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Reducing Rural Fire Risk through the Development of a Sustainable Supply Chain Model for Residual Agroforestry Biomass Supported in a Web Platform: A Case Study in Portugal Central Region with the Project BioAgroFloRes

Margarida Casau [1,2], Marta Ferreira Dias [1,2], Leonor Teixeira [1,3], João C. O. Matias [1,2] and Leonel J. R. Nunes [1,2,4,5,*]

[1] Departamento de Economia, Gestão, Engenharia Industrial e Turismo, Campus Universitário de Santiago, Universidade de Aveiro, 3810-193 Aveiro, Portugal; amcasau@ua.pt (M.C.); mfdias@ua.pt (M.F.D.); lteixeira@ua.pt (L.T.); jmatias@ua.pt (J.C.O.M.)
[2] GOVCOPP, Unidade de Investigação em Governança, Competitividade e Políticas Públicas, Campus Universitário de Santiago, Universidade de Aveiro, 3810-193 Aveiro, Portugal
[3] Instituto de Engenharia Eletrónica e Informática de Aveiro, Campus Universitário de Santiago, Universidade de Aveiro, 3810-193 Aveiro, Portugal
[4] PROMETHEUS, Unidade de Investigação em Materiais, Energia e Ambiente Para a Sustentabilidade, Escola Superior Agrária, Instituto Politécnico de Viana do Castelo, Rua da Escola Industrial e Comercial de Nun'Alvares, 4900-347 Viana do Castelo, Portugal
[5] Centro de Estudos Florestais, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
* Correspondence: leonelnunes@esa.ipvc.pt

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Abstract: In the European Mediterranean region, rural fires are a widely known problem that cause serious socio-economic losses and undesirable environmental consequences, including the loss of lives, infrastructures, cultural heritage, and ecosystem services such as carbon sequestration and the provisioning of raw materials. In the last decades, the collapse of the traditional rural socioeconomic systems that once characterized the Mediterranean region, along with land-use changes, have created conflicts and additional driving factors for rural fires. Within Europe, Portugal is the most affected country by rural fires. This work intends to demonstrate the importance of recovering and valorizing residual agroforestry biomass to reduce rural fire risk in Portugal, and thus contributing to a fire resilient landscape. From the results of the known causes of fires in Portugal, it becomes very clear that it is crucial to educate people to end risky behaviors, such as the burning of agroforestry leftovers that causes 27% of fires in Portugal each year. The valorization of the existing energy potential in the lignocellulosic biomass of agroforestry residues favors the reduction of the probability of rural fires, this being the focus of the project BioAgroFloRes—Sustainable Supply Chain Model for Residual Agroforestry Biomass supported in a Web Platform—introduced and explained here.

Keywords: rural fires; biomass energy; residual biomass; fire risk reduction; biomass recovery; web platform

1. Introduction

In the Southern European region, rural fires are a widely known problem causing socio-economic losses and undesirable environmental consequences, including loss of lives, infrastructures, cultural heritage, and ecosystem services [1,2]. Different authors point out to the fact that rural fires have been increasing in extent and severity over the last decades [3–5]. Natural rural fires are important for the ecosystems since they are responsible for renewing the vegetation and recycling available nutrients [6]. However, in the last decades, rural fires have become larger and more severe, causing profound changes in the structural and functional processes of ecosystems [7,8].

In recent years, weather conditions have become the warmest on record, impacting many countries [9]. Historically, increased temperatures create the perfect scenario for extreme fires, as demonstrated by the events in Portugal in 2017, and more recently in Australia and California [7,10,11]. Climate change impacts rural fire regimes in different ways such as longer fire seasons and newly vulnerable ecosystems, such as occurring in Central and Northern Europe [12,13]. New potentially catastrophic fire regimes are emerging from these dynamics, while impacts become harder to predict once fire regime changes have occurred [14]. In fact, megafires (fires burning areas higher than 10,000 ha) have been affecting some European countries, namely, Portugal [7,15]. The capacity of the countries to control these megafires can be considered a challenge, as stated by Oliveira et al. regarding Portugal, which registered 1,158,175 ha of burnt area between 2010 and 2017, representing a cumulative loss of 37% of the total forest area, with the northern and central regions being the most affected areas [7]. Despite climate change being associated with the increase in the number of fires and their intensity by several authors, it is also of great importance to understand that although climatic and meteorological parameters are key elements in the occurrence of fires, these factors do not totally justify the increase in the burnt area registered in recent years in Portugal [8,16,17].

Changes associated with demography and land use, namely, the rural exodus that is occurring since a few decades ago, changed the landscape, with the abandonment of the agro-silvo-pastoral activity, contributing to the accumulation of large amounts of biomass likely to burn when weather conditions are favorable [14,18,19]. Since the climate and the weather cannot be controlled, the root causes of fires and other factors associated with demography and land use must be addressed [20,21]. In fact, many studies suggest that the increasing incidence and impact of fires in Mediterranean environments can be mainly attributed to the decline in the landscape mosaic that has historically characterized Mediterranean rural areas [22–25].

According to Wunder et al., in the European Mediterranean region, around two thirds of all fires are originated in agricultural practices, since farmers still use fire to remove crop residues or rejuvenate pastures [14]. In Portugal, the misuse of fire and negligent attitudes towards it, mainly associated with the burning of leftovers resulting from agricultural activity or forestry operations, are the leading causes behind rural fires [3]. Agroforestry residuals are currently dealt with through burning because there is not a market and functioning supply chain for the biomass. This burning reduces fuels in rural environments but also causes many wildfires. As stated by Nunes et al., the data made available by ICNF (Instituto da Conservação da Natureza e das Florestas) show that up to 27% of fires, of a total of 41% attributed to all negligent causes, were caused by this misuse of fire in 2020. This scenario remains in line with the data available for the 2010–2019 decade [3]. This traditional use of fire to dispose of waste materials from agriculture and forestry practices, eliminating leftovers, contribute to increase the risk of fire occurrence but also present an opportunity for new options to manage agroforestry residues [26–28]. In this same line, Wunder et al. stated that instead of reinforcing the efforts in fire suppression-centered strategies, the author defends the idea that it is of utmost importance to develop new approaches that shift emphasis towards the root causes of fires, along the entire risk management cycle of prevention, preparedness, response, and recovery [14]. Reducing the risk of occurrence of rural fires can be analyzed from several perspectives. For example, Martin et al. analyzed the risk of rural fires from the perspective of the factors influencing the reduction in risk behaviors on the part of populations that inhabit rural areas, with the authors concluding that populations often do not have a direct perception of how their traditional practices influence rural fire risk and what mitigation practices they should adopt [29]. BrenKert-Smith et al., on the other hand, in their analysis of the behavior of rural populations regarding the risk of rural fires occurrence, concluded that these populations, when they perceive high levels of risk, tend to acquire behaviors to mitigate this risk [30], that is, strengthening the biomass marketplace through improved supply chain management. This should replace the fuel reduction efforts of current burning practices while reducing rural ignition sources.

Mitigating the risk of rural fires is so crucial in Portugal that the Fundação para a Ciência e Tecnologia (FCT), which is the government institute that selects and finances scientific research projects, launched a call for funding scientific research and technological development projects in the field of fire prevention, with 10 of the 56 projects focusing on rural biomass utilization. The project BioAgroFlores—Sustainable Model for the Management of the Residual Agro-Forest Biomass Supply Chain supported on a Web Platform—falls within the subject area of Biomass Management and Enhancement projects in rural areas. This project is unique in that it would both reduce biomass in rural environments and the risky burning practices of rural industries that start many rural fires. In other words, the reduction in risk is not based solely on removing the fuel load but essentially on the reduction in/elimination of the burning of leftovers, traditionally used by forestry operators and farmers to eliminate the residues resulting from their activity, which is one of the main causes of rural fire ignition in Portugal. Thus, this article is intended to show the importance of recovering residual agroforestry biomass, to reduce the risk of rural fires in Portugal and thus contribute to a more fire resilient landscape. It is intended to explore the project BioAgroFloRes, currently in development. This platform will promote the collection and recovery of agroforestry residual biomass and contribute to reducing rural fire risk in the central region of Portugal. The region was chosen for having the most important forest area in the country and the most severely punished yearly by rural fires. At the same time, it is intended to contribute to creating new value chains for residual agroforestry materials from a biocircular economy perspective.

2. Materials and Methods

2.1. Area under Study

Portugal is a southern European state, covering a total area of 92,225 km^2. Mainland Portugal (89,102 km^2) is located on the Iberian Peninsula, in the extreme Southwest of Europe, bordering Spain to the North and East and the Atlantic Ocean to the West and South. The Portuguese territory also includes two autonomous regions, in the archipelagos of Madeira (801 km^2) and the Azores (2322 km^2), located in the Atlantic Ocean, which were not included in this study. Despite its modest land area, the physical environment significantly varies all over the territory regarding mainland Portugal. The northwest landscape is mountainous and is characterized by the abundance of water and fertile soils, and the property is structured around the minifundium. In the southern region, open rolling plains and smooth hills characterize the relief, with water scarcity, poor soils, and agriculture developed in a latifundium structure.

In terms of territorial organization, the Portuguese government uses the NUTS system (Nomenclature of Territorial Units for Statistics), which subdivides the economic territory of the European Union into three different levels, NUTS I, II, and III regions moving from larger to smaller territorial units, respectively. Currently, the 308 municipalities in Portugal are grouped into 25 NUTS III, 7 NUTS II, and 3 NUTS I regions, as shown in Figure 1. As observed in other European countries, significant demographic and socio-economic changes have also affected the Portuguese rural areas over the last decades, mainly related to population loss. As shown in Table 1, the population variation shows a negative trend, indicating the active population decreased in most of the NUTS III regions in mainland Portugal, primarily associated with rural population decline and the increase in urban populations.

The exodus of the Portuguese rural population can be explained by many factors, such as a lack of employment options; uncompetitive farm structures, characterized by small plots; remoteness of the centers of consumption and services; and encouragement by the European Union of Common Agrarian Policy (CAP) to withdraw agriculture activity, especially cereal crops, through the payment of subsidies [31]. Exception can be highlighted for the northernmost regions and the southernmost regions of the country, namely, Alentejo

Central and Algarve. The central region has a mixed trend, with some NUTS III regions growing. In contrast, others decrease in population, most likely due to regional migration, with populations originating from NUTS III regions, such as Viseu Dão Lafões, Beira Baixa, or Médio Tejo, looking for better living conditions in NUTS III regions, such as Oeste, Coimbra, or Beiras e Serra da Estrela. From the point of view of the Aging Index, in the last 40 years, there has been generalized ageing of the population in all regions, and even the external migratory flows coming from the PALOPs (African Countries of Portuguese Language), Eastern Europe, Southeast Asia, and South America have not managed to counteract it. The agricultural area decreased in all NUTS III regions, except those included in the Alentejo (NUTS II region). Even here, the Alentejo Central region decreased. In the central region of the country, Viseu Dão Lafões is the only one that grows in terms of population in the area. If, in the case of Alentejo, the growth of the agricultural area is related to the increase in the areas of intensive and super-intensive production of almond and olive groves. In the case of the Viseu Dão Lafões region, the growth of the agricultural area is related to the increase in vineyard area. Regarding the evolution of the forest area for the years 2005 and 2015 (which corresponds to the most recent data provided by the IFN6), there is a stabilization since the differences verified in the total area for each NUTS II region are not significant. In the northern region an increase of 185 km^2 is verified; in the central region, there is an increase of 114 km^2; in the Área Metropilotana de Lisboa, there is a decrease of 7 km^2; in Alentejo, there is a decrease of 198 km^2; and in Algarve, there is an increase of 29 km^2.

All these factors contributed to the abandonment of large areas of land, which is covered mostly by shrubs and herbaceous vegetation, which are favorable to fire occurrence. In 2015, Portugal had 3305 Mha of forest land, 2241 Mha of agriculture land, and 2818 Mha of shrubs and pastureland. Water, urban area, and unproductive land account for the remaining 859 Mha. The 35.8% of forest area places Portugal within the average of the 28 EU countries (38.3%). According to the IFN6, the national forest is mostly constituted by indigenous forest species (72%). In structural, functional, and landscape terms, the forest can be organized into four major groups: pine and other softwood forests; evergreen hardwood forests; deciduous hardwood forests; industrial productive hardwood forests; and other species [32].

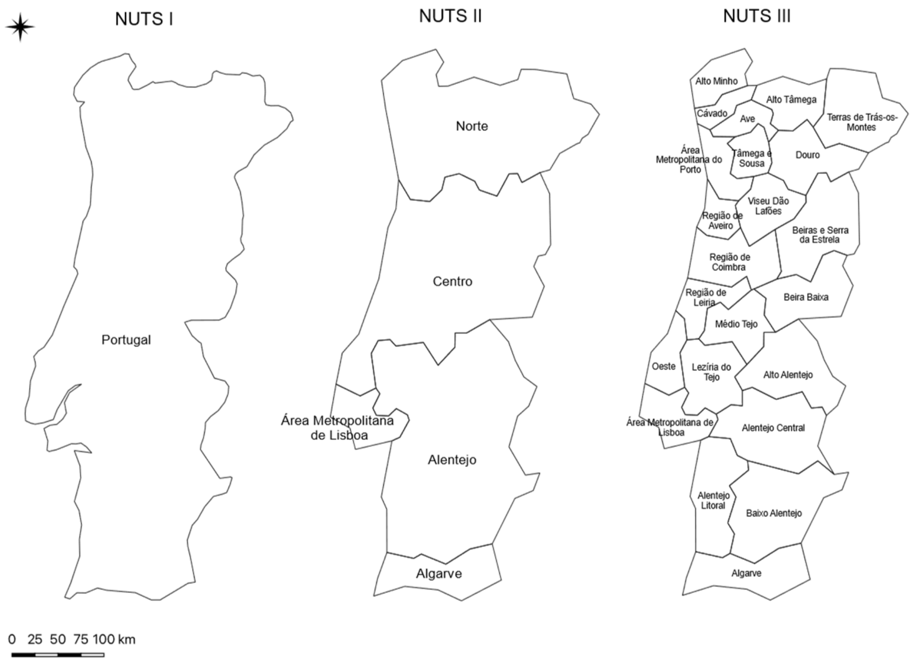

Figure 1. Mainland Portugal NUTS subdivision.

Table 1. Demography and land use characteristics of the sub-regions of Portugal (Portugal mainland NUTS III, where PV is the Population Variation; DP is the Density of Population; AI is the Ageing Index; AA is the Agriculture Area; and FA is the Portugal mainland NUTS II Forest Area).

NUTS III	Demography				Land Use			
	PV	DP	AI		AA		FA	
	1981–2020	2020	1981	2021	1989	2019	2005	2015
	(%)	(Inhab./km^2)	(%)	(%)	(ha)	(ha)	(km^2)	(km^2)
Alto Minho	−11.2	103.2	51.7	252	87,077	70,898	5664	5849
Cávado	21.6	324.2	27	146.5	43,719	29,554		
Ave	10.6	282.6	26.3	167.3	53,414	40,419		
Área Metropolitana do Porto	13.1	846.4	32.1	174.7	45,143	No data		
Alto Tâmega	−35	29.3	43.4	383.9	105,485	No data		
Tâmega e Sousa	3.4	225.8	28.2	149.5	56,640	No data		
Douro	−27.5	47.1	44.4	274.4	147,687	No data		
Terras de Trás-os-Montes	16.2	163.2	51.9	185.4	106,495	69,416		
Oeste	15.1	216.9	41.7	185.6	36,963	21,492	10,817	10,931
Região de Aveiro	−7	100.5	60.6	243.9	80,120	44,272		
Região de Coimbra	9.1	117.1	46.2	201.7	37,297	24,568		
Região de Leiria	−11.4	78	53.1	246.3	76,882	39,516		
Viseu Dão Lafões	−26	17.3	108.1	330.9	155,389	164,985		
Beira Baixa	−12.4	69.8	69.1	253.8	67,862	48,136		
Médio Tejo	−26.4	33.5	75.7	337.9	266,232	220,914		
Beiras e Serra da Estrela	15	951.5	41.4	150.9	97,243	90,733		
Área Metropolitana de Lisboa	−9.9	17.5	66.9	223.5	267,172	318,161	670	663
Alentejo Litoral	−27.6	13.5	79.1	217.9	586,063	698,507	13,544	13,346
Baixo Alentejo	1	55.4	61.1	199.6	186,236	206,666		
Lezíria do Tejo	−27.8	17	93.3	253.6	419,671	473,272		
Alto Alentejo	−16.5	20.4	71.8	224.1	580,222	654,126		
Alentejo Central	35.1	87.7	75.2	176.7	136,779	100,605		
Algarve	35.1	87.7	75.2	176.7	136,779	100,605	1424	1453

2.2. Data Acquisition

For the present work, different database sources were used, all available on the internet:

- ICNF (https://www.icnf.pt/, accessed on 15 February 2022)—Instituto de Conservação da Natureza e das Florestas—provides a data bank (http://www.icnf.pt/portal/florestas/dfci/estatisticas, accessed on 15 February 2022) regarding all fires that have occurred in Portugal, from 1980 until 2015, but it is only from 2001 that the tables have more detailed information. Each record contains certain relevant information, such as geographic location, date, burned area in hectares and cause of the ignition, reported when the fire was investigated by the competent authorities. Since 2001, this Institute releases an annual report regarding the Portuguese forest fires.
- PORDATA (https://www.pordata.pt, accessed on 15 February 2022) is a statistical database that collects, compiles, systematizes, and disseminates data on multiple areas of society for Portugal and its municipalities, namely, demographic and socioeconomic information.
- INE (https://www.ine.pt, accessed on 15 February 2022)—Instituto Nacional de Estatística, is the national statistical survey, namely, concerning demographic and socioeconomic information.

3. Results

3.1. The European Context

As stated previously, the wildfire occurrence in the Mediterranean region is a well-known problem. A comparative analysis of the most affected southern countries of this region (Spain, France, Greece, Italy, and Portugal) should be considered. As presented in Table 2, Portugal is the smallest of this group. It is therefore surprising that the burnt area is so significant (Figure 2).

Table 2. Comparative Southern European countries area (adapted from http://www.pordata.pt, accessed on 14 December 2021).

Country	Spain	France	Greece	Italy	Portugal
Area (km^2)	505,983	638,475	131,694	302,073	92,227

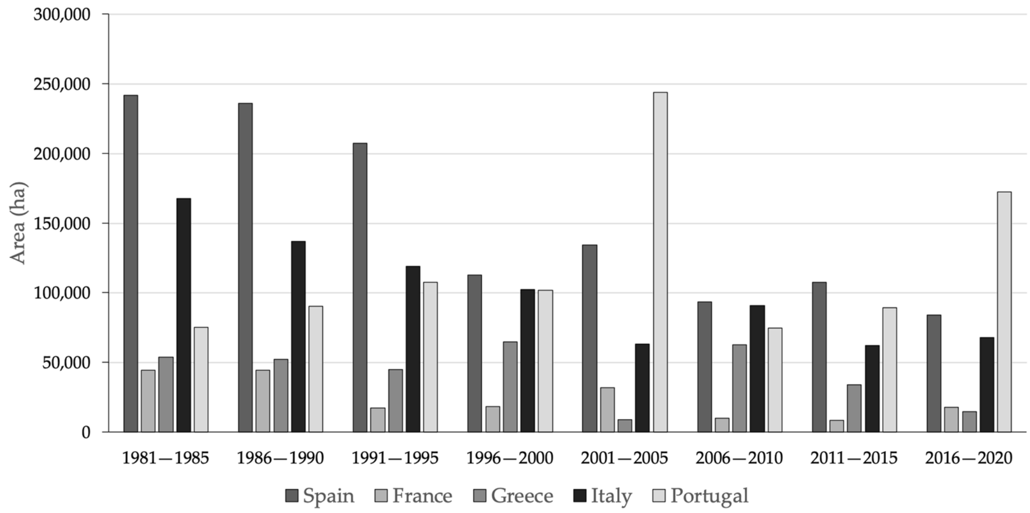

Figure 2. Average burnt area (hectares) per five-year period in five southern European countries (adapted from http://www.pordata.pt, accessed on 14 December 2021).

It is possible to observe a decreasing trend in the average burnt area from 1981 until 2020 in Spain, France, Greece, and Italy. On the contrary, in Portugal, an almost continuous increase in the average burnt area within each subsequent five-year period can be observed, mainly caused in 2001–2005 and 2016 to 2020.

3.2. The Portuguese Situation

Although the statistics show that the average burnt area in Europe decreased in the last 35 years, Portugal presents the opposite trend, being the European country more affected by rural fires, with countless ecological, social, and economic losses [33]. The problem related to wildfires in Portugal has evolved very rapidly over the last decades. According to Félix and Lourenço, until the 1970s, large forest fires were considered to be all those whose burned area was equal to or greater than 10 hectares, while nowadays, to be considered large, a forest fire must have 50 times more burned area [19]. Over time, the Portuguese population has become used to the occurrence of wildfires, while at the same time, the public policies seem to have no real effect on reducing the problem. The yearly burnt area shows a high annual variability, reaching maximum levels in the years 2003, 2005, and 2017, when the total burned area reached 471,750 ha, 346,718 ha, and 539,921 ha, respectively. Between 1980 and 2020, there was an average of 19,202 forest fires per year, corresponding to 117,433 hectares of burnt area per year, but looking to the last decade (2011–2020), this average increases up to 130,706 ha.

Considering the type of land cover burnt, from 2011 to 2020, an average of 63,809 ha (49%) corresponded to forest stands, 58,004 ha (44%) corresponded to bushes and natural pastures, while 8893 ha (7%) corresponded to agricultural land. Maritime pine and eucalyptus are the species which have suffered most severely, corresponding to 83% of the area of forest burnt in the aforementioned period. This situation has been contributing, in mainland Portugal, to a sharp reduction in the area of maritime pine (273,700 ha less between

1995 and 2015) and to an increase in the area of bushes (226,600 ha), according to data of the IFN6 (6th National Forest Inventory, released in 2019). On the other hand, the agriculture area lost 314,400 ha within the same period and according to the same inventory.

Another important aspect to consider is the distribution of fires within the different regions of Portugal. Figure 3 presents the distribution of burnt area according to the NUTS II subdivision in mainland Portugal. On average, between 2001 and 2020, the north and center regions of Portugal were responsible for 43% and 39% of the total burnt area in mainland Portugal, respectively. Although the north and center regions account for 81% of the fires in mainland Portugal, these subregions occupy only 55% of the territory.

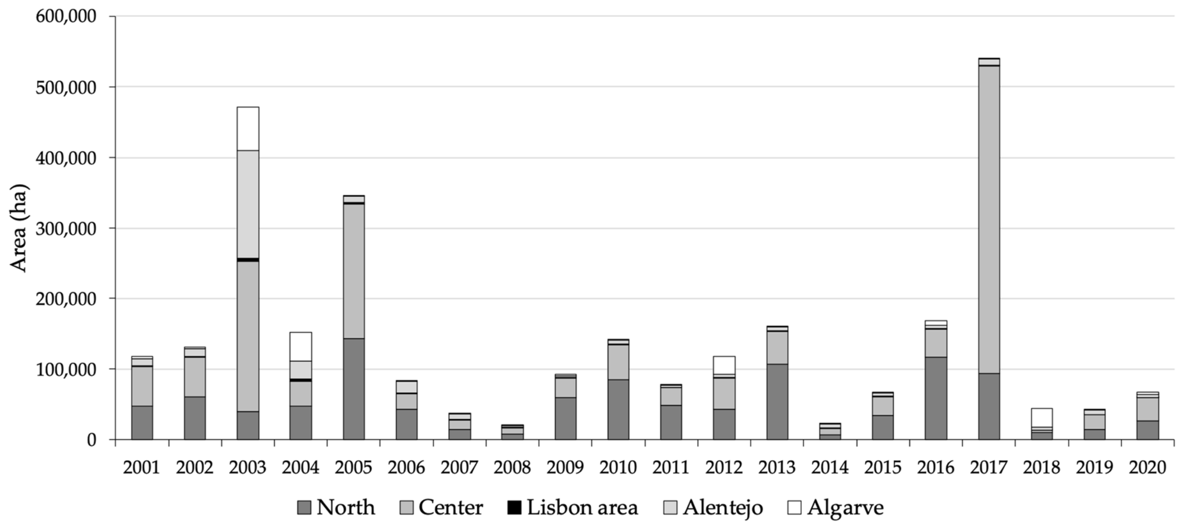

Figure 3. Distribution of burnt area according to the NUTS II subdivision in mainland Portugal (adapted from http://www.ine.pt, accessed on 14 December 2021).

3.3. Causes of Rural Fires

ICNF lists the causes of rural fires in five categories: intentional (incendiarism and arson, mainly resulting from behaviors and attitudes reacting to the constraints of agro-forestry management systems and conflicts related to land use), neglectful (the misguided use of fire in activities such as burning trash, mass burning of agricultural and forest fuels, fun and leisure activities; failure to extinguish cigarettes by smokers properly; the dispersal and transport of incandescent particles from chimneys, among others); unknown (absence of sufficient objective evidence to determine the cause of the ignition); natural (lightning generated in thunderstorms); and reactivations (burning of an area over which a fire has previously passed, but where fuel has been left that is later ignited by latent heat, sparks, or embers). As shown in Figure 4, the causes of rural fires in Portugal are mainly anthropogenic.

Efforts have been made to identify the causes of fires within the last years. However, only a small proportion of fires were investigated to identify their causes prior to 2007. From 2016 and onward, the ICNF has ceased to provide such detailed information in the form of Excel spreadsheets, but the data on each fire are available through their GIS platform (https://geocatalogo.icnf.pt/websig/, accessed on 12 January 2022), but there is not information regarding the specific causes for each fire. However, the global percentages can be seen in the Annual Rural Fires Report (http://www2.icnf.pt/portal/florestas/dfci/relat/rel-if, accessed on 12 January 2022). Within the accidental causes, "*transports and communication*" and "*machinery use*" are included, while the category "*fire use*" includes "*extensive fires for pasture management*", "*extensive fires of agroforestry wastes*", "*burning of piles of agroforestry wastes*", "*garbage burns*", and "*making bonfires*". On average, from 2011 until 2020, within the successfully investigated causes, the use of fire was responsible for 40.1%. The use of fire to dispose agroforestry waste represents 27% of the ignitions occurred in the same period.

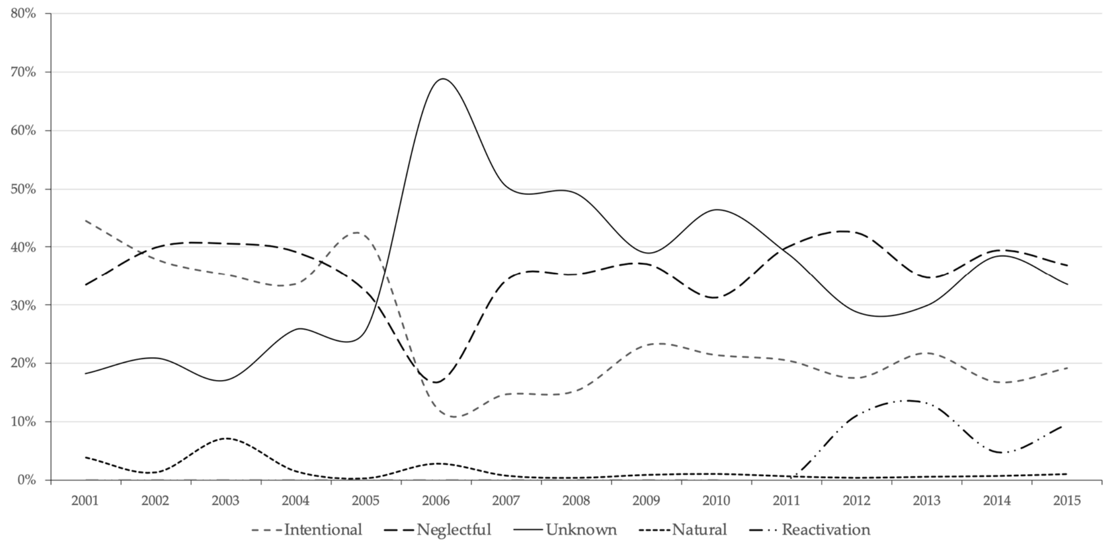

Figure 4. Causes of rural fires in Portugal between 2001 and 2015 (adapted from http://www.icnf.pt/, accessed on 12 January 2022).

3.4. Biomass

Biomass is the oldest energy source that humans have used since the discovery of fire. In 1850, biomass represented 85% of the energy consumption worldwide and before then was practically the only source used, other than wind (e.g., for sailing and windmills), domesticated animals, and small amounts of coal for heating. There are many biomass energy sources, with wood and wood waste being the most important. The National Forestry Inventory (IFN), in addition to evaluating the areas occupied by the forest and its species, also presents statistics on biomass production, which are fundamental for planning and regulating the exploitation of this resource. According to the IFN6, in 2015, Portugal had 172 Mm^3 of wood growing, an identical result to what was found in the IFN5 (2005), showing a balance, with woodcuts and losses due to fires or pests being compensated by the growth of the forest. However, the IFN6 characterizes the state of the forest in 2015, which is different from its current situation in 2022, especially considering the consequence of the severe rural fires of 2017 and 2018. Table 3 displays the total volume (including growing and dead biomass) by species in mainland Portugal and the central region.

Table 3. Total existing volume by species, in mainland Portugal, in 2015 (adapted from http://www.icnf.pt, accessed on 18 December 2021).

Species	Total Volume (Mm^3)	
	Mainland Portugal	**Portugal Central Region**
Maritime pine	68.06	43.99
Eucalyptus	43.78	24.39
Cork oak	25.76	2.14
Holm oak	7.08	0.4
Oaks	5.78	1.94
Stone pine	5.25	0.87
Chestnut	3.22	0.56
Carob tree	0.2	-
Acacias	2.07	1.07
Other hardwoods	9.08	4.03
Other softwoods	5.39	2.06

The analysis of the data regarding the estimation of agroforestry biomass is very important, since the on-site burning of these wastes is one of the main causes of fires in Portugal. This means that there is a real potential for fire risk reduction if solutions for collecting, distributing, and valorizing residual agroforestry biomass are implemented. This way, the solution presented by the project BioAgroFloRes, which can contribute to reduce the risk of rural fire occurrence. The project intends to develop an operational solution to increase the efficiency and effectiveness of the residual agroforestry biomass (RAFB) supply chain. The logistic costs, the low heating value, and the lack of collaboration among entities can inhibit the RAFB valorization as a natural resource and hold back the disposal of these wastes. The web platform will enable the contact between all stakeholders and subsequently will present optimized suggestions to the necessary logistics operations in the central region of Portugal (NUTS II). In this way, a platform that promotes the information management between all the actors involved in the supply chain, bringing supply and demand needs closer together may be a solution. Thus, Figure 5 presents the operational framework of the web-based platform.

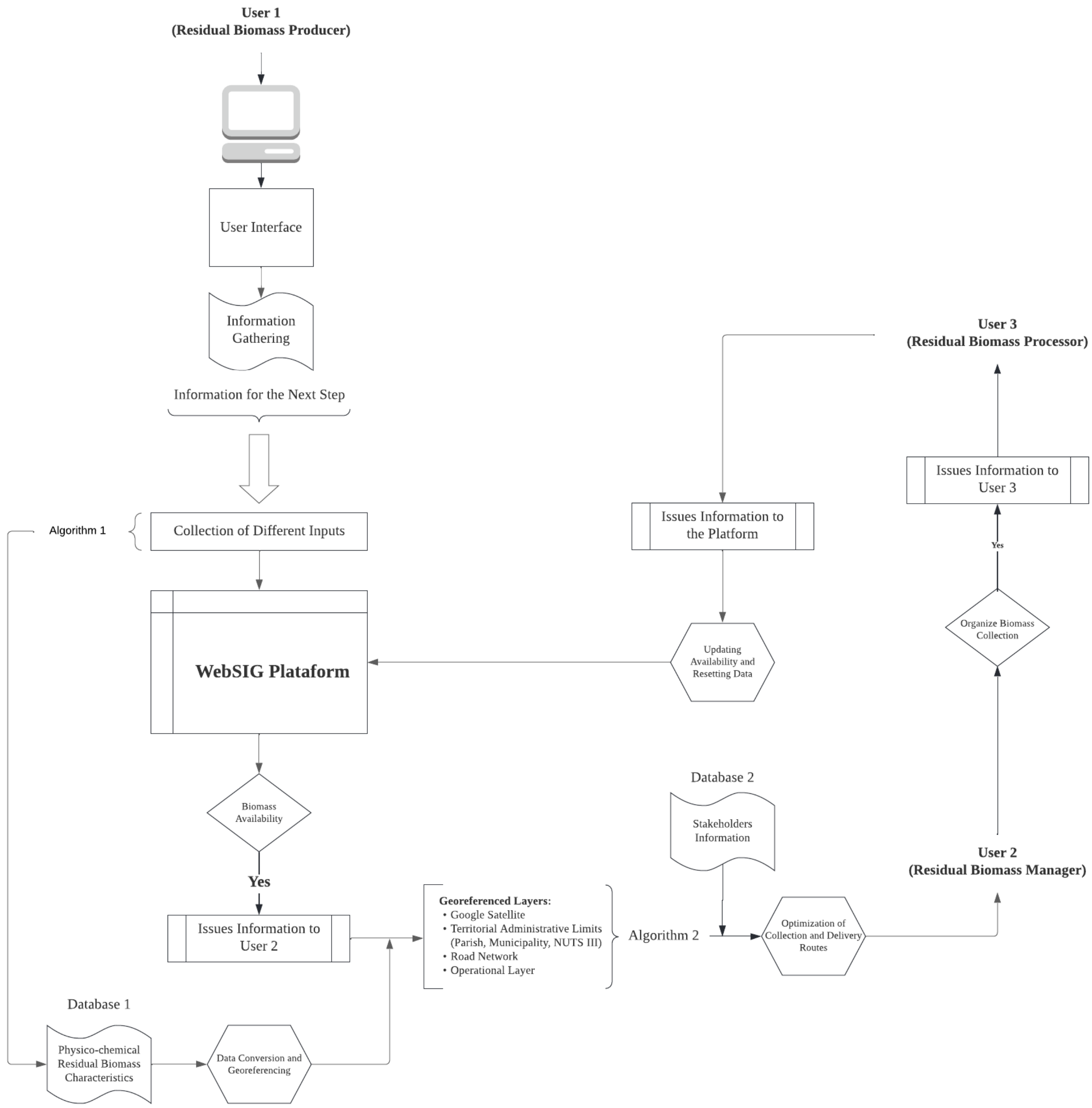

Figure 5. Operational framework of the residual biomass management platform to support the BioAgroFloRes project.

As shown in Figure 5, the operational framework of the web platform aims to promote communication between the stakeholders belonging to the RAFB supply chain, as well as information management on the amounts of residual biomass that may have resulted from agricultural and forestry activities, such as, for example, pruning fruit trees, or the residues of forest clearing operations.

The BioAgroFloRes platform presupposes the identification of stakeholders with potential intervention in the platform, which are distributed across different levels of interaction, usually known as actors of the system, as shown in Figure 6.

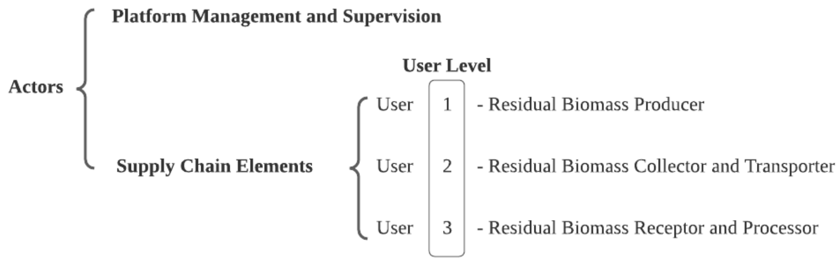

Figure 6. Definition of actors and different levels of intervention.

In this way, the Administration/Management of the Platform corresponds to the profile (or actor) responsible for managing the platform's content and ensuring and monitoring its operation by assigning access permissions to other actors. This can be defined or selected according to the scale of operation level and the geographic scope of the platform, ranging from the scale of parish, municipality, association of municipalities, and NUTS III or NUTS II regions, for example. On the other hand, the actors related to the supply chain are distributed over three access levels representing three different types of user profiles that perform a set of functionalities according to their role in the biomass supply chain.

Table 4 details some characteristics of the platform actors, representing stakeholders with additional characteristics of users, contributing with data input and/or information visualization. Some high-level functionalities, which these actors can carry out, are also presented in Table 4.

In this way, the platform can manage the supply chain, presenting notifications to the stakeholders from when residual biomass is produced until the moment it is transported to a point where it is processed/recovered. The platform starts from some assumptions, namely, through the mapping of supply and demand, the characterization of the types of biomass available and their origins, and the analysis of the different possible supply chains. For example, the supply chain can be of a simple linear type, such as Producer → Transporter → Receiver, or it can be of a complex type, presenting intermediate stages/processes of value adding before reaching the destination, such as Producer → Transporter 1 → Receiver 1 → ... → Transporter n → Final Receiver.

The characterization of different types of consumption also emerges as an important assumption since different types of biomass can be sent to different destinations and uses. The collection of information by the platform, which is provided by the users (each one with different levels of interaction), and the essential information that supports the functioning of the decision-making support algorithms, are essential aspects of the functioning of the platform since the quality of the information generated and transmitted to the next level of users depends on them. Figure 7 presents the information flow for the different stages of the process.

The type of interaction required between level 1 users (User 1) must occur in a simple and direct way. Similar to what already happens with other platforms, namely, with the platform where these residual biomass producers already carry out the mandatory registration of the burning of leftovers (https://fogos.icnf.pt:8443/queimasqueimadas/QueimaSeguraRapidaadd.asp, accessed on 27 March 2022). In other words, the objective of the platform proposed by the BioAgroFloRes project is to replace the process of burning the leftover waste materials, by introducing them into the supply chain of biomass derivatives, through the creation of a process similar to the one that already exists today, in a platform of mandatory registration, and in this way contribute to reducing the risk of rural fires. As already seen in the previous sections, the negligent and accidental use of fire represents a very significant percentage of the known/investigated causes of rural fires.

Table 4. Types of stakeholders and their functionalities.

Stakeholder Type	Description	Actors	Functionalities
Platform Administration/Management	Parish, Municipality, Association of Municipalities, NUTS III, NUTS II, . . .	Administrator	• Validate pre-registrations of the potential producer (User 1); • Validate pre-registration of potential receivers (User 3); • Register producers; • Register receivers; • Introduce auxiliary information to support the management of the platform; • View indicators; • Measuring and disseminating results.
Supply Chain Elements	Residual Biomass Producer	User 1	• Pre-register as a potential producer (User 1); • Record information on the residual biomass produced; • Register availability and conditions for collection.
	Waste Biomass Collector and Transporter	User 2	• View collection points; • View characteristics of the waste material to be collected; • Introduce the characteristics of transport; • Register the check-in of the cargo (status is in transit); • Register the check-out of the cargo (status is captive).
	Residual Biomass Receiver/Processor	User 3	• Validate the check-out status to the carrier; • Validate the check-in as a receiver (status is captive); • Reset the platform.

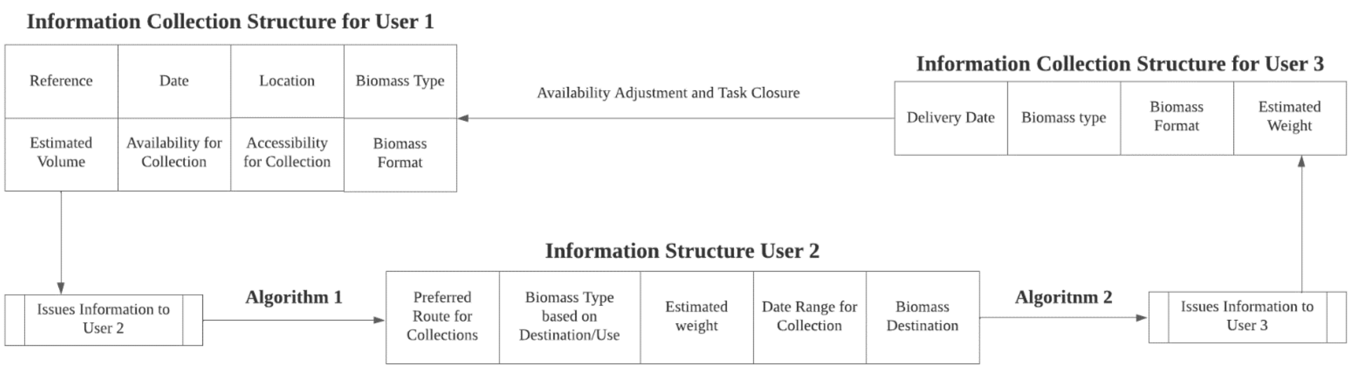

Figure 7. Information flow and information collection tables in the user-friendly interface.

4. Discussion

Within Europe, Portugal is the country most affected by rural fires [34]. This trend has been accentuated in the recent decades and is likely due to the transformation of the Portuguese landscape in the last century [35]. Afforestation and rural abandonment transformed the rural landscape that once was multifunctional, integrating agriculture, shrublands, and forests in a complementary way [36]. With this mosaic-like landscape, rural fires had smaller dimensions and were rapidly extinguished [33]. According to Gomes, the land cover has progressively changed to the monoculture of fast-growing species, first (mid-19th century) with *Pinus pinaster* Aiton. and later (since the 1950s of the 20th century) with *Eucalyptus globulus* Labill. [37].

Despite the rural exodus that has been happening since the second half of the 20th century, ancient traditional agricultural practices keep being used, such as the use of fire to prepare the soil for new crops, acting also as a waste elimination procedure, and to promote the growing of grass to be used for cattle feedstock [38]. This practices, if not correctly managed, can induce forest fires [39]. In addition to this, another factor that aggravates the problem of forest fires in Portugal is the inadequate management of forests, such as the lack of bush and forest wastes collection and the lack of economic resources for prevention and firefighting [40,41]. Although fire is one natural aspect of Mediterranean forests, the structural, social, and political aspects are more significant, making this a public calamity and ecological disaster in Portugal [42].

In fact, the government's periodic structural reforms have not been able to reverse the rural fire crisis, and its capacity to intervene is very reduced in the absence of a private-sector counterpart. The fact that private ownership of land extends over 94.3% of Portugal makes structural forest reforms very difficult to achieve by the state [43,44]. Fire management policies have strengthened fire control capacities instead of focusing on timber and land conservation and agriculture, energy, and soil regulation [16]. Fire prevention measures have been left to second plan, while the focus of the national strategy has been on firefighting capacity, showing striking similarities to the US approach to forest fire prevention over the past century, with similarly ineffective results [45–48]. Without addressing fuel loads management, a firefighting-only approach leads to larger conflagrations with exponentially greater economic and societal costs [49].

Over the last decades, different management, control, and financial measures have been implemented, with constant revisions, sometimes with conflicting results, which can be counterproductive [50]. The constant regulatory changes, the difficulty to control and apply those rules due to the lack of resources, and the failure to take a consistent direction towards a successful performance has led to what seems like a dead end [51]. The constant revisions and the quantity of strategic documents is indicative of this uncertainty in the system (Table 5).

Table 5. Portuguese forest strategies (adapted from [33]).

Year	Plan
1996	Forest Policy Bases Law
1999	Portuguese Forest Sustainable Development Plan
2003	Action Plan for the Forest Sector
2003	Forest Sector Structural Reform
2005	Operational Plan of Forest Fires Prevention and Suppression
2006	National Plan of Forest Defense Against Fires (2006–2018)
2006	National Forest Strategy
2020	National Plan for Integrated Fire Management
2020	National Forestry Accounting Plan—Portugal 2021–2025

The national system for forest fire protection was established in 2006 (Decree-Law 124/2006, of 28 June), including the definition of fuel management criteria [33]. Although it is mentioned that the problem of rural fires must be tackled with structural prevention measures, mainly related to the reorganization of the existing landscape, this has not been the case. In addition to the national regulation, there are also forest fire protection plans at the regional, municipal, and local scales, but their framework is complex, without criteria and scale integration and with simultaneous negative consequences in forest governance efficiency. In 2019, the regional forest landscape plans were revised, which was an opportunity to change towards a structural transformation in the land-use planning system, including new targets to fire-resilient landscapes, tree species, and other sustainable land-uses. However, the revised plans still consider a policy target for 2050 with a dominant and high *Pinus pinaster* and *Eucalyptus globus* forest cover area, representing between 60% and 90% of the total forest area [33].

From the data gathered, it is possible to conclude that there are multiple causes for the forest fires in Portugal, and most of them are structural, which means that there is still a long way to go. First, the Portuguese forest is characterized by the monoculture of highly flammable species—pine and eucalyptus—due to their essential oils, instead of autochthonous species that are fire-resistant such as oaks (*Quercus* sp.), cork oak (*Quercus suber*), and holm oak (*Quercus rotundifolia*). Secondly, the rural exodus that led the rural populations to the cities had multiple effects: the abandonment of land that was previously used for non-intensive agriculture and now is occupied by fire-prone vegetation, the agroforestry residues are no longer used for heating or cooking purposes, and the fire prevention capability formed by village inhabitants disappeared. Another structural and significant issue is the fragmentation of land holdings into small plots, with the state only owning around 3% of the Portuguese forest and 12% of the area with no landowner and, thus, not subject to any management system. Although, there has been a great effort from the government to identify the landowners through the BUPi (Balcão Único do Prédio) platform.

There is also a lack of human and material resources dedicated to managing and coordinating the forests. As previously stated, the policies have been directed towards increasing firefighting capacity instead of prevention, educational programs, and reducing the use of forest fuels. From the known causes of forest fires in Portugal, it becomes obvious that it is crucial to educate people to end risky behaviors such as the burning of agroforestry residues, which accounts for 27% of the fires in Portugal each year. These negligent behaviors are also very seldom penalized, contributing to their continuation. Arson is also common but also infrequently penalized.

The use of agroforestry waste biomass increases rural development and reduces rural fires thanks to clearing forests and not burning these wastes on-site. These wastes are particularly important, especially when a large quantity is available, since it contributes to the circular economy and decarbonization. The central region of Portugal is rich in agroforestry waste, and until now, it is usually left on-site or burnt since the costs for collecting them are high. The development and implementation of a web platform that will foster the use of RAFB in the production of energy or as raw material for other industries, such as biomass pellets, charcoal, or fertilizers, through the enhancement of the RAFB supply-chain, linking supply and demand. Small farmers and landowners that nowadays leave the residual biomass on the ground or burn it will be able to find a destination for the RAFB produced, while the logistics operation will be optimized through the platform. This will solve the problem caused by the burning of leftovers, reducing the risk of rural fire occurrence while closing the loop in the biomass waste recovery.

Due to its territorial organization and the type of land cover and use, the central region of mainland Portugal presents a high propensity for the occurrence of rural fires. This has been the most recurrent scenario in recent years, with the region checking year after year, the top places in terms of the number of occurrences and burnt areas. Using a tool like the one being developed in the BioAgroFloRes project comes as an option, in fact, without presenting a significant change in the existing mandatory by law procedure for recording the burning of leftovers and piles. In other words, residual biomass producers must register whenever they intend to dispose of this biomass waste, so this platform gives residual biomass producers the possibility of having an alternative to the usual procedure.

The development of a campaign focused on aspects related to the origin of rural fires and the negative impacts caused could constitute a launching pad for creating a collective awareness that leads to a change in habits.

5. Conclusions

The valorization of the existing energy potential in the lignocellulosic biomass of agroforestry residues favors the reduction in the probability of rural fires because of the cleaning of the forests from these residues that constitute a high fuel load that, in hot and dry weather, can fuel rural fires. By removing these forest residues, cleaning forests will benefit forest ecosystems, preserving them as an essential carbon dioxide sink. On the other hand, it instils economic dynamism in inland regions that have suffered from the rural exodus being the most disadvantaged and isolated in Portugal, contributing to the minimization of the depopulation of these territories. The use of tools such as the one being developed in the BioAgroFloRes project presents itself as a contribution to reducing the risk of rural fires by mitigating the well-known causes of these occurrences.

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