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Transforming Rural Landscape towards Fire Resilience and Landscape Sustainability

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Abstract

After the fires that occurred in 2017 and 2018 in Portugal, the imperative need to plan for sustainable and fire resilient landscapes led to the implementation of the Landscape Transformation Program. However, it is still lacking a landscape planning methodology to achieve those resilient landscapes. This paper presents a landscape plan for a fire-prone landscape located in the Centre region of continental Portugal - Serras da Lousã e Açor. This landscape is characterised by steep slopes (70% of the total area) and is dominated by highly combustible coverings, such as eucalyptus (27.89 %), maritime pine (28.06 %), other coniferous (10.08 %) and shrubs (18.91 %). Fires have occurred frequently and 96 % of the case study's total area was burned between 1975 and 2020.

The landscape plan here presented was based on the FIRELAN model and goes a step further by proposing a progressive landscape transformation. FIRELAN integrates fire resilience, ecological sustainability, and economic viability. In this model, the landscape components, which can be physical, biological or cultural, are organised in two main infrastructures - the Ecological Network and the Fire Resilient Landscape Network - and in Complementary Areas.

The Ecological Network ensures the ecological functioning of the landscape by emphasising the quality or potentiality of biophysical components, in articulation with the nature conservation and at-risk areas, underlying the provision of multiple functions valuable to society.

The Fire Resilient Landscape Network integrates fire behaviour knowledge related to land morphology, promotes the landscape discontinuities according to it, is made of less combustible land uses, and includes the cultural management in the urban-rural interface, roads, and power grid. This network is divided in two, the Primary and the Secondary Fire Resilient Landscape Networks. The last one includes the areas with slopes greater than 25%, located outside the Fire Resilient Primary Network.

As to the Complementary Areas, these correspond to the interstices (compartments with slopes less than 25%) of both of networks. Since these areas have low ecological value, they can allocate more artificial land uses.

The implementation of the landscape plan is defined in two temporal phases: the landscape plan for the Scenario 2030, which consists on the implementation of the Primary Fire Resilient Landscape Network (51%), and the landscape plan for the Scenario 2050, that adds the implementation of the Secondary Fire Resilient Landscape Network (37%) and Complementary Areas (9 %). This landscape plan represents a paradigm shift from a landscape dominated by eucalyptus and maritime pine to a dominant forest of native species (such as oaks), archetypical species (such as chestnut, walnut - both for wood or fruit - the wild cherry and others) and also riparian species (alder, willows, poplar, ash, elm, etc.).

Differentiating the final proposal into two phases makes it possible to distinguish implementation priorities, since the application of the model implies a substantial transformation of the current landscape, with high implementation costs. The payment for ecosystem services to the landowners during the paradigm transition period, which is expected to be 20 to 30 years, is recommended to allow the plan implementation.

1. The landscape planning model

Despite long Portuguese forest legislation, only in 2020 the transformation of vulnerable into sustainable and fire resilient landscapes via landscape planning has been formally introduced in legislation with the Landscape Transformation Program (RCM No. 49/2020). However, the methodology to achieve those resilient landscapes is not regulated. The planning of rural landscapes to prevent rural fires must include sustainable land uses and well-defined management measures. This approach goes beyond obtaining marketable goods of materials and energy since it delivers other ecosystem services provided by a multifunctional and biodiverse forest, including water quality, soil and biodiversity conservation, climate regulation, tourism and scientific data. In addition, it offers intangible benefits such as human contact with nature, recreation and leisure. The availability of forest ecosystem services depends on forest planning and management to avoid and prevent uncontrollable fires.

The three major factors influencing rural fires are climatic conditions, land morphology and land cover. Assuming that it is impossible to radically change the first two factors, the proposed landscape planning methodology assumes that the transformation of the landscape by changing the land cover and land use reorganisation should guarantee the three significant vectors of sustainability: fire resilience, ecological sustainability, and economic viability. Landscape fire resilience is determined by several interrelated factors, namely: fire behaviour as a function of the land morphology (Viegas, 2006), combustibility of plant species (Calviño-Cancela et al., 2017; Silva et al., 2009), landscape discontinuities (Agee et al., 2000, Cui et al., 2019, Povak et al., 2018), and rural-urban interface (Gibbons et al., 2018, Badia et al., 2019). Ecological sustainability of the landscape is achieved by the delimitation of the Ecological Network (EN) (Forman, 1995; Magalhães, 2001; Cunha e Magalhães, 2019) and its correct implementation, supported by land suitability analysis for land uses (McHarg, 1967).

Regarding fire behaviour, biophysical factors can contribute to some extent to reducing fire risk and therefore should be taken into account when planning, namely: i) slopes facing north, with a slope greater than 25%, as they receive less radiation throughout the year, burn less than other slopes (Oliveira et al., 2014); ii) The rate of fire progression doubles for every 10º (about 17%) increase in slope and can increase continuously on steep slopes, from bottom to top, at approximately 5-6 km/h fire speed (Viegas, 1989); iii) Above slopes greater than 30º (57%), the relationship between slope and fire velocity is almost exponential (Viegas, 2006); iv) When the fire reaches the top of the watershed (the ridge), if it does not advance to the opposite slope, due to the slope's breeze, it starts to plough along the contour lines, losing speed. Thus, steep slopes, ridgelines, headwaters and valley bottoms should be strategically covered with less combustible vegetation, to break fire progression.

The proposed landscape planning methodology is based on the landscape transformation model named FIRELAN (Magalhães et al., 2021; Pena et al., 2021) developed in the SCAPEFIRE research project (PCIF/MOS/0046/2017) that includes the present study area as case study), integrates fire resilience, ecological sustainability, economic viability and the simulation of fire behaviour. This paper focuses on fire resilience and ecological sustainability. Other sub-teams dealt with the last two issues which are not covered in this presentation.

The planning design unit of the FIRELAN model is the watershed and is defined by the configuration of landscape infrastructures in its biophysical and cultural systems. Those landscape infrastructures consist of a **Primary and a Secondary Fire Resilient Landscape Networks,** including many components of the Ecological Network. The EN ensures the ecological functioning of the landscape by improving the quality and quantity of biophysical components (water, soil, and biodiversity) in articulation with the nature conservation and at-risk areas, underlying the provision of multiple functions valuable to society (Magalhães, 2013; Cunha & Magalhães, 2019).

Furthermore, the Fire Resilient Network assures the landscape discontinuities recommended by current knowledge of fire behaviour (Viegas, 2006) related to land morphology namely on streams and valley bottoms, ridges lines (Cunha et al., 2018), and the headwaters system areas (Pena et al., 2018). These discontinuities are obtained from less combustible land uses and vegetation types, as well as cultural system management/measures namely in the urban-rural interface, roads, and power grid. The protection buffers around rural settlements and roads contemplated in law and integrated in this methodology, are high priority intervention areas, as they contribute to the direct safety of local population and land properties in case of fire. The different FIRELAN components are presented in Table 1.

The FIRELAN model includes also the Complementary Areas that correspond to the interstices (compartments) of the infrastructures with low ecological value. Those areas have relevant socio-economic functions although less critical from an ecological point of view, therefore can allocate more artificial land uses (Magalhães, 2001; Magalhães et al., 2007).

Table 1 - FIRELAN components and its organisation in ecological network, fire resilient landscape network and complementary areas

System	***Sub-systems***	***Landscape Components***	***Ecological Network***	***Fire Resilient Landscape Network***		***Complementary Areas***
				Primary Network	***Secondary Network***	
Physical	*Water*	*Streams*				
		Valley bottoms				
		Water bodies				
		Headwater system areas				
	Soil	*Rocky outcrops*				
		Steep slope areas (slope> 25%)				
Biological	*Biodiversity*	*Vegetation with conservation interest*				
		Natura 2000				
		Low ecological value				
Cultural	*Agriculture*	*Existent agriculture*				
	Rural settlements	*Rural protection buffer area*				
		Rural protection buffer area in steep slopes (> 25%)				
		Rural settlements				
	Cultural Network	*Power infrastructure protection buffer area*				
		Road infrastructure protection buffer area				
		Road Network				

The proposed methodology promotes a paradigm shift from a landscape dominated by eucalyptus and maritime pine to a dominant forest of native species (such as oaks), archetypical species (such as chestnut, walnut - both for wood or fruit - the wild cherry and others) and also riparian species (alder, willows, poplar, ash, elm, etc.). The economy of this new forest is increasingly valued since it is composed of woody and non-woody products.

However, it can be noted that its profitability comes from producing much more valuable hardwoods that are scarce in the market and valuable non-wood products such as cork, mushrooms, honey, aromatic and medicinal plants, berries, etc. In addition, in a region where today there are few and mostly aged people, the installation of new activities as a result of the multifunctional and biodiverse landscape as management shepherding, hunting, tourism and management will involve new jobs and the settling of people.

2. Case study

The case study is located in the central region with an area of 54839 ha (Figure 1A). This area covers part of the Mondego river basin to the North, and the Tagus river basin to the South. Its dominant characteristics are hilly and rugged terrain with predominating altitudes above 500 m, such as Serra do Açor (1418 m) and Serra da Lousã (1205 m). The geological formations are mainly schist with some quartzite outcrops, giving rise to an enclosed valley bottoms with abrupt and extensive hillslope morphology.

About 70% of the total area is characterised by steep slopes (greater than 25%). The southern area is represented by a less rugged morphology, although hillslopes between 12 and 25 % of slope predominate. It is noteworthy that only 7% of the intervention area has slopes below 12%, which are mainly in the surroundings of the two largest urban agglomerations of Castanheira de Pera and Pedrógão Grande.

The land use map (DGT, 2019) (Figure 1B) shows an occupation dominated by eucalyptus (27.89 %), maritime pine (28.06 %), other coniferous (10.08 %), shrubs (18.91 %), which together make up about 85 % of the area with highly combustible coverings. This situation significantly contributed to the fires between 1975 and 2020 (Figure 1C), corresponding to 52.656 ha of burned area, representing 96 % of the case study's total area.

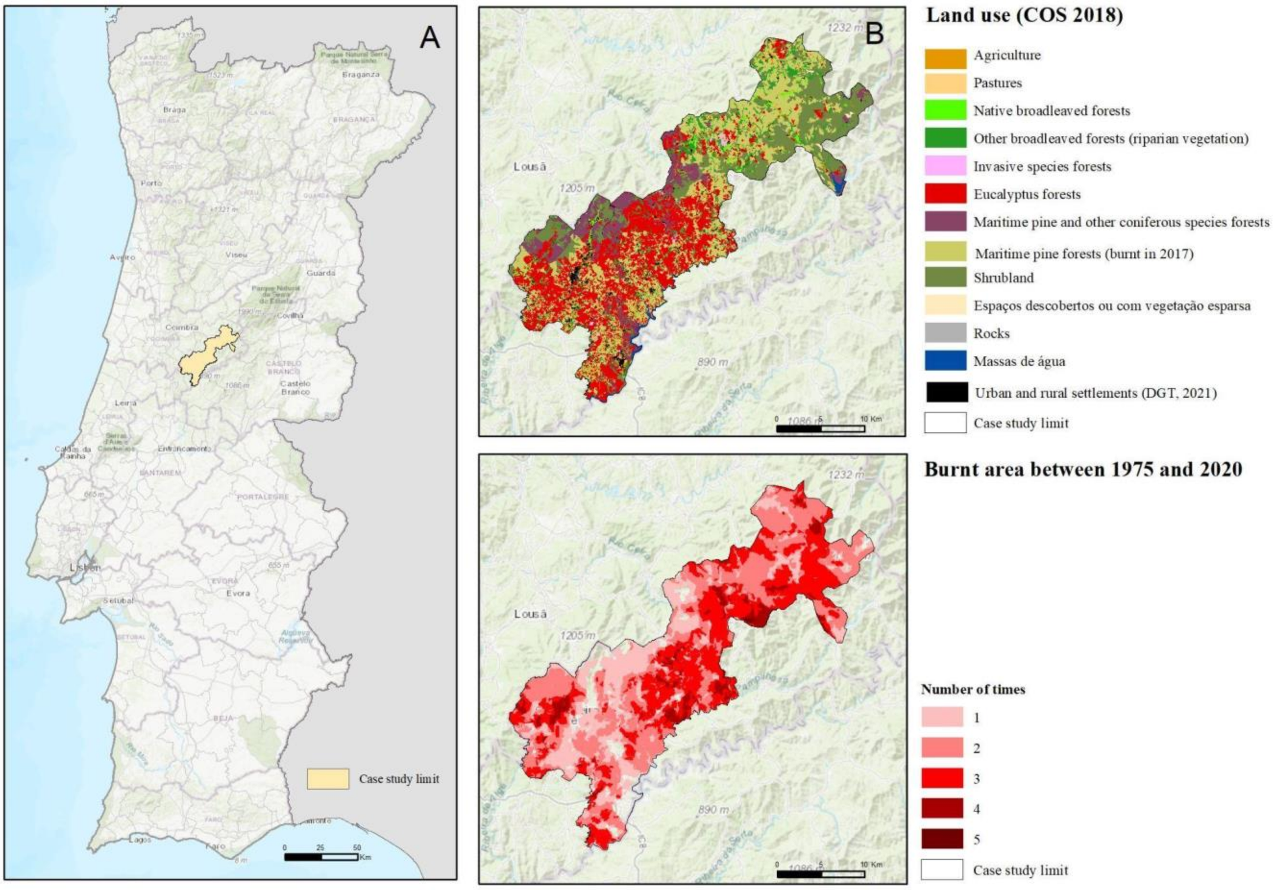

Figure 1 - Case study location (A), current land use (B) and fire frequency between 1975 and 2020 (C)

3. Landscape Plan of Serras da Lousã and Açor

The landscape plan of Serras da Lousã and Açor is the result of FIRELAN model application to the case study area. It corresponds to the biophysical and cultural systems according to the mapped landscape components (Table 1) and a set of potential land uses for each situation.

The implementation of the landscape plan is defined in two temporal phases, presented in the Scenario 2030 and Scenario 2050. The first temporal phase runs until 2030, an important goal in fulfilling European commitments, such as the Biodiversity Strategy 2030 (EC, 2020) and the New Forest Strategy for 2030 (EC, 2021), included in the European Green Deal (EC, 2019). The 2050 Scenario is coincident with the implementation of other long-term European targets up to 2050, such as the Climate Neutral Strategies by 2050 (EC, 2018). This phasing is intended to allow for a progressive transformation of the Landscape. The desired situation is one that should be considered as the "benchmark of a new economy of rural territories, which promotes a multifunctional, biodiverse and resilient forest that is more profitable, with greater capacity for carbon sequestration and capable of producing better services from ecosystems" (RCM No. 49/2020). This will be achieved after the implementation of the two scenarios by 2050.

The 2030 Scenario (Figure 2) represents the first phase of implementation of the proposal and consists of Primary Fire Resilient Landscape Network (51% of the case study area), implemented with less combustible land uses, integrating the essential components for compartmentalised landscape:

- the two fundamental landforms/features that simultaneously play a role at the ecological level and in fire resilience:
  - i) streams and associated valley bottoms (riparian gallery; riparian forest or agriculture) - 2737 ha;
  - ii) headwater systems (native and archaeophytes mixed forest) - 15362 ha.
- the existing land uses:
  - iii) natural vegetation with conservation interest - 4239 ha;
  - iv) agriculture - 1694 ha.
- buffer protection areas:
  - v) to rural settlements (agriculture/pastures/native forest) - 1472 ha;
  - vi) to road network (pasture/native forest) - 1112 ha;
  - vii) to power grid (agriculture/pasture/lowland scrubland) - 582 ha.
- the Natura 2000 Network (to be intervened by structures and to guarantee the conservation of existing Habitats)

In this Scenario (2030), to be carried out in a first phase, also included is the intervention in all areas with invasive forests (114 ha), the "compartments" generated by the FRLPI, maintain their use until financing and other conditions for their implementation are in place. These areas are fundamentally characterised by:

- hillslopes with slopes greater than 25 % located outside the FRLPI (20085 ha);
- Low ecological value areas with slopes of less than 25% (4899 ha).

Although there is no intervention at this stage, these areas should be subject to silvo-environmental measures.

The 2050 Scenario (Figure 3) represents the second phase of the proposed landscape plan. It assumes the implementation of the Fire Resilient Landscape Primary Network 2030 and the implementation of interventions located in the Secondary Fire Resilient Landscape Network and Complementary Areas.

The Secondary Fire Resilient Landscape Network includes areas with slopes greater than 25%, located outside the Primary Network, occupying about 37% of the case study area (20085 ha). These areas present high risks of soil erosion, high velocity of water runoff, which decreases infiltration (this condition is aided by the nature of the geological substrate consisting of shale). These conditions together lead to soil loss and thus infertility in these areas and contribute to a faster rate of fire progression. The proposed uses are native hardwoods or native bushland.

The Complementary Areas are the "compartments" with slopes less than 25% generated by the Fire Resilient Landscape Network (4899 ha), represented in pink in Figure 3. In the case study area these areas are of low ecological value. Their use is more flexible, and alternatives depend on the suitability of the soil to the various trees and shrubs species or crops and the choice of their promoters.

Regarding soil and water conservation management techniques, minimum mobilization and the use of manual or mechanical-manual practices are recommended above slopes of 35%. Also, reforestation should be based on the promotion of natural regeneration and intensive forest management should be replaced by close-to-nature forestry (Carvalho, 2018), semi-intensive, extensive or very extensive.

Other recommended techniques are the green firebreaks, which are strips of vegetation with low combustibility, cultivated in strategic locations on the landscape with the aim of slowing down or stopping the progress of a fire. The headwaters, riparian galleries and other suitable hedges can be considered green firebreaks. When compared to the fuel management buffers contemplated in law, characterised by the absence of vegetation, green firebreaks represent a more sustainable option, with benefits such as increasing biodiversity, restoring ecosystems (soil, water and air) and the economic value associated with its products (Wang et al., 2021). In addition, although their installation is more demanding than that of the fuel management buffers, the maintenance costs are reduced in the medium to long term.

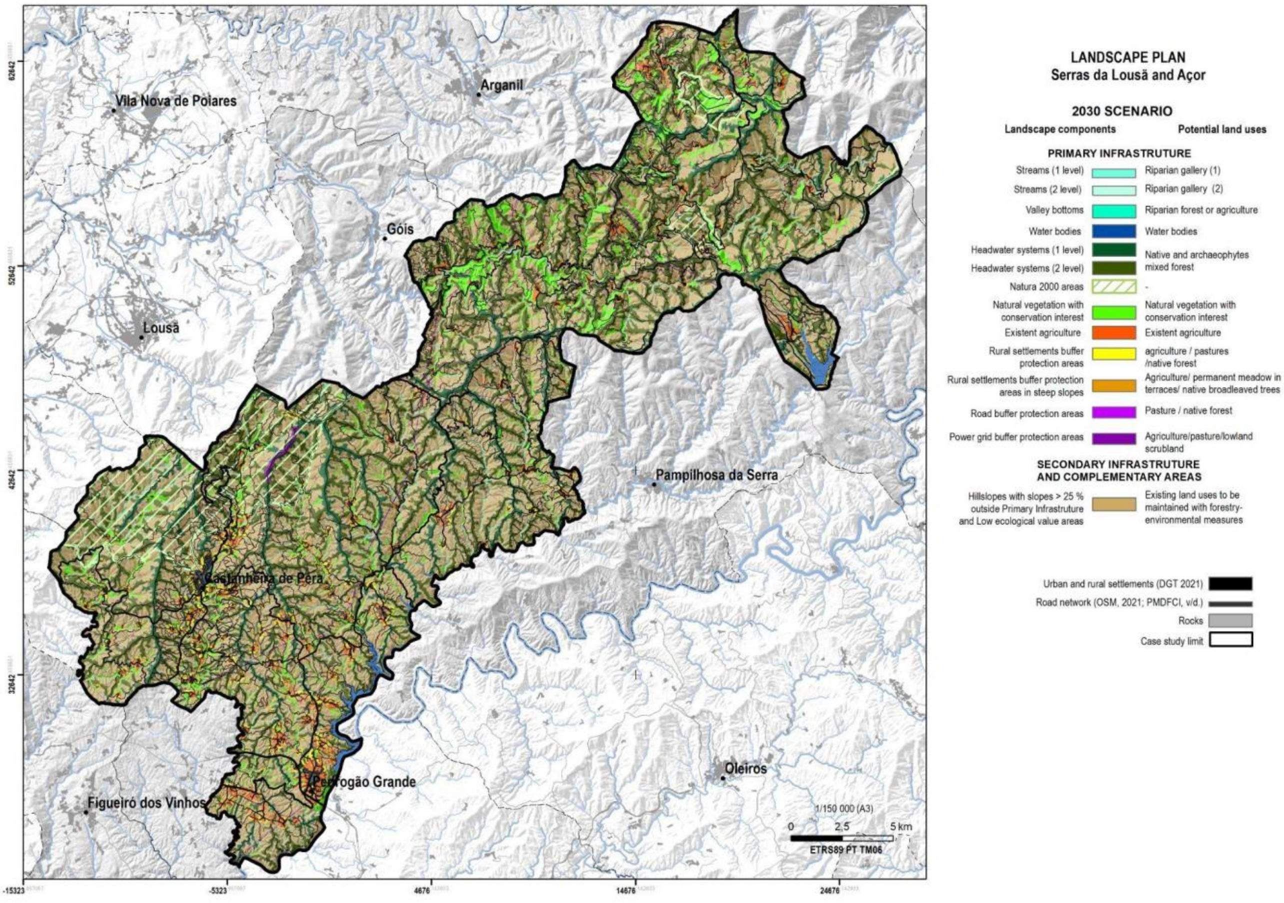

Figure 2 - Landscape Plan - 2030 Scenario

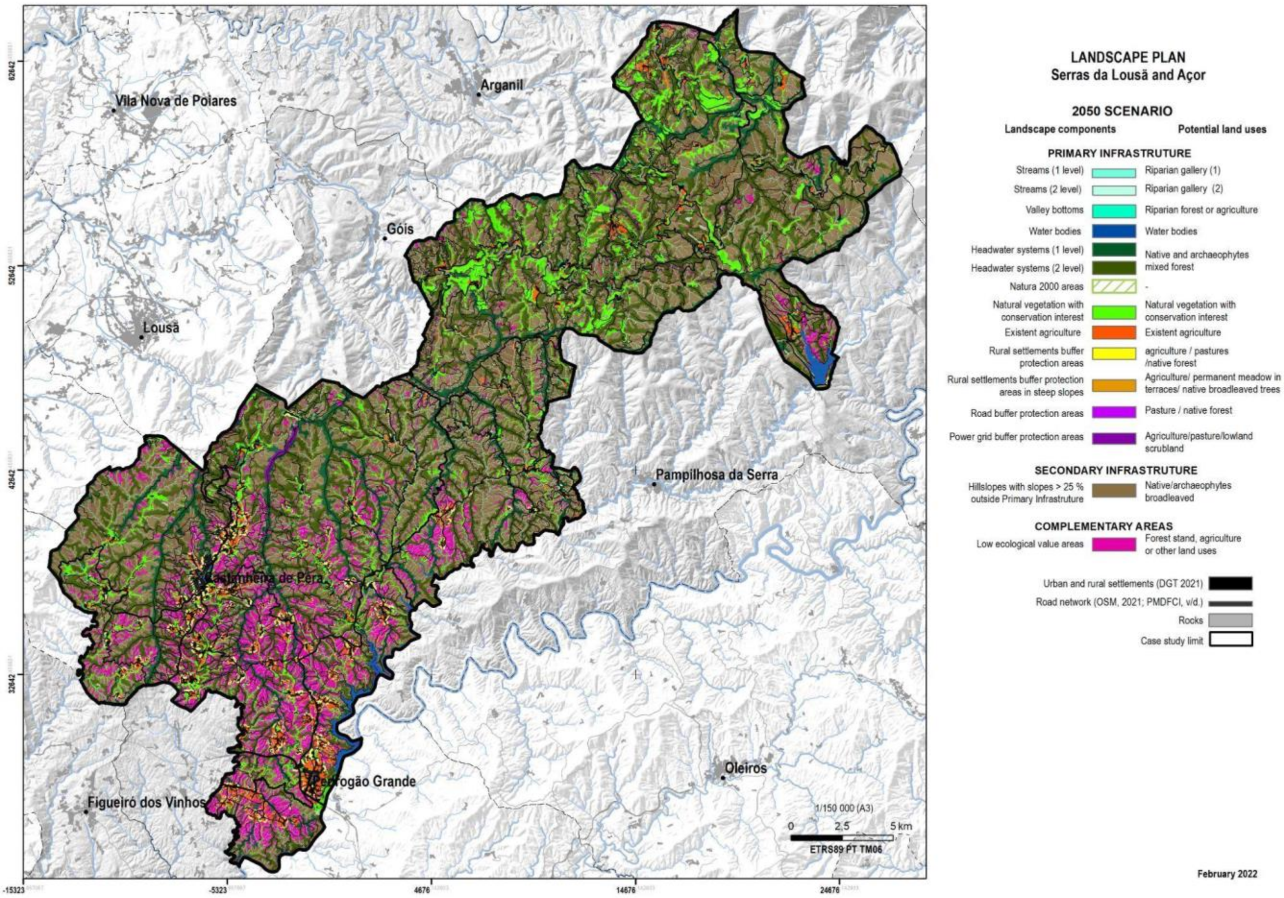

Figure 3 - Landscape Plan - 2050 Scenario

This landscape plan was accompanied by several public participation workshops, involving representatives of the landscape transformation stakeholders who were open to the transformation, except for pulp/paper companies and large landowners whose properties are covered with eucalyptus.

Specialised teams in the simulation of fire behaviour, the evaluation of implementation costs and also the evaluation of ecosystem services evaluated these two phases (Scenario 2030 and Scenario 2050). These components of the Landscape Plan are not developed in this paper. However, we refer to some of the conclusions obtained by specific teams.

The simulation of fire behaviour shows that the transformations proposed for the landscape leads to a reduction in fire intensity levels (and all associated characteristics), especially from the 2018 scenario to the long-term scenario (2050).

Regarding the evaluation of ecosystem services (ES), this was conducted in two phases. In a first phase, the evaluation of the ES (Biomass supply, Food supply, Regulation of water cycles, Soil protection, Carbon Sequestration, Biodiversity, Cultural Functions) in the current landscape and proposed transformations was based on a qualitative exercise of the supply potential. In a second phase, a quantitative assessment of the flow of ES in the different landscape scenarios and respective economic valuation was carried out. The analysis allowed to conclude that the proposed transformation improve the landscape's ability to provide regulatory and cultural services.

4. Conclusion

The final proposal of the FIRELAN model application to the case study was differentiated in two phases (scenarios) to allow for the distinction of implementation priorities, since the proposed transformation implies a substantial change of the current landscape, with high implementation costs.

It was therefore considered that, in a first phase, the linear components of the Fire Resilient Landscape Network should be implemented, fundamentally made up of the primary and secondary streams and valley bottom systems and the watershed headwaters, as these are the ones that, conceptually, will have a determining role in fire containment. Although the transformation of the Secondary Fire Resilient Landscape Network has been relegated to the 2nd phase, it is admitted that, given its characteristics, areas with slopes greater than 25%, also these, when covered by highly combustible uses such as eucalyptus and maritime pine, contribute greatly to fire risk, so it is also considered very important to implement these areas according to the plan.

The rationale for the option of low combustible land uses was based on existing literature and observation of post-fire landscape cases. This option implies a very significant change in the existing areas of eucalyptus and maritime pine (from 56% to a maximum of 9% in the 2050 scenario), so it is proposed to pay for ecosystem services to the landowners during the paradigm transition period, which is expected to be 20 to 30 years, depending on the species to be used.

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