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People&Fire webGIS tool for wildfire risk assessment

Nelson Mileu*, José Luís Zêzere, Rafaello Bergonse

University of Lisbon, Centre of Geographical Studies, Institute of Geography and Spatial Planning, 1600-276 Lisbon, Portugal

R E V I E W H I G H L I G H T S

• People&Fire webGIS tool allows the computation of wildfire risk scenarios centred on land use transformation.

A R T I C L E I N F O

Method name:
Wildfire risk assessment

Keywords:
Wildfire risk assessment
Wildfire hazard
Decision support
Webgis
Risk scenarios

A B S T R A C T

People&Fire webGIS tool is an application for wildfire risk assessment, focused on obtaining simulating hazard and risk scenarios centred on land use transformation. This tool is a decision-support platform created in the context of a research project, which was dedicated to testing a new analytical framework for supporting the development and evaluation of new, integrated, and people-centred policy approaches to wildfires. The simulator used in the tool is based on the wildfire risk model that results from the combination of three components: hazard (H), exposure (E), and social vulnerability (SV). Based on the wildfire risk model and using real data, from a study region particularly susceptible to forest wildfires the as-is and to-be scenarios demonstrate People&Fire webGIS capacity. People&Fire webGIS tool is available for download at https://github.com/nmileu/peopleandfire.

Specifications table

Subject area	Earth and Planetary Sciences
More specific subject area	*Risk, Hazard, Vulnerability*
Name of the reviewed methodology	*Wildfire risk assessment*
Keywords	*wildfire risk assessment, wildfire hazard, decision support, webgis, risk scenarios*
Resource availability	⟨13:italic ⟩https://github.com/nmileu/peopleandfire⟨/13:italic⟩
Review question	*Is it possible to provide a simple wildfire risk simulator that does not require expertise in geospatial analysis, allowing local stakeholders to support decision-making processes related to land use transformation, and providing fast and easy-to-interpret contextual data*

Method details

Introduction

Wildfires pose a serious threat to communities in many countries worldwide as they can be extremely destructive, killing people and destroying homes and other structures [1]. The Emergency Event Database EM-DAT reports disaster impacts per country and per hazard type, taking into account the following inclusion criteria: at least ten deaths (including dead and missing); at least 100 affected (people affected, injured, or homeless); and a call for international assistance or an emergency declaration [2]. From 1911 to 2022, the Emergency Event Database EM-DAT recorded 455 wildfires ((include the subtypes: Forest fire, Land fire and Wildfire) worldwide, resulting in the loss of 4682 lives and affecting 18 million individuals. The problem of wildfires and the possible solutions

* Corresponding author.
E-mail address: nmileu@edu.ulisboa.pt (N. Mileu).

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for its mitigation have been analysed from different perspectives of risk theory, namely the minimisation of exposure, vulnerability, or hazard.

Decision support systems (DSS) are one of the tools and approaches adopted for supporting wildfire management, allowing stakeholders involved in land management to estimate all primary components of wildfire fire risk.

Wildfires are described by Newman et al. [3] as one of the hazards most frequently targeted in decision support systems, despite being responsible for relatively low losses.

Despite their wide application, the focus and application of wildfire risk DSS varies [4]. Most focus on the fire simulation/modelling component [5–7], and include different perspectives as to how to visualise and exploit the geographic information considered essential for wildfire management. The system proposed by Bonazountas et al. [7], is an example of a desktop GIS approach that uses a common user interface to produce an integrated computer system based on fuel maps, socio-economic risk modelling and probabilistic models for forest fire prevention, planning and management. Other developments use web-centric systems, as is the case of Gumusay and Sahin [8] who present a web viewer for a spatial dataset from different sources, or Kalabokidis, et al. [9] who developed a platform that assists with early fire warning, fire planning, fire control and coordination of firefighting forces by providing online access to information essential for wildfire management. More recent developments include a mobile data capture component that interacts with the DSS, enabling the use of GIS technology and visualization dashboards and allowing for faster and more informed decisions to reduce the impact of wildfires [10]. In addition to fire simulation/modelling, other aspects of wildfire risk, such as exposure or vulnerability, have been explored in the development of DSS. The works of Haas et al. [11] or Aretano et al. [12] are examples of these systems. The calculation and assessment of wildfire risk constitute another feature that has been included in DSS [13,14]. However, quantifying and geoprocessing wildfire risk can be a complex and time-intensive task, often requiring expertise in geospatial analysis [15]. To overcome these difficulties, Thompson et al. [15] developed a geospatial wildfire risk calculation tool to inform federal wildfire management and planning, allowing researchers and land managers alike to benefit from standardized and streamlined wildfire risk estimation capabilities.

In this work, we describe a decision-support platform created in the context of the research project People&Fire, which was dedicated to testing a new analytical framework for supporting the development and evaluation of new, integrated, and people-centred policy approaches to wildfires proposed by Bergonse et al. [16].

The lack of webGIS tools to support decisions regarding the transformation of land use to minimize dangers and risks of forest fires, constituted, in the context of the research project, the justification for the development of the wildfire risk simulator. Following the review question, the system aim is to provide a simple wildfire risk simulator that does not require expertise in geospatial analysis, allowing local stakeholders to support decision-making processes related to land use transformation, and providing fast and easy-to-interpret contextual data. To achieve this objective, a detailed approach at the parish scale (small administrative unit in Portugal) was adopted to characterize a study area of regional dimension in the centre of mainland Portugal with regard to the three dimensions of wildfire risk: hazard, exposure and vulnerability.

The first three sections present the background methodology, the conceptual approach and workflow of risk analysis, and the architecture used for the development of the simulator, together with the data model design and calculation procedures of the prototype risk tool. In section “Applying People&Fire webGIS to case study”, we demonstrate the components of the simulator using a local data set from the Pinhal Interior region in Portugal, where wildfire events are frequent and cause severe consequences. Finally, a discussion of limitations and potential improvements of the risk analysis tool is presented.

Method description

From a conceptual and methodological standpoint, the simulator is based on the wildfire risk model proposed by Bergonse et al. [16]. Following this approach, wildfire risk (WR) results from the combination of three components: hazard (H), exposure (E), and social vulnerability (SV). These are combined using the following formulation:

$$\mathbf{WR} = \mathbf{H}^{1/3} \times \mathbf{E}^{1/3} \times \mathbf{SV}^{1/3} \quad (1)$$

Regarding wildfire hazard, Bergonse et al. used the methodology previously proposed by Oliveira et al. [17], which has been officially adopted by the Portuguese state agency for the conservation of nature and forests (ICNF) for producing yearly wildfire hazard maps for mainland Portugal. As both the above articles include detailed methodological expositions, we will present here only the definitions and methodological outline of each component of the wildfire risk model, describing how the calculations were adapted for the webGIS framework.

Conceptual approach and workflow of risk analysis

Exposure

Exposure encompasses people, assets, systems, or other elements that are subject to potential loss on account of being situated in hazardous areas. It was quantified for each parish as the mean between two variables: total number of residents, and the percentage of the total residents outside of urban areas [16]. Before calculating the mean, both variables were rescaled to values between 0 and 1.

Social vulnerability

Vulnerability, which was considered only in its social dimension, expresses the degree to which exposed elements are likely to be negatively affected by the occurrence of a wildfire. Social vulnerability was expressed in terms of two dimensions: criticality and support capability. Criticality expresses individual characteristics that are related to vulnerability and to the potential for recovery (for example age or employment). Support capability describes the collective equipment and infrastructure (whether public or private) held by a particular territory that contribute to the contingency of activities, the collective and individual recovery and rehabilitation, and the consequential decrease in the impact caused by a wildfire.

Following Bergonse et al. [16], both criticality and support capability were quantified using Principal Component Analysis (PCA), respectively resulting from the combination of 20 and 11 input variables. Each parish's criticality was quantified as the sum of its scores in each of the six criticality principal components (PC), weighted by the respective PC's proportion of explained variance. Similarly, each parish's support capability was defined as the sum of its scores in each of the four PCs describing this dimension, weighted by the proportion of variance explained by each. The values of both dimensions were re-scaled to values between 0 and 1 and combined into a final vulnerability value using multiplication.

Hazard

Wildfire hazard is calculated as the product between susceptibility (the terrain's propensity to suffer a wildfire or to support its spreading as dictated by its intrinsic characteristics such as slope) and wildfire probability (the unconditioned probability that a given spatial unit will burn on any given year).

Susceptibility was defined for each parish in the study area by combining the likelihood ratios (LR) associated with elevation (in m), slope angle (in degrees) and land cover. The LRs for each class in each of these variables were obtained by cross-tabulating each of these classified variables with past burnt areas (1975–2018 for slope and elevation; 1995–2018 for land use/land cover) for the whole of mainland Portugal, as described in Oliveira et al. [17].

Land cover was obtained from official state maps for the years 1995, 2007, 2010, and 2015. To combine these maps, LR scores were calculated for each land cover class considering the specific timeframe represented by each map: 12 years for the 1995 map (1995–2006), 3 years for the 2007 map (2007–2009), 5 years for the 2010 map (2010–2014), and 4 years for the 2015 map (2015–2018). The final LR score for each land cover class was calculated as the weighted average of the scores within the successive land-cover maps, with the number of years covered by each map used as weight.

As the webGIS employs parishes as units of analysis, it was necessary to adapt the methodology of Oliveira et al. (which uses the individual pixel as unit of analysis) to be able to associate a single LR value to each parish regarding elevation, slope, and land cover. In the cases of elevation and slope, which are invariant within the simulator, each 25-m pixel within the parish was associated to the LR corresponding to its class. The mean values between the pixels within each parish were subsequently calculated and adopted to express the parish's general LRs regarding the two variables.

For the sake of eliminating unnecessary complexity regarding land cover, several class aggregations were performed, reducing the 30 original land cover classes present in the study area to 7 major classes. Each of these major classes was associated to the mean LR amongst its constituents, as shown in Table 1.

The LR scores of the major land cover classes served as basis for calculating a land cover LR score for each parish, with calculations following two steps: (i) the fraction of parish area occupied by each major land cover class was calculated from its absolute area (ha); (ii) the parish LR score was calculated as a weighted mean between the LRs of the major land cover classes present, using the fraction of parish area occupied by each as weight.

This final LR score was integrated with those associated to slope and elevation to obtain wildfire susceptibility for each parish. This was done according to the following formulation:

$$\mathbf{WS} = (\mathbf{SL} + \mathbf{EL})/\mathbf{2} * \mathbf{LC} \tag{2}$$

where WS is the parish's wildfire susceptibility, SL is its slope LR, EL is its elevation LR, and LC is its land cover LR. It is noteworthy that this formulation stands in contrast with that employed by Oliveira et al. [17] and Bergonse et al. [16], which consisted of a simple sum of the LRs for the three variables. We opted by the above approach to give equal importance to land cover and topography, as summing the three variables would in practice result in topography (expressed by both slope and elevation) having double the importance of land cover. Moreover, unlike topography, land cover can potentially negate fire or its propagation (as may be assumed in well-managed agriculture), thus justifying ascribing it an increased weight in the final susceptibility value.

To obtain wildfire hazard for each parish, its susceptibility score was multiplied by its probability of burning each year. This was obtained by calculating the ratio between the number of years that each pixel within the parish was burnt between 1975 and 2018 and the total number of years within this period, and then defining the mean probability value amongst all parish pixels.

The resulting map was classified in five classes as required by the Portuguese Forest Authority, according to the breaks of the success-rate curve and the predictive capability of the hazard model [17]. Finally, wildfire hazard was quantified for each of the 972 parishes as the percentage of the parish area classified in the two highest hazard classes.

Table 1
Land cover class aggregations performed, the major land cover classes created, and the corresponding likelihood ratio (LR) scores. Land cover class designations follow the 2018 national land cover map (Direção-Geral do Território).

Land Cover Class	LR	Major land cover class	LR
Temporary irrigated and dryland crops	0.1983	**Agriculture**	0.2808
Protected agriculture and nurseries	0.03946		
Vineyards	0.1256		
Orchards	0.1509		
Olive groves	0.2613		
Improved pastures	0.3030		
Temporary cultures and/or improved pastures associated to vineyards	0.1682		
Temporary cultures and/or improved pastures associated to orchards	0.3749		
Temporary cultures and/or improved pastures associated to olive groves	0.3676		
Complex cropland systems	0.3261		
Agriculture with natural and semi-natural areas	0.7283		
Agroforests of cork oak	0.1370		
Agroforests of other oaks	0.6688		
Agroforests of stone pine	0.0728		
Agroforests of other species	0.5741		
Agroforests of cork oak and holm oak	0.0960		
Agroforests of mixed forest species	0.1812		
Forests of cork oak	0.5304	**Native broadleaves**	1.1166
Forests of holm oak	0.3880		
Forests of other oaks	1.6969		
Forests of chestnut trees	1.7682		
Florests of other broadleaves	1.1995		
Forests of maritime pine	1.5656	**Maritime pine**	1.5656
Forests of stone pine	0.2609	**Other pines**	0.6744
Forests of other conifers	1.0880		
Forests of eucalyptus	1.5305	**Eucalyptus**	1.5305
Forests of invasive species	1.3856	**Invasive species**	1.3856
Natural herbaceous vegetation	0.9107	**Shrubland/natural herbaceous vegetation**	2.4675
Shrubland	2.8573		
Sparsely vegetated areas	3.6347		

Fig. 1. webGIS tool architecture.

Risk

Wildfire risk (WR) results from the combination of the three above components hazard (H), exposure (E) and social vulnerability (SV), using the formulation [16]:

$$\mathbf{WR} = \mathbf{H}^{1/3*} \times \mathbf{E}^{1/3*} \times S\mathbf{V}^{1/3} \quad (3)$$

Prior to multiplication, each component was re-scaled by dividing each of its values by the maximum value. This resulted in equivalent scales for all components, ensuring equal influence over the final wildfire risk value.

Simulator development and architecture

To provide a simple wildfire risk simulator a webGIS application was written in Javascript, with the main architecture (Fig. 1) provided by the Node.js framework. The interface was designed with HTML, CSS and Javascript. The mapping component was implemented using Leaflet open-source JavaScript library, with basemaps provided by OpenStreetMap. For the hazard and risk calculation component, the processing is done mainly within a Javascript library (Simulator.js).

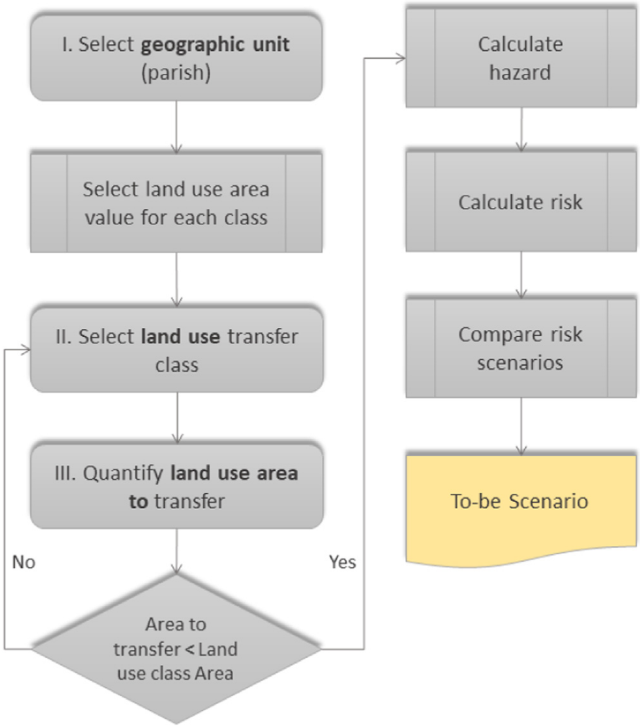

Fig. 2. Workflow of the hazard and risk calculation components, illustrating the inputs information for the generation of to-be scenario.

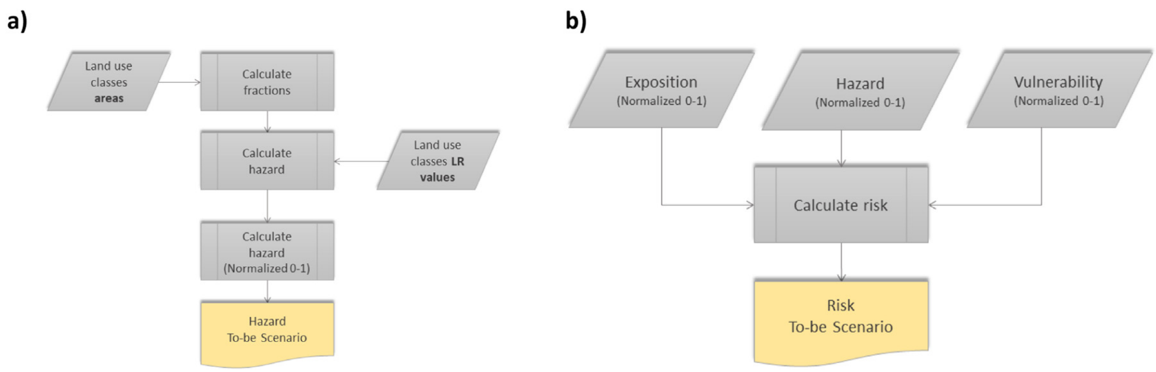

Fig. 3. Workflow of the hazard a) and risk b) calculation component.

To carry out the simulation of a risk scenario (Fig. 2), without requiring expertise in geospatial analysis, the user must select the geographical administrative unit hierarchically, starting with the district, followed by the municipality and ending with the parish. The choice of parish allows the user to know the distribution of areas amongst existing land use classes. The next step is the identification of the land use class to be converted, followed by the area to be transferred to the new class. The area to be transferred to the new land use is validated by the simulator to ensure that the total area of the geographical unit is not exceeded. Based on the new areas of the land use classes, the calculation of the hazard begins, followed by the calculation of the wildfire risk. The processing results are implemented in a virtual layer where the calculated value for hazard and risk can be consulted. The results of the to-be scenario (description of future wildfire risk, based on local stakeholder decisions related to land use transformation) are compared with the results of the as-is scenario (baseline scenario that considers the consequences of continuing current trends in land use), allowing the user to evaluate the increase or decrease in the risk of forest fire due to the eventual transformation of land use.

The processing of wildfire hazard begins with the calculation of the relative areas of the land use classes, followed by the multiplication of these values by the LR probabilities obtained in the as-is scenario (Fig. 3a). The new hazard values are normalized between 0 and 1 resulting in the to-be wildfire hazard scenario.

The risk calculation is based on a multiplicative model of the exposure, vulnerability and hazard components (Fig. 3b). The simulator is a decision support tool in situations of possible transformation of land use by a local stakeholder that enable risk mitigation

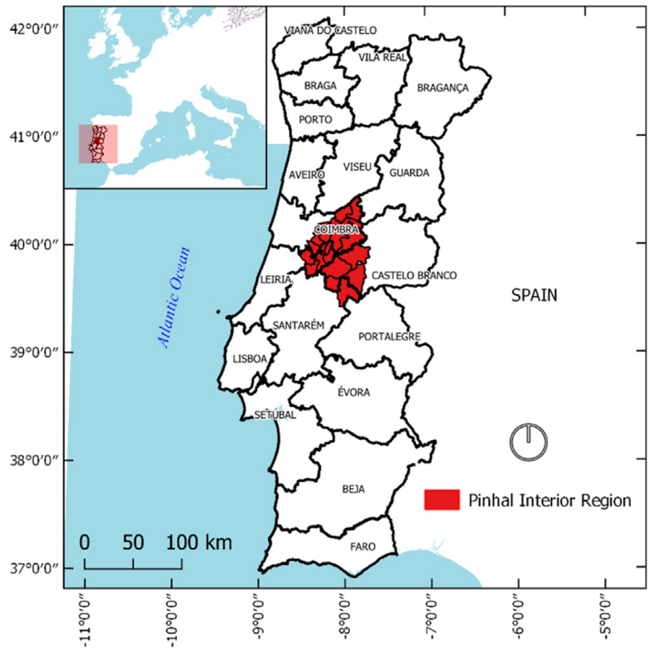

Fig. 4. Case study location.

through the choice of adequate land uses to reduce wildfire hazard. For this reason, the exposure and vulnerability components are used as constant inputs in the risk calculation.

Applying People&Fire webGIS to case study

Case study: Pinhal Interior, Portugal

The study area used to develop and test the webGIS tool is the region of Pinhal Interior, Portugal (Fig. 4). The Pinhal Interior region is located in the NUTS 2 region "Centro" and comprises nineteen municipalities. These are Proença-a-Nova, Oleiros, Sertã, Vila de Rei, belonging to the district of Castelo Branco; Vila Nova de Poiares, Góis, Arganil, Lousã, Penela, Tábua, Oliveira do Hospital, Pampilhosa da Serra, Miranda do Corvo, belonging to the district of Coimbra; Castanheira de Pêra, Pedrógão Grande, Figueiró dos Vinhos, Alvaiázere and Ansião, belonging to the district of Coimbra, and Mação which belongs to the district of Santarém. With a total area of 4521 km^2, the region comprises 121 parishes that constitute the smallest administrative division in Portugal and are the unit of analysis adopted in the risk analysis model implemented in the webGIS tool.

The study area is a hilly region with altitudes between 25 m and 1347 m where the Serra da Lousã, Serra do Moradal and Serra de Alvelos stand out. Land use is dominated by forests (47.1%) and agriculture (32.6%), with scrubland and open spaces with low vegetation having less expression (9.77%). The forest area is mainly composed of eucalyptus (41%), maritime pine (35%) and other hardwoods (15%). The artificial territories, which include urban areas, have a reduced expression in the context of the study area and present a high dispersion with approximately 1954 places. This is a low population density territory (223 inhabitants/km^2) where the highest-density parishes correspond to the municipalities' main urban centres, while the lowest-density parishes are rural and peripheral. The demographic evolution in the last decades, namely between 2001 and 2021, registers a negative trend marked by the absolute loss of −26,686 inhabitants (−14.6%). With a high ageing index (316) in 2021, there is a high increase of elderly people, accompanied by a decrease of young people, reflecting the progressive ageing of the last decades. It is a region frequently affected by large wildfires. In the period from 2012 to 2022, the accumulated burnt area was 2614 km^2, corresponding to 56% of the study area. In this period, the year 2017 stands out for the consequences in terms of human losses and large extension of the burnt area (2081 km^2).

Datasets

The variables used in the calculations of hazard and wildfire risk for implementing As-Is and To-Be scenarios are listed in Table 2. The geographical unit of analysis was the parish, obtained from the official administrative map of Portugal, and this layer was used in the application in geoJSON format. The calculation of the land use areas for each parish had the Land Use and Occupation Map for 2018 from the Directorate-General for Territory (*Direção-Geral do Território*) as reference. Since the objective of the simulator is focused on the analysis of the consequences of possible options regarding land use transformation on wildfire hazard and risk, and

Table 2
Source datasets used in hazard and risk simulator.

Dataset	Description	Source
Official Administrative Division of Portugal	Unit of analysis adopted in the risk analysis model	Directorate-General for Territory (DGT) https://geo2.dgterritorio.gov.pt/caop/CAOP_Continente_2022-shp.zip
Land use class area (ha)	Non-combustible, agriculture, Native broadleaves, Maritime pine, Other pines, Eucalyptus, Invasive species, Shrubland/natural herbaceous vegetation land use classes	Land Use and Occupation Map (COS) for 2018 from the Directorate-General for Territory (DGT) https://geo2.dgterritorio.gov.pt/cos/COS2018/COS2018v2-shp.zip
Likelihood ratio scores	LR for slopes, elevation and land use	https://doi.org/10.5281/zenodo.7078455
Exposure	Risk component used in the scenarios as constant	https://doi.org/10.5281/zenodo.7078455
Social vulnerability	Risk component used in the scenarios as constant	https://doi.org/10.5281/zenodo.7078455

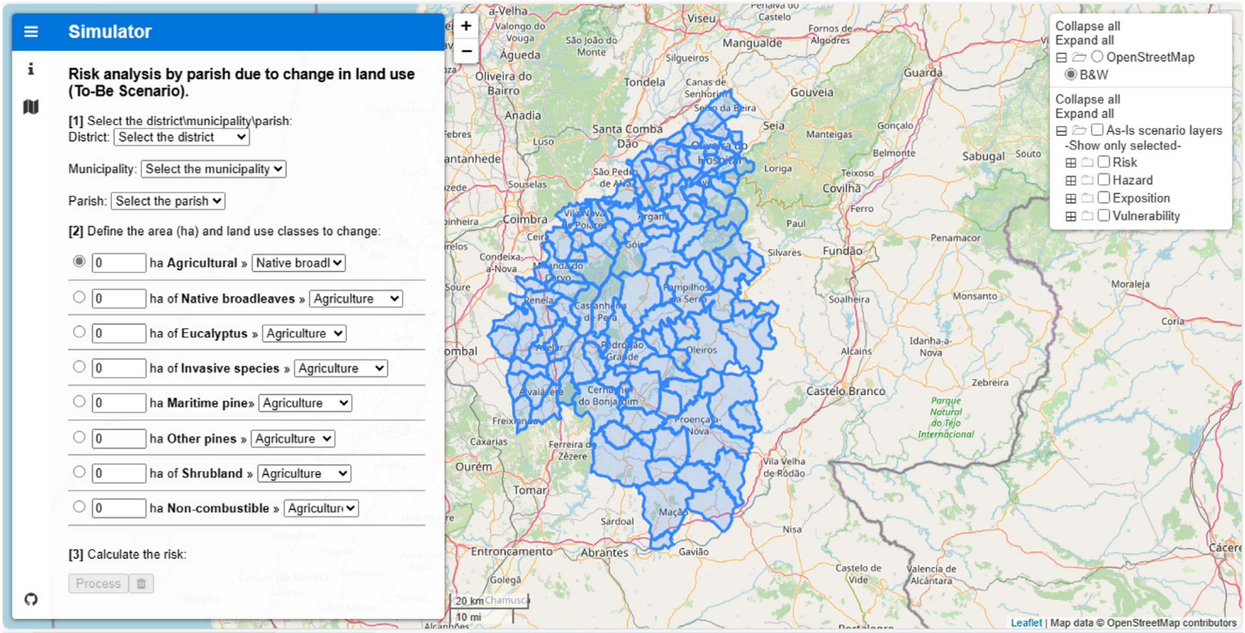

Fig. 5. Screen capture of the webGIS tool main map and risk simulator tab.

the slope and elevation components are constant, these were statically integrated in the model as attributes of the units of analysis. The likelihood ratio scores that underlie the wildfire hazard calculation were obtained from the study by Bergonse et al. [16]. The wildfire risk model was based on the dynamic hazard component expressed through the land use variable, and the static components of exposure and social vulnerability [16]. Although the exposure and social vulnerability components are of fundamental importance in the risk model, they were treated as static components because the simulator is focused on informing stakeholders regarding the consequences of land use transformation.

Risk analysis

The simulator tool and interface

To provide a simple wildfire risk simulator, the webGIS tool can be accessed via a web browser on a desktop or mobile device at https://nmileu.github.io/peopleandfire/. The site has the main map area where the user can access the results of the As-Is risk scenario in the Tree Layers Control, namely the layers of social vulnerability, exposure, hazard and risk. In the main map the user can zoom or pan around the map and access the attributes of the current land use classes and the results of the As-Is risk scenario for each parish (Fig. 5).

The main map has also three main tabs (‘Simulator tool’, ‘About’ and ‘Legends’). The first of these, the Simulator tab, controls the wildfire hazard and risk To-Be scenario. The first step is the user selection of the parish after choosing the district and municipality. The next step consists in identifying the land use class that the user intends to transform (non-combustible, agriculture, hardwood, eucalyptus, invasive, wild pine, other pine and shrubland/natural herbaceous vegetation), defining the project area (ha) and identifying the land use class that the user intends to implement in the transformation project. After defining the initial data, and avoiding

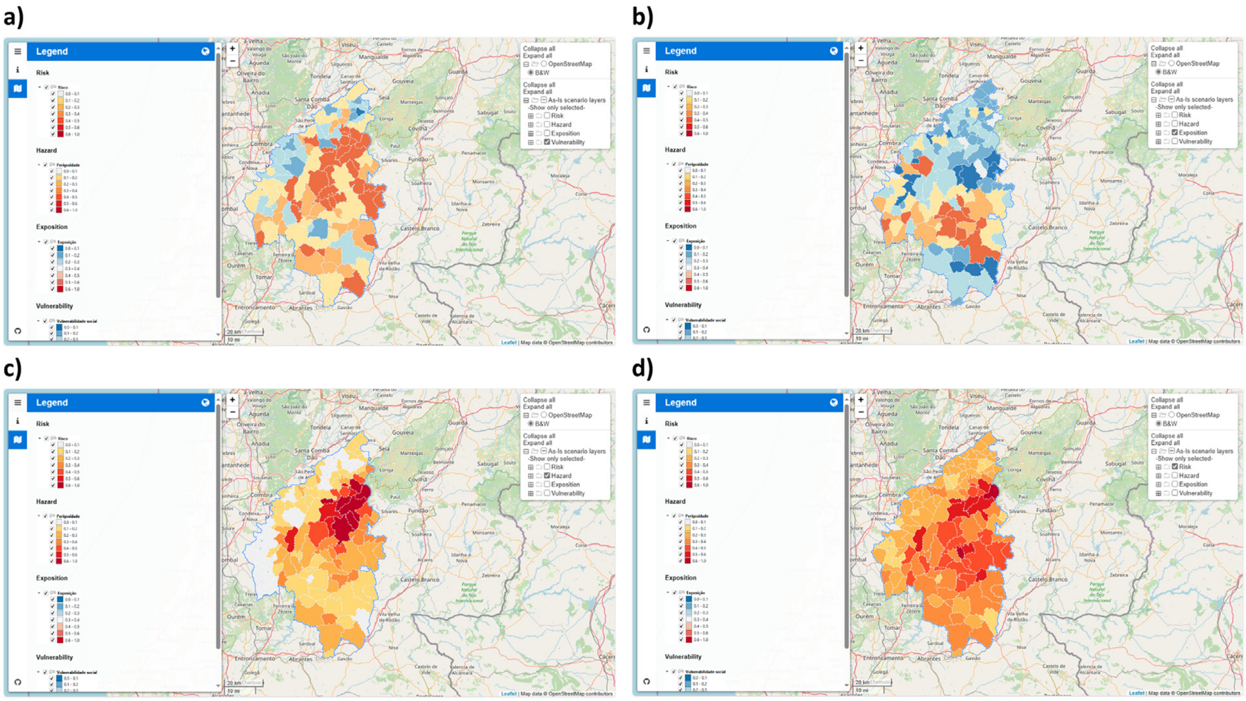

Fig. 6. Screen capture of the social vulnerability (a), exposure (b), hazard (c) and risk (d) As-Is scenario maps.

the need for expertise in geospatial analysis the last step consists of calculating the scenario. The wildfire hazard and risk To-Be scenario is shown in the form of the selected parish risk map and of a relative comparison between the risk values of the As-Is and the To-Be scenarios, and allows the user to explore them. By comparing hazard and risk within and between maps, the user can make decisions about which land use class to prioritise in the land use transformation project or identify the most suitable land use class uses for the parish under consideration. The second tab gives the description of the "People&Fire: Reducing Risk, Living with Risk" research project and a summary of how the simulator works and the suggested user workflow. The last tab is dedicated to showing the legends for the layers.

As-Is scenario

Fig. 6 shows the cartographic results of the As-Is scenario, namely the social vulnerability (Fig. 6a), exposure (Fig. 6b), hazard (Fig. 6c), and risk layers (Fig. 6d). These layers reveal the risk profile of the parishes of the Pinhal Interior Region as they are today. The social vulnerability component is characterised by the geographical dispersion of the highest values, especially in the parishes of Álvaro in the municipality of Oleiros, Benfeita in the municipality of Arganil, São João do Peso in the municipality of Vila de Rei, Campelo in the municipality of Figueiró dos Vinhos and the Union of the parishes of Cadafaz and Colmeal in the municipality of Góis. Regarding exposure, the parishes of Pedrógão Pequeno, Sertã, Carvalhal, and Troviscal, all belonging to the municipality of Sertã and also the parish of União das freguesias de Lousã e Vilarinho in the municipality of Lousã show a high value. The geographical distribution of the hazard shows a concentration in the municipality of Arganil, with emphasis on the parishes of Piódão, Pomares, the União das Freguesias de Cepos e Teixeira, and in the municipality of Pampilhosa da Serra, where the parishes of Cabril, Fajão-Vidual and Pampilhosa da Serra stand out.

The results for the wildfire risk show a concentration of high risk on the axis between Serra do Açor and Serra da Lousã, in the parishes of three municipalities: Arganil, Góis and Pampilhosa da Serra, with emphasis on the parishes of Celavisa, Pomares, Piódão, União das freguesias de Cepos e Teixeira, União das freguesias de Cadafaz e Colmeal, and Fajão-Vidual. The parishes of Isna, Álvaro and Sobral in the municipality of Oleiros and Campelo in the municipality of Figueiró dos Vinhos also stand out for presenting a high wildfire risk despite being more spatially dispersed within the study area.

To-Be scenarios

The To-Be land use change scenarios show the hypothetical hazard and risk. Four parishes from different municipalities were selected and several land use class transformation possibilities (To-Be scenarios) were equated to calculate the forest fire risk in the parishes and evaluate it against the As-Is scenarios, providing fast and easy-to-interpret contextual data.

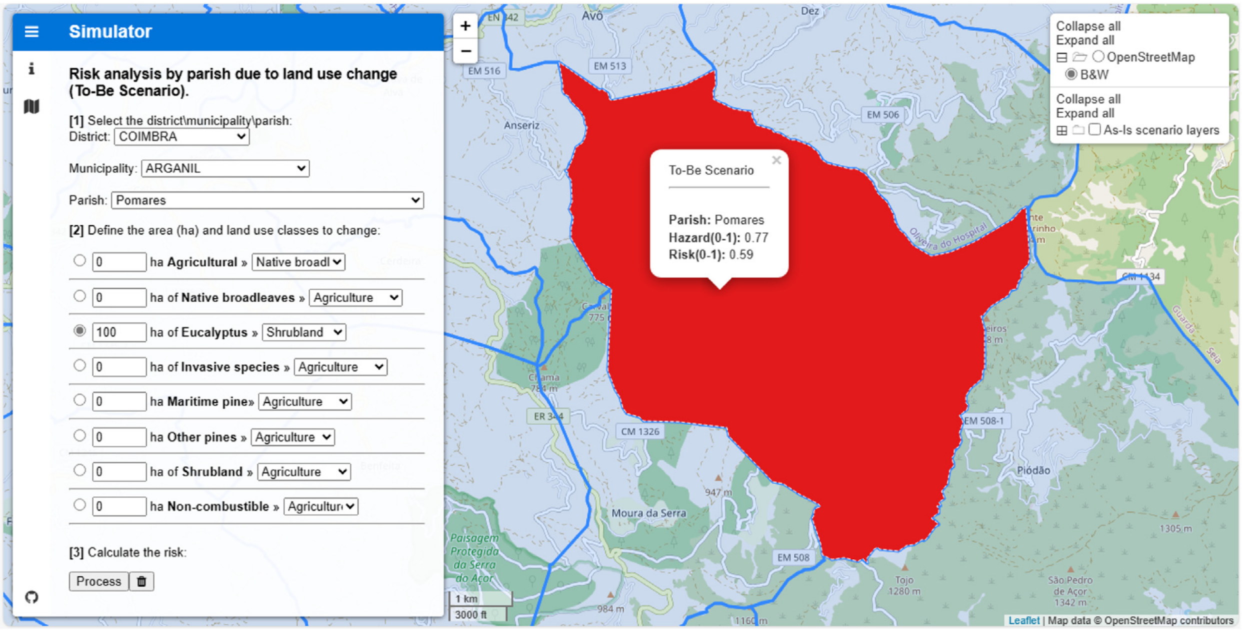

Fig. 7. Screen capture of Pomares parish To-Be risk scenario.

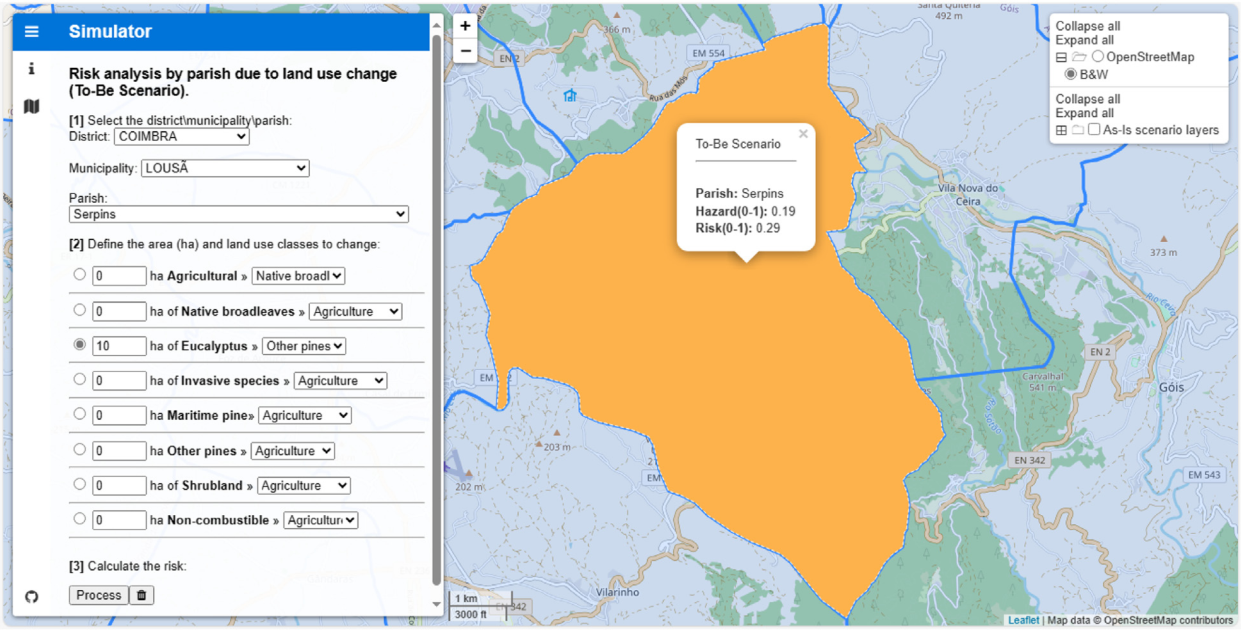

Fig. 8. Screen capture of Serpins parish To-Be risk scenario.

In the first scenario the user first selected the parish of Pomares in the municipality of Arganil (Fig. 7). In the next step an area of 100 ha of eucalyptus was defined to be transformed into shrubland. The simulation results in an increase of the risk in the parish of +0.6% compared to the As-Is risk scenario.

The parish of Serpins in the municipality of Lousã was selected for the second scenario (Fig. 8). In this scenario an area of 10 ha of eucalyptus was defined to be transformed into "other pine trees". The simulation results in a decrease of risk in the parish of −0.1% compared to the As-Is risk scenario.

The parish of Espinhal in the municipality of Penela was selected for the third scenario (Fig. 9). In this scenario, an area of 10 ha of shrubland/natural herbaceous vegetation was selected to be converted into agriculture. This simulation results in a risk reduction in the parish of 0.2%, compared to the As-Is risk scenario.

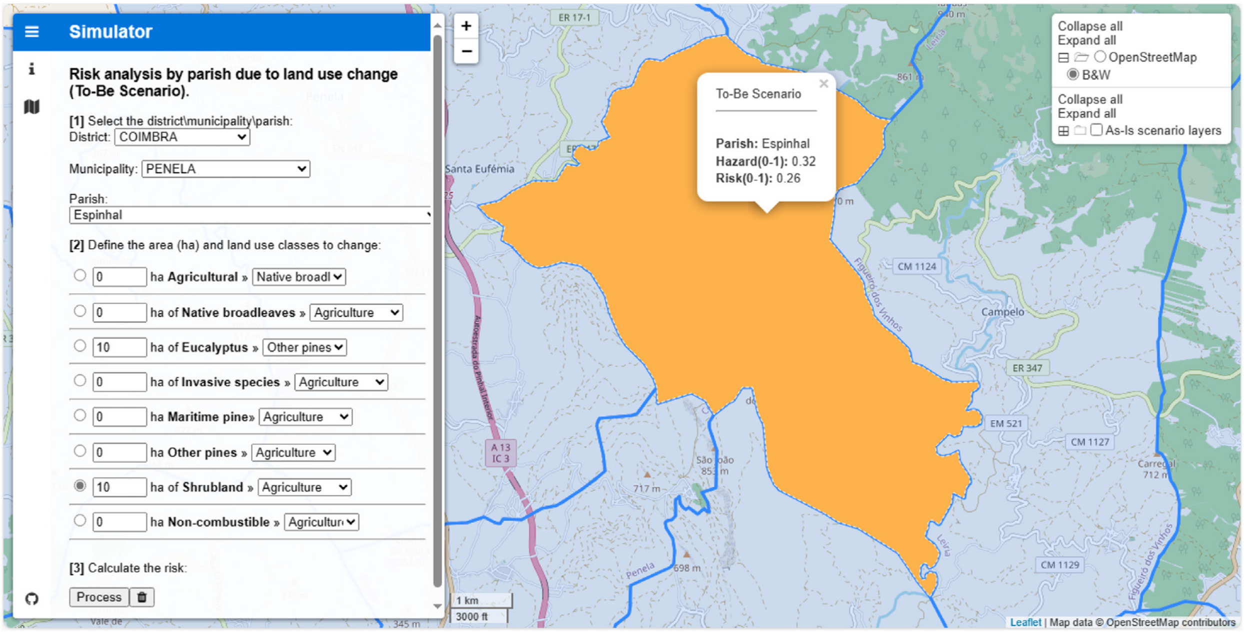

Fig. 9. Screen capture of Espinhal parish To-Be risk scenario.

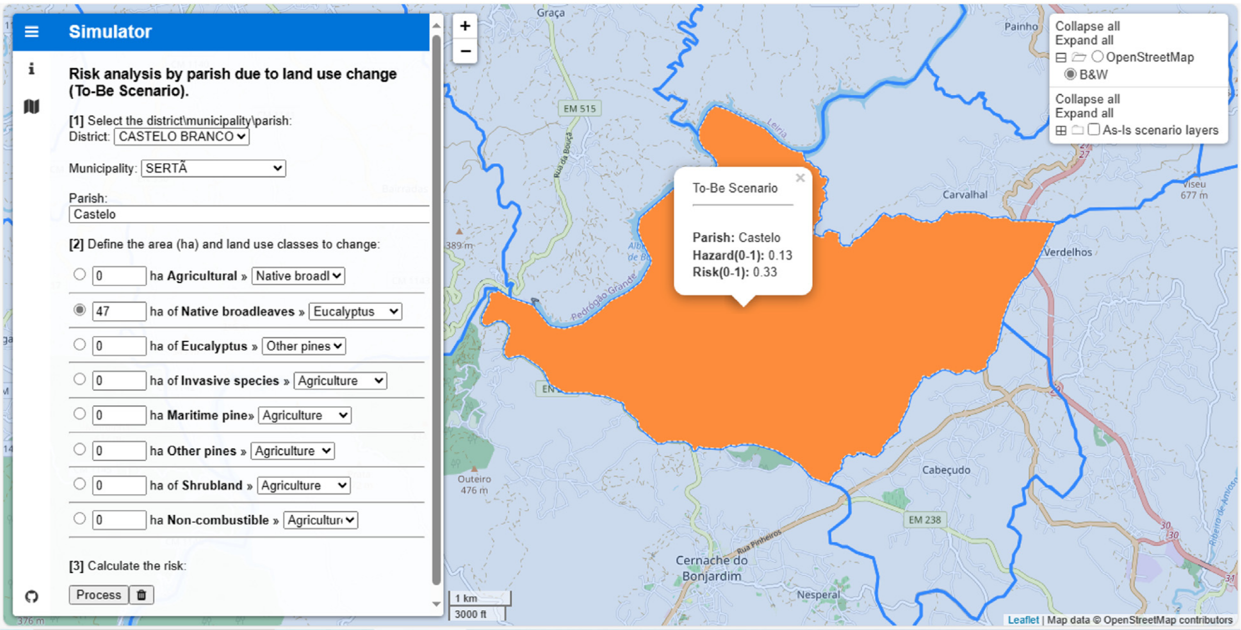

Fig. 10. Screen capture of Castelo parish To-Be risk scenario.

The parish of Castelo in the municipality of Sertã was the focus of the last scenario (Fig. 10). In this scenario the total area of native broadleaves, corresponding to 47 ha, was converted into eucalyptus. This simulation results in an increase of the risk in the parish of +0.2% compared to the As-Is scenario.

Discussion and conclusion

This work has presented the design and development of a webGIS tool for wildfire risk assessment, focused on simulating hazard and risk scenarios centred on land use transformation. The risk analysis tool has been developed based on the feedback of stakeholders of the People&Fire research project, using a data set from Pinhal Interior region located in Portugal, where wildfires occur with severe consequences for human lives, infrastructure, and forest. The project stakeholders identified the priorities in the scenario definition to be the ease of choice of the geographical unit of analysis (parish), the possibility of land use transfer between classes, and that the sum of the new land use arrangements does not exceed the area of the parish. The development of the WebGIS tool was based on a simple architecture and on open-source components that allowed implementing a flexible and easily updatable solution.

The WebGIS simulator is simple and fast-to-use, requiring no advanced knowledge in geographical information systems. It is an efficient tool for supporting risk assessment and eventual land use transformation decisions in particularly susceptible regions like the Pinhal Interior. The ability to visualise and explore the As-Is scenarios regarding the different risk components, namely hazard, exposure, and vulnerability, allows highlighting areas with lower or higher risk mitigation potential. On the other hand, the ease in quantitatively assessing risk at the parish scale by creating To-Be scenarios through a structured and systematic process provides opportunities for the evaluation of land use transformation projects, as well as the comparison of fire management alternatives and the analysis of commitments.

It is important to highlight that, in parallel to supporting decisions, the simulator can also play an important role in raising awareness to the close relation between land use/land cover and wildfire hazard and risk amongst non-decision makers. Thus, for example, a user can quantify the hypothetical consequences, in term of wildfire hazard, of the conversion of agriculture to shrubland/natural herbaceous vegetation through simple abandonment, or of the conversion of relatively low fire-proneness agriculture to relatively high fire-proneness eucalyptus or maritime pine. It also allows users to become aware of the consequences of the increase in the area covered by relatively fire-prone forests of invasive species in their parishes. Although these users may not have any responsibility on land use planning or policymaking, the increased awareness of the effect of land use in wildfire hazard provided by the simulator may influence their degree of support for public policies regarding land abandonment, fire prevention, and risk management.

Overall, the simulator draws attention to the greatly contrasting degrees of fire-proneness amongst the various land uses, from the highest (shrubland/natural herbaceous vegetation, forests of eucalyptus and maritime pine) to the lowest (agriculture in general) (Table 1), allowing for a quantitative perspective on the practical consequences of land use transformation in the parishes of Pinhal Interior.

Considering that the webGIS risk analysis tool is in the development phase but presents an added value in supporting potential land-use change decisions, further improvements can be identified. One of the aspects indicated by the project stakeholders that could constitute an improvement is the automatic identification of the parish from its location on the map, or the possibility of interactively drawing of the area for hypothetical land use transformation. Another of the limitations mentioned by stakeholders focuses on the To-Be risk scenario being restricted at this stage to only one land use class. Land use transformation projects often encompass several land use classes, not only because of economic factors, but also with the purpose of making landscapes more resilient to wildfire (for example by promoting diverse land use mosaics that restrain fire propagation).

It is expected that scenario results produced using the simulator will in time be used to inform strategic planning instruments such as forest fire defence plans and/or land management instruments. This evolution is in line with what is stated in other works, where it is referred that assessing wildfire risk in a quantitative, spatial framework is essential for landscape planning [3], or that these tools will naturally become part of the decision-making processes related to planning and land management instruments [18].

To conclude, despite the limitations and avenues for improvement identified for future development of the decision-support platform, the implementation of the prototype in the context of the research project allowed to demonstrate that it is possible to obtain spatially referenced scenarios, based on simplified calculations using real data, from a study region particularly susceptible to wildfires. The results of the risk scenarios highlight the added value of the tool for researchers and land managers, providing a standardised and simplified capability to estimate wildfire risk [15]. Future development of the risk assessment tool will involve testing it in a formal decision environment within a spatial planning or strategic forestry planning context.

Ethics statements

No ethics statement necessary.

CRediT author statement

Nelson Mileu: Writing- Original draft preparation, Software, Conceptualization **José Luís Zêzere**: Writing- Reviewing and Editing, Validity tests, Supervision **Rafaello Bergonse**: Writing- Reviewing and Editing, Methodology, Investigation, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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