FIREURISK - DEVELOPING A HOLISTIC, RISK-WISE STRATEGY FOR EUROPEAN WILDFIRE MANAGEMENT

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Executive Summary

The activities and products generated in WP2 focused on fire risk reduction. The application of activities in a joint and integrated way improves the reduction of fire risk.

This document reports the outputs obtained regarding the activities performed in Task 2.5, "Integration and validation of fire risk reduction strategies." WP2 focuses on Fire risk reduction activities. However, the activities performed produced varied types of outputs. Task 2.5 gathers all the products and geospatial data produced within WP2 to integrate the information and prove the connection between the partners' different activities. Therefore, the main purpose of this document is to showcase how the joint effort of the different activities developed in the study and demonstration areas have produced positive results toward fire risk reduction.

This Deliverable focuses on presenting the geospatial outputs produced by the different activities performed in WP2. It provides practical examples of how all the activities are integrated within the study areas and demonstration areas. The output of this deliverable is contained in the form of Story Maps. This tool allows the showcasing of the interrelations between different kinds of results and products in a way that can be distributed to all audiences.

Key Take Away messages



GEOSPATIAL DIMENSION

WP2 has produced many types of products, including reports, handbooks, and geospatial products. However, all these outputs and activities are integrated within the PS and DA. The results of the interrelation of the activities are showcased in the form of Story Maps.



FITTING LIKE PIECES OF A PUZZLE:

We present practical examples of how all the activities are integrated within the study areas and demonstration areas, as well as the positive results of the activities reported to reduce fire risk.



NAVIGATING FUTURE SCENARIOS

The analysis performed in the PS and DA connected with the work developed in WP3, in which different climatic scenarios were combined with LMS strategies and urban growth models.



PREPAREDNESS IS KEY TO FIRE RISK REDUCTION

The activities and products developed in WP2 contributed to improving the preparedness of communities and firefighters. Being ready and well-informed reduces the communities' vulnerability to fire.

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Table 1-1: List of Acronyms ..... **Erro! Marcador não definido.**

List of Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]				
[AD.2]				
[AD.3]				
[AD.4]				
[AD.5]				
[AD.6]				

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1 Introduction

The **FirEUrisk** project aims to develop a holistic approach to wildfire management that integrates prevention, mitigation, response, and recovery measures. **WP2 of FirEUrisk** focused on developing innovative methods and analysing alternatives for fire risk reduction regarding all risk assessment factors: ignition propagation and vulnerability exposure. The alternatives for fire risk reduction activities and measures under current conditions were analysed considering relevant EU and national policies. The main geospatial products and activities developed in WP2 are summarized below.

Reduction of fire ignitions

Humans cause most fires in European territory. In addition, ignitions related to human activities can be prevented by understanding the main drivers of fire occurrence (O6). The activities in WP2 studied human-caused ignitions, considering a) citizen-driven ignitions, that is, intentional or accidental uses of fire, and b) operations-based ignitions related to energy and transport networks (Varela et al., 2023). Several participatory activities were conducted with different communities in the study sites and demonstration areas (DA) to understand the drivers behind citizen-driven ignitions. The role of different fire suppression and fire risk management policies was evaluated at the EU and country levels (Varela et al., 2023).

Prescribed burning has proven to be a useful and necessary management strategy. However, in some cases, fires in rural areas used to burn agricultural waste can turn into wildfires due to landowners' insufficient knowledge. To help reduce the risk of fire in this regard, activities in WP2 focused on developing, testing, and evaluating training guides and protocols for practitioners in several DAs (mainly Sardinia and Southern France), with the support of firefighters and expert technicians (Lahaye et al., 2024).

Regarding operations-based ignitions, WP2 activities developed a methodology using satellite and UAV images to assess critical areas with higher fire risk, considering the proximity of vegetation and the probability of ignition in the areas surrounding the energy and transport networks.

Land management strategies (LMS) to reduce wildfire risk

Fire occurrence can be reduced by applying land management activities. The Mediterranean landscape was formerly managed using agropastoral burns and agriculture. However, in the last decades, due to rural abandonment, shrubs have colonized agropastoral areas and grown in high density, favouring fire propagation. In addition, a lack of forest management results in a dense tree population or an overgrown understory which favours vertical continuity, increasing fire risk and vulnerability. Wildfires in such landscapes, especially in steep slopes, are likely to be more challenging to control than those occurring in areas with greater heterogeneity of fuel characteristics (such as a mosaic landscape). On the other hand, in northern Europe where forest management is well implemented, the higher fire occurrence and increased fire risk were attributed to increases in the number of days with fire-prone meteorological conditions (heat waves, high winds, high temperatures, drought) due to climate change (European Commission et al., 2020; Jones, Matthew W. et al., 2020; Turco et al., 2018).

WP2 activities analysed the suitability of three land management strategies (LMS) commonly used to create more heterogeneous landscapes, thereby reducing fire risk (Chuvieco et al., 2023; Moreira et al., 2011). We focused on (1) the use of herbivores (specifically, browsing and grazing by goats, sheep, and wild ungulates); (2) mechanical fuel removal, including pruning, thinning, and harvest for management and industrial purposes; and (3) prescribed burning.

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The integration and efficacy of these three LMS depend on different geophysical, environmental, and socioeconomic factors, including climate conditions, current land cover and use, topography, socioeconomic constraints, traditional/cultural practices, etc, which vary spatially across Europe (Neidermeier et al., 2023b). We analysed the spatial suitability of herbivory, mechanical fuel removal, and prescribed burns for fuel management in Europe, identifying suitability factors through a literature review (Neidermeier et al., 2023a). The resulting maps demonstrate an initial assessment of the viability and spatial variability of the suitable LMS that could be used for landscape-scale policymaking (Neidermeier at al., 2024).

Improvements in fire response

Current strategies for fire response in Mediterranean Europe are effective but have limitations when facing extreme fire conditions (Lahaye et al., 2018). WP2 activities focused their efforts on improving firefighters' preparedness by producing a set of tools, protocols, and guidelines. We produced a new near real-time tool for predicting extreme fire behaviour (e.g., eruptive fires, crown fires) based on a model previously developed by several project partners (D2.5, Miranda et al, 2024). The tool also includes a module to simulate fire smoke dispersion to provide responders and decision-makers with information for monitoring exposure to very high pollutant concentrations and setting up warnings to the population to prevent health impacts.
In addition, WP2 has produced a Handbook with guidelines for firefighters to face extreme fires, fires in WUI and high latitudes/altitudes, which was elaborated in collaboration with practitioners and used in the practical training of firefighters. The document provides detailed information on fire behaviour, and the particular conditions of fires in WUI and high latitudes/altitudes (D2.6, Lahaye et al., 2024). It revises firefighters' methodologies to provide safety recommendations in operational cases.

Reduction of communities' vulnerability to fire

Reducing vulnerability and exposure and increasing socio-economic and ecological resilience is a critical component of fire risk reduction strategies. To address the challenge of communities' vulnerability, WP2 performed several workshops with communities in study areas and demonstration areas, which were destined to raise awareness and improve the preparedness of the population living in the WUI.
WP2 activities also analysed 20 major European wildfires from 2021 and 2022, spanning 10 countries. Analysing real fire events is crucial to understanding the behaviour of extreme fires and validating the outputs of fire behaviour models. The experience from studying these fires resulted in developing a protocol to gather information about fires that could serve as a reference for other researchers analysing fires (D2.7, Almeida et al., 2024). This protocol provided a template to harmonize the information gathered from different fires, thus enabling the comparison of results from studies across different fire events. The protocol developed to gather information on large fires also included information about their impact on people's health and safety and the resistance of houses and socio-economic conditions.

Deliverable D2.9 focuses on showcasing the geospatial outputs produced by the different activities performed in WP2. In addition, this deliverable shows practical examples of how all the activities are integrated within the study areas and demonstration areas, as well as the positive results of the activities reported to reduce fire risk. The output of this

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deliverable is contained in the form of Story Maps. This tool allows the showcasing of the interrelations between different kinds of results and products in a way that can be distributed to all audiences.

1.1 Purpose of the document

This document reports the outputs obtained regarding the activities performed in Task 2.5, "Integration and validation of fire risk reduction strategies." WP2 focuses on Fire risk reduction activities. However, the activities performed produced varied types of outputs. Task 2.5 gathers all the products and geospatial data produced within WP2 to integrate the information and prove the connection between the different activities carried out by the partners. Therefore, the main purpose of this document is to showcase how the joint effort of the different activities developed in the study and demonstration areas have produced positive results toward fire risk reduction.

1.2 Structure of the Document

This deliverable integrates the work of all the previous activities developed in WP2. Therefore, Chapter 2 details the geospatial products generated within WP2 related to Fire risk reduction. Chapter 3 summarizes the Story Maps created for this deliverable including the associated links. Chapter 4 offers a summary of the document and some conclusions.

2 Geospatial data produced for forest fire risk reduction

As presented in the introduction, different outputs have been developed within the WP2 activities, such as protocols, guidelines, methodologies, and analysis of land management strategies. In this section, we focus on reviewing the geospatial products generated in WP2 or information that can have a spatial representation.

- Reducing operations-based ignitions.
  Task 2.1 focused on reducing operation-based ignitions. Operation-based ignitions are those ignitions derived from human infrastructures and activities. To reduce the accidental ignitions around infrastructures we have to detect the areas where the probability of ignition is higher so the managers and decision-makers can coordinate effectively the fuel treatment of those areas. To accomplish this objective, we developed a fuel reduction priority map related to human-based ignitions, which included three priority classes of fuel treatment. To produce this map, we used information on power lines, road and railway networks (Figure 1), topography, fuel type (based on the FirEUrisk fuel map), climatic characteristics, ignition points of past fires caused by accidents, and fire simulation for a selected weather scenario (for a detail explanation, see Varela et al., 2021 – D2.1).
  We identified risk areas by overlapping the infrastructure network (with a buffer of 1 km) with the fuel map. Then, in high-risk areas, we produced a high-resolution vegetation map using drones, enabling precise identification of specific locations where vegetation is too close to the operational network, necessitating fuel treatment. Finally, we produced the final fuel reduction priority map by combining the past ignition density, topographic characteristics, and the rate of spread simulated under a climatic scenario (for a detailed explanation, see Varela et al., 2021 – D2.1).

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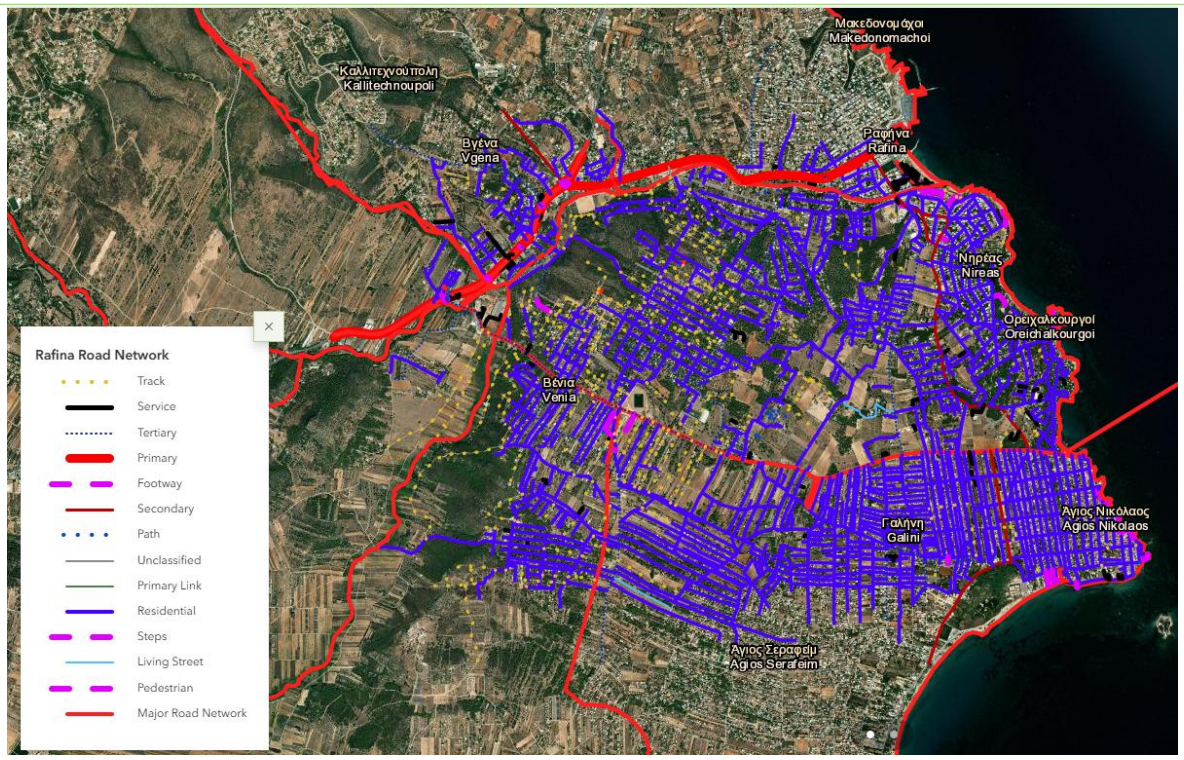


Figure 1. Map of the road network in Raffina (Greece). Fuel Management Framework for the Reduction of Operational Ignitions" was adapted for linear and point critical infrastructures (i.e power grids, roads, railways) to depict and prioritize the areas that need to be treated. Extracted from the Story Map

- Land management strategies to reduce wildfire risk (detailed information on these maps in D2.4., Neidermeier et al., 2024).
  Fuel-relevant land management activities (FRLMS) aim to reduce fire risk by applying different strategies, such as reducing the amount of fuel, the vertical continuity of the fuel and the fine fuel density. To know which strategy would be more efficient in the different regions of Europe, in Task 2.2 we studied the suitability of (1) the use of herbivory animals, mechanical fuel removal, and prescribed burning. The application and efficacy of these three FRLMS depend on different geophysical, environmental, and socioeconomic factors that vary spatially across Europe (Neidermeier et al., 2023b). That is the reason why the methods were analysed separately and then they were integrated into the final map showing the most suitable methods for FRLMS.

    - Suitability map for prescribed burning
      The suitability map for prescribed burning combines areas with (1) a higher number of days with safe and effective prescribed burn conditions ('prescribed burn days'), (2) greater accessibility to allow for the transport of equipment and labour, and (3) sufficient distance from major settlements (which may be exposed to the resulting smoke).

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- Suitability map for herbivory

  The suitability map was built by combining information on sheep and goat livestock presence and diversity, wild ungulate presence and diversity, pasture quality, livestock mobility, and distance to large city centres. In summary, the suitability map for herbivory encompasses areas that (1) have a greater presence or diversity of domesticated or wild ungulate grazers or browsers; (2) have greater accessibility to livestock and can allow for transportation of livestock products; (3) have a greater share of suitable pasture. This map shows the areas where using domesticated and wild herbivores to reduce fire risk is more effective.

- Suitability map for mechanical fuel removal

  The suitability map for mechanical fuel removal, including pruning, silvicultural activities, and extraction for industry, was represented by areas with (1) greater forest biomass availability, (2) greater proximity to documented biomass powerplants, (3) greater accessibility for transportation of raw materials and products, and (4) were located on suitable degrees of slope for machine and labor access. This map shows the areas where mechanical fuel removal could be utilized to mitigate fire risk.

- Priority areas for LMS

  We used the Wildfire Danger by Thermal Anomaly (WDTA) dataset, developed by EFFIS (Joint Research Centre European Commission, 2022a; https://effis.jrc.ec.europa.eu/apps/fire.risk.viewer/), to prioritize the results by areas most affected by wildfire in Europe. The variables were classified into three classes to create the bivariate choropleth maps.

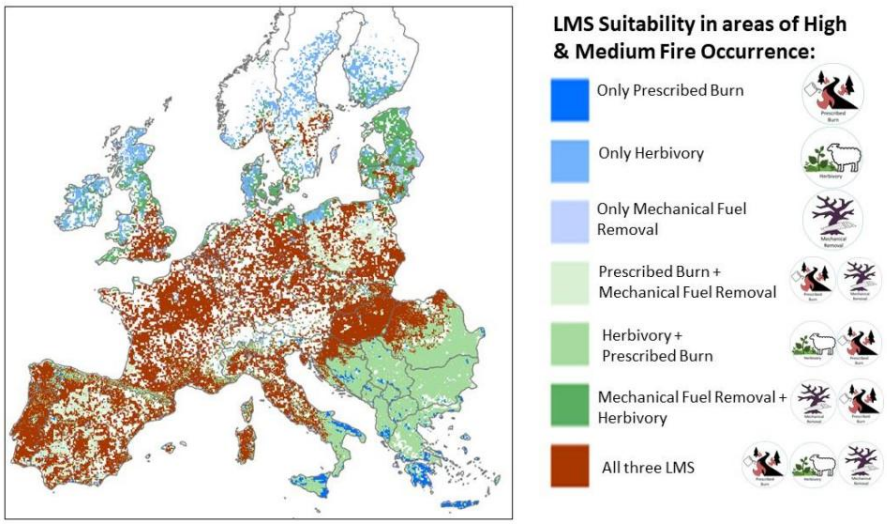


Figure 2. Areas of high and medium (>33%) FRLMS suitability in areas of high and medium (>33%) fire occurrence. Areas in white had low FRLMS suitability and/or low fire occurrence. Source: D2.4, Neidermeier et al., 2024.

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- Smoke dispersion simulations.

To protect the health of populations, it is important to provide information about the areas covered by the smoke from wildfires and the concentration of atmospheric pollutants. Activities in Task 2.4 focused on developing a smoke dispersion model adapted to the European territory. The mesoscale CHIMERE model and ground-based and satellite aerosol optical measurements were used to assess the dispersion of fire emissions and quantify the associated radiative effects during large fires in Portugal (PS3) and Greece (PS5). The CHIMERE model was run for two nested domains (D01 and D02), as shown in Figure 9. In the first domain, D01, the model has a horizontal resolution of 25 km, and the second domain has a resolution of 5 km. The simulation period was selected to cover the time the fires were active.

Figures 10 and 11 show the spatial distribution of simulated PM10, CO, and O3 concentrations for several hours of the simulation period, considering the most relevant atmospheric emissions sources in Portugal and Greece, respectively. The calculated performance metrics indicated a reasonable performance of the modelling system, supporting its usefulness in predicting smoke transport and chemistry and delivering information to prevent human exposure to smoke.

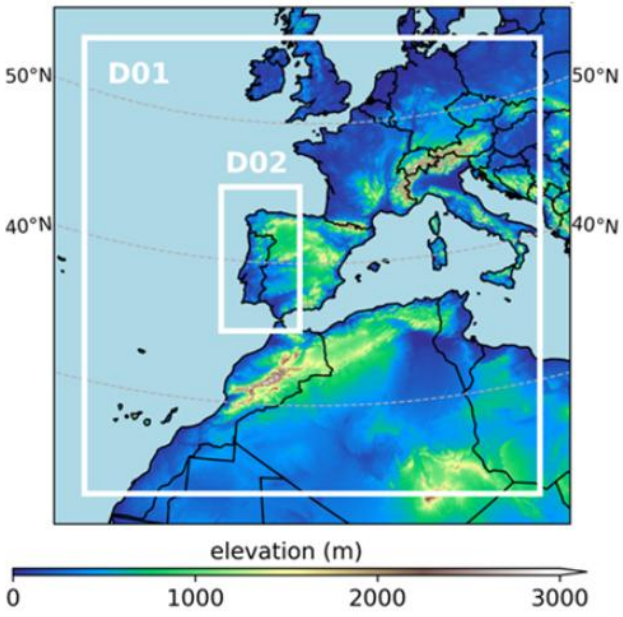


Figure 3. Spatial domains used for modelling smoke dispersion in PS3 in Portugal. Source: D2.5, Miranda et al., 2024.

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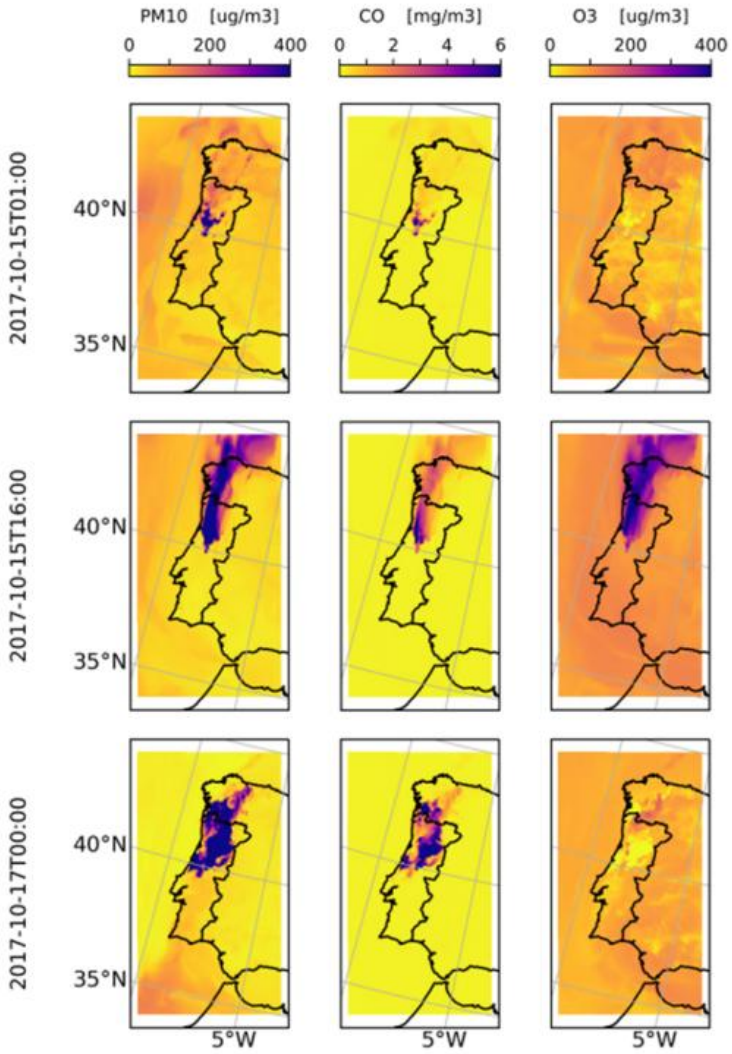


Figure 4. Example of PM10, CO, and O_3 hourly simulated concentrations considering the most relevant atmospheric emissions sources, for 01 and 16 UTC on 15 October and 00 UTC on 17 October 2017 in Portugal (PS3). Source: D2.5, Miranda et al., 2024.

- Location of the large fires studied in D2.7. Lessons learned from past cases.

  A team of internal and external researchers to the FirEUrisk project Consortium analysed 8 wildfires in 2021 and 12 fires in 2022. We followed a template of sections to harmonise the reporting of the analysed cases. The report included geospatial data, such as meteorological condition analyses, a fire risk map for specific fire dates, and fire impacts estimated from satellite images.

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Figure 5. Wildfires analysed and described in the 2022 Fires Report (D2.7, Appendix B). The pink colour used for Ukraine highlights that the respective chapter did not describe a specific wildfire event but rather the country's situation in times of war within the context of wildfires.

- WUI vulnerability analysis

The potential damage of wildfires to human infrastructure and lives is concentrated in areas where buildings and forests intertwine. Those areas are known as wildland-urban interface (WUI). We were interested in knowing how the growth of urban areas would affect fire risk. To obtain the answers we performed several simulations based on future climate scenarios and the simulation of the changes in WUI over the years. We analysed the changes in some fire risk variables, such as the rate of spread, the burn probability, or the fire line intensity. These variables were analysed particularly in the WUI areas. These results were used to perform the vulnerability analysis.

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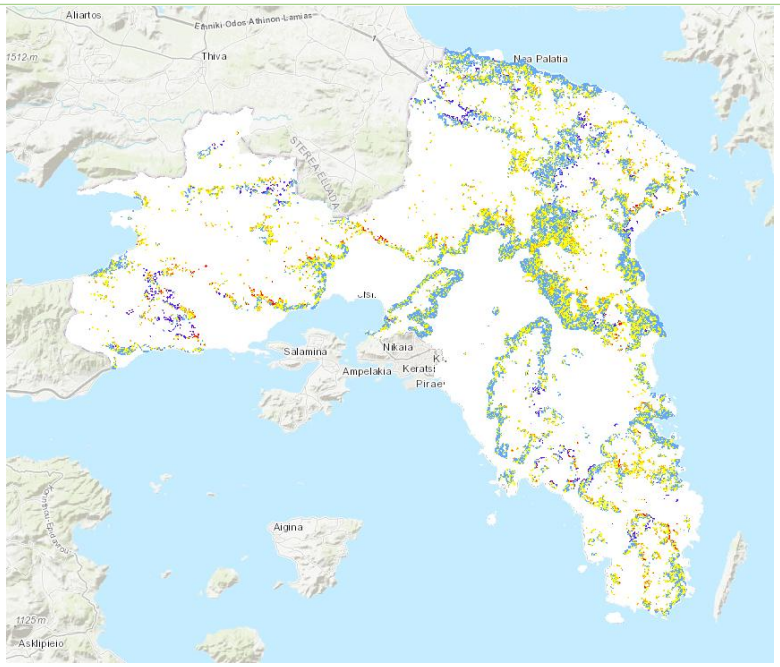


Figure 6. Maps of future changes of Burn Probability in PS5 only within the WUI areas, based on the simulation scenarios SSP1_2050_P95_RCP85 and SSP1_202. Extracted from the Story Map.

3 Showcase of geospatial results of WP2

To showcase the integration and relationship between the geospatial products created in WP2 and other WP, we have created three Story Maps covering the PS in Greece and the DA of Sardinia.

3.1 Greece Story Map (PS5)

The Story map built for PS5, located in the Attica region of Greece, contains information about the general description of the area, which explains the challenging situation for wildfire management due to the extensive areas of Wildland-Urban Interface (WUI). Then, it displays the vegetation and fuel type maps, as well as the wildfire ignitions that occurred in the region from 2020 to 2024, data produced for WP1.

It presents the general schema of the FirEUrisk Fire risk index and then focuses on the work performed in WP2, specifically the analysis of Fuel management for reducing operational ignitions. It shows the map of power lines, roads, and railway networks and shows the final output of their analysis as a map of fuel reduction priority within the buffer areas around the networks. It focused on three specific areas to showcase the areas where the fuel reduction priority is high.

Next, it showed the results of the simulation scenarios that were part of the WP3 activities and explored the consequences of those scenarios for WUI vulnerability. We concluded that even though the maps indicate that changes only within the WUI areas appear relatively mild, there are adjacent areas where the changes are more

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pronounced. These significant changes are expected to substantially increase the vulnerability and exposure of the related WUI areas.
Finally, a section shows the changes in the Fire weather index and its components under different climate scenarios calculated at coarse resolution.

This Story Map integrates the work performed in WP1, 2, and 3 on FirEURisk, focusing on fuel management for fire risk reduction and the analysis of WUI vulnerability to fire.
The link to the Story Map: https://storymaps.arcgis.com/stories/03ba827d168447f0a78e0b4285f57d2c

3.2 Sardinia Story Map (DA4)

The Story map built for Sardinia contains information about most the activities performed on WP2. Sardinia is the second largest island in Europe, with an extension of 24,000 km^2. The region is fire-prone due to its climate and vegetation. Therefore, consistent fuel management is needed to help reduce fire risk. The physical conditions of the island, combined with the partnership established between the Sardinian Forest Service and the CNR, made the development of several trainings for the firefighters and campaigns of prescribed burning possible.

The structure of the Story Map starts by describing the island's land uses and climatic regions. Then, it analyses the recent fire history of Sardinia and includes a map showing the burned areas over the last 5 years. It continues describing the land management suitability analysis performed on D2.4. and details all the prescribed burning activities and prescribed burning trainings developed during the FirEURisk project. The following section presents the results of the analysis of human structures' exposure to fire. The method used for estimating exposure to fire was based on applying a wildfire spread and behavior modeling approach that allowed to derive objective measures of risk variables, such as burn probability, flame length, or wildfire transmission. These measures were integrated into an Incoming fire index (Salis et al., 2021). The last section includes the results of the simulations performed within the WP3 activities, in which the WUI growth is simulated to analyse the future exposure analysis using several climatic scenarios. Knowing the spatial distribution of future risk management plans can help create plans to reduce communities' vulnerability to fire.

This Story Map illustrates the integration of the various tasks in WP2, ranging from training sessions to land management strategy analysis and reducing communities' vulnerability to fire.

The link to the Story Map: https://storymaps.arcgis.com/stories/3face05185b04cc9a4ffa21feae1b4b0

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4 Conclusions

In this document, we reviewed the activities performed on WP2 and reported on the geospatial products developed as a result. WP2 focuses on Fire risk reduction activities. However, the activities performed produced various outputs, including reports, handbooks, training sessions, smoke exposure analysis, and fuel management strategies suitability maps. As stated, most of them were not a geospatial product. However, all results had a spatial reference.

Task 2.5 gathered all the products and geospatial data generated within WP2 to integrate the information and prove the connection between the partners' different activities. Deliverable D2.9 presents a description of the data and focuses on showing the geospatial outputs produced by highlighting their integration and interrelation.

We provided practical examples of how the activities can be integrated within a study area and a demonstration area. Two Story Maps were created to showcase the integration and interrelation of the WP2's activities:

- The Story Map focused on Greece showcases the integration of the work performed in WP1, 2, and 3 on FirEUrisk, focusing on fuel management for fire risk reduction and the analysis of WUI vulnerability to fire.
- The Story Map focused on Sardinia showcases the integration of the different Tasks of WP2, from training sessions to land management strategies analysis and reducing communities' vulnerability to fire.

Story Maps not only allow combining different types of multimedia and visualising geospatial products, but they are also a powerful tool that can be used to communicate and disseminate our results to a broader audience since the output is more visually attractive than a document, and some of the elements are interactive.

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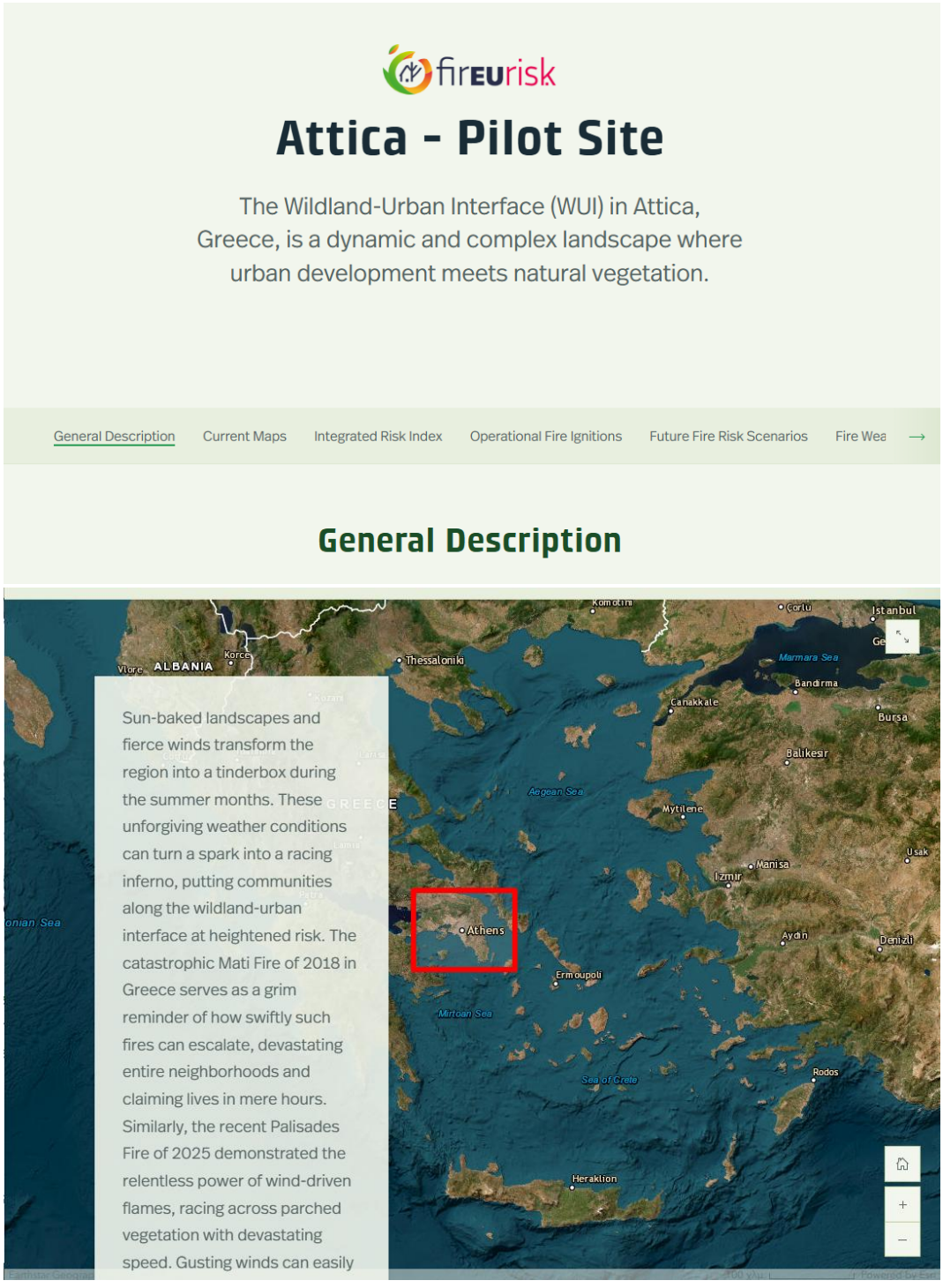
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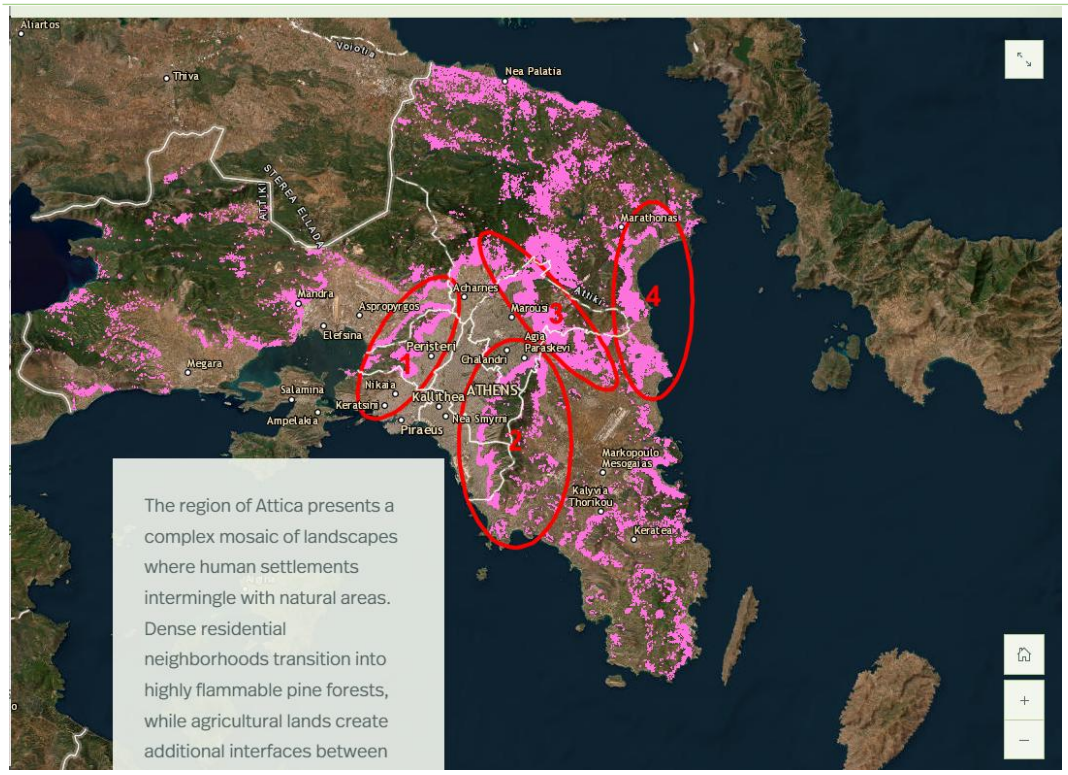
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6 ANNEX A. Story Map of Attica Pilot site

In this section, we present the content of the Story Map, designed to showcase the work done in the PS5 within WP2, with a focus on developing fire risk reduction strategies.



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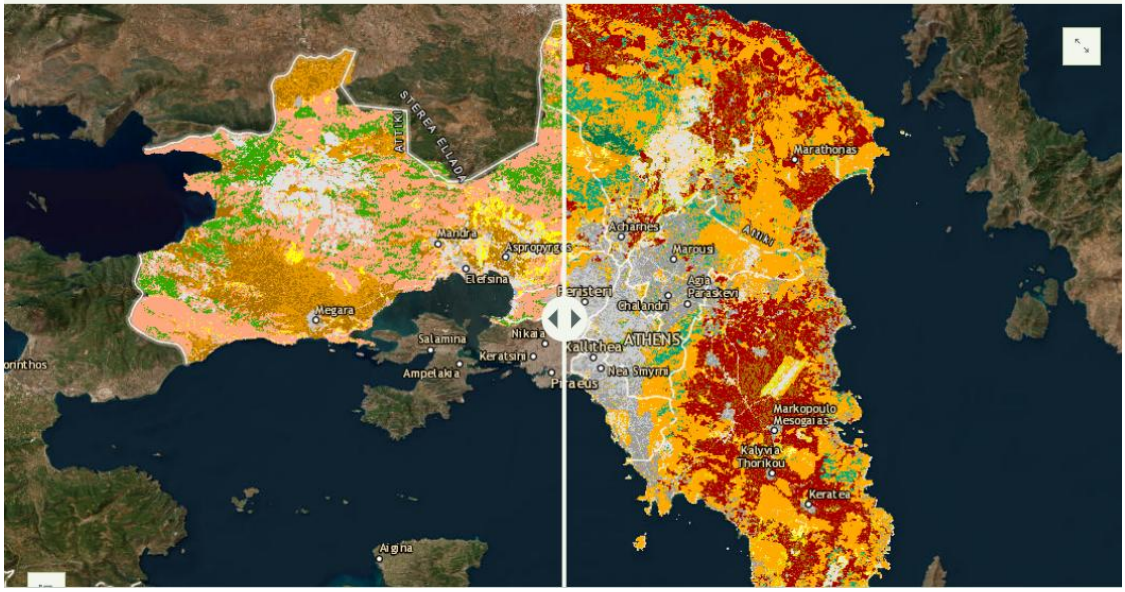


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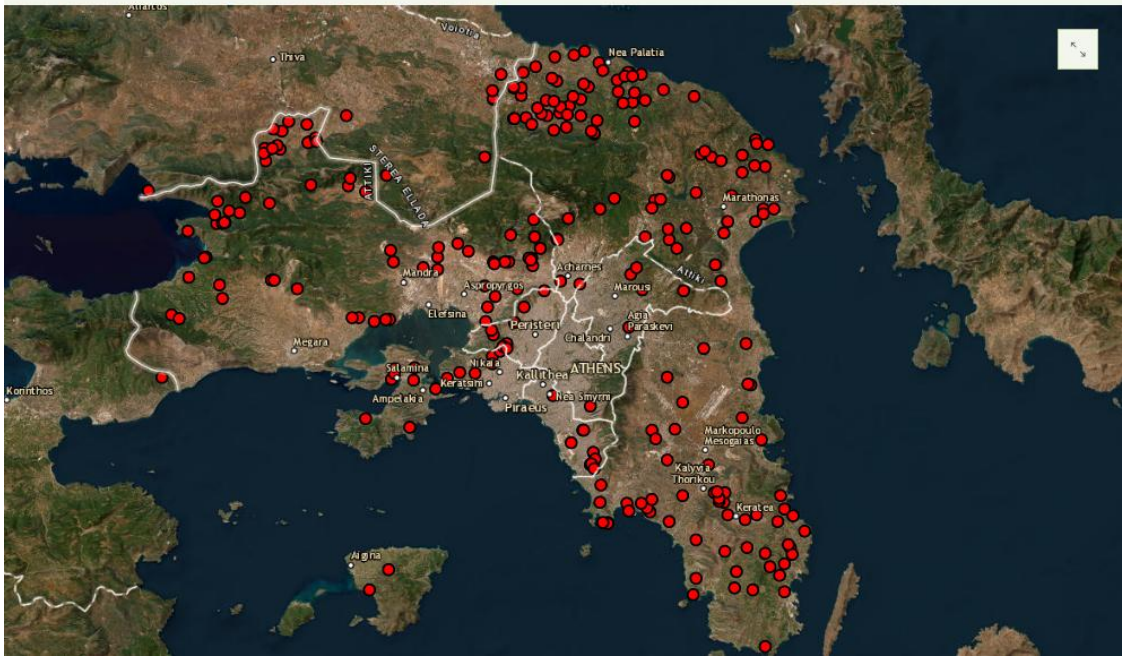
Current Maps

The development of the fuel map was based on a novel hierarchical fuel classification system adapted to the European conditions.

Vegetation Map (Left) **Fuel Type Map (Right)**



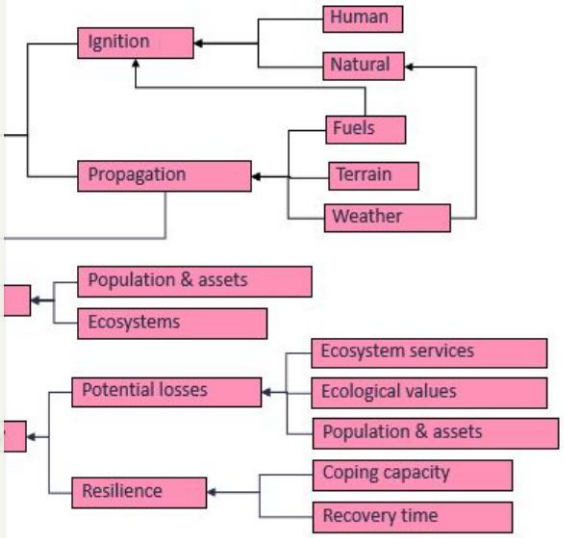
Wildfire Ignitions 2020-2024



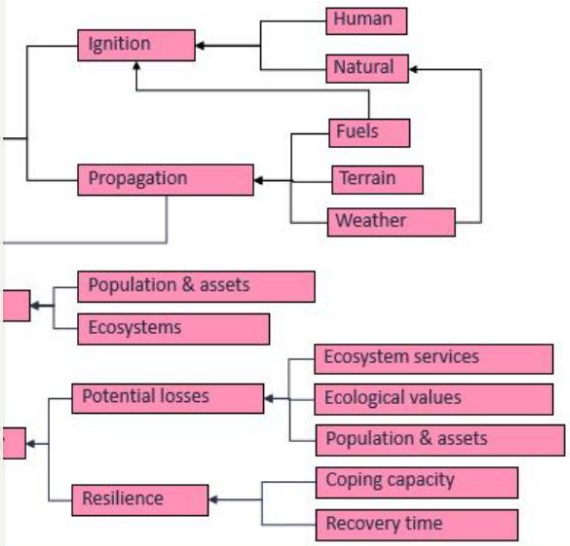
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Integrated Risk Index

- **Danger:** probability (or likelihood) that a fire ignites and propagates in a certain area and period.
- **Exposure** indicates the extension to which people, infrastructure, and other tangible human assets, as well as natural values, could be adversely affected by fires.
- **Vulnerability** refers to the potential damages caused by wildfires on a particular landscape or society, including the losses directly caused by fires but also the ability (or lack of) to recover afterwards Exposure (elements that might be affected).
- Risk = f (Danger, Exposure, Vulnerability).



- ***Social values:*** human assets (houses, infrastructures).
- ***Ecosystem services:*** benefits generated by natural assets such as forest, water, soil, or minerals. For FirEUrisk, timber, perennial crops, livestock and urban values were considered.
- ***Ecological values:*** defined only for the ET area based on species and functional diversity, richness, exceptionality, conservation areas and human pressure.
- ***Resilience:*** indicates the capacity of a certain resource to resist the fire (or to avoid being affected by) and recover the pre-fire value after it occurs. Includes:
- ***Coping capacity / resistance:*** *reduction in the pre-fire values as a result of fire, which was linked to the system resistance, the fire characteristics and the level of exposition.*
- ***Recovery time:*** *Regeneration time and rate.*

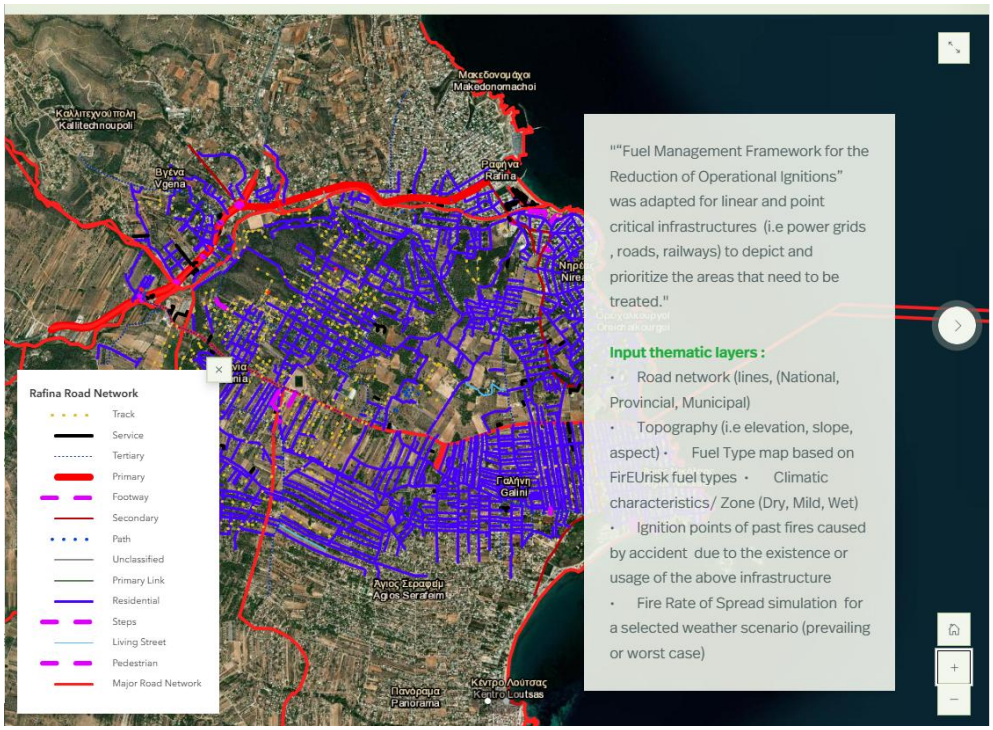


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Operational Fire Ignitions

Fuel Reduction Priorities Along the Rafina Road Network





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Future Fire Risk Scenarios

Simulation of Scenarios

Comparison of Scenarios

Future changes to the WUI in the PS5, up to 2050, involve areas changing from WUI to urban or areas changing from rural or bushland to WUI with the building of new summer or permanent housing.

The assessment of vulnerability and exposure and future changes in the case of this PS is quite complex and depends on factors related on:

- The conditions within the WUI zone in any given time period (i.e. fire weather, fire behavior).
- The WUI distribution in relation to the rest of the landscape and vegetation in the broader of Attica which is also affected by significant fires every year. The type and distribution of vegetation in and around WUI zones play a crucial role. Dense, dry vegetation can act as fuel, making fires more intense and harder to control (Mahmoud et al, 2020).
- The direction of change to and from the WUI environment. The expansion of urban areas into previously rural or bushland regions increases the exposure of homes and infrastructure to wildfires. New developments often occur in areas that are naturally prone to fires, heightening the risk. A significant portion of building losses occurs within close proximity to wildland vegetation. Studies show that 95% of losses happen within 100 meters, and 100% within 850 meters of wildland vegetation (Caggiano et al 2020).

In order to study the changes in the vulnerability and exposure along the WUI in PS5, we followed two steps of analyses a. the estimation and study of fire weather changes in the Attica region through the FWI system indices and b. fire simulations for the estimation of fire behavior within and around the WUI areas with the methodology presented in the Future Fire Risk Scenarios section.

The most important results and maps that are illustrated below, derived from the simulations of the twelve (12) scenarios are presented and discussed for the subareas defined as WUI in the historical (2020) and future period (2050) and for the whole area of Attica in which these WUI areas are included.

For future fire simulations on the PS5, the 90th and 95th percentile values of climate data were generated for both the historical period (1990–2004) and the near future period (2035–2050) under RCP4.5 and RCP8.5 scenarios, specifically for the fire season from June to September.

The input data was resampled at 100m, and the fire behavior assessment was performed at a resolution of 100m as well, with all results being resampled to match the resolution of the more detailed WUI projections (10m), enhancing the analysis change in the propagation potential.

The maps below illustrtate the Rate of Spread, Fireline Intensity, and Burn Probability for the simulation scenarios under SSP1 and SSP3 for the years 2020 and 2050, considering very high fire weather danger (95th percentile) and RCP8.5. These maps indicate that fire behavior is quite severe in most WUI and wildland areas in Attica.

The fire behaviour parameters are projected to increase across all future scenarios. Comparing future and historical values reveals changes ranging from mild to significant.

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Future Fire Risk Scenarios: Analysis and Simulation

The evolution of WUI zones in PS5 through 2050 follows two primary trajectories: existing WUI areas transitioning to fully urban environments, and rural or bushland areas transforming into new WUI zones through seasonal or permanent housing development.

Vulnerability Assessment Framework The assessment of future vulnerability and exposure in PS5 is built on three critical dimensions:

1. Temporal WUI Conditions Dynamic factors within WUI zones, including fire weather patterns and predicted fire behavior, shape the immediate risk landscape.
2. Spatial Context and Vegetation The WUI's position within Attica's broader landscape, which experiences significant annual fires, is crucial. Vegetation characteristics–both type and distribution–significantly influence fire intensity and control difficulty, with dense, dry vegetation serving as potential fuel (Mahmoud et al, 2020).
3. WUI Transition Patterns Urban expansion into rural or bushland areas increases infrastructure exposure to wildfires. Research indicates that wildfire-related building losses are highly concentrated near wildland vegetation, with 95% occurring within 100 meters and all losses within 850 meters (Caggiano et al 2020).

Methodology Our analysis followed a two-pronged approach:

- Evaluation of fire weather changes in Attica using FWI system indices
- Fire behavior simulations within and around WUI areas, following methods detailed in the Future Fire Risk Scenarios section

Simulation Parameters

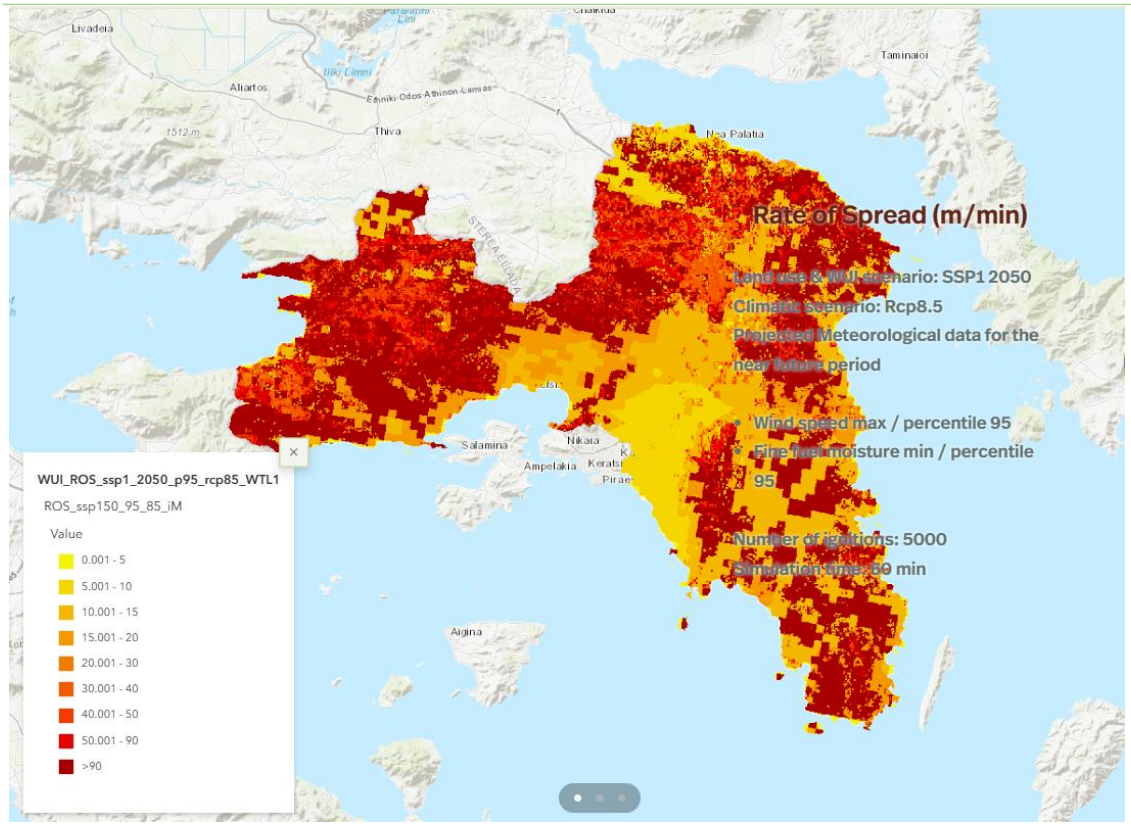
- Temporal scope: Historical period (1990-2004) and near future (2035-2050)
- Climate scenarios: RCP4.5 and RCP8.5
- Season focus: June to September
- Data resolution: Initial 100m analysis, resampled to 10m for detailed WUI projections
- Weather conditions: 90th and 95th percentile values

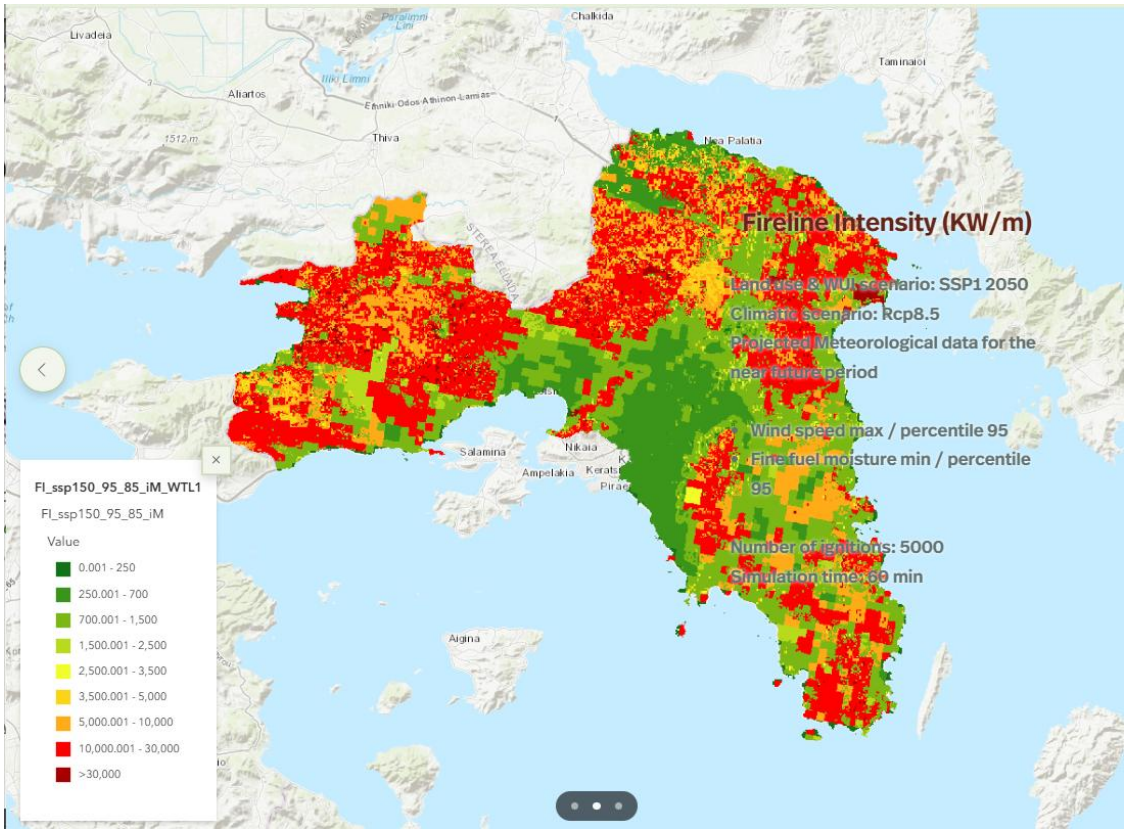
The resulting maps demonstrate Rate of Spread, Fireline Intensity, and Burn Probability across SSP1 and SSP3 scenarios for 2020 and 2050, under RCP8.5 and 95th percentile fire weather conditions. These simulations reveal severe fire behavior potential in most WUI and wildland areas of Attica, with fire behavior parameters projected to intensify across all future scenarios, showing variations from moderate to significant increases when comparing future to historical values."

Simulation of Scenarios

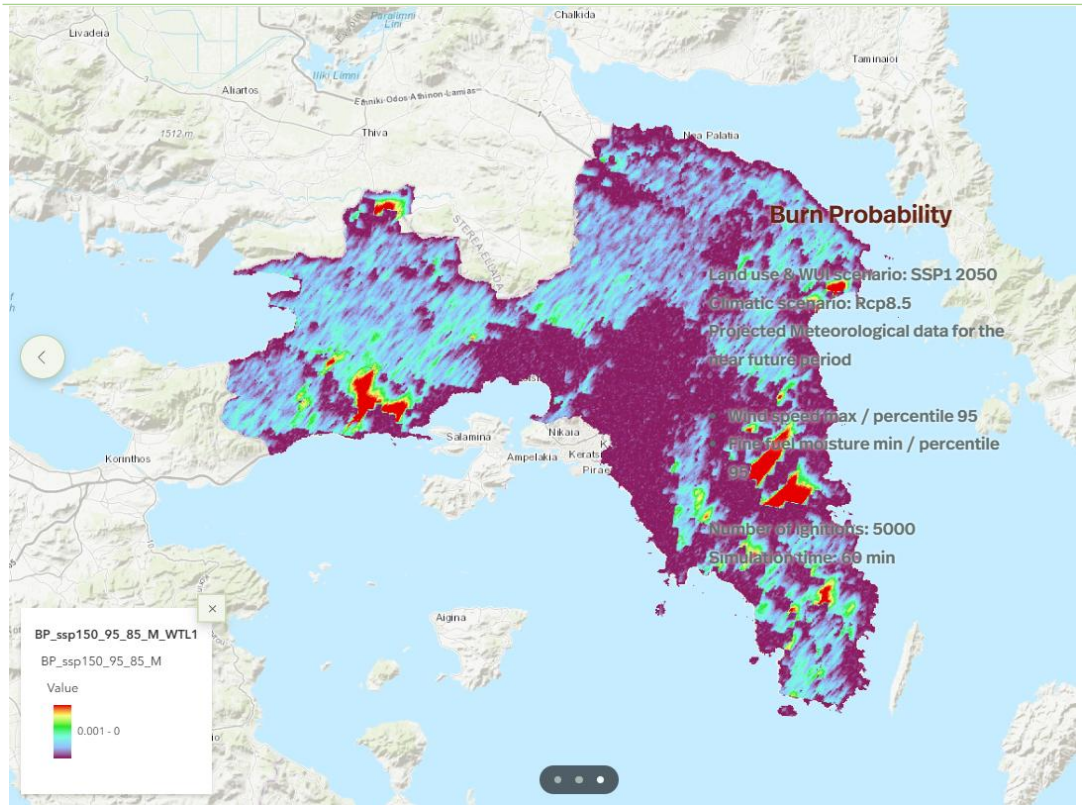
Simulation Scenario SSP1_2050_P95_RCP85

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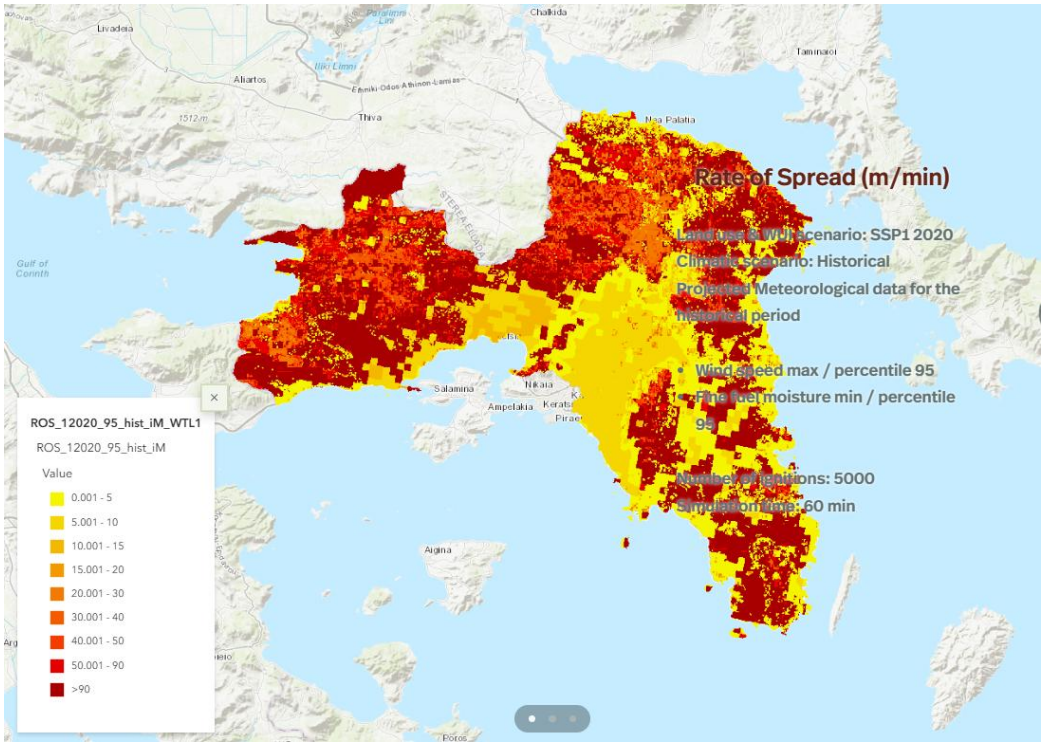




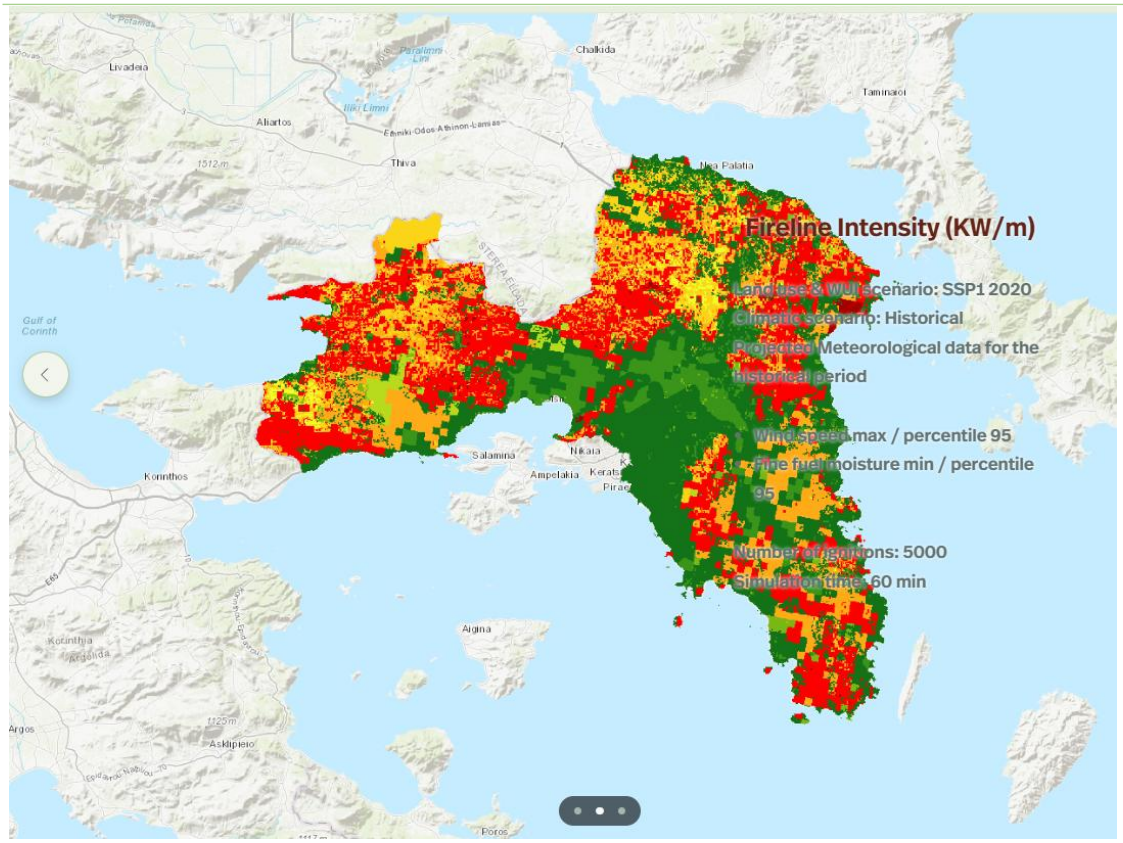
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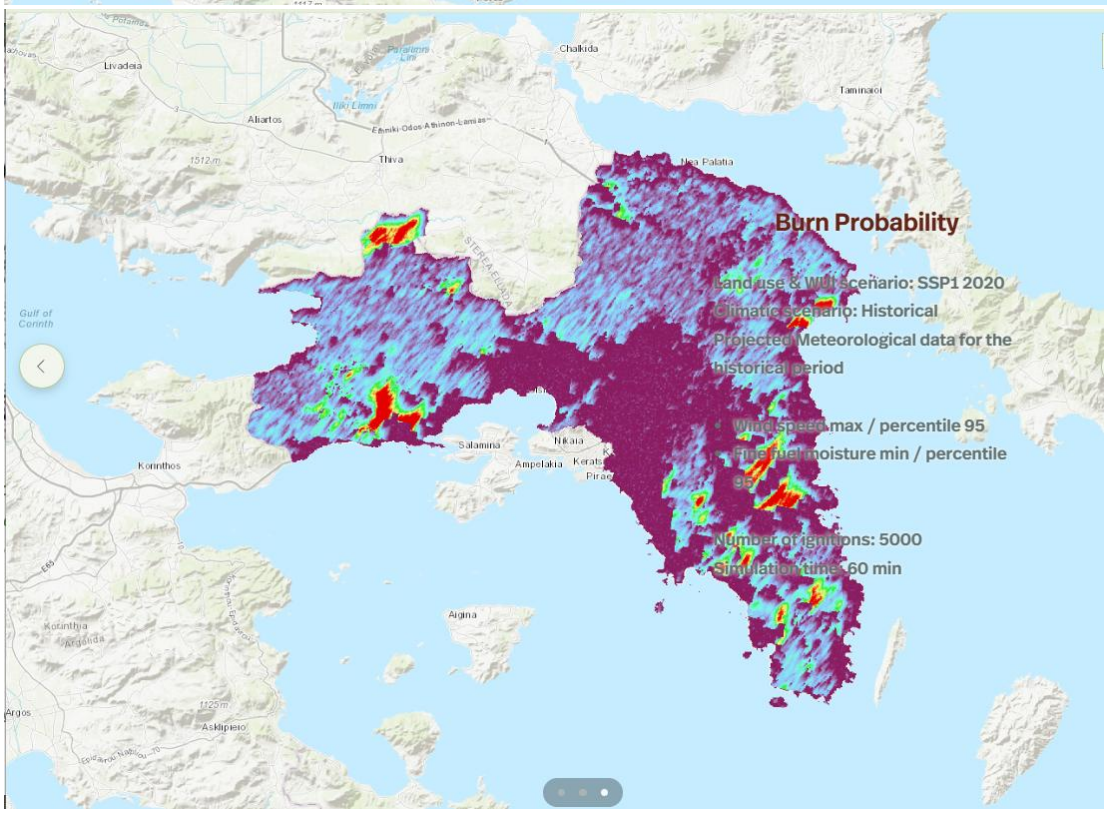


Simulation Scenario SSP1_2020_P95_Hist



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Tables

Scenario	Min	Max	Mean
ssp3-2050_p95_rcp45	1	402	18.2
ssp3-2050_p95_rcp85	2	420	18.6
ssp3-2050_p90_rcp85	1	383	14.1
ssp3-2050_p90_rcp45	1	380	14.02
ssp1-2050_p95_rcp45	2	361	18.18
ssp1-2050_p95_rcp85	2	364	18.38
ssp1-2050_p90_rcp45	2	361	12.2
ssp1-2050_p90_rcp85	2	364	12.4
ssp3-2020_p90_hist	1	359	15.77
ssp3-2020_p95_hist	1	353	17.70
ssp1-2020_p90_hist	1	355	6.49
ssp1-2020_p95-hist	1	352	7.42

Rate of Spread (m/min) within the WUI areas for each scenario

Scenario	Min	Max	Mean
ssp3-2050_p95_rcp45	134	54,313	1217.76
ssp3-2050_p95_rcp85	136	55,388	1231.18
ssp3-2050_p90_rcp85	86	48,564	821.50
ssp3-2050_p90_rcp45	87	48,345	817.45
ssp1-2050_p95_rcp45	134	54,351	1243.07
ssp1-2050_p95_rcp85	136	55,388	1252.86
ssp1-2050_p90_rcp45	86	46,231	723.23
ssp1-2050_p90_rcp85	86	48,345	753.15
ssp3-2020_p90_hist	14	49,265	779.5
ssp3-2020_p95_hist	16	54,910	870.59
ssp1-2020_p90_hist	14	38,800	240.3
ssp1-2020_p95-hist	16	42,086	271.67

Fireline Intensity (kw/m) within the WUI areas for each scenario

The table below presents the maximum, and average burned area from the 60-minute fire simulations for each scenario, for the whole area of Attica. This parameter is important for identifying changes in the size of fires during the first hour of their spread, where the response from firefighting forces is a critical factor in reducing the threat of developing into a significant fire spreading in WUI environments.

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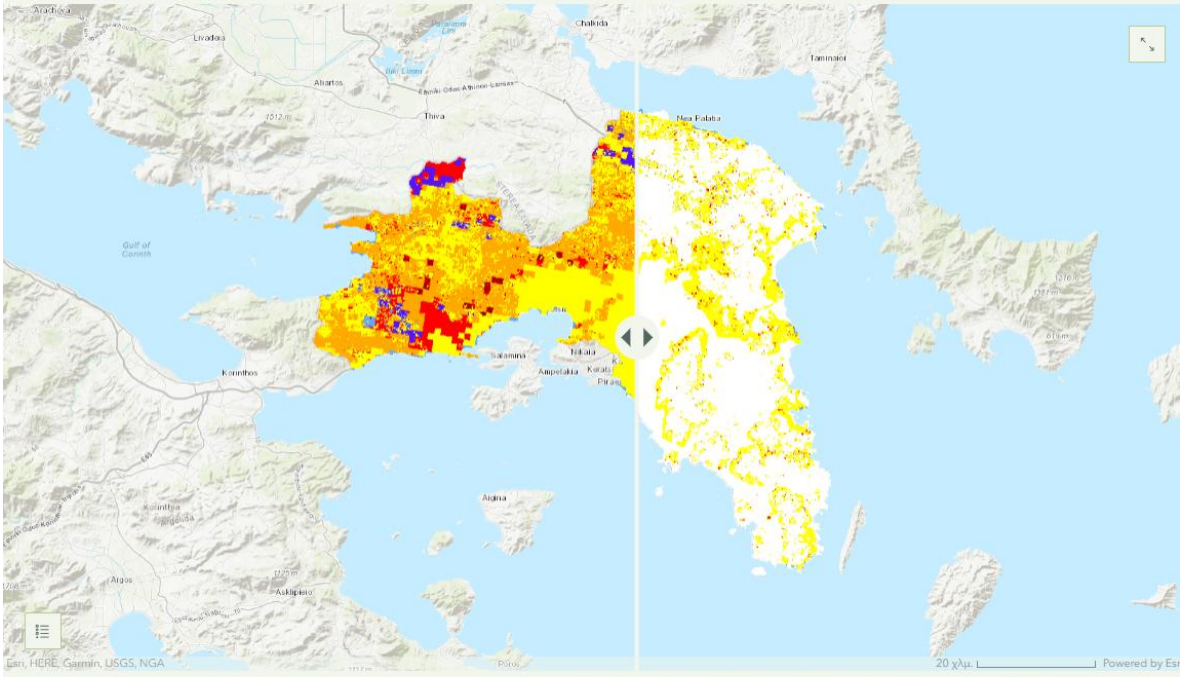
Scenario	Average burned area (ha)	Standard Deviation (ha)	Maximum burned area (ha)
ssp1_2050_P95_rcp45	78.56819	94.77604	862
ssp1_2050_P95_rcp85	79.08237	95.04732	864
ssp1_2050_P90_rcp45	67.4523	89.5573	772
ssp1_2050_P90_rcp85	68.258	89.997	783
spp3_2050_P95_rcp45	93.16724	111.8069	862
ssp3_2050_P95_rcp85	93.90798	112.6723	865
ssp3_2050_P90_rcp45	85.4561	105.3428	768
ssp3_2050_P90_rcp85	86.1327	106.2861	786
ssp1_2020_P90_Hist	68.24484	84.83461	599
ssp1_2020_P95_Hist	71.47342	90.45642	671
ssp3_2020_P90_Hist	70.14436	88.51605	599
ssp3_2020_P95_Hist	73.45815	94.1777	671

PS5- Burned areas in hectares for each scenario in 60 minutes simulation time

Comparison of Scenarios in WUI Area

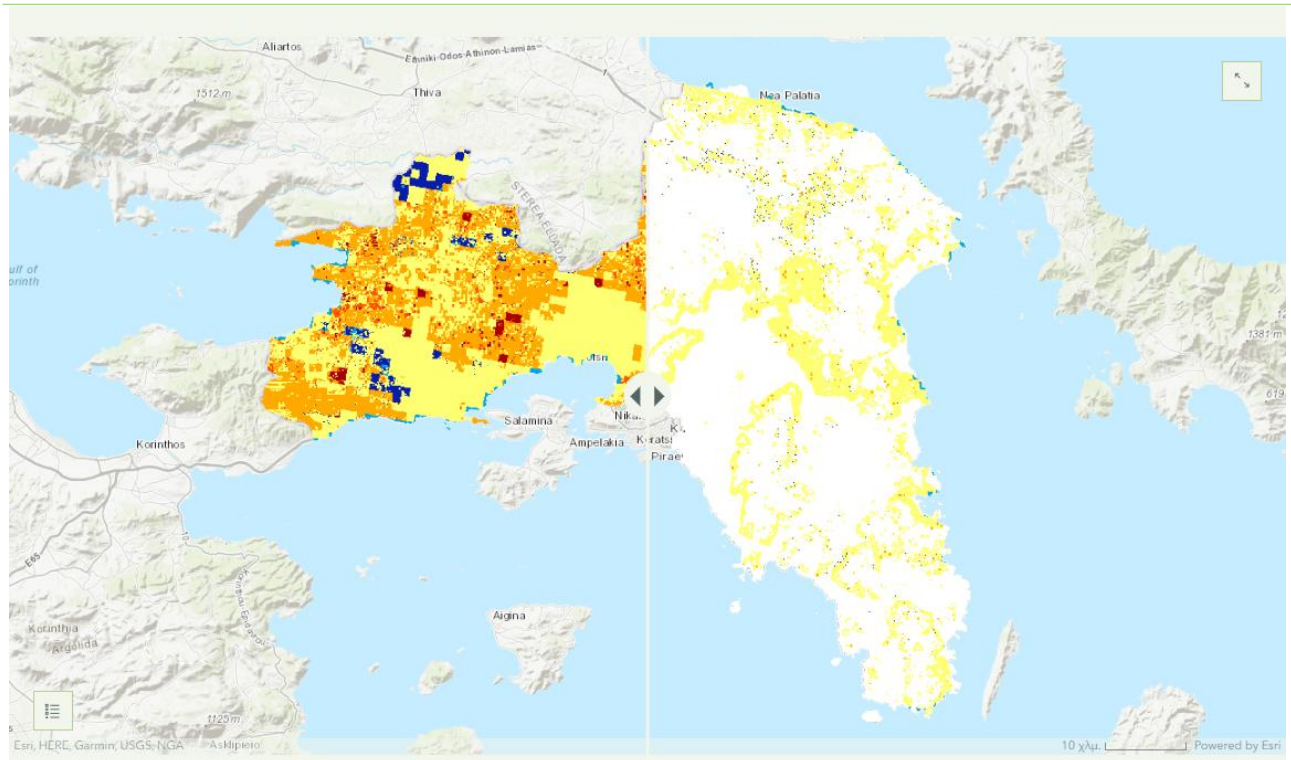
The maps below indicate that while changes only within the WUI areas appear relatively mild, there are adjacent areas where the changes are more pronounced. These significant changes are expected to substantially increase the vulnerability and exposure of the related WUI areas.

Land Use & WUI Scenarios: SSP1 2050 & 2020
Climatic Scenarios: RCP8.5 & Historical
Wind Speed Max / percentile 95
Fine Fuel Moisture min / percentile 95

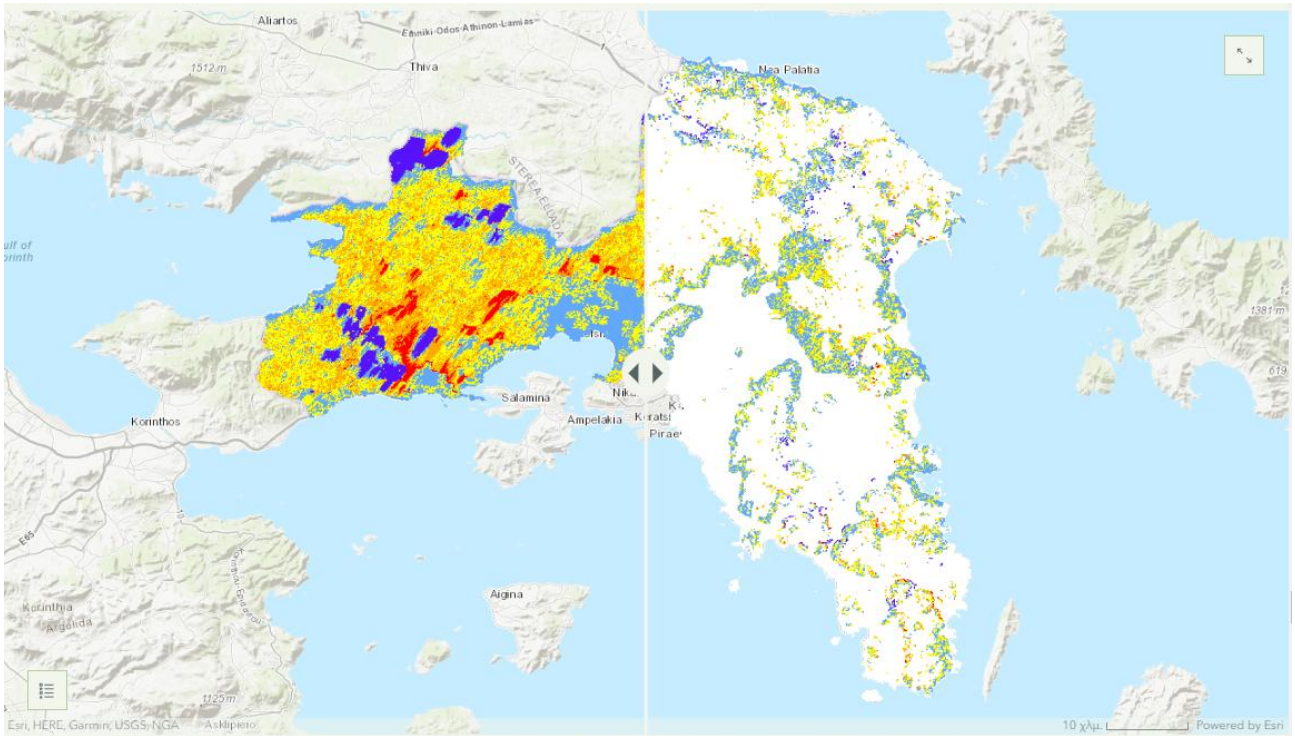


PS5 Maps of future changes of Rate of Spread a) for the whole area and b) only within the WUI areas, based on the simulation scenarios SSP1_2050_P95_RCP85 and SSP1_2020_P95_Hist

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PS5 - Maps of future changes of Fireline intensity a) for the whole area and b) only within the WUI areas, based on the simulation scenarios SSP1_2050_P95_RCP85 and SSP1_2020_P95_Hist



PS5 - Maps of future changes of Burn Probability a) for the whole area and b) only within the WUI areas, based on the simulation scenarios SSP1_2050_P95_RCP85 and SSP1_2020_P95_Hist

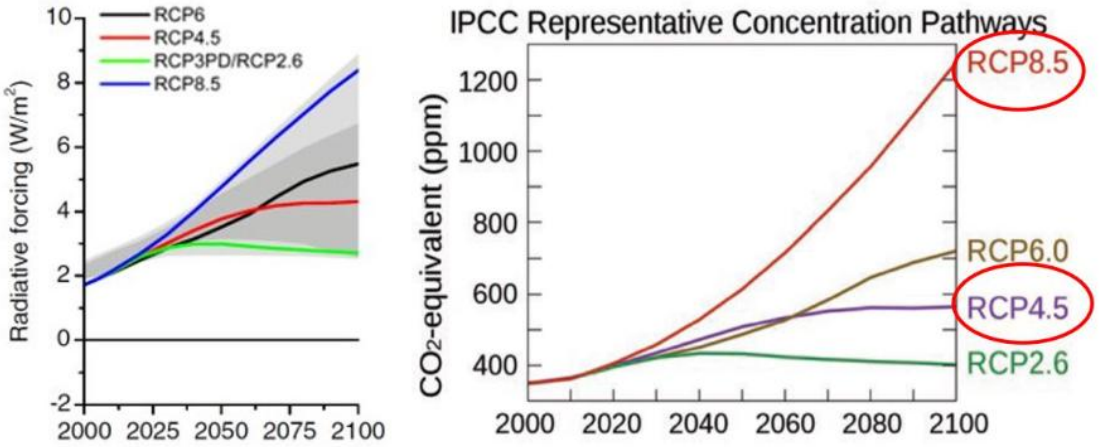
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Fire Weather Danger Assessment under RCP4.5 and RCP8.5 climate Change Scenarios

Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations

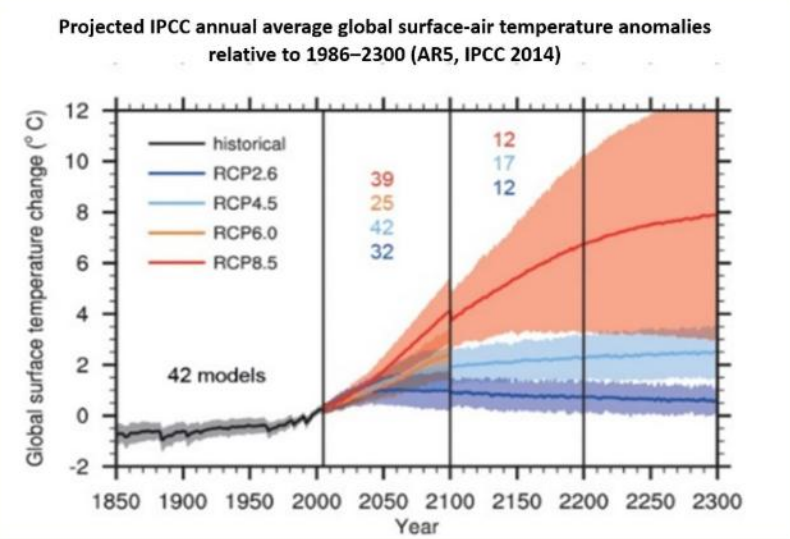
Developed by NCSR "Demokritos" - Nadia Politi, Diamando Vlachogiannis, Athanasios Sfetsos

Representative Concentration Pathways (RCPs) of Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC -AR5, 2014)



Different RCP scenarios result in different predicted greenhouse gas concentrations in the atmosphere (from 2000 to 2100).

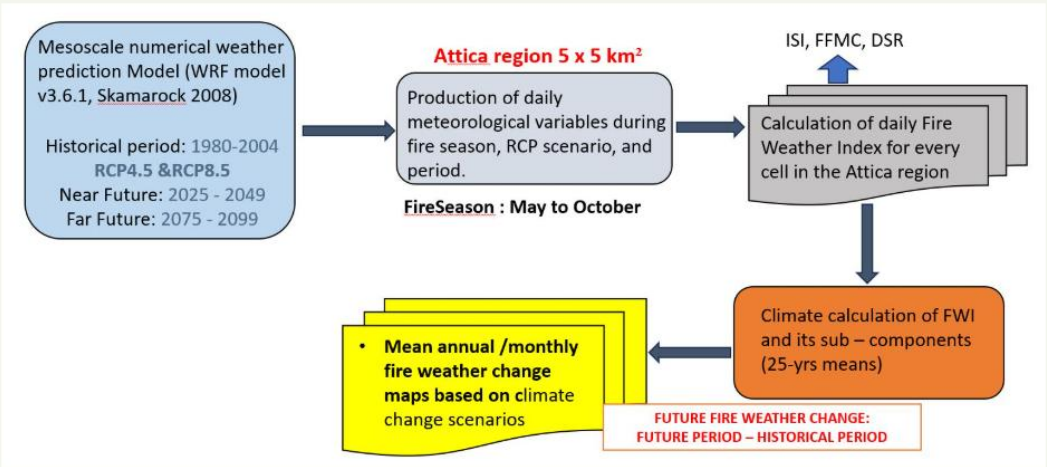
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RCP4.5 & RCP8.5

The pathways describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come. The two most frequently RCPs used by almost all modeling groups (as well for the scope of this work), are RCP4.5 and RCP8.5. The later RCP8.5, regarded as the most severe scenario, is built on the assumption that the emissions rise throughout the twenty-first century (Riahi et al. 2011) implying at its end a radiative forcing of 8.5 W/m2 relative to the pre-industrial era. On the other hand, RCP4.5 (Clarke L. et al. 2007; Moss et al. 2010) scenario represents an increase of 4.5 W/m2 in radiative forcing relative to the pre-industrial era. It is a scenario according to which emissions peak around 2049 and stabilize until 2099 by the employment of a range of technologies and strategies for reducing greenhouse gas emissions. By the year 2099, the corresponding RCP4.5 and RCP8.5 greenhouse gas concentrations become equivalent to 650 and more than 1370 parts per million (ppm) carbon dioxide (CO2), respectively, (Moss et al. 2010).

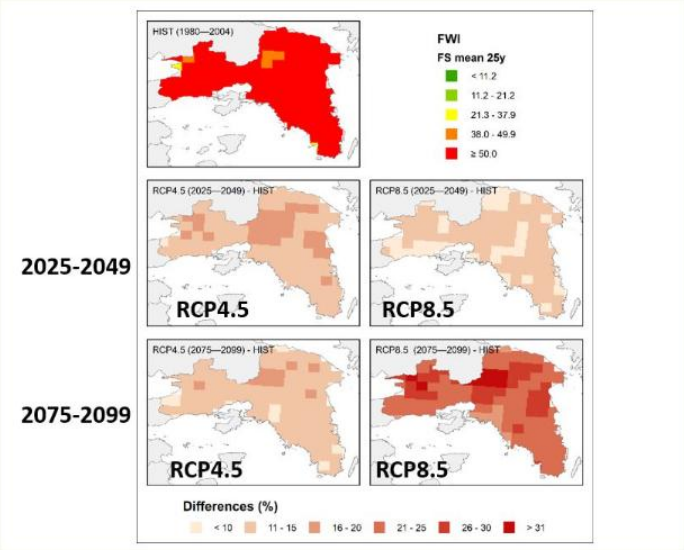
Scheme representation of the working methodology



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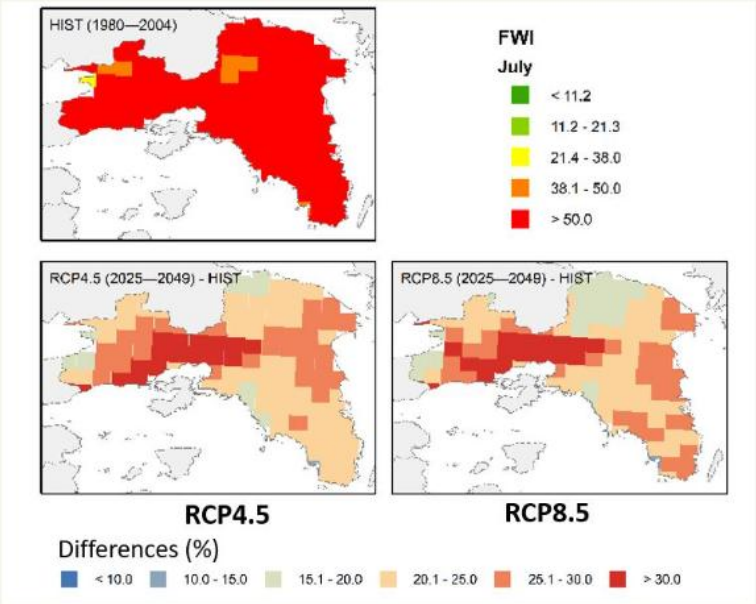
Products

Estimation of mean FWI change for the Fire season in the near and far future for RCP4.5 and RCP8.5



Increase of >10-20% in the near future under both scenarios
Increase of >30% in the far future under RCP8.5

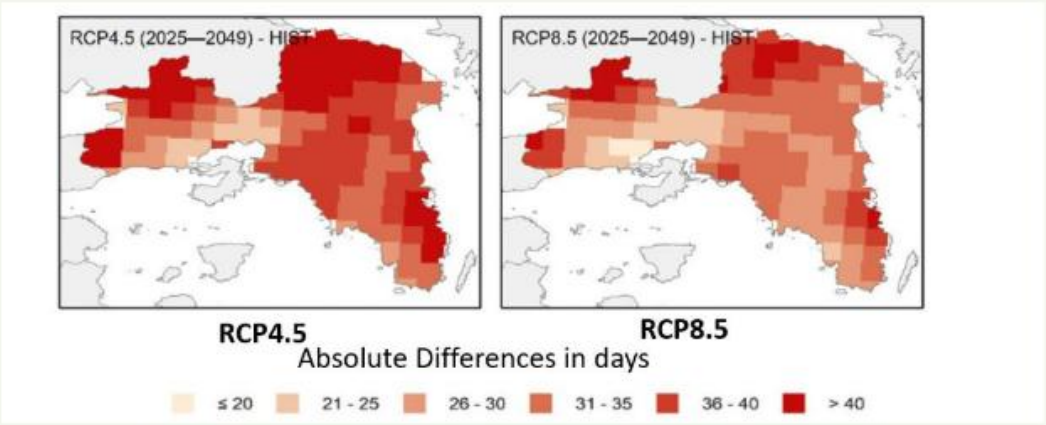
Estimation of mean monthly (JULY) FWI change in the near future for RCP4.5 and RCP8.5



Notable increase under both scenarios, especially in July (>25%)

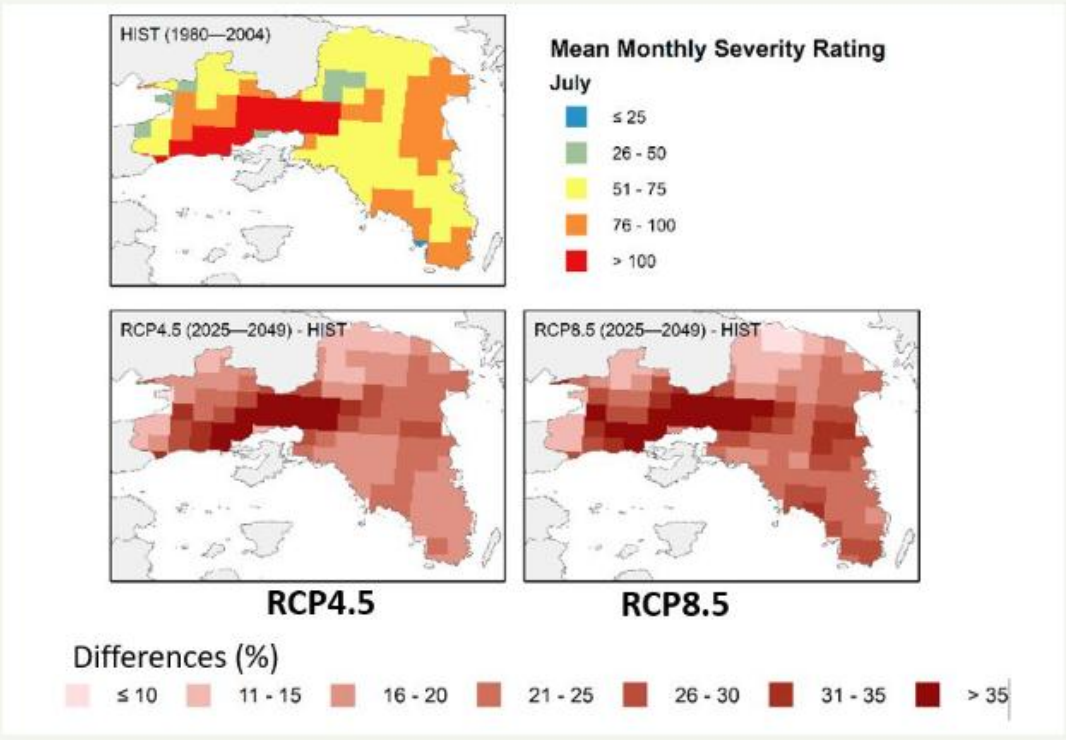
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Absolute differences of Number of days with FWI > 50 in the near future under RCP4.5 και RCP8.5 for the entire fireseason



Increase in the number of days with extreme fire weather danger in both scenarios.

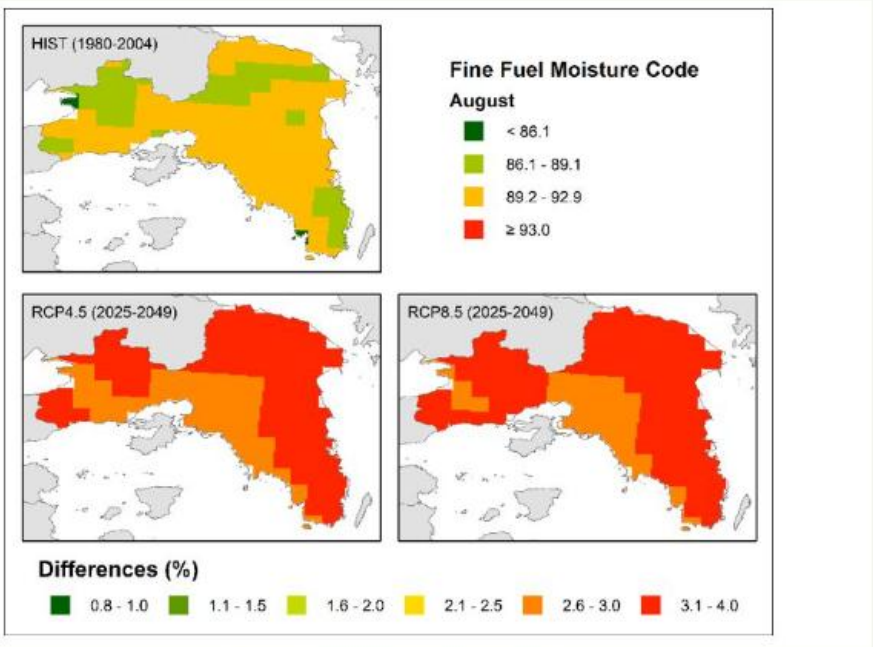
Estimation of mean Monthly (JULY) Severity Rate (DSR) change in the near future for RCP4.5 and RCP8.5



Notable increase under both scenarios in July

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Estimation of mean monthly (JULY) FFMC change in the near future for RCP4.5 and RCP8.5



Increase under both scenarios of >2,5%

Main Conclusions

- The future assessment of the I fire weather index FWI, in the context of climate change, indicated a consistent increase in fire risk throughout the pilot area. Similar results were also observed for the sub-components (FFMC, DSR).
- The high spatial resolution of 5x5km² distinguishes areas with a smaller or larger increase for the near future under both climate change scenarios.
- Similar or greater increase of FWI and DSR is observed in the near future under the intermediate scenario (RCP4.5), while the increase in the far future is greater under the worst scenario (RCP8.5).
- These results could raise awareness of the authorities of civil protection and may support the development of fire risk management policies in a national plan for fire management and prevention of forest fires to reduce the risk of wildfires and enhance climate change adaptation.

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Handbooks

The risk of wildfire has rapidly evolved in Europe in the recent years, causing new challenges for responders:

- Extreme fires and extreme fire behaviours;
- Fires in the wildland-urban interfaces;
- Fires in higher altitudes and higher latitudes which were not so impacted before.

Observing and anticipating such developments, scientists are constantly producing knowledge about the risk. However, the transfer of this knowledge to responders and the transformation into guidelines is insufficient because of the gap between the research and the operational communities. Additionally, the firefighting community is very fragmented in Europe – with local / departmental / regional / national authorities – which makes the levels of training very disparate. As a result, responders are insufficiently informed and prepared to face the new challenges associated with wildfires. This hamper both their efficiency and their safety.

The "Handbook with Guidelines for fire fighters to face to extreme fires, fires in WUI and fires in high latitudes/ altitudes" compiles the outputs of the research on fire behaviour done by FirEUrisk partners. This research is presented in a simplified form, so that it is accessible to practitioners. The first chapters detail the fundamental of fire behaviour and then the extreme fire behaviours. The following chapters describe fires in specific areas – WUI, high altitude and high latitude; and the mechanism of smoke emission and dispersion. The final chapters analyse firefighting methodologies in different contexts and then provide safety recommendations and study cases.

About

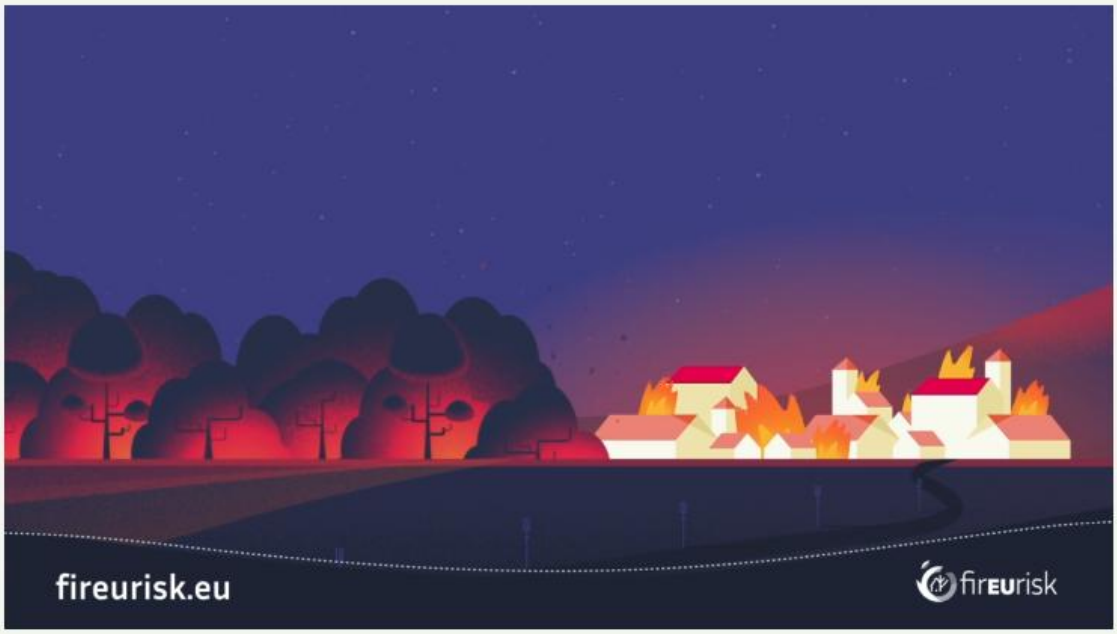
Story Map Creators
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7 ANNEX B. Story Map of Sardinia (DA4)

In this section, we present the content of the Story Map, designed to showcase the work done in DA4 within the activities of WP2, with a focus on integrating the job done within the work package.



Fire Risk Reduction Strategies in Sardinia

Sardinia encompasses many of the activities perform in WP2 of FirEUrisk project, showcasing the Integrated Fire Managing approach.

Patricia Oliva (UAH), Michele Salis (CNR), Liliana del Giudice (CNR)

8 de marzo de 2025

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Introduction

Wildfires are an important disturbance agent to European forests and rural areas, causing significant damage to ecosystems, human infrastructure, and in some cases, the loss of human lives. The Mediterranean region has historically been the most affected by fires within Europe. In the last two decades, more than 1 million wildfires have ignited in southern Europe, burning approximately 7.6 million hectares (San Miguel-Ayanz et al., 2020). Even though a decreasing trend in the number of fires and total burned area has been observed in southern European countries (Andela et al., 2017; Turco et al., 2016), extreme wildfire events occur more frequently, derived from the meteorological and forest management conditions (6, 7, 8).

The concept of Integrated Fire Management (IFM) has been introduced in the last decade to define a management approach aimed at reducing the extent and severity of extreme wildfires and mitigating the impacts of large catastrophic fire events while maintaining biodiversity, ecosystem services and human wellbeing (Fernandes, 2020). Some of these actions include different types of fuel treatments such as controlled and prescribed burning, silviculture treatments, understory reduction, and grazing. To achieve its goals, IFM needs the support of fire science, fire policy and local communities through a strong cross-sectoral and interdisciplinary collaboration between experts from different sectors and disciplines that can address ecological, economic, and social aspects of fires.

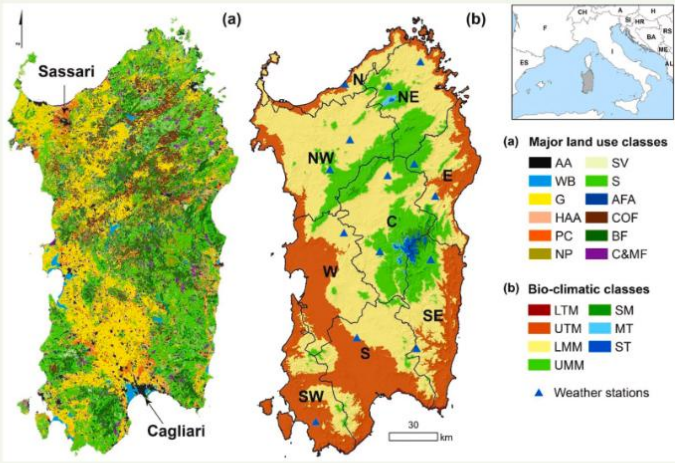
Developing adequate and effective strategies to reduce fire risk and wildfires' ecological and social impacts remains challenging, especially when considering long-term perspectives and the spatial diversity in wildfire regimes and socio-environmental driving factors of the different European countries (Salis et al., 2021). Within this context, WP2 of FirEUrisk, focusing on Fire Risk Reduction, performed several activities to help reduce Fire risk in Europe:

1. Review the fire management and suppression policies to assess each country's situation and propose changes (D2.1 Guidelines for reducing fire ignitions).
2. Create priority areas to reduce human-caused accidental fire ignitions (D2.1 Guidelines for reducing fire ignitions).
3. Analysing the suitability of fuel management strategies in Europe (D2.3 and D2.4).
4. Increasing public awareness of wildfire risk and safety (D2.2).
5. Improving fire managers' and first responders' training and knowledge (D2.2 and D2.6).
6. Analysing population exposure to smoke (D2.5)
7. Analysis of large fires' impacts to guide fire and fuel management and planning (D2.7).

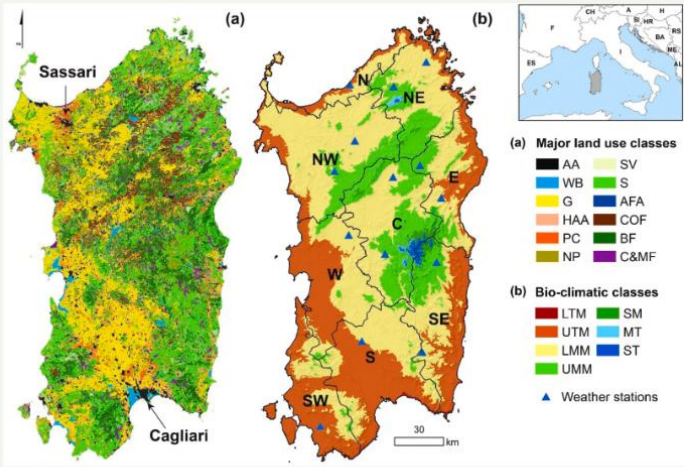
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Sardinia's land cover

Sardinia, Italy, is located in the western part of the Mediterranean Basin and encompasses about 24,000 km^2 (Fig. 1). Sardinia is the second largest island of the Mediterranean Basin and one of the most relevant fire-prone areas. Approximately 1.7 million people live in the area year-round, mostly near the main towns of Cagliari and Sassari, but this number grows from April to October due to the tourist fluxes towards the coastal areas. The island's topography consists of rolling hills and low mountains, mainly on the eastern side. The average elevation is about 350 m above sea level (a.s.l.), while the highest peak is 1850 m a.s.l. The largest plains, i.e., Campidano in the South, and Nurra in the North, are in the western part of the island.



Approximately half of the island is covered by forest fuels. Broadleaf forests (~23%) are mostly represented by *Quercus ilex* L., *Q. suber* L., *Q. pubescens* Willd. and *Q. congesta* Presl. (Fig. 1*a*). At higher elevations, *Q. pubescens* Willd. is the most representative oak formation, and *Castanea sativa* Mill., Taxus *bacata* L. and *Ilex aquifolium* L. are also present. Mediterranean shrubs and garrigue (~27%) comprised primarily of *Pistacia lentiscus* L., *Arbutus unedo* L., Erica arborea L., *Myrtus communis* L., *Olea europea* L. var. *sylvestris* Brot., *Phyllirea spp., Juniperus spp.*, Cistus *spp. and* Euphorbia *spp.*. With the progressive abandonment of forest and rural areas, the shrubland vegetation type gradually evolves towards high-fuel load shrublands and broadleaf forests. Conifer stands (~2%) are primarily concentrated in the coastal areas and mostly include plantations of Pinus pinea L. and *P. halepensis* Mill.. A significant portion of Sardinia, particularly in the western part, is covered by grasslands, mixed agricultural areas, and herbaceous pastures (~40%) (Fig. 1*a*). Permanent crops include olive groves, vineyards and orchards, and cover about 3% of the territory. Urban and anthropic areas, which were mapped from high-resolution data and cover approximately 4% of Sardinia.

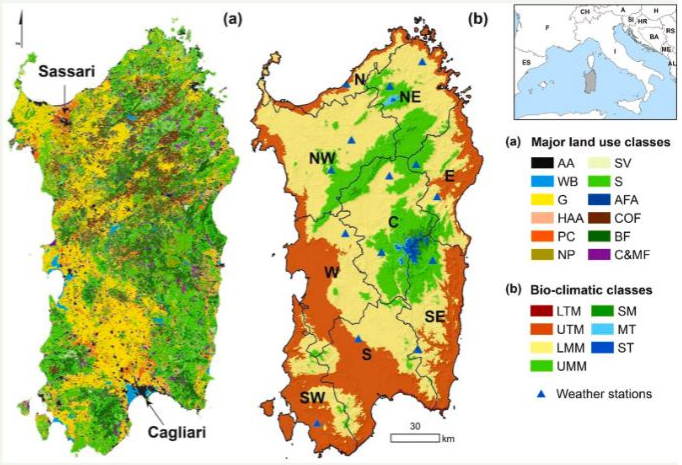


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Fig. 1. (a) **Major land use classes of Sardinia**, Italy, according to the 2008 Sardinia Land Use Map (www.sardegnageoportale.it), along with the main towns. AA= anthropic areas; WB = water bodies; G = grasslands; HAA = heterogeneous agricultural areas; PC = permanent crops; NP = natural pastures; SV = sparse vegetation; S = shrublands; AFA = agro-forestry areas; COF = cork oak forests, BF = broadleaf forests; C&MF = conifer and mixed forests.

(b) **Bio-climatic classification of Sardinia**, along with the meteorological stations used for the definition of the dominant wind direction scenarios. LTM = lower thermomediterranean; UTM = upper thermomediterranean; LMM = lower mesomediterranean; UMM = upper mesomediterranean; SM = supramediterranean; MT = mesotemperate; ST = supratemperate.

Figure from Salis et al. 2021

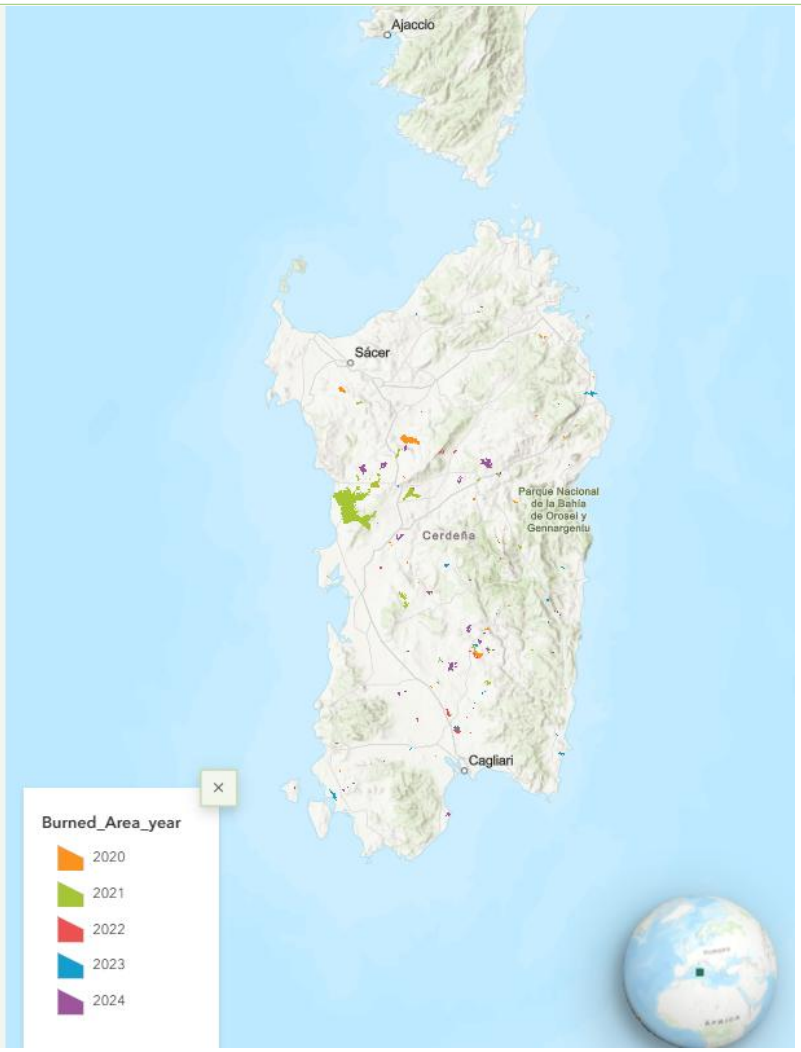


Fire occurrence

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To determine historical patterns of wildfire ignitions and spread in Sardinia, we used data provided by the Sardinia Forest Service from 2000 to 2023. The wildfire database contains date and municipality of ignition, ignition coordinates, and fire size; since 2003, wildfire perimeters are also available.

About 60% of Sardinian wildfire ignitions are concentrated in Campidano, the large plain located in southern Sardinia. The years with annual burned area greater than 30,000 ha were associated with prolonged drought conditions, intense heat waves and strong winds, and fine dead fuels accumulation. On the other hand, five years had annual area burned lower than 9000 ha. Wildfires largely (>90%) occurred from June to September, with an evident peak of ignitions and area burned in July. Most wildfires have anthropogenic causes (>95%) and approximately 93% of all fires burned less than 10 ha, accounting for only 17% of the total area burned (Fig. 2). While only the 3% of the burned areas produced the 60% of the total area burned.



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In the map, we can observe a large fire occurring in 2021 near Bosa on the west coast of Sardinia, while in 2024, there were many medium-sized fires all over the island.

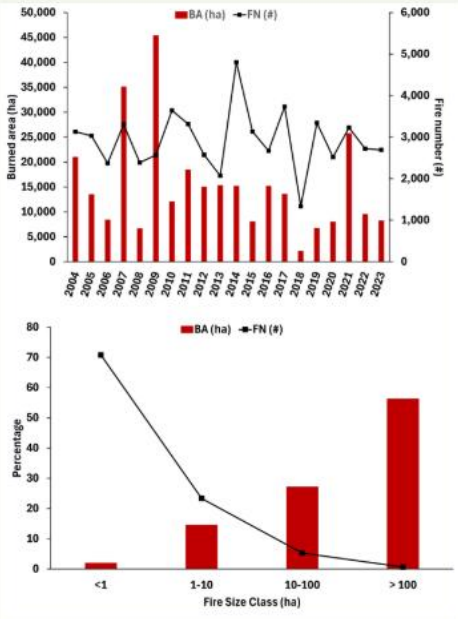
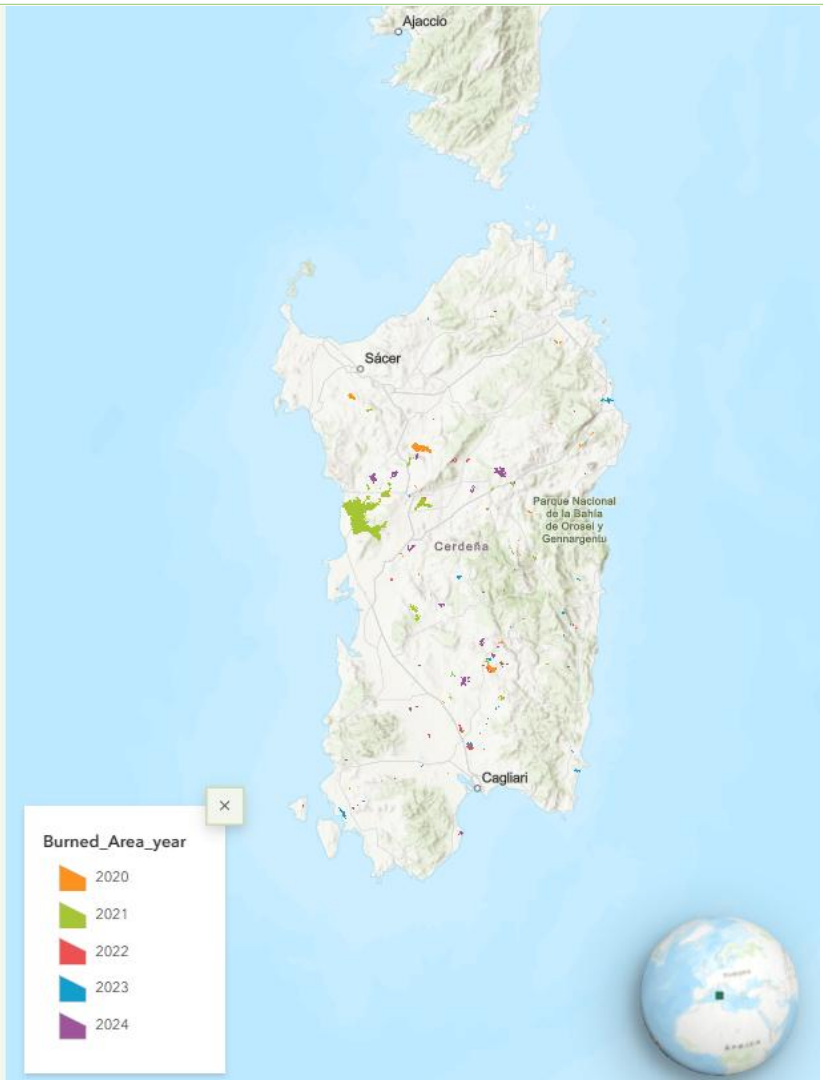


Fig. 2. The top plot represents the number of fires and burned areas from 2004 to 2023 in Sardinia. The bottom plot represents the percentage of fires and the number of burned areas by fire size in Sardinia.



Fire management

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Land management strategies (LMS)

Sardinia represents a typical Mediterranean coastal area where shrubs and pastures cover most natural areas. That disposition makes the island suitable for using prescribed burning and grazing as fuel management strategies to reduce fire risk.

In addition, in the forested areas covered by holm oak, cork oak, and pubescent oak, those two fuel management strategies are also used to maintain the production and good health of the trees.

However, some of these practices may result in wildfires due to the lack of knowledge of rural citizens.

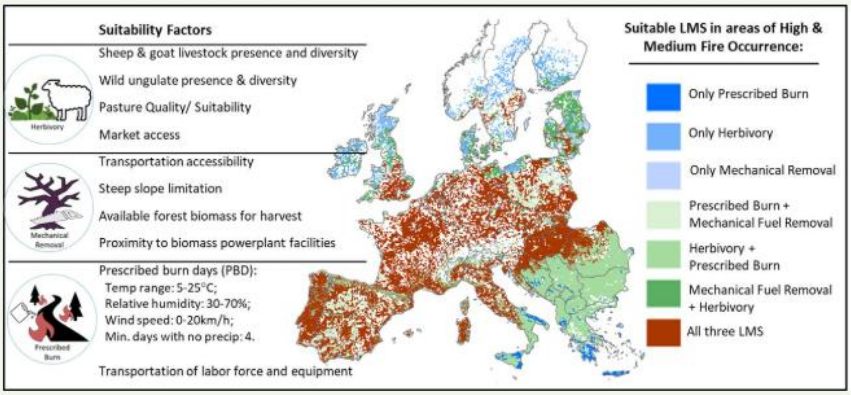


Fig. 3. European map of suitable LMS in areas of high and medium fire occurrence. The three LMSs considered were Herbivory, Mechanical fuel removal, and prescribed burning. This figure was extracted from D2.4 "Map of LMS options at European scale".

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Prescribed burning

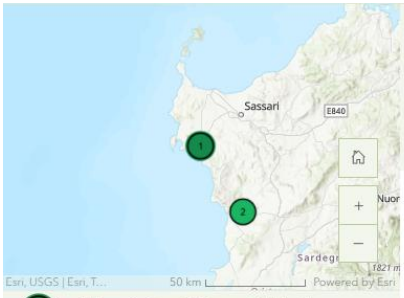
The term Prescribed Fire (PF) or Prescribed Burning (PB) refers to the planned use of fire, adopting specific prescriptions and operating procedures, to achieve precise and clearly defined objectives. This technique is characterized by legislative prescriptions, i.e., precise indications regarding the season and frequency of burnings, environmental conditions in which performing the activities, and techniques to be adopted to control fire characteristics and potential behavior.

Large areas of central and northern Sardinia are characterized by agroforestry management, with extensive livestock farming: in these areas, fire has been largely used as pasture management tool in the past. Today, such agro-silvopastoral zones are increasingly affected by abandonment, resulting in an increasing risk of severe and extreme wildfire spread, due to heavy fuel load, the horizontal and vertical continuity of fuels, and a hilly orography.

The use of fire could enable better management of these areas and thus could become a tool for preventing wildfires with severe and extreme behavior, as well as to support grazing management and weed control. Unfortunately, the window for the implementation and application of prescribed burning interventions (usually in September in areas mostly covered by herbaceous fuels), especially with dry fuels and relatively risky weather patterns, could conflict with

the laws and regulations of the Sardinian Region.

After a first collaboration with the Sardinian Forest Service (CFVA) in training on techniques for conducting controlled burnings and, in general, on the use of fire for prevention activities, the positive results encouraged the continuation of the training sessions that were performed as part of the activities of Task 2.2.



1 Municipality of Alghero

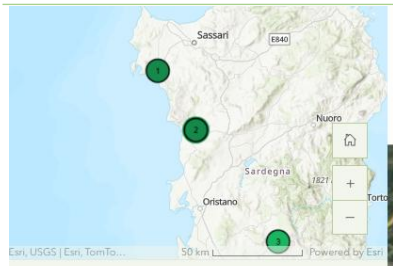
Sardinian Forest Service training (October 2023)

The prescribed burning plan to be carried out in the municipality of Alghero (location of Surigheddu), prepared by the territorial Inspectorate of Sassari, was characterized by two main objectives: (1) to conduct several training sessions aimed at training personnel engaged in wildfire prevention and fighting; (2) to carry out fuel management interventions, through controlled burnings, in a public area



01 /

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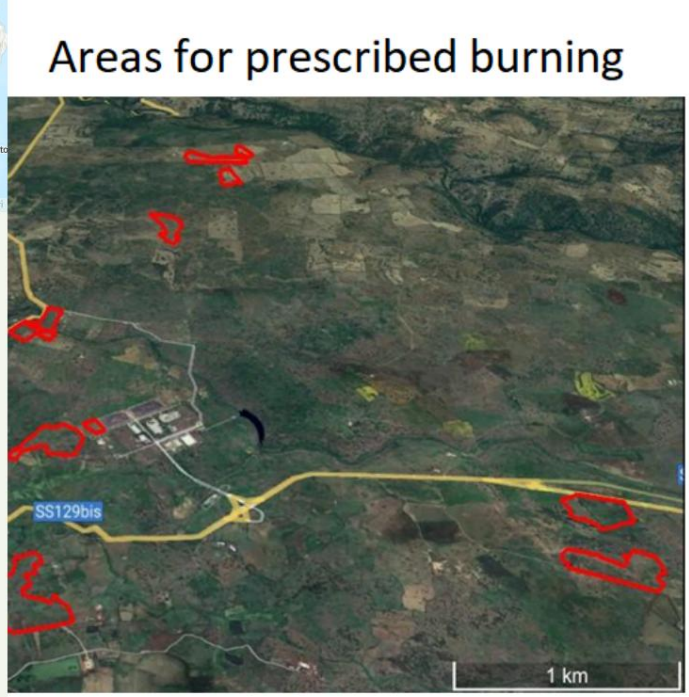
2 Municipality of Suni

Prescribed burning campaign of 100 ha in September-October 2023.

The idea of a collaboration among the Sardinia Forest Service (CFVA), the local communities, and the stakeholders who, at the local level, have an interest in better management of agro-pastoral territories was first developed in the municipality of Suni, where a pilot activity was established.

02 / 04

Pictures adapted from D2.2 Report on training sessions for agricultural uses of prescribed burnings









3 Municipality of Isili

In the Isili municipality (central Sardinia), prescribed burnings carried out in 2021 and 2022 involved an agro-silvopastoral area with variable canopy cover but in some cases, with closed vegetation trees. The use of fire was aimed at reducing shrub biomass and necromass and ensuring the vertical continuity of vegetation. The area treated is located within a penitentiary colony with a large forest area that requires preventive interventions, particularly near a provincial road that could be a source of ignitions.

03 / 04



Methods to charge and use the drip torches.



Training on the use of blowers-sprayers.

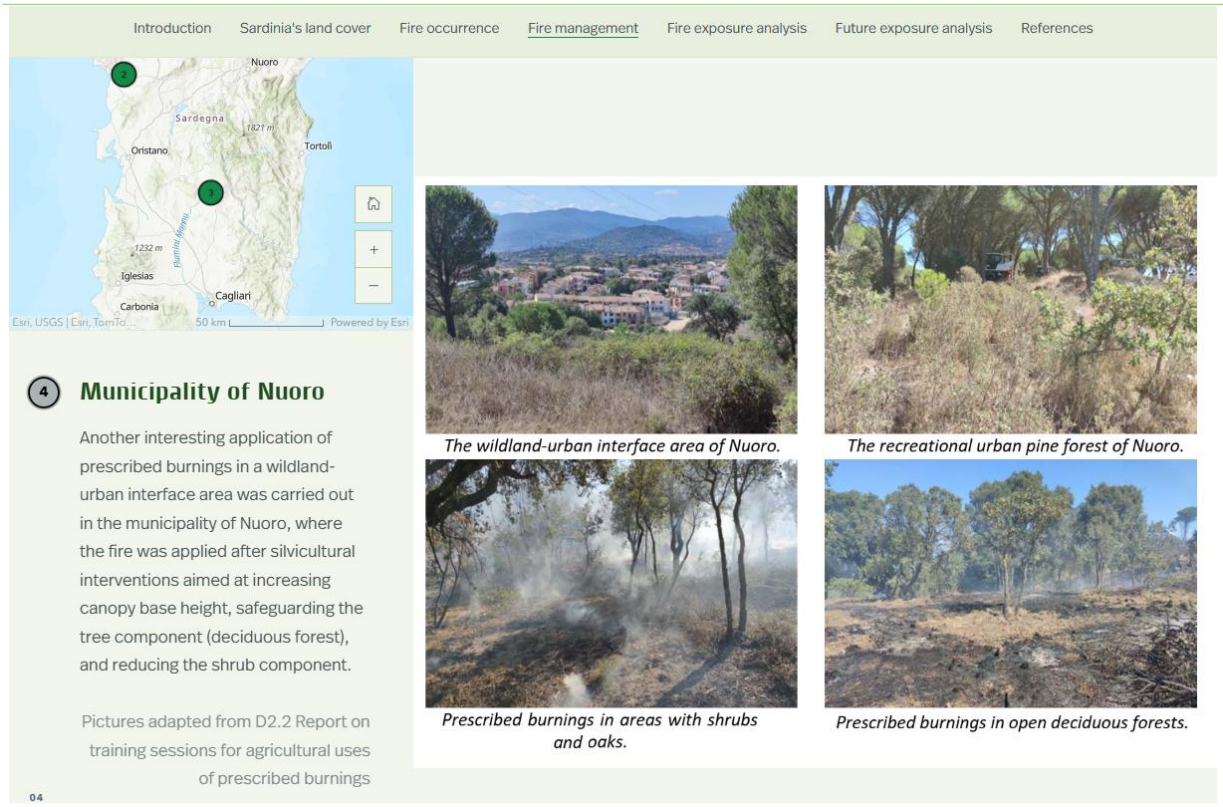


Pastures and wooded pastures.



Pastures with a prevalent shrub component.

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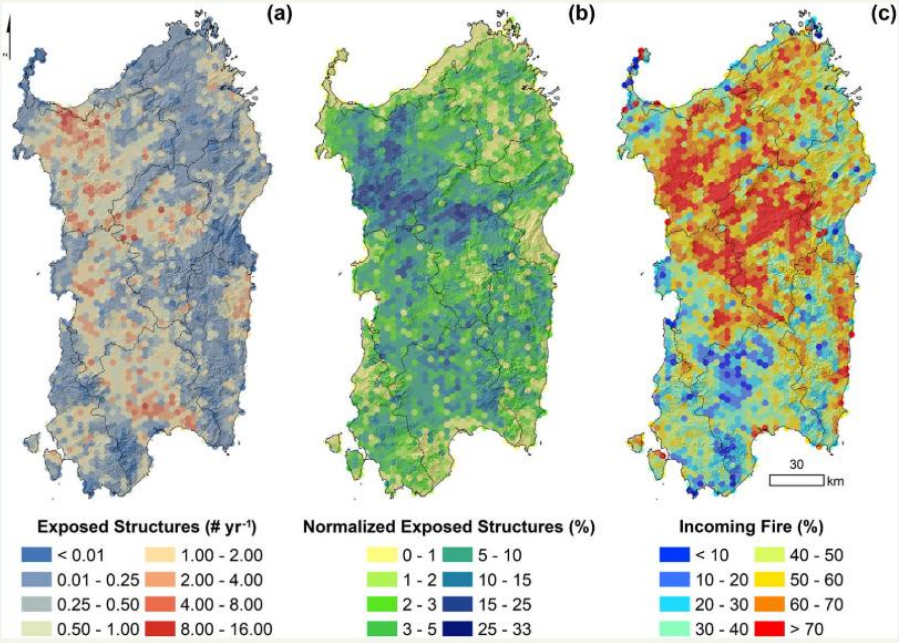


Fire exposure analysis

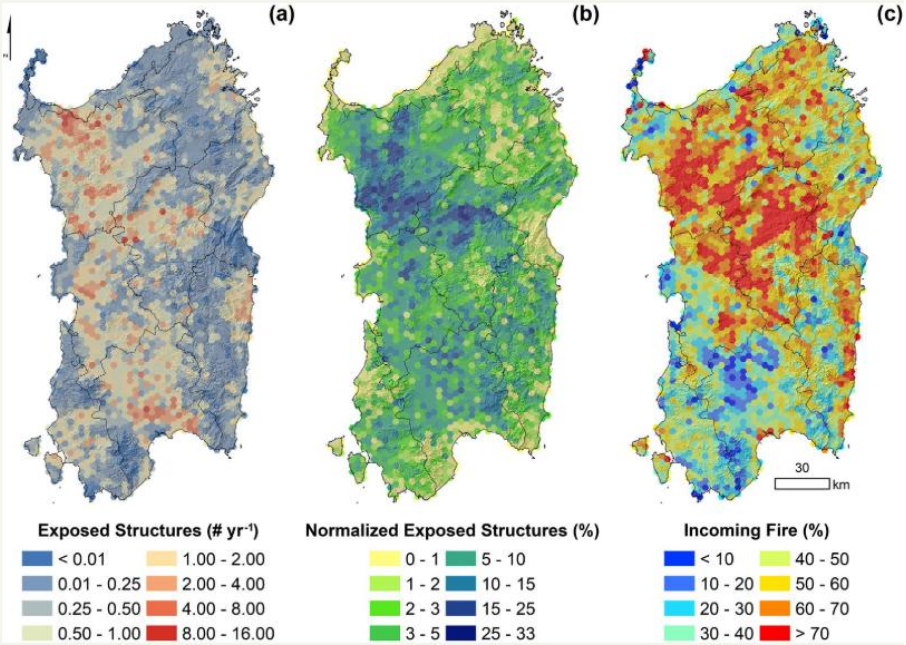
This analysis offers a novel, comprehensive, and quantitative method to assess wildfire exposure and transmission across Mediterranean fire-prone ecosystems. The method is based on applying a wildfire spread and behavior modeling approach that allows us to derive objective measures of risk variables such as burn probability, flame length, or wildfire transmission. The variables simulated are then compared with the number of exposed structures and the Incoming fire index, which was computed from the historical fires and the simulations.

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Wildfire exposure to communities varied very substantially across the study area. In terms of overall exposure, the highest values (>15 exposed str. yr^{-1}) were mainly located in the municipalities of the Northwest, where Sassari concentrated the bulk of exposure (about 100 exposed str. yr^{-1}) (Salis et al. 2021). Other populated and vast municipalities on the island, such as Alghero, Nuoro, Ozieri, and Oristano) also presented exposure results above the average (>15 exposed str. yr^{-1}). The coastal sites of northeastern Sardinia showed a high exposure cluster with values peaking in Olbia (about 32 exposed str. yr^{-1}). The overall exposure values were generally lower in southern Sardinia, except for a few communities located in dryland agricultural plains and close to the coast.



The normalization of the annual amount of structures exposed, by dividing the annual exposure of structures and the number of structures per hexcell, allowed highlighting the high exposure of some communities in remote rural areas, mostly located in central and western Sardinia: in those zones, the considerable likelihood of large wildfires was combined with the low number of structures, which resulted in a high annual probability (15–35%) of the structures to be affected by wildfires. Conversely, about 2/3 of the island presented normalized values of structures annually exposed below 5%. So, the relationships among wildfire ignition density, large wildfire propagation, and exposed structures follow complex spatial patterns, and a high wildfire frequency does not necessarily connote a high wildfire risk (Salis et al, 2021).



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The average amount of incoming wildfires in Sardinia varied from a low of <10% (colder colors) to a high of >70% (warmer colors), using hexcells with 1000 ha cell size. The zones with the highest percentage (>70%) of incoming wildfires are located in Central, Northwestern and Western Sardinia, which are the zones where the occurrence of very large wildfires was more frequent for both the historical wildfires during the study period and the simulations. Lands with colder colors, and therefore with lower amounts of incoming fires, are mostly located in southern Sardinia, particularly in grasslands, where the percentage of incoming events is generally lower than 50%. These results can be linked with the fact that Southern Sardinia land uses present a large amount of non-transmitted wildfires, related to the high number of events that have very limited size and therefore cannot spread to other land uses.

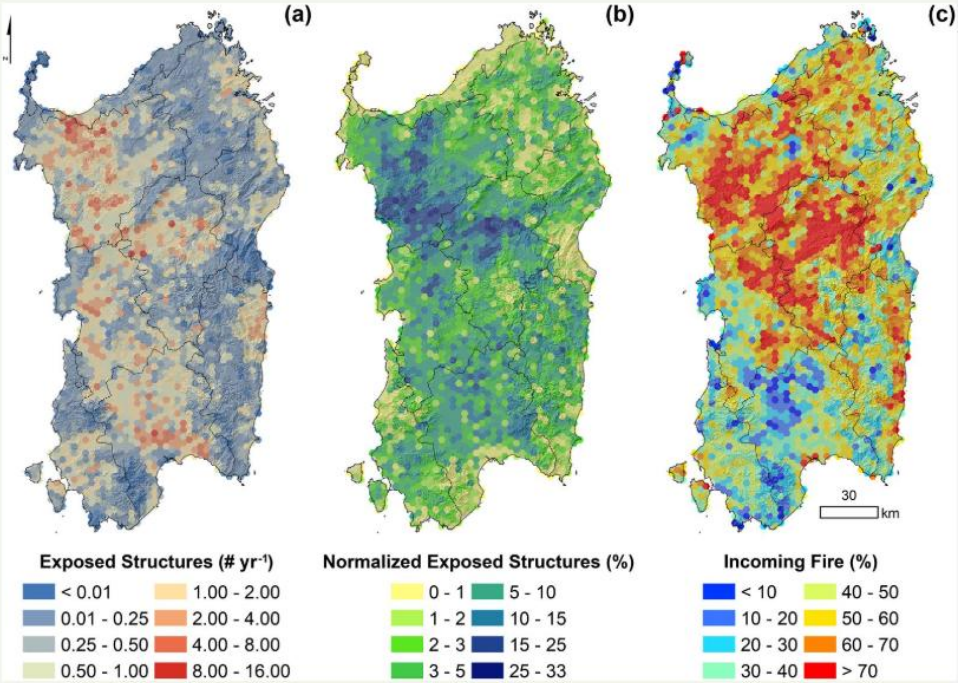


Figure adapted from Salis et al, 2021

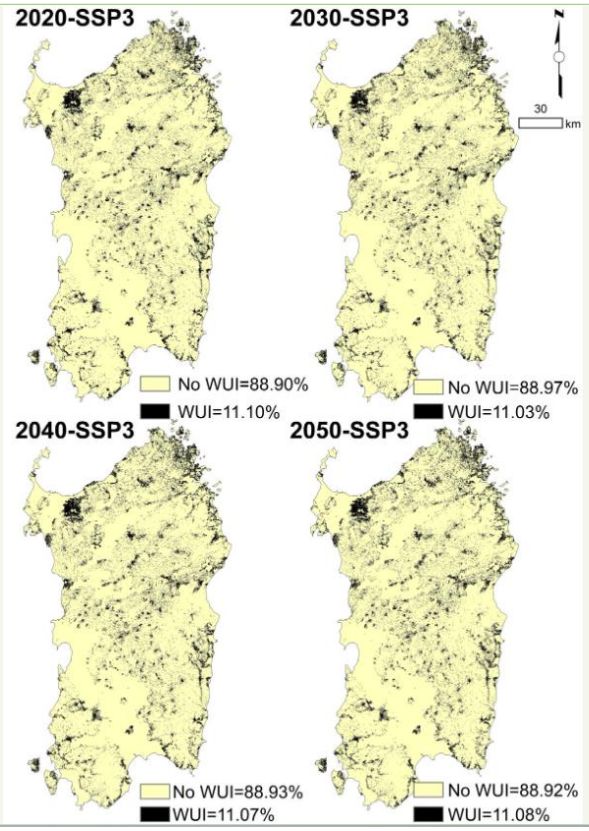
Future exposure analysis

WP3 of FirEUrisk focuses on estimating Fire risk under different climate scenarios (D3.6). For Sardinia (DA5), 39 scenarios were considered, resulting from the combination of 4 climatic models (ERA5, ACCESS-CM2, EC-EARTH3, MPI-ESM1-2-HR), 3 SSPs (SSP1-2.6; SSP2-4.5; SSP5-8.5) for future conditions, and 2 climatic periods: 1985-2014 for historical conditions and 2035-2064 for the future conditions. The simulations were done at 150 m resolution for a study area of about 24,000 km2. They replicated a hundred wildfire seasons focusing on wind conditions and fuel moisture related to high wildfire danger days, using as inputs the information coming from the climate data provided.

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Considering the 2020 data, WUI areas in Sardinia cover approximately 2,680 km2, corresponding to about 11.2% of the regional territory. The main WUI areas are in northern Sardinia and the north-eastern coastal zone. Many dispersed WUI areas are distributed throughout the island, particularly inner areas. The WUI projections for Sardinia show quite important changes for SSP1, which indicated increases in WUI areas (+155 km2) from 2020 to 2040 and a significant reduction from 2040 to 2050 (-139 km2) (Table below). On the contrary, projections based on SSP3 evidenced limited variations in WUI areas, with changes below 8 km2 per decade in most cases. These differences in WUI projections between SSP1 and SSP3 are due to the respective land use input data. In fact, SSP1 scenario depicted a relevant increase in the anthropic areas for the coming decades, while SSP3 was more conservative and evidenced a much lower growth in anthropic areas for Sardinia.

Considering that, in our opinion, SSP1 scenarios were projecting a too strong increase in anthropic areas (close to 300% in 30 years, that means that in the period 2020-2050 about 280,000 ha of lands in Sardinia would be occupied by anthropic areas), we decided to discard this scenario for our spread simulations and WUI impact analysis.

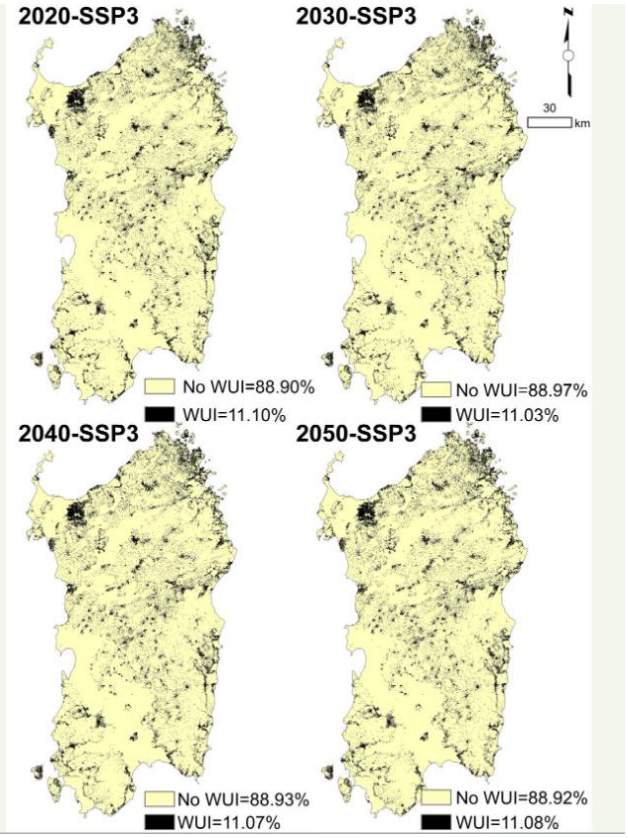


areas for Sardinia.

Considering that, in our opinion, SSP1 scenarios were projecting a too strong increase in anthropic areas (close to 300% in 30 years, that means that in the period 2020-2050 about 280,000 ha of lands in Sardinia would be occupied by anthropic areas), we decided to discard this scenario for our spread simulations and WUI impact analysis.

Socioeconomic Path	Year	Area (km²)	Percentage from DAS
SSP1	2020	2680.6	11.2
	2030	2757.1	11.5
	2040	2835.9	11.9
	2050	2697.0	11.3
SSP3	2020	2680.6	11.2
	2030	2661.1	11.1
	2040	2668.4	11.2
	2050	2672.4	11.2

Projected WUI area in Sardinia from 2020 to 2050 for SSP1 and SSP3 scenarios. Extracted from D3.6.



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