variety in land uses and those with predominant land uses.

A system has been designed to facilitate understanding of the technique utilized and the criteria for selecting case studies (**Figure 9**).

Literature review Data collection	Applied Methodology: Geographic Information Systems (GIS) CORINE Land Cover (CLC)	Study area analysis Data analysis (obtained values)	Land-Use Change from 1990 to 2018 — Portugal — Alto Tâmega
Stage 1	Stage 2	Stage 3	Stage 4

Figure 9.
Summary of the methodology's selection criteria and case study selection process (Source: Authors).

4. Results

The results come from the analysis of the land-use changes for the Alto Tâmega region in the years 1990, 2000, 2006, 2012 and 2018. The results will be exposed through the tables, and thematic cartography. This typology of results exposed allows for extracting the most relevant information and characterizing the evolution of land use based on the 44 land uses determined by CLC in level 3. The information is organized and presented with the help of different plots and tables obtained using ArcGIS 10.5 Geographic Information Systems (GIS) management software, and CLC, in percentage, according to the following order of description of the Municipalities of Boticas, Chaves, Montalegre, Ribeira de Pena, Valpaços and Vila Pouca de Aguiar.

As an example, in **Figure 10**, we present the results shown in **Table 3**, namely the Evolution of land uses according to level 3 of the CLC nomenclature in the Alto

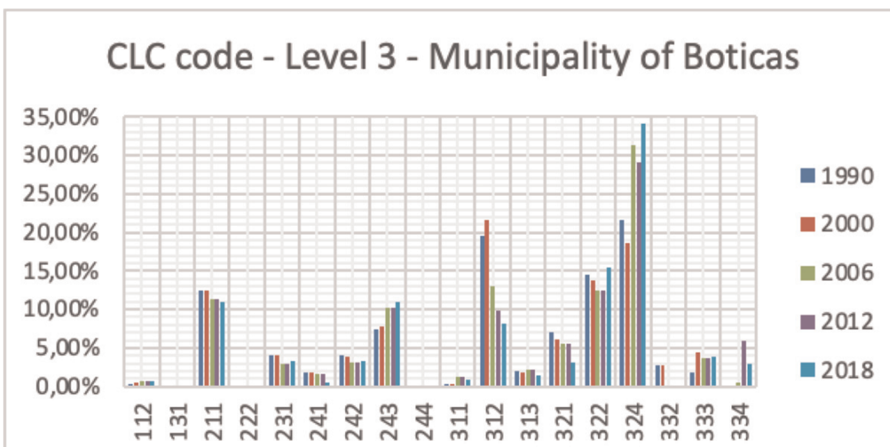

Figure 10.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Boticas in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

CLC Code\Year	1990	2000	2006	2012	2018
112	0.36%	0.46%	0.71%	0.71%	0.71%
131	0.00%	0.10%	0.09%	0.09%	0.09%
211	**12.41%**	**12.42%**	**11.36%**	**11.36%**	**11.05%**
222	0.08%	0.08%	0.08%	0.08%	0.00%
231	4.03%	4.03%	2.90%	2.90%	3.25%
241	1.80%	1.80%	1.58%	1.58%	0.58%
242	3.97%	3.88%	3.20%	3.20%	3.35%
243	**7.46%**	**7.81%**	**10.12%**	**10.12%**	**11.05%**
244	0.19%	0.00%	0.00%	0.00%	0.00%
311	0.38%	0.38%	1.31%	1.29%	0.95%
312	**19.47%**	**21.70%**	**12.99%**	**9.90%**	**8.12%**
313	2.08%	1.77%	2.14%	2.12%	1.49%
321	7.08%	6.08%	5.53%	5.53%	3.12%

CLC Code\Year	1990	2000	2006	2012	2018
322	**14.56%**	**13.74%**	**12.47%**	**12.49%**	**15.44%**
324	**21.65%**	**18.56%**	**31.41%**	**29.00%**	**34.11%**
332	2.66%	2.66%	0.00%	0.00%	0.00%
333	1.80%	4.36%	3.67%	3.67%	3.82%
334	0.02%	0.16%	0.44%	5.94%	2.88%

**Values in bold corresponding to the higher value founded.*

Table 3.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Boticas (Source: authors).

Tâmega Region - Boticas Council in 1990, 2000, 2006, 2012 and 2018. This will be the same procedure for the remaining municipalities analyzed in this study.

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated.

From the information in **Table 4**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 3** - Values in bold

CLC Code\year range	2000–1990	2006–2000	2012–2006	2018–2012
112	0.10%	0.25%	0.00%	0.00%
131	0.10%	−0.01%	0.00%	0.00%
211	0.02%	−1.06%	0.00%	−0.31%
222	0.00%	0.00%	0.00%	−0.08%
231	0.00%	−1.13%	0.00%	0.35%
241	0.00%	−0.22%	0.00%	−1.00%
242	−0.09%	−0.68%	0.00%	0.14%
243	**0.35%**	**2.31%**	0.00%	0.92%
244	−0.19%	0.00%	0.00%	0.00%
311	0.00%	0.92%	−0.02%	−0.34%
312	**2.23%**	**−8.70%**	**−3.09%**	**−1.78%**
313	−0.31%	0.37%	−0.01%	−0.63%
321	−1.00%	−0.55%	0.00%	−2.41%
322	−0.82%	−1.27%	**0.02%**	**2.95%**
324	**−3.09%**	**12.85%**	−2.40%	5.10%
332	0.00%	−2.66%	0.00%	0.00%
333	2.56%	−0.69%	0.00%	0.14%
334	0.14%	0.28%	5.51%	−3.07%

**Values in bold corresponding to Land-Use Changes - significant changes.*

Table 4.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Boticas (Source: authors).

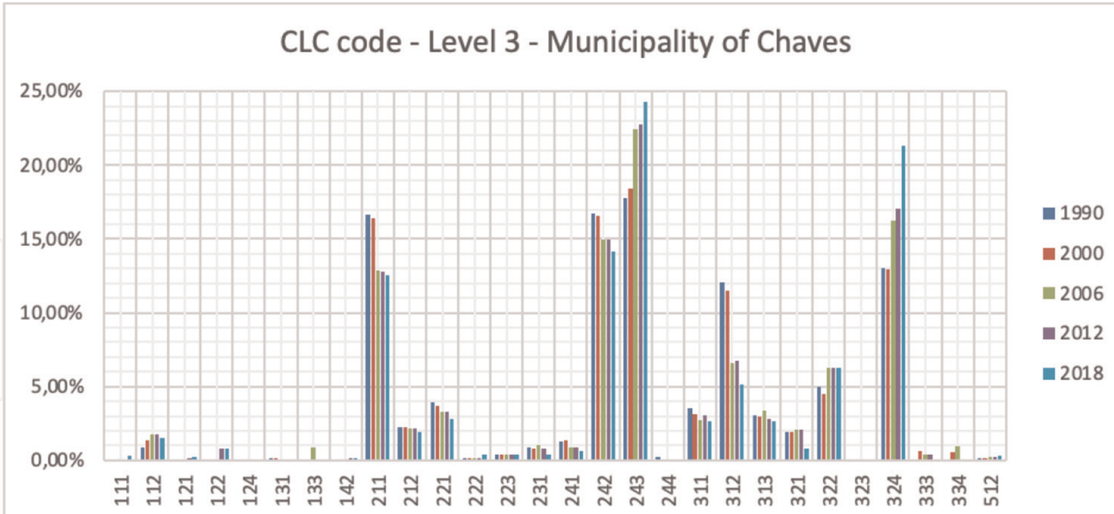

Figure 11.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Chaves in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

corresponding to the higher value founded) 243 between 2000 and 2006 (growing), 312 between 2000 and 2006 (decreasing), 322 between 2012 and 2018 (growing), and 324 between 2000 and 2006 (growing) (**Figure 11**).

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated (**Table 5**).

From the information in **Table 6**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 5** - Values in bold corresponding to the higher value founded) 211 between 2000 and 2006 (decreasing),

CLC Code\Year	1990	2000	2006	2012	2018
111	0.08%	0.08%	0.08%	0.08%	0.33%
112	0.84%	1.38%	1.78%	1.78%	1.50%
121	0.00%	0.00%	0.07%	0.15%	0.27%
122	0.00%	0.00%	0.00%	0.77%	0.77%
124	0.00%	0.00%	0.05%	0.05%	0.05%
131	0.14%	0.14%	0.10%	0.10%	0.10%
133	0.00%	0.00%	0.89%	0.10%	0.10%
142	0.07%	0.07%	0.07%	0.11%	0.16%
211	**16.63%**	**16.43%**	**12.88%**	**12.81%**	**12.54%**
212	2.21%	2.26%	2.13%	2.13%	1.91%
221	3.92%	3.66%	3.28%	3.29%	2.83%
222	0.13%	0.13%	0.17%	0.17%	0.41%
223	0.37%	0.37%	0.36%	0.36%	0.42%
231	0.86%	0.77%	1.06%	0.75%	0.39%

CLC Code\Year	1990	2000	2006	2012	2018
241	1.25%	1.38%	0.91%	0.91%	0.64%
242	**16.72%**	**16.57%**	**14.92%**	**14.93%**	**14.18%**
243	**17.81%**	**18.38%**	**22.42%**	**22.77%**	**24.28%**
244	0.26%	0.00%	0.00%	0.00%	0.00%
311	3.52%	3.15%	2.74%	3.05%	2.64%
312	**12.06%**	**11.46%**	**6.59%**	**6.71%**	**5.12%**
313	3.04%	2.99%	3.39%	2.83%	2.61%
321	1.93%	1.91%	2.07%	2.06%	0.80%
322	4.97%	4.52%	6.25%	6.30%	6.30%
323	0.05%	0.00%	0.00%	0.00%	0.00%
324	**13.00%**	**12.94%**	**16.24%**	**17.08%**	**21.31%**
333	0.00%	0.65%	0.39%	0.39%	0.06%
334	0.00%	0.57%	0.92%	0.06%	0.00%
512	0.13%	0.18%	0.24%	0.24%	0.28%

**Values in bold corresponding to the higher value founded.*

Table 5.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Chaves (Source: authors).

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
111	0.00%	0.00%	0.00%	0.25%
112	0.54%	0.40%	0.00%	−0.29%
121	0.00%	0.07%	0.08%	0.12%
122	0.00%	0.00%	0.77%	0.00%
124	0.00%	0.05%	0.00%	0.00%
131	0.00%	−0.05%	0.00%	0.00%
133	0.00%	0.89%	−0.78%	−0.01%
142	0.00%	−0.01%	0.05%	0.04%
211	**−0.20%**	**−3.56%**	−0.07%	−0.27%
212	0.06%	−0.13%	0.00%	−0.22%
221	−0.26%	−0.38%	0.01%	−0.46%
222	0.00%	0.05%	0.00%	0.24%
223	0.00%	−0.01%	0.00%	0.05%
231	−0.09%	0.29%	−0.31%	−0.36%
241	0.13%	−0.47%	0.00%	−0.26%
242	−0.15%	−1.64%	0.01%	−0.75%
243	**0.58%**	**4.04%**	0.35%	1.50%
244	−0.26%	0.00%	0.00%	0.00%

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
311	−0.37%	−0.41%	0.31%	−0.40%
312	**−0.60%**	**−4.87%**	0.12%	−1.59%
313	−0.05%	0.40%	−0.56%	−0.22%
321	−0.03%	0.17%	−0.02%	−1.25%
322	−0.45%	1.73%	0.05%	0.00%
323	−0.05%	0.00%	0.00%	0.00%
324	**−0.06%**	**3.30%**	**0.84%**	**4.23%**
333	0.65%	−0.26%	0.00%	−0.33%
334	0.57%	0.35%	−0.86%	−0.06%
512	0.05%	0.05%	0.00%	0.04%

**Values in bold corresponding to Land-Use Changes - significant changes.*

Table 6.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Chaves (Source: authors).

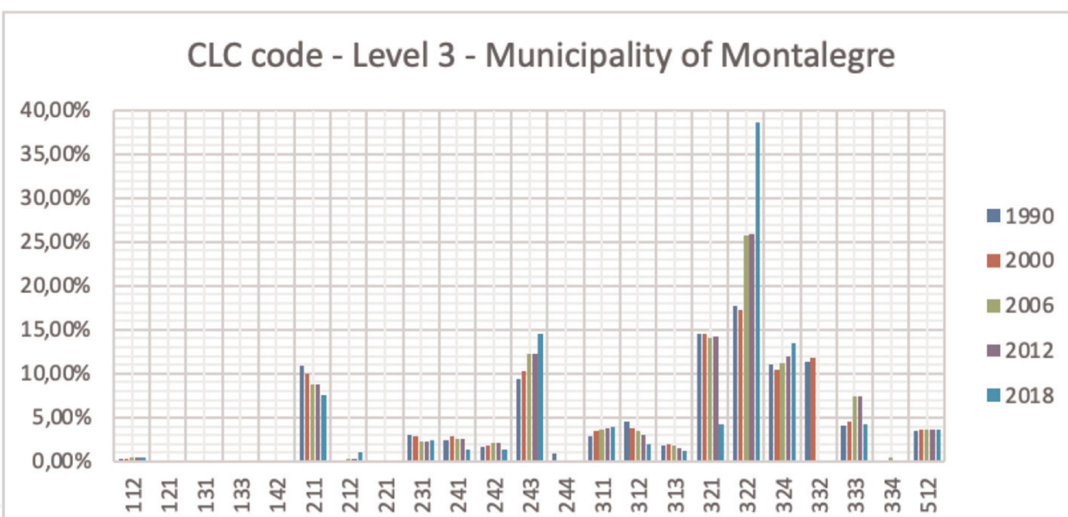

Figure 12.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Montalegre in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

243 between 2000 and 2006 (growing), 312 between 2000 and 2006 (decreasing), and 324 between 2000 and 2006 (growing) (**Figure 12**).

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated (**Figure 13**) (**Table 7**).

From the information in **Table 8**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 7** - Values in bold corresponding to the higher value founded) 243 between 2012 and 2018 (growing), 321 between 2012 and 2018 (decreasing), 322 between 2000 and 2006 and 2012 and 2018 (growing), and 332 between 2000 and 2006 (decreasing) (**Figure 14**).

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated (**Table 9**).

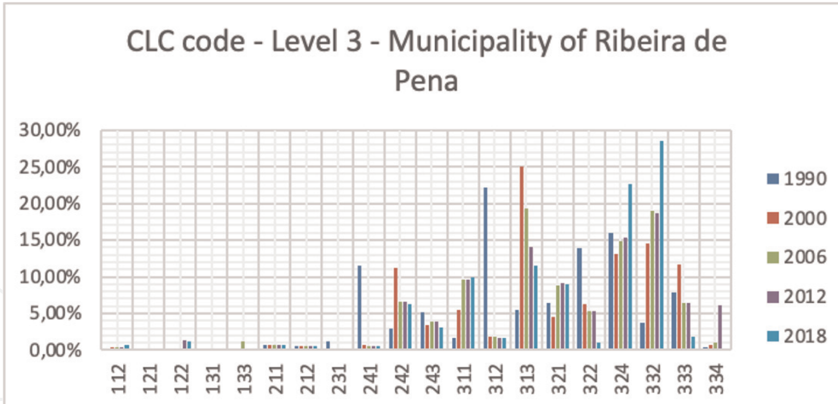

Figure 13.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Ribeira de Pena in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

CLC Code\Year	1990	2000	2006	2012	2018
112	0.22%	0.34%	0.37%	0.37%	0.43%
121	0.00%	0.00%	0.03%	0.03%	0.03%
131	0.06%	0.06%	0.06%	0.06%	0.06%
133	0.00%	0.05%	0.00%	0.00%	0.00%
142	0.00%	0.00%	0.05%	0.05%	0.05%
211	**10.89%**	**10.03%**	**8.75%**	**8.75%**	**7.58%**
212	0.00%	0.00%	0.22%	0.22%	1.04%
221	0.13%	0.13%	0.00%	0.00%	0.00%
231	2.99%	2.82%	2.25%	2.25%	2.34%
241	2.42%	2.91%	2.50%	2.50%	1.29%
242	1.68%	1.87%	2.06%	2.06%	1.37%
243	**9.44%**	**10.31%**	**12.29%**	**12.30%**	**14.46%**
244	0.84%	0.15%	0.00%	0.00%	0.00%
311	2.82%	3.43%	3.65%	3.83%	3.96%
312	4.48%	3.77%	3.48%	2.99%	1.92%
313	1.86%	1.89%	1.75%	1.45%	1.16%
321	**14.55%**	**14.54%**	**14.14%**	**14.17%**	**4.29%**
322	**17.63%**	**17.22%**	**25.75%**	**25.86%**	**38.68%**
324	**10.99%**	**10.51%**	**11.13%**	**11.94%**	**13.39%**
332	**11.40%**	**11.77%**	0.00%	0.00%	0.00%
333	4.05%	4.50%	7.42%	7.45%	4.29%
334	0.07%	0.11%	0.41%	0.05%	0.00%
512	3.48%	3.58%	3.66%	3.66%	3.66%

**Values in bold corresponding to the higher value founded.*

Table 7.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Montalegre (Source: authors).

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
112	0.12%	0.02%	0.00%	0.06%
121	0.00%	0.03%	0.00%	0.00%
131	0.00%	0.00%	0.00%	0.00%
133	0.05%	−0.05%	0.00%	0.00%
142	0.00%	0.05%	0.00%	0.00%
211	−0.86%	−1.28%	0.00%	−1.18%
212	0.00%	0.22%	0.00%	0.82%
221	0.00%	−0.13%	0.00%	0.00%
231	−0.16%	−0.57%	0.00%	0.09%
241	0.49%	−0.41%	0.00%	−1.21%
242	0.19%	0.19%	0.00%	−0.69%
243	0.87%	1.99%	**0.01%**	**2.15%**
244	−0.68%	−0.15%	0.00%	0.00%
311	0.61%	0.22%	0.18%	0.13%
312	−0.71%	−0.29%	−0.49%	−1.07%
313	0.03%	−0.14%	−0.30%	−0.29%
321	−0.01%	−0.40%	**0.03%**	**−9.88%**
322	**−0.41%**	**8.53%**	**0.11%**	**12.82%**
324	−0.48%	0.62%	0.81%	1.46%
332	**0.36%**	**−11.77%**	0.00%	0.00%
333	0.45%	2.92%	0.03%	−3.16%
334	0.04%	0.30%	−0.36%	−0.05%
512	0.10%	0.08%	0.00%	0.01%

**Values in bold corresponding to Land-Use Changes - significant changes.*

Table 8.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Montalegre (Source: authors).

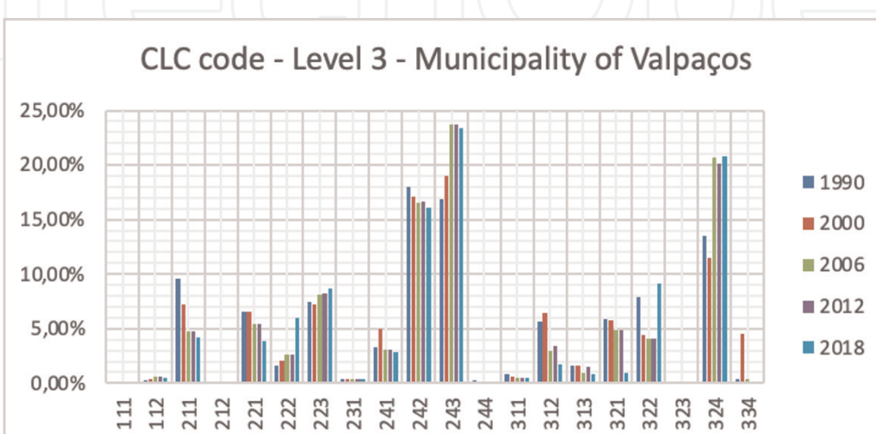

Figure 14.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Valpaços in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

From the information in **Table 10**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 9** - Values in bold corresponding to the higher value founded) 241 between 1990 and

CLC Code\SWYear	1990	2000	2006	2012	2018
112	0.16%	0.31%	0.46%	0.46%	0.65%
121	0.00%	0.00%	0.00%	0.00%	0.27%
122	0.00%	0.00%	0.10%	1.32%	1.24%
131	0.00%	0.00%	0.00%	0.00%	0.06%
133	0.00%	0.00%	1.24%	0.00%	0.13%
211	0.75%	0.75%	0.75%	0.75%	0.77%
212	0.49%	0.49%	0.47%	0.47%	0.61%
231	1.22%	0.00%	0.00%	0.00%	0.00%
241	**11.57%**	0.72%	0.54%	0.54%	0.54%
242	2.98%	**11.15%**	6.54%	6.54%	6.28%
243	5.20%	3.47%	3.83%	3.83%	3.06%
311	1.59%	5.54%	9.61%	9.61%	9.95%
312	**22.23%**	1.78%	1.78%	1.59%	1.73%
313	5.53%	**25.05%**	**19.24%**	**14.05%**	**11.56%**
321	6.49%	4.52%	8.74%	9.12%	9.02%
322	**13.89%**	6.28%	5.31%	5.31%	1.03%
324	**15.94%**	**13.17%**	**14.90%**	**15.27%**	**22.71%**
332	3.77%	**14.47%**	**19.06%**	**18.60%**	**28.57%**
333	7.81%	**11.62%**	6.46%	6.46%	1.81%
334	0.39%	0.68%	0.98%	6.09%	0.00%

**Values in bold corresponding to the higher value founded.*

Table 9.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Ribeira de Pena (Source: authors).

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
112	0.15%	0.15%	0.00%	0.19%
121	0.00%	0.00%	0.00%	0.27%
122	0.00%	0.10%	1.22%	−0.07%
131	0.00%	0.00%	0.00%	0.06%
133	0.00%	1.24%	−1.24%	0.13%
211	0.00%	0.00%	0.00%	0.02%
212	0.00%	−0.02%	0.00%	0.14%
231	−1.22%	0.00%	0.00%	0.00%
241	**−10.84%**	**−0.19%**	0.00%	0.00%

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
242	**8.17%**	**−4.60%**	0.00%	−0.26%
243	−1.73%	0.36%	0.00%	−0.77%
311	3.95%	4.06%	0.00%	0.34%
312	**−20.45%**	**0.01%**	−0.20%	0.15%
313	**19.53%**	**−5.81%**	**−5.19%**	**−2.49%**
321	−1.97%	4.22%	0.38%	−0.10%
322	**−7.61%**	**−0.97%**	**0.00%**	**−4.28%**
324	**−2.77%**	**1.73%**	**0.38%**	**7.44%**
332	**10.71%**	**4.59%**	**−0.46%**	**9.96%**
333	**3.80%**	**−5.16%**	**0.00%**	**−4.65%**
334	0.29%	0.30%	**5.11%**	**−6.09%**

**Values in bold corresponding to Land-Use Changes - significant changes.*

Table 10.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Ribeira de Pena (Source: authors).

2000 (decreasing), 242 between 1990 and 2000 (growing) and 2000 and 2006 (decreasing), 312 between 1990 and 2000 (decreasing), 313 between 1990 and 2000 (growing) and 2000 and 2006, 2006 and 2012, 2012 and 2018 (decreasing), 322 between 1990 and 2000 and 2012 and 2018 (decreasing), 324 between 2012 and 2018 (growing), 332 between 1990 and 2000, 2000 and 2006, 2012 and 2018 (growing), and 333 between 1990 and 2000 (growing), 2000 and 2006, 2012 and 2018 (decreasing).

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated (**Figure 15**) (**Table 11**).

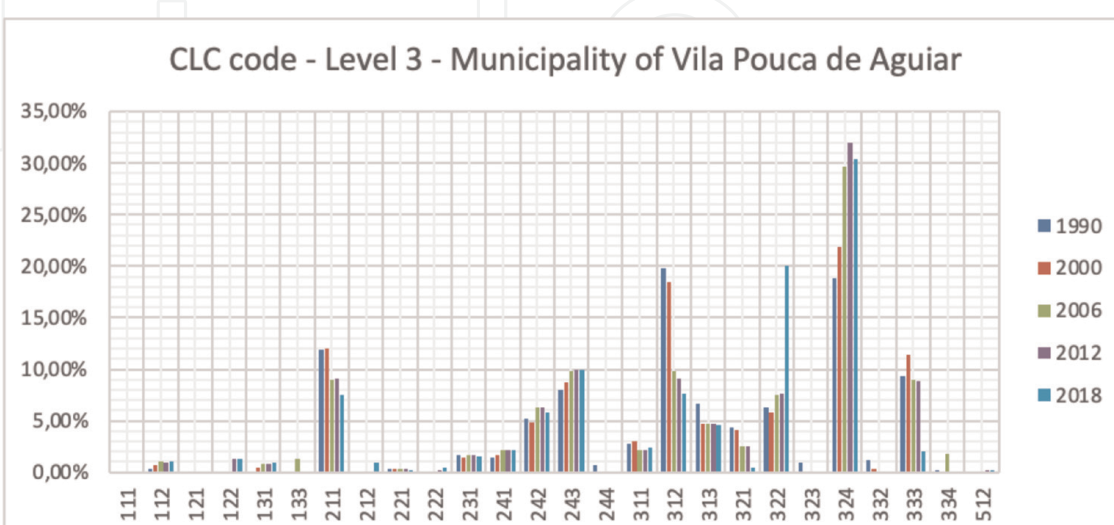

Figure 15.
Evolution of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Vila Pouca de Aguiar in 1990, 2000, 2006, 2012, and 2018 (Source: Authors by ESRI ArcGIS, 2020).

From the information in **Table 12**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 11** - Values in bold corresponding to the higher value founded) 243 between 2000 and 2006 (growing), and 324 between 2000 and 2006 (growing).

CLC Code\Year	1990	2000	2006	2012	2018
111	0.00%	0.00%	0.00%	0.00%	0.20%
112	0.28%	0.39%	0.64%	0.66%	0.48%
211	9.59%	7.23%	4.79%	4.79%	4.17%
212	0.00%	0.00%	0.00%	0.00%	0.10%
221	6.52%	6.58%	5.41%	5.42%	3.91%
222	1.61%	2.06%	2.63%	2.64%	5.96%
223	7.42%	7.25%	8.16%	8.25%	8.67%
231	0.44%	0.44%	0.42%	0.42%	0.33%
241	3.32%	4.98%	3.12%	3.12%	2.86%
242	**17.95%**	**17.08%**	**16.58%**	**16.65%**	**16.07%**
243	**16.87%**	**18.96%**	**23.76%**	**23.75%**	**23.39%**
244	0.23%	0.00%	0.00%	0.00%	0.00%
311	0.81%	0.66%	0.46%	0.50%	0.50%
312	5.69%	6.44%	2.94%	3.37%	1.69%
313	1.57%	1.61%	0.98%	1.48%	0.86%
321	5.86%	5.82%	4.88%	4.86%	0.91%
322	7.86%	4.46%	4.10%	4.03%	9.15%
323	0.18%	0.00%	0.00%	0.00%	0.00%
324	**13.45%**	**11.46%**	**20.70%**	**20.07%**	**20.75%**
334	0.35%	4.57%	0.43%	0.00%	0.00%

**Values in bold corresponding to the higher value founded.*

Table 11.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Valpaços (Source: authors).

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
111	0.00%	0.00%	0.00%	0.20%
112	0.12%	0.25%	0.02%	−0.18%
211	−2.36%	**−2.44%**	**0.00%**	−0.62%
212	0.00%	0.00%	0.00%	0.10%
221	**0.06%**	**−1.17%**	**0.01%**	**−1.51%**
222	0.46%	0.57%	**0.00%**	**3.32%**
223	**−0.18%**	**0.91%**	0.09%	0.43%
231	0.00%	−0.01%	0.00%	−0.09%

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
241	**1.66%**	**−1.86%**	0.00%	−0.26%
242	−0.87%	−0.50%	0.07%	−0.57%
243	**2.10%**	**4.80%**	**−0.01%**	−0.36%
244	−0.23%	0.00%	0.00%	0.00%
311	−0.15%	−0.20%	0.04%	0.00%
312	0.75%	−3.50%	0.42%	−1.68%
313	0.03%	−0.63%	0.50%	−0.61%
321	−0.04%	−0.94%	−0.02%	−3.95%
322	**−3.39%**	**−0.37%**	**−0.06%**	**5.11%**
323	−0.18%	0.00%	0.00%	0.00%
324	**−1.99%**	**9.24%**	**−0.63%**	**0.68%**
334	**4.23%**	**−4.15%**	**−0.43%**	0.00%
**Values in bold corresponding to Land-Use Changes - significant changes.*				

Table 12.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Valpaços (Source: authors).

In order to know what are the differences in area extension for every land use, the differences in percentage areas between years are calculated (**Table 13**).

From the information in **Table 14**, it can be seen that the four greatest differences occur for land uses (according to the land uses identified in **Table 13** - Values in bold corresponding to the higher value founded) 312 between 2000 and 2006 (decreasing),

CLC Code\Year	1990	2000	2006	2012	2018
111	0.00%	0.00%	0.00%	0.00%	0.15%
112	0.32%	0.69%	1.02%	0.95%	1.04%
121	0.00%	0.00%	0.00%	0.00%	0.00%
122	0.00%	0.00%	0.07%	1.36%	1.33%
131	0.12%	0.46%	0.85%	0.86%	0.95%
133	0.00%	0.00%	1.31%	0.00%	0.00%
211	**11.90%**	**12.01%**	9.01%	9.03%	7.45%
212	0.00%	0.00%	0.00%	0.00%	0.96%
221	0.28%	0.28%	0.29%	0.29%	0.26%
222	0.00%	0.00%	0.10%	0.21%	0.48%
231	1.69%	1.48%	1.68%	1.68%	1.55%
241	1.44%	1.67%	2.12%	2.17%	2.20%
242	5.18%	4.83%	6.28%	6.28%	5.86%
243	8.01%	8.76%	9.87%	9.91%	9.93%
244	0.72%	0.00%	0.00%	0.00%	0.00%

CLC Code\Year	1990	2000	2006	2012	2018
311	2.73%	3.05%	2.15%	2.19%	2.42%
312	**19.84%**	**18.40%**	9.81%	9.08%	7.57%
313	6.70%	4.69%	4.71%	4.75%	4.60%
321	4.39%	4.15%	2.52%	2.52%	0.48%
322	6.28%	5.85%	7.53%	7.60%	**20.01%**
323	0.88%	0.00%	0.00%	0.00%	0.00%
324	**18.87%**	**21.90%**	**29.71%**	**31.95%**	**30.41%**
332	1.22%	0.28%	0.15%	0.15%	0.15%
333	9.27%	**11.41%**	8.99%	8.86%	2.02%
334	0.15%	0.08%	1.84%	0.00%	0.00%
512	0.00%	0.00%	0.00%	0.17%	0.17%

**Values in bold corresponding to the higher value founded.*

Table 13.
Percentage difference of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Vila Pouca de Aguiar (Source: authors).

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
111	0.00%	0.00%	0.00%	0.15%
112	0.37%	0.33%	−0.07%	0.09%
121	0.00%	0.00%	0.00%	0.00%
122	0.00%	0.07%	1.29%	−0.03%
131	0.35%	0.38%	0.01%	0.09%
133	0.00%	1.31%	−1.31%	0.00%
211	**0.11%**	**−3.00%**	**0.02%**	**−1.58%**
212	0.00%	0.00%	0.00%	0.96%
221	0.00%	0.01%	0.00%	−0.03%
222	0.00%	0.10%	0.11%	0.28%
231	−0.21%	0.20%	0.00%	−0.13%
241	0.23%	0.45%	0.05%	0.04%
242	−0.35%	1.44%	0.00%	−0.41%
243	0.75%	1.11%	0.04%	0.01%
244	−0.72%	0.00%	0.00%	0.00%
311	0.32%	−0.90%	0.04%	0.24%
312	**−1.44%**	**−8.59%**	**−0.73%**	−1.51%
313	**−2.01%**	**0.02%**	0.04%	−0.15%
321	**−0.25%**	**−1.63%**	**0.00%**	**−2.04%**
322	**−0.42%**	**1.68%**	**0.07%**	**12.40%**
323	−0.88%	0.00%	0.00%	0.00%

CLC Code\Year Range	2000–1990	2006–2000	2012–2006	2018–2012
324	**3.04%**	**7.80%**	**2.25%**	**−1.54%**
332	−0.94%	−0.14%	0.00%	0.00%
333	**2.14%**	**−2.42%**	**−0.14%**	**−6.84%**
334	**−0.07%**	**1.77%**	**−1.84%**	**0.00%**
512	0.00%	0.00%	0.17%	0.00%

**Values in bold corresponding to Land-Use Changes - significant changes.*

Table 14.
Percentage of land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region – Municipality of Vila Pouca de Aguiar (Source: authors).

322 between 2012 and 2018 (growing), 324 between 2000 and 2006 (growing) and 333 between 2012 and 2018 (decreasing).

In addition, using ArcGIS 10.5 Geographic Information Systems (GIS) management software, it was possible to more accurately represent the location of each area (thematic cartography) – i.e., according to their respective CLC nomenclature and temporal variance, **Figures 16**–**20**.

The results showed a gradual Land-Use Changes related to "Agricultural areas" and "Forests and semi-natural areas". According to **Tables 4**, **6**, **8**, **10**, **12** and **14**, it seems that the increase in certain kinds of land uses such as "243 the land occupied by agriculture" and "322 moors and heathland" is compensated by the decrease of other land uses like "312 coniferous forest", "332 bare rock" and "333 sparsely vegetated áreas". Nonetheless, it is advisable to execute more exhaustive study research to know it.

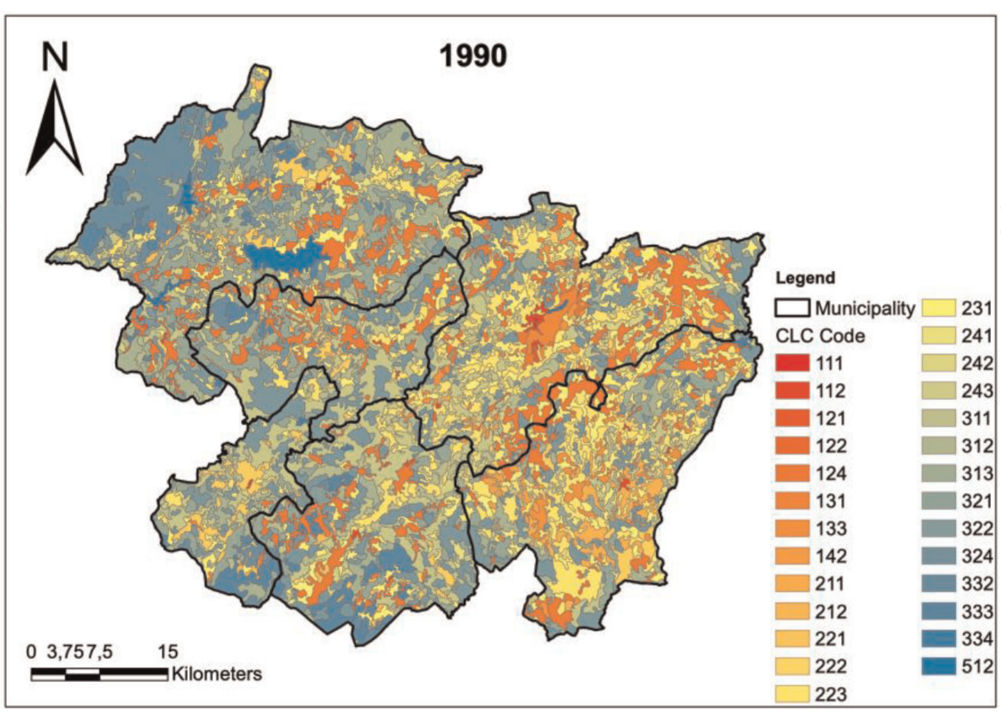

Figure 16.
Land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region in 1990 (Source: Authors by ESRI ArcGIS, 2020).

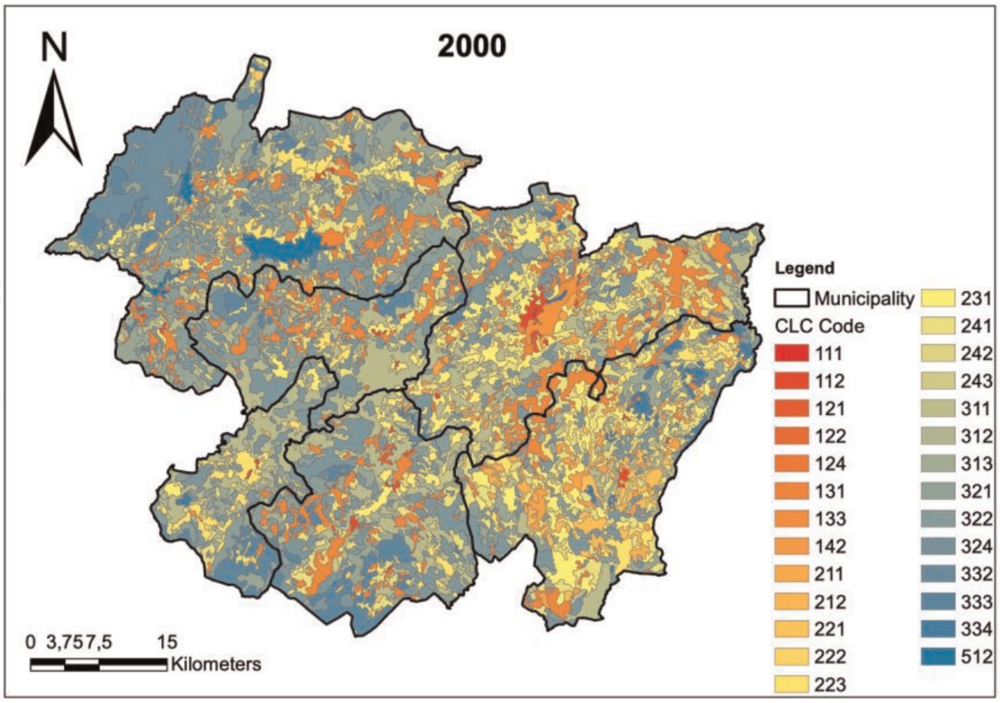

Figure 17.
Land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region in 2000 (Source: Authors by ESRI ArcGIS, 2020).

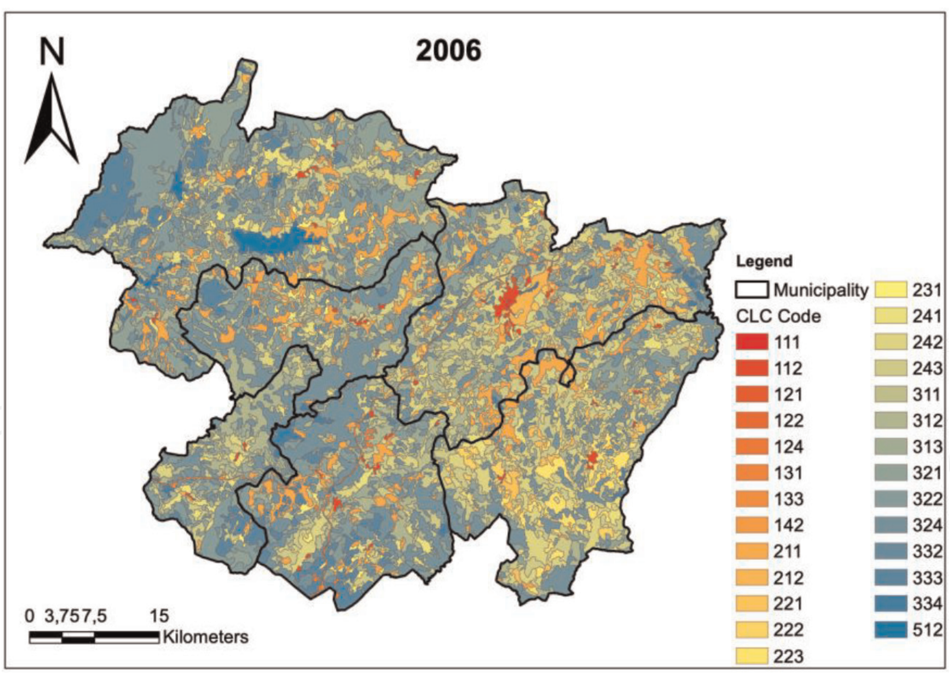

Figure 18.
Land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region in 2006 (Source: Authors by ESRI ArcGIS, 2020).

In summary, most land-use changes for the Alto Tâmega region in the years 1990, 2000, 2006, 2012 and 2018, in the Municipalities of Boticas, Chaves, Montalegre, Ribeira de Pena, Valpaços and Vila Pouca de Aguiar, according to the methodology presented (**Table 2**), namely CLC in level 1, correspond to areas related to "Agricultural areas" and "Forests and semi-natural areas".

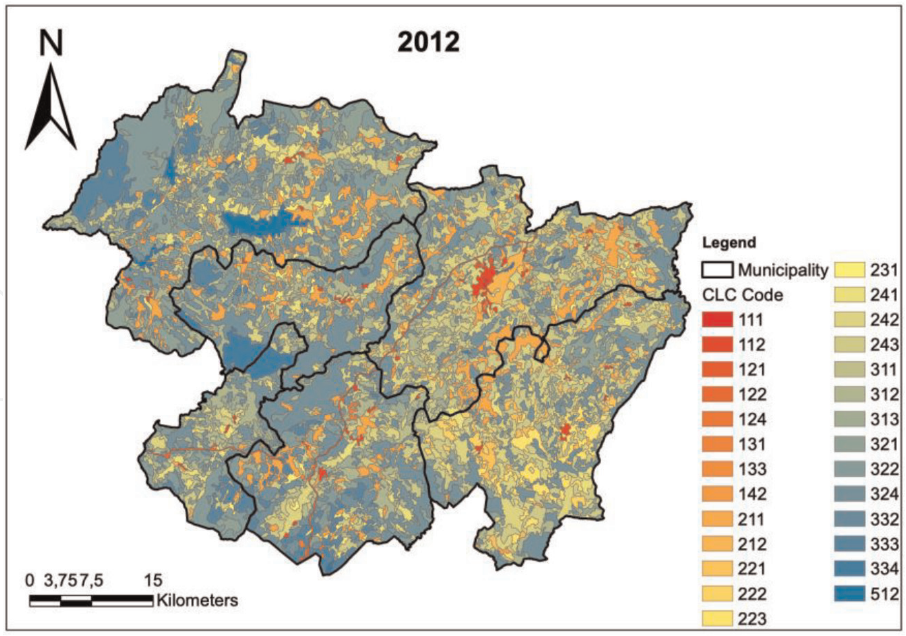

Figure 19.
Land uses according to level 3 of CLC nomenclature in the Alto Tâmega Region in 2012 (Source: Authors by ESRI ArcGIS, 2020).

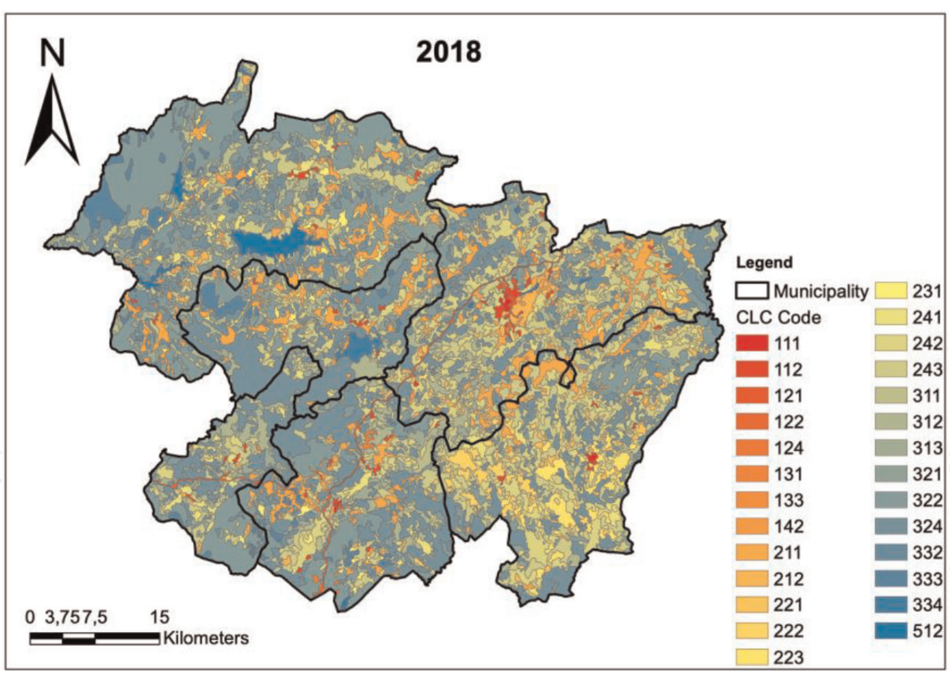

Figure 20.
Land uses according to level 3 of CLC nomenclature in the Alto Tâmega Regio in 2018 (Source: Authors by ESRI ArcGIS, 2020).

5. Discussion and conclusions

In this section, we will address the results that come from the analysis of the land-use changes for the Alto Tâmega region in the years 1990, 2000, 2006, 2012 and 2018.

Therefore, the results presented through the tables and thematic cartography, in the previous section are related to the characterization of the evolution of land use based on the 44 uses of the soil determined by CLC. So, as we are analyzing the Land-Use Changes, we will give more importance to the CORINE Land Cover nomenclature associates, not neglecting the rest.

As described earlier in the penultimate paragraph of the discussion section, and can be validated by the observation of the thematic cartography (**Figures 16–20**). Corroborating what has already been portrayed concerning the Alto Tâmega Region, namely climatology, the rural depopulation, are factors that contribute to the increase of the Land-Use Changes related to "Agricultural areas" and "Forests and semi-natural areas" [76–79].

This temporal evolution – in the Municipalities of Boticas, Chaves, Montalegre, Ribeira de Pena, Valpaços and Vila Pouca de Aguiar – has been influenced by the land tenure regime and, as expected, by the land management carried out [80].

In addition, the demographic aspects linked to these territorial units have contributed, directly or indirectly, to these agricultural and forestry changes. The valorization of the agricultural and forestry heritage of the Alto Tâmega Region should be preserved and protected in a sustainable way. So, we continue to have densely populated areas in each of the municipalities (centers), however and due to the demographic reduction, the sustainable growth of agricultural and forestry areas, do not have a relevant weight, possibly due to the lack of economic incentives towards the future owner's of these areas [80, 81].

The research of Land-Use Changes is critical for understanding regional trends and developments [82, 83]. It was feasible to discern changes in all CLC levels in the Alto Tâmega Region from 1990 to 2018 throughout this examination.

Thus, it was credible to establish that these Land-Use Changes of the Alto Tâmega Region suffered some changes, characterized by increasing and decreasing periods. Some of those decreasing values are disturbing and should have special attention by the government authorities to provide preservation and conservation of these unique Alto Tâmega landscapes and environments.

The changes in the Land-Use could be understood as a direct manifestation of human activity over natural environments [84, 85]. Therefore, the natural factors and features—i.e., geomorphology, slope, relief, soil, and vegetation, among many others— are critical for the proper organization and distribution of the territory and their consequent land uses [84]. The lack of knowledge aligned with the existence of planning conducts to the destruction of the natural resources causing a relevant (negative) impact on the local communities [86].

Therefore, the study of the Land-Use Changes is seen as pivotal to understanding the dynamics and tendencies of these territories as well as to provide clues for the main actors to where the efforts toward sustainable development and growth should be placed.

In the final remarks, the Land-Use Changes could be understood as another tool for the knowledge of the territory—assessing the past and envisioning the future.

6. Limitations of the study and future research directions

Despite all the material discussed in this chapter, regarding the dynamics, trends, and specificities related with the variations occurred within Alto Tâmega Region land-use changes, it becomes clear that there's a need for more research on this topic, in order to find new variables that will, eventually, lead to relevant findings.

Due to frequent changes, mainly in terms of policies and people's behavior in this region, it's fundamental to accurately monitor and analyse possible variations in terms of land-use. Furthermore, it's important that the data obtained from the monitoring and analysis aforementioned is also applied in sustainable development strategies.

Still, if this issue wasn't previously identified, some land-use in this region wouldn't be considered in this study because of CLC's minimum cartographic unit that was used – 25 hectares. Therefore, resorting to more recent versions of CLC that have a higher level of resolution can mostly avoid this type of problems.

Moreover, future research in this region should be able to combine cartography with aspects such as its protected natural spaces, their multiple figures, and land-use changes throughout time. Additionally, although this study's focus on barriers and opportunities regarding sustainable development in this region, to obtain more specific limitations and chances, considering all the specificities of Alto Tâmega Region, other aspects, methodologies, and prospects should be also taken into account.

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Conflict of interest

"The authors declare no conflict of interest."

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References

[1] Assumma V, Bottero M, Caprioli C, Datola G, Mondini G. Evaluation of ecosystem services in mining basins: An application in the Piedmont region (Italy). Sustainability. 2022;**14**:872. DOI: 10.3390/su14020872

[2] Yaakub NF, Masron T, Marzuki A, Soda R. GIS-based spatial correlation analysis: Sustainable development and two generations of demographic changes. Sustainability. 2022;**14**:1490. DOI: 10.3390/su14031490

[3] Zhang S, Xu M, Yang Y, Song Z. Technological innovation, production efficiency, and sustainable development: A case study from Shenzhen in China. Sustainability. 2021;**13**:10827. DOI: 10.3390/su131910827

[4] Ciegis R, Ramanauskiene J, Martinkus B. The economic conditions of enterprise functioning the concept of sustainable development and its use for sustainability scenarios. n.d.

[5] Yumashev A, Ślusarczyk B, Kondrashev S, Mikhaylov A. Global indicators of sustainable development: Evaluation of the influence of the human development index on consumption and quality of energy. Energies. 2020;**13**: 2768. DOI: 10.3390/en13112768

[6] Ranängen H, Cöster M, Isaksson R, Garvare R. From global goals and planetary boundaries to public governance—A framework for prioritizing organizational sustainability activities. Sustainability. 2018;**10**:2741. DOI: 10.3390/su10082741

[7] Purvis B, Mao Y, Robinson D. Three pillars of sustainability: in search of conceptual origins. Sustainability Science. 2019;**14**:681-695. DOI: 10.1007/s11625-018-0627-5

[8] Mensah J. Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. Cogent Social Sciences. 2019;**5**:1653531. DOI: 10.1080/23311886.2019.1653531

[9] Westin L, Hallencreutz J, Parmler J. Sustainable development as a driver for customer experience. Sustainability. 2022;**14**:3505. DOI: 10.3390/su14063505

[10] Dahlsrud A. How corporate social responsibility is defined: An analysis of 37 definitions. Corporate Social Responsibility and Environmental Management. 2008;**15**:1-13. DOI: 10.1002/csr.132

[11] Botticini F, Auzins A, Lacoere P, Lewis O, Tiboni M. Land take and value capture: Towards more efficient land use. Sustainability. 2022;**14**:778. DOI: 10.3390/su14020778

[12] Bottero MC, Polo Pérez I, Taddia G, Lo RS. A geodatabase for supporting planning and management of mining activities: the case of Piedmont Region. Environment and Earth Science. 2020; **79**:83. DOI: 10.1007/s12665-020-8815-x

[13] World Population Prospects - Population Division - United Nations. n. d. Available from: https://population.un.org/wpp/ [accessed October 17, 2022]

[14] Pilogallo A, Scorza F. Regulation and Maintenance Ecosystem Services (ReMES): A Spatial Assessment in the Basilicata Region. Southern Italy: Cham: Springer; 2021. pp. 703-716. DOI: 10.1007/978-3-030-87007-2_50

[15] Pilogallo A, Scorza F. Mapping regulation ecosystem services specialization in Italy. Journal of Urban

Planning and Development. 2022;**148**: 04021072. DOI: 10.1061/(ASCE) UP.1943-5444.0000801

[16] Pilogallo A, Scorza F. Ecosystem services multifunctionality: An analytical framework to support sustainable spatial planning in Italy. Sustainability. 2022;**14**: 3346. DOI: 10.3390/su14063346

[17] Nelson E, Sander H, Hawthorne P, Conte M, Ennaanay D, Wolny S, et al. Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. PLoS One. 2010;**5**:e14327. DOI: 10.1371/journal.pone.0014327

[18] Jukneliené D, Kazanavičiūtė V, Valčiukienė J, Atkocevičienė V, Mozgeris G. Spatiotemporal patterns of land-use changes in Lithuania. Land. 2021;**10**:619. DOI: 10.3390/land10060619

[19] Paul A. Longley, Michael F. Goodchild, David J. Maguire, David W. Rhind. Geographic Information Science and Systems, 4th Edition — New York: Wiley; WileyCom. 2015. Available from: https://www.wiley.com/en-us/Geographic+Information+Science+and+Systems%2C+4th+Edition-p-9781119031307 [accessed October 17, 2022]

[20] Stylianidis E, Karanikolas N, Kaimaris D. A GIS for urban sustainability indicators in spatial planning. International Journal of Sustainable Development and Planning. 2012;**7**:1-13. DOI: 10.2495/SDP-V7-N1-1-13

[21] Felke TP. Geographic information systems: Potential uses in social work education and practice. Journal of Evidence-Based Social Work. 2006;**3**: 103-113. DOI: 10.1300/J394v03n03_08

[22] Andreev DV. The use of GIS technology in modern conditions. IOP Conference Series: Earth and Environmental Science. 2020;**421**: 042001. DOI: 10.1088/1755-1315/421/4/042001

[23] Burrough PA. Principles of geographical information systems for land resources assessment. Geocarto International. 1986;**1**:54-54. DOI: 10.1080/10106048609354060

[24] Jachimowicz AM. Morphology of Warsaw city structure using urban indexes and GIS tools. Land. 2022;**11**:135. DOI: 10.3390/land11010135

[25] Gillespie MAK, Baude M, Biesmeijer J, Boatman N, Budge GE, Crowe A, et al. A method for the objective selection of landscape-scale study regions and sites at the national level. Methods in Ecology and Evolution. 2017;**8**:1468-1476. DOI: 10.1111/2041-210X.12779

[26] Bielecka E. GIS spatial analysis modeling for land use change. A bibliometric analysis of the intellectual base and trends. Geosciences. 2020;**10**: 421. DOI: 10.3390/geosciences10110421

[27] Mondal B, Das DN, Bhatta B. Integrating cellular automata and Markov techniques to generate urban development potential surface: A study on Kolkata agglomeration. Geocarto International. 2017;**32**:401-419. DOI: 10.1080/10106049.2016.1155656

[28] Musiaka Ł, Nalej M. Application of GIS tools in the measurement analysis of urban spatial layouts using the square grid method. ISPRS International Journal of Geo-Information. 2021;**10**:558. DOI: 10.3390/ijgi10080558

[29] Murshed SM, Duval A, Koch A, Rode P. Impact of urban morphology on energy consumption of vertical mobility in Asian cities—A comparative analysis with 3D city models. Urban Science.

2019;**3**:4. DOI: 10.3390/urbansci3010004

[30] Lousada S, Gonçalves L, Atmaca A. Hydraulic planning in insular urban territories: The Case of Madeira Island—São Vicente. Water. 2022;**14**:1-19. DOI: 10.3390/w14010112

[31] Lousada S, Cabezas J, Castanho RA, Gómez JM. Hydraulic planning in insular urban territories: The case of Madeira Island-Ribeira Brava. Water. 2021;**13**. DOI: 10.3390/w13212951

[32] Bildirici ME, Lousada S, Yılmaz Genç S. Terrorism, Freshwater, and environmental pollution: Evidence of Afghanistan, Burkina Faso, Iraq, Arab Republic of Egypt, Cameroon, Mali, Mozambique, Niger, Nigeria, Somalia, Syrian Arab Republic, and Pakistan. Water 2022;14. DOI: 10.3390/w14172684.

[33] Baig MF, Mustafa MRU, Baig I, Takaijudin HB, Zeshan MT. Assessment of land use land cover changes and future predictions using CA-ANN simulation for Selangor, Malaysia. Water. 2022;**14**:402. DOI: 10.3390/w14030402

[34] Naranjo Gómez JM, Lousada S, Garrido Velarde J, Castanho RA, Loures L. Land-use changes in the canary archipelago using the CORINE data: A retrospective analysis. Land. 2020;**9**:232. DOI: 10.3390/land9070232

[35] Bielecka E, Jenerowicz A. Intellectual structure of CORINE land cover research applications in web of science: A Europe-Wide review. Remote Sensing. 2019;**11**:2017. DOI: 10.3390/rs11172017

[36] Bielecka E, Jenerowicz A, Pokonieczny K, Borkowska S. Land Cover Changes and Flows in the Polish Baltic Coastal Zone: A Qualitative and Quantitative Approach. Remote Sensing. 2020;**12**:2088. DOI: 10.3390/rs12132088

[37] Statuto D, Cillis G, Picuno P. Analysis of the effects of agricultural land use change on rural environment and landscape through historical cartography and GIS tools. Journal of Agricultural Engineering. 2016;**47**:28-39. DOI: 10.4081/jae.2016.468

[38] CIEP – Corine. n.d. Available from: http://clc.gios.gov.pl/index.php/o-clc/program-clc [accessed October 17, 2022]

[39] Martínez-Fernández J, Ruiz-Benito P, Bonet A, Gómez C. Methodological variations in the production of CORINE land cover and consequences for long-term land cover change studies. The case of Spain. International Journal of Remote Sensing. 2019;**40**:8914-8932. DOI: 10.1080/01431161.2019.1624864

[40] Melchiorri M, Florczyk AJ, Freire S, Schiavina M, Pesaresi M, Kemper T. Unveiling 25 years of planetary urbanization with remote sensing: Perspectives from the global human settlement layer. Remote Sensing. 2018;**10**:768. DOI: 10.3390/rs10050768

[41] Washaya P, Balz T. SAR coherence change detection of urban areas affected by disasters using sentinel-1 imagery. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2018;**XLII–3**:1857-1861. DOI: 10.5194/isprs-archives-XLII-3-1857-2018

[42] Myga-Piątek U, Żemła-Siesicka A, Pukowiec-Kurda K, Sobala M, Nita J. Is there urban landscape in metropolitan areas? An unobvious answer based on Corine land cover analyses. Land. 2021;**10**:51. DOI: 10.3390/land10010051

[43] Houghton RA. The Worldwide extent of land-use change: In the last few

centuries, and particularly in the last several decades, effects of land-use change have become global. Bioscience. 1994;**44**:305-313. DOI: 10.2307/1312380

[44] Middle-range theories of land system change — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.gloenvcha.2018.08.006.

[45] Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, et al. Global consequences of land use. Science. 2005;**309**:570-574. DOI: 10.1126/science.1111772

[46] The emergence of land change science for global environmental change and sustainability. n.d. DOI: 10.1073/pnas.0704119104.

[47] Song X-P, Hansen MC, Stehman SV, Potapov PV, Tyukavina A, Vermote EF, et al. Global land change from 1982 to 2016. Nature. 2018;**560**:639-643. DOI: 10.1038/s41586-018-0411-9

[48] Peters MK, Hemp A, Appelhans T, Becker JN, Behler C, Classen A, et al. Climate–land-use interactions shape tropical mountain biodiversity and ecosystem functions. Nature. 2019;**568**:88-92. DOI: 10.1038/s41586-019-1048-z

[49] The superior effect of nature based solutions in land management for enhancing ecosystem services — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.scitotenv.2017.08.077

[50] Changes in the global value of ecosystem services — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.gloenvcha.2014.04.002

[51] Lai Y, Huang G, Chen S, Lin S, Lin W, Lyu J. Land use dynamics and optimization from 2000 to 2020 in East Guangdong Province, China. Sustainability. 2021;**13**:3473. DOI: 10.3390/su13063473

[52] Sustainability — Free full-text — Cartography and landscape of Agrarian colonisation villages in Spain during the 20th Century: Graphic recording and reconstruction of the productive territory, the case of El Chaparral (Granada) n.d. Available from: https://www.mdpi.com/2071-1050/14/7/4324 [accessed September 29, 2022]

[53] Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.landusepol.2015.08.001

[54] Heredia-R M, Torres B, Cabrera-Torres F, Torres E, Díaz-Ambrona CGH, Pappalardo SE. Land use and land cover changes in the diversity and life zone for uncontacted indigenous people: Deforestation hotspots in the Yasuní biosphere reserve, Ecuadorian Amazon. Forests. 2021;**12**:1539. DOI: 10.3390/f12111539

[55] Future scenarios based on a CA-Markov land use and land cover simulation model for a tropical humid basin in the Cerrado/Atlantic forest ecotone of Brazil — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.landusepol.2020.105141

[56] Scenarios of land use and land cover change for NW Amazonia: Impact on forest intactness — Elsevier Enhanced Reader. n.d. DOI: 10.1016/j.gecco.2019.e00567

[57] Haindongo PN, Kalumba AM, Orimoloye IR. Local people's perceptions about land use cover change (LULCC) for sustainable human wellbeing in Namibia. GeoJournal. 2022;**87**:1727-1741. DOI: 10.1007/s10708-020-10337-7

[58] Akinyemi FO. Vegetation Trends, Drought Severity and Land Use-Land Cover Change during the Growing Season in Semi-Arid Contexts. Remote Sensing. 2021;**13**:836. DOI: 10.3390/rs13050836

[59] Searchinger TD, Wirsenius S, Beringer T, Dumas P. Assessing the efficiency of changes in land use for mitigating climate change. Nature. 2018;**564**:249-253. DOI: 10.1038/s41586-018-0757-z

[60] Llerena-Montoya S, Velastegui-Montoya A, Zhirzhan-Azanza B, Herrera-Matamoros V, Adami M, de Lima A, et al. Multitemporal analysis of land use and land cover within an oil block in the Ecuadorian Amazon. ISPRS International Journal of Geo-Engineering. 2021;**10**:191. DOI: 10.3390/ijgi10030191

[61] dos Santos JYG, Montenegro SMGL, da Silva RM, Santos CAG, Quinn NW, Dantas APX, et al. Modeling the impacts of future LULC and climate change on runoff and sediment yield in a strategic basin in the Caatinga/Atlantic forest ecotone of Brazil. Catena 2021;203:105308. DOI: 10.1016/j.catena.2021.105308.

[62] Dosdogru F, Kalin L, Wang R, Yen H. Potential impacts of land use/cover and climate changes on ecologically relevant flows. Journal of Hydrology. 2020;**584**:124654. DOI: 10.1016/j.jhydrol.2020.124654

[63] Global change pressures on soils from land use and management - Smith - 2016 - Global Change Biology - Wiley Online Library. n.d. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcb.13068 [accessed October 18, 2022]

[64] Genç SY, Behradfar A, Castanho RA, Kırıkkaleli D, Gómez JMN, Loures L. Land use changes in turkish territories: Patterns, directions and socio-economic impacts on territorial management. Current World Environment: An International Research Journal of Environmental Sciences. 2021;**16**:105-122. DOI: 10.12944/CWE.16.1.11

[65] Kundzewicz ZW, Kanae S, Seneviratne SI, Handmer J, Nicholls N, Peduzzi P, et al. Flood risk and climate change: Global and regional perspectives. Hydrological Sciences Journal. 2014;**59**:1-28. DOI: 10.1080/02626667.2013.857411

[66] Armaş I. Social vulnerability and seismic risk perception. Case study: The historic center of the Bucharest Municipality/Romania. Natural Hazards. 2008;**47**:397-410. DOI: 10.1007/s11069-008-9229-3

[67] Barichivich J, Gloor E, Peylin P, Brienen RJW, Schöngart J, Espinoza JC, et al. Recent intensification of Amazon flooding extremes driven by strengthened Walker circulation. Science Advances. 2018;**4**:eaat8785. DOI: 10.1126/sciadv.aat8785

[68] Vieira I, Barreto V, Figueira C, Lousada S, Prada S. The use of detention basins to reduce flash flood hazard in small and steep volcanic watersheds – A simulation from Madeira Island. Journal of Flood Risk Management. 2018;**11**:S930-S942. DOI: 10.1111/jfr3.12285

[69] INE - Plataforma de divulgação dos Censos 2021 – Resultados Provisórios. n.d. Available from: https://www.ine.pt/scripts/db_censos_2021.html [accessed September 28, 2022]

[70] Caracterização – CIM Alto Tâmega. n.d. Available from: https://cimat.pt/caracterizacao/ [accessed September 28, 2022]

[71] A Região – Visit Alto Tâmega. n.d. Available from: https://visitaltotamega.com/a-regiao/ [accessed October 19, 2022]

[72] Rodrigues E, João F, Mendes L. Desenvolvimento Turístico na CIM Alto Tâmega "Ecomuseu do Barroso". Seia: Polytechnic Institute of Guarda – ESTH. 2018.

[73] Tâmega A. Wikipédia Enciclopédia Livre. 2022

[74] Caracterização – AMAT. n.d. Available from: https://www.amat.pt/caracterizacao/ [accessed October 20, 2022]

[75] CORINE Land Cover — European Environment Agency. n.d. Available from: https://www.eea.europa.eu/publications/COR0-landcover [accessed April 28, 2022]

[76] López-Rodríguez G, Rodríguez-Vicente V, Marey-Pérez MF. Study of Forest Productivity in the Occurrence of Forest Fires in Galicia (Spain). Sustainability. 2021;**13**:8472. DOI: 10.3390/su13158472

[77] Chas-Amil M-L, García-Martínez E, Touza J. Iberian Peninsula October 2017 wildfires: Burned area and population exposure in Galicia (NW of Spain). International Journal of Disaster Risk Reduction. 2020;**48**:101623. DOI: 10.1016/j.ijdrr.2020.101623

[78] de Diego J, Rúa A, Fernández M. Designing a model to display the relation between social vulnerability and anthropogenic risk of Wildfires in Galicia, Spain. Urban Science. 2019;**3**:32. DOI: 10.3390/urbansci3010032

[79] Alexandre Castanho R, Lousada S, Manuel Naranjo Gómez J, Escórcio P, Cabezas J, Fernández-Pozo L, et al. . In: Carlos Loures L, editor. Dynamics of the land use changes and the associated barriers and opportunities for sustainable development on peripheral and insular territories: The Madeira Island (Portugal), Land Use - Assess. Past Envisioning Future. London: IntechOpen; 2019. DOI: 10.5772/intechopen.80827

[80] Marey Pérez M, Rodríguez Vicente V, Crecente MR. Using GIS to measure changes in the temporal and spatial dynamics of forestland: experiences from north-west Spain. Forestry: An International Journal of Forest Research. 2006;**79**:409-423. DOI: 10.1093/forestry/cpl027

[81] Marey-Pérez M, Díaz-Varela E, Calvo-González A. Does higher owner participation increase conflicts over common land? An analysis of communal forests in Galicia (Spain). iForest - Biogeosciences and Forestry. 2015;**8**: 533-543. DOI: 10.3832/ifor1060-008

[82] Gómez N, Manuel J. Impacts on the social cohesion of mainland Spain's future motorway and high-speed rail networks. Sustainability. 2016;**8**:624. DOI: 10.3390/su8070624

[83] Vulevic A, Castanho RA, Naranjo Gómez JM, Loures L, Cabezas J, Fernández-Pozo L, et al. Accessibility dynamics and regional cross-border cooperation (CBC) perspectives in the Portuguese—Spanish borderland. Sustainability. 2020;**12**:1978. DOI: 10.3390/su12051978

[84] Gao P, Niu X, Wang B, Zheng YL. Land use changes and its driving forces in hilly ecological restoration area based on gis and rs of northern china. Scientific Reports. 2015;**5**:11038. DOI: 10.1038/srep11038

[85] Bertrand N, Vanpeene-Bruhier S. Periurban landscapes in mountain areas. Journal of Alpine Research - Revue de Géographie Alpine. 2007:69-80. DOI: 10.4000/rga.363

[86] Loures L. Land Use: Assessing the Past, Envisioning the Future. BoD – Books on Demand. London: IntechOpen Limited; 2019