D5.14 Development of a Pan-European system to define management priorities to mitigate fire impact

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Abstract: Fire has long been a defining element of many global landscapes, causing significant environmental, societal, and economic impacts. This study introduces a spatial prioritization methodology for identifying fire management zones using a multi-criteria approach. The need for supranational information systems to support strategic decision-making has led to the development of a system that includes harmonized data at the continental scale, a server to manage such data, and a multi-criteria assessment system to define criteria, rules, and map priorities. In addition to the whole set of modules required for the development of the prioritization system, we tested its usefulness on a supranational study covering the whole Iberian Peninsula.

Key words: Multi-criteria, spatial, fire prevention, EU level, harmonization, data server, QGis Plugin

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1. INTRODUCTION

Wildfire risk has increased Europe in recent decades due to interconnected climatic, ecological, and socio-economic factors, reflecting a trend also observed more broadly across Europe (Aparício et al., 2022). Rising temperatures, declining precipitation, and prolonged droughts are contributing to more frequent and intense fire events (Sousa et al., 2015), with fire weather indices such as the Fire Weather Index (FWI) showing an upward trend, especially in summer and winter months (Orgambides-García et al., 2024). Changes in land use have also played a key role. Agricultural abandonment has led to fuel accumulation, particularly in rural and mountainous regions of Southern Europe (Viedma & Moreno, 2015; Lecina-Diaz et al., 2023), while expansion of the wildland-urban interface (WUI) has increased the vulnerability of human settlements to fire (Ganteaume et al., 2021). These trends are further compounded by human activity, which accounts for approximately 90% of wildfire ignitions, including both arson and negligence (Vilar del Hoyo et al., 2011; Parente et al., 2024). Future projections indicate that burnt areas could double or triple by 2075, and fire regimes are expected to become more severe and prolonged, with fire-prone zones expanding northward (Sousa et al., 2015; Calheiros et al., 2021). Addressing these challenges will require a combination of fire-smart land use planning and strengthened preventive measures, including improved fire management, public awareness, and international cooperation (Lecina-Diaz et al., 2023; Abrham et al., 2025; Neidermeier et al., 2023).

In this context, strategic prioritization of fuel management has become essential to mitigate wildfire risk, optimize limited resources, and enhance landscape and community resilience (Gonzalez-Olabarria et al., 2019; Krsnik et al., 2024; Ager et al., 2025). Financial and operational constraints limit the extent and effectiveness of conventional fuel treatments (Karimi et al., 2024; Woolsey et al., 2024). To address these challenges, decision support systems (DSSs) are increasingly used to guide prioritization by providing spatially explicit assessments of wildfire risk and treatment needs (Colavito 2021, Keane et al., 2014).

Spatial prioritization is a vital tool for integrating data on the distribution of key features, their associated threats, and potential management actions. A well-structured prioritization approach provides valuable insights for the optimal allocation of limited resources (Kyttä et al., 2023). Key steps in this process include classifying and combining criteria and mapping the resulting priorities, which are essential for developing effective landscape planning strategies. The spatial representation of needs and objectives generated through prioritization should facilitate the communication and acceptance of specific management measures (Ignatieva, 2017; Karimi et al., 2024). These principles can also be applied to identify high-priority areas for implementing fuel management strategies in fire-prone landscapes. Selecting and parameterizing relevant indicators and criteria to prioritize management zones aimed at preventing large forest fires is crucial for efficient resource allocation and strategic decision-making. Employing simple, participatory processes involving multiple stakeholders and experts should form the basis of a methodology that is adaptable and replicable across different contexts. Considering that different regions may have varying perceptions of needs, and that data sources across Europe differ due to limitations in standardization and harmonization at the national or regional level, the method should emphasize simplicity, robustness, and flexibility in handling diverse criteria and datasets. Moreover, cross-boundary coordination, such as managing fuels across different ownerships, is critical for landscape-level effectiveness (Thompson et al., 2022). As fire regimes intensify, integrating these strategic and participatory approaches into fuel management planning becomes increasingly urgent.

To support these prioritization efforts, expert-informed Multi-Criteria Decision Analysis (MCDA) frameworks have proven to be effective tools in forest fuel management planning (Martins et al., 2021). By integrating expert knowledge, these frameworks facilitate the evaluation of complex trade-offs among technical, environmental, and socio-economic criteria, allowing for more informed and context-sensitive decision-making (Uhde et al., 2015; Kpadé et al., 2024), as demonstrated in Catalonia, where spatial MCDA was used to guide fuel reduction efforts across diverse management zones (Krsnik et al., 2024). Moreover, expert-informed MCDA has been applied to post-fire contexts, such as erosion risk monitoring or restoration needs prioritizations, further highlighting its utility in supporting both proactive and reactive forest management strategies (Ronco et al., 2025; Casados et al., 2025). The inclusion of expert judgment also enhances the transparency and legitimacy of prioritization processes, increasing the likelihood of acceptance among stakeholders (Krsnik et al., 2024; Viqueira et al., 2005).

Alongside advances in expert-informed decision frameworks, the availability of harmonized geospatial data (Kutchartt et al., 2024) has created new opportunities for applying spatially explicit, policy-relevant planning tools. These spatial datasets enable consistent assessment of forest fuels-related variables across regions and countries (Murgante et al., 2011, June). When combined with participatory, expert-driven MCDA and GIS tools, they can support more transparent, scalable, and evidence-based prioritization processes (Ali et al., 2024). However, the potential of these tools remains largely untapped in efforts to guide policy development and allocate wildfire prevention resources across national or subnational jurisdictions (Fernandez-Anez et al., 2021; Moreira et al., 2020). Greater emphasis on such integrative approaches is needed to inform cross-border strategies and align with broader European goals for landscape resilience and wildfire risk reduction (De Rigo et al., 2017).

Despite increasing efforts to address wildfire risk, a major gap persists in the strategic allocation of public resources for fuel management at national and cross-regional levels. The recent availability of harmonized forest fuel datasets across Europe presents a valuable opportunity to move beyond ad hoc or politically driven resource distribution. By combining these consistent, high-resolution data with expert-informed decision frameworks, it becomes possible to identify priority areas where fuel treatments can be most effective, ensuring that investments are targeted, transparent, and aligned with broader wildfire prevention goals.

In this innovation action, we present a methodology to support wildfire prevention prioritization by integrating expert knowledge into a MCDA framework. The development of pan European fuel datasets, fire spread simulators, and a MCDA system able to work with large datasets (Figure 1) was required to implement this methodology. In addition to the new datasets (chapters 2 and 3), and systems to replicate assessments across EU, this action presents a prioritization tailored to the European context, together with a participatory process integrating expert knowledge within a MCDA framework, applied across the Iberian Peninsula.

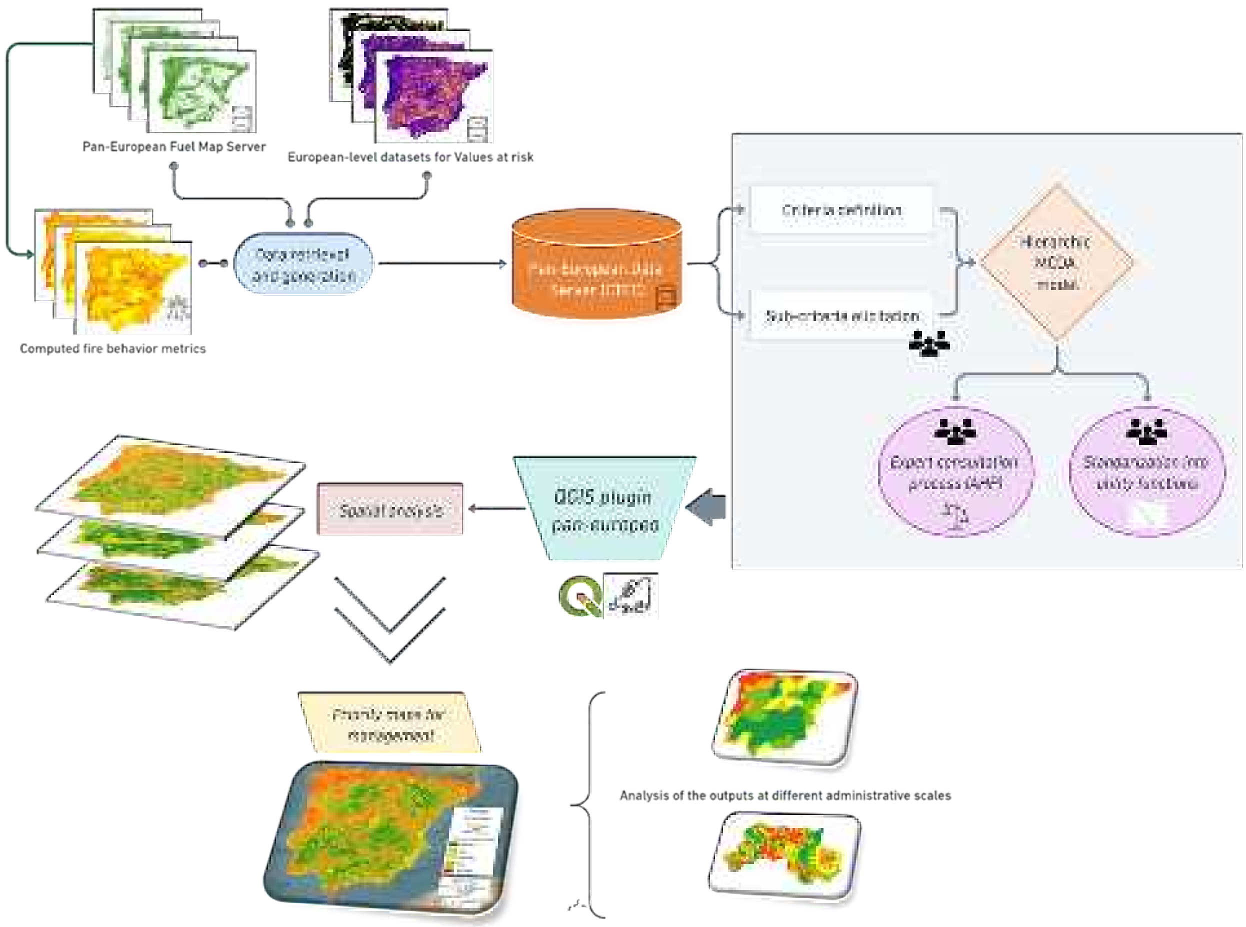


Figure 1: Integration of the different components of the innovation action (Rodríguez-Fernández et al., in process)

2. PAN-EU Fuel mapping

The main aim was to develop the canopy fuel models - Canopy Base Height (CBH) and Canopy Bulk Density (CBD) - and superficial fuel types at the pan-European scale using different Earth observation products, artificial intelligence and allometry approaches. The outcome was a landscape file, combining previous remote sensing products, such as the canopy cover or canopy height, where the end-users can get the information harmonized in the same geographical coordinate system and spatial resolution (100 m). Therefore, a friendly server was developed using the app of the Google Earth Engine, making the data available at different NUTS levels. In that sense, any end-user can interact and download the information and run their own forest fire simulations in specific areas of interest.

2.1 Above ground biomass map

The first goal was to produce an aboveground biomass map at EU level, which was updated to the year 2020 and produced at 100 m spatial resolution, being an important input to extract later the foliage biomass, essential to compute the CBD.

For that purpose, we applied machine learning algorithms, to assemble a model based on the evaluation of 49 potential covariates (bioclimatic, topographic, canopy related, vegetation indexes derived from Landsat, landcover maps, features from RADAR, or from vegetation maps). The resulting map (Figure 2 and 3, from Pirotti et al., 2023) was evaluated by a comparison with an existing biomass map at EU level provided by the ESA Climate Change Initiative Biomass (Santoro and Cartus, 2021), with the largest differences concentrated in the Alpine and Pyrenean areas.

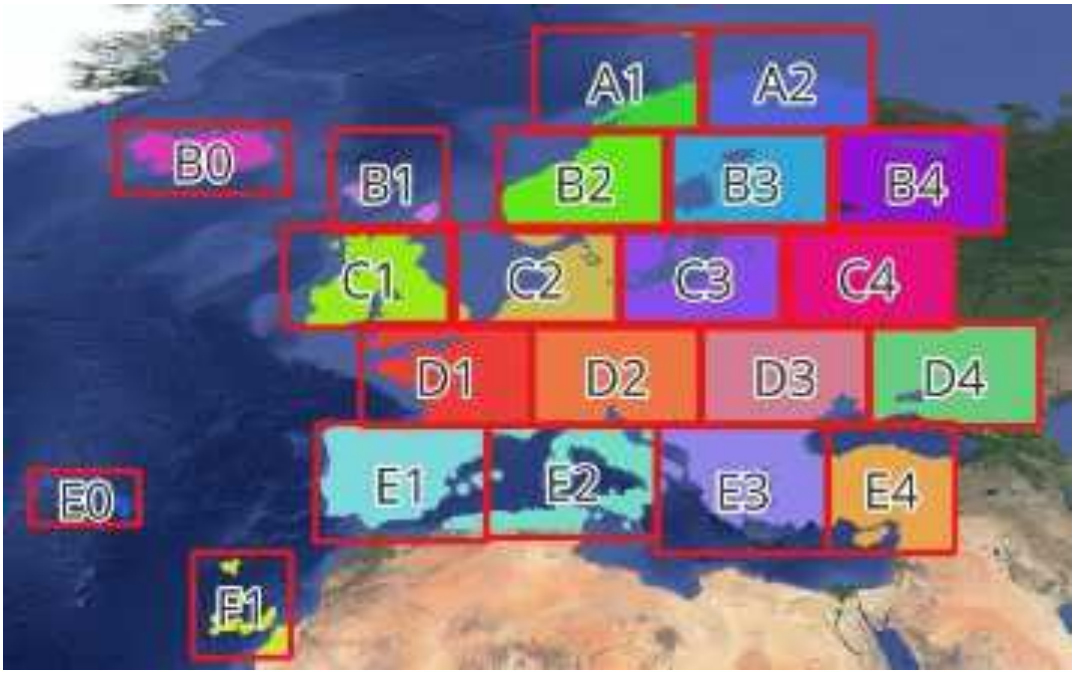


Figure 2: Tiles covering the entire Europe, defining specific training and testing areas to reduce variance among different geographical regions (Pirotti et al., 2023)

Figure 3: Visualization of the aboveground biomass map through the Google Earth Engine App (Pirotti et al., 2023), which later was updated, and the information is available in GeoTIFF format at different NUTS level for the entire Europe (Kutchartt et al., 2024a)

2.2 Canopy fuel variables related to fire behaviour

The previously estimated aboveground biomass, together with associated covariates such as the probability of tree species occurrence (Bonannella et al., 2022) and the canopy height (Lang et al., 2023), were combined with a set of species-specific allometric functions explicitly selected or developed for this purpose. Therefore, we were able to define the canopy base height (CBH), the apparent canopy volume, the foliar biomass and canopy bulk density (CBD), following the workflow indicated in Figure 4. In this process, the information used from the tree species was weighted on the basis of their occurrence probability, in order to more correctly assign the allometric equations used to predict the CBH and to extract the foliage biomass (see more details in Kutchartt et al. 2024b).In addition to the topographical features, canopy cover and canopy height, CBH and CBD play an important role as potential fuel hazard variables and as key inputs for the fire growth simulators, which include the initiation and active spread of crown fires.

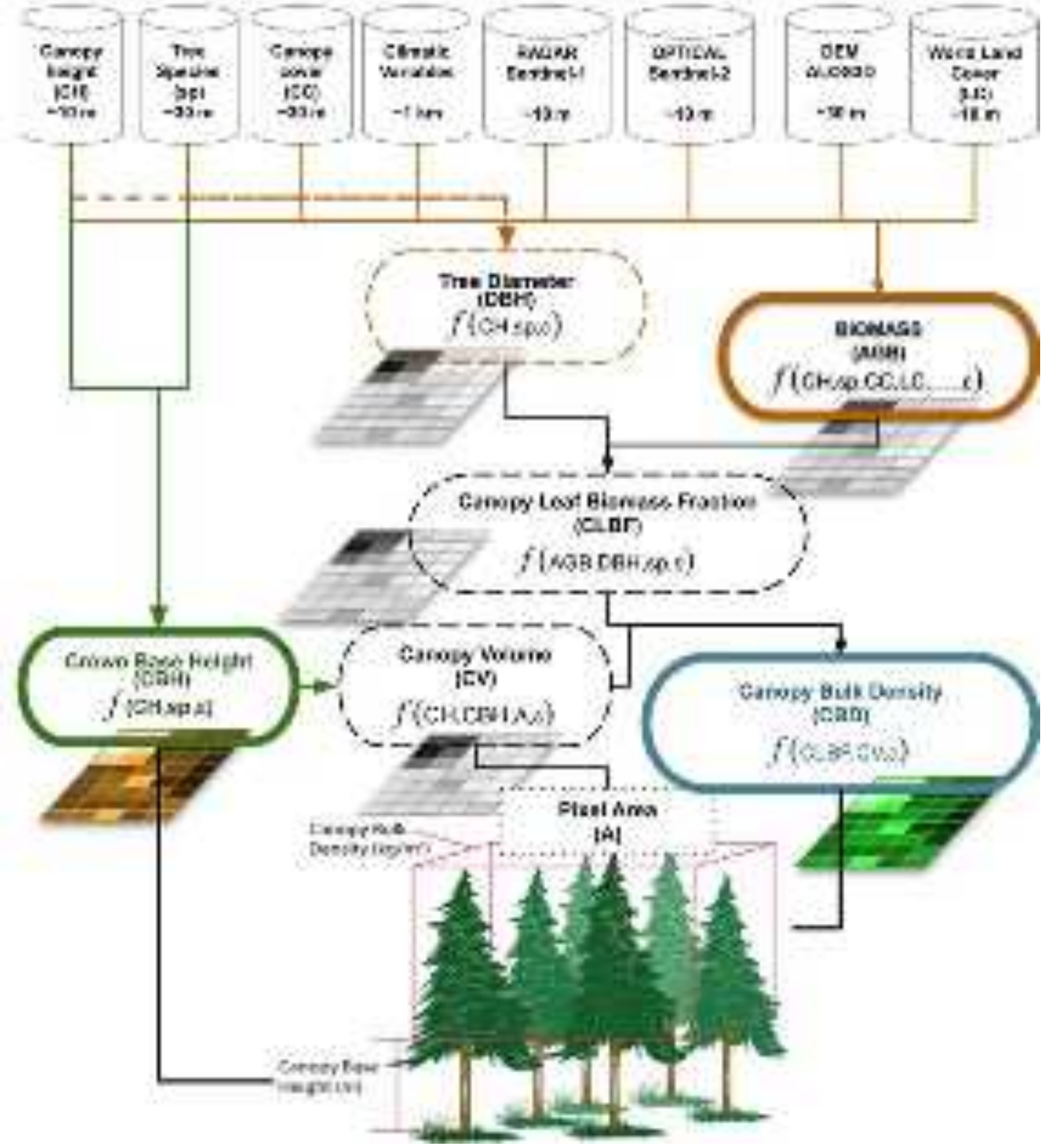


Figure 4: Combining multiple imagery data sources and modelling approaches, it was possible to define the vertical profile of the canopies and the apparent canopy volume, and canopy bulk density (Kutchartt et al., 2024b)

A relevant part of the modelling process involved the integration of satellite-derived data with several allometric equations obtained from a compendium of harmonized allometric equations for the entire Europe provided by Forrester et al. (2017). These equations, which include both total and biomass components, were necessary to define the percentages of foliage biomass to be extracted. On the other hand, an important set of field data from national forest inventories or data provided by the FIRE-RES consortium (living labs), were used either for modelling species specific functions to predict the CBH or directly to validate both canopy fuel variables (Figure 5).

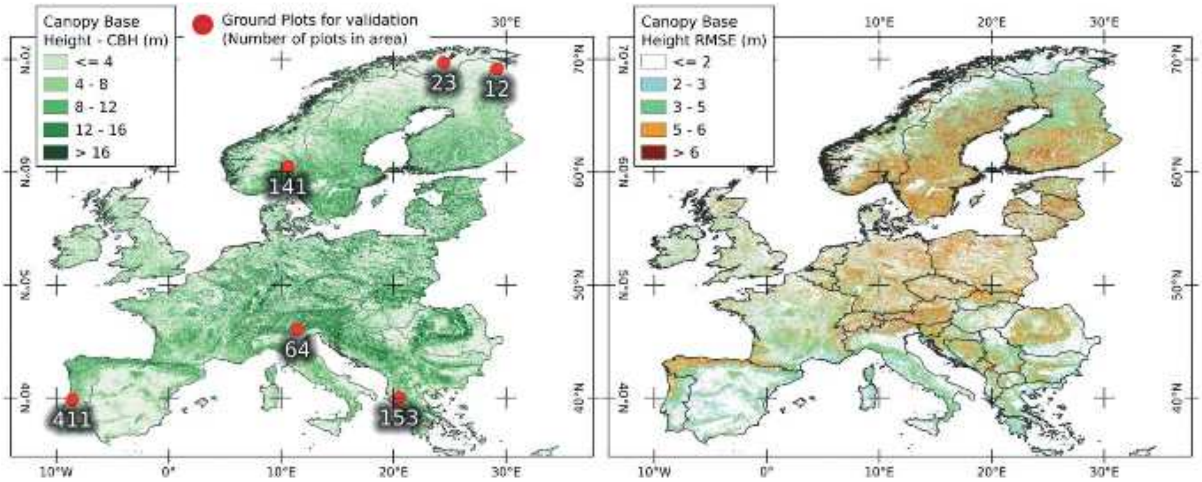


Figure 5: Resulting CBH map and number of ground plots used for validation in Portugal, Greece, Italy, and Norway, from Kutchartt et al. (2024b)

2.3 Fuel maps

With the same spatial resolution used to display the previous canopy variables (100 meters), we created a map of fuel models based on the classification of Scott and Burgan (2005). Following the mapping principles of Aragoneses et al. (2023), we re-estimated and re-escalated the classification of the fuel models. For this purpose, we assigned the corresponding fuel class through a consensus among different land cover maps, canopy maps, and aridity maps. We used the following existing maps: the CORINE 2018 at 100 m resolution, the Copernicus global land cover (GLC) at 100 m resolution, and the ESA World Cover 2021 v200 at 10 m resolution (based on Sentinel-1 and Sentinel-2 data).

In addition, in the future we expect to identify wrong classifications, which can be corrected by geotagged images, being collected by the FIRE-RES Geo-Catch app (Kutchartt et al., 2023), which are images that characterise the vegetation of different landscapes (Figure 6). These images can validate main fuel types by segmenting the images as demonstrated in Pirotti et al. (in press), using different training deep learners.

Figure 6: Preliminary results of segmentation process of two images by training deep learners in deciduous and coniferous forests (Pirotti et al., in press)

2.4 Pan-European fuel map server

Provide the necessary spatial datasets for fuel hazard mapping and fire behaviour simulation is a requirement for mapping fire risk, and the first step required for developing a Pan-European prioritization system for mitigating wildfire risk. In addition to develop all those maps required to measure fuel related hazard or fire behaviour (canopy fuels and surface fuel models, topographic features and other canopy attributes such as stand height and canopy cover), we need to maximise the potential usage and impact of this new information. Either internally, within the Pan EU FIRE-RES prioritization system, or for the use of other users outside the project, if maximise the usability of these results is an objective, we need to accomplish two tasks. First, it was necessary to generate harmonized maps at the same spatial scale, and at a scale that is both useful for strategic and tactical assessment. Through the provision of these maps and related open-access scientific publications, Pirotti et al. (2023) and Kutchartt et al. (2024b) explain the methodologies used to produce these maps, corresponding to the first task completed. Second, the data and information should be available for all users, within or outside FIRE-RES, where an interactive Web-GIS was produced and documented by Kutchartt et al. (2024a). Here, all users can view, query and download single layers of interest, or download the whole pan-European dataset. All layers are in raster format and co-registered in the same reference system, extent and spatial resolution (100 m). Viewing and downloading is available at all NUTS scales, ranging from country level (NUTS0) to province level (NUTS3), thus facilitating data management and access. The system was implemented using R for part of the processing and Google Earth Engine (https://www.cirgeo.unipd.it/fire-res/app/). The final app is openly available to the public for accessing the data at various scales. Through the server, we are able to deliver a fuel cartography in a findable, accessible, interoperable and reusable manner as per FAIR guiding principles for research data stewardship, discussing about technologies behind sharing large raster datasets via web-GIS platforms and highlight advances and novelty of the shared data (Figure 7).

Figure 7: Pan-European Fuel Map Server (Kutchartt et al., 2024a) with an overall view of fuel model for all Europe. The system allows also to select different NUTS levels and download the data in GeoTIFF format with the specific shapes of the interest areas

3. Fire Behaviour simulation and metrics

3.1 General overview

Wildfire Analyst® (WFA) (Ramírez et al., 2011) is a software tool intended to help firefighters, fire managers, and other stakeholders in making well-informed decisions about responding to and managing wildfires and wildfire risk. In order to facilitate real-time decision making, the WFA FireSim module simulates the spread of wildfires in seconds and offers real-time analysis of wildfire behaviour.

These outcomes, such as Arrival Time, Rate of Spread, Flame Length, Fireline Intensity, etc., can be used to improve wildland fire management workflows and enhance the Decision Support Service. FireSim results allow to automatically delimit geographically and temporally relevant AOIs, concentrating preventive or suppression tasks in areas with the highest expected fire activity or in areas with the earliest consequences.

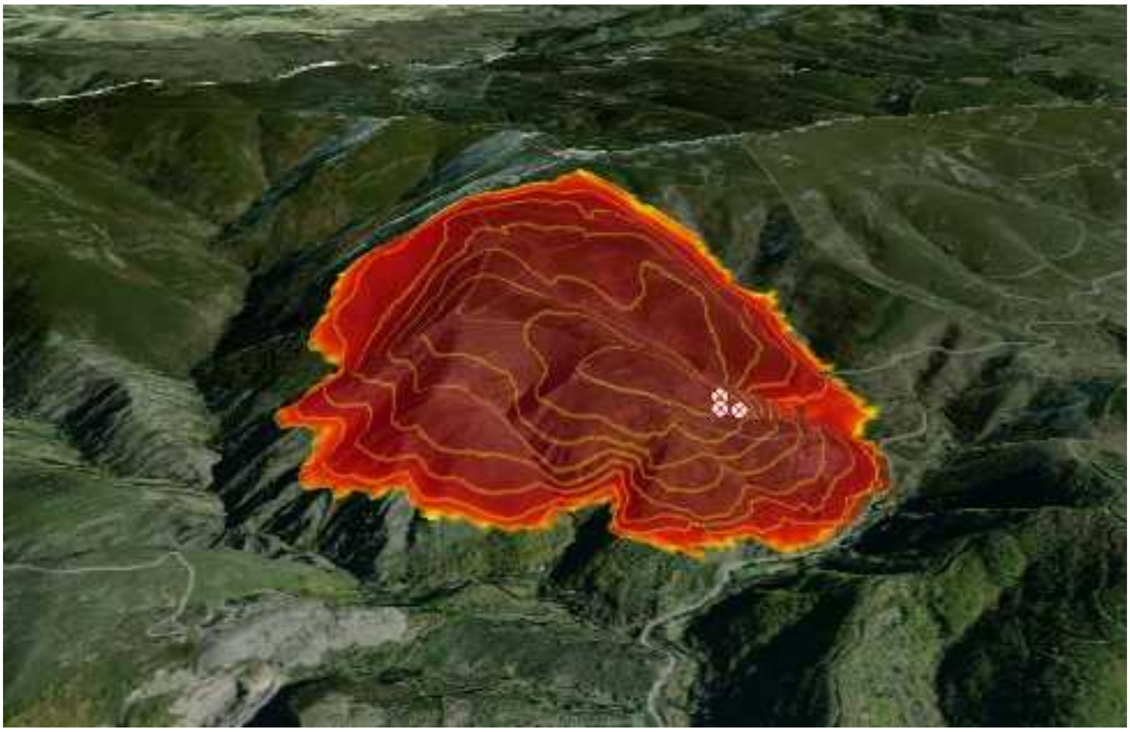


Figure 8: Example of arrival time output

3.2 Fire simulation tool

3.2.1 FireSim main components

The main components of FireSim are briefly described below.

- **Simulation engine core**

The fire simulator's main component is the simulation engine core. It is the engine that receives input parameters and simulation requests, hosts the algorithms that calculate the fire simulations' outputs, and serves as a container for processing and producing these results.

The main surface fire model is based on the Rothermel model (Rothermel, 1972) which integrates the modifications proposed by Albini (Albini, 1976) and the necessary extension to incorporate fuel types from Scott & Burgan family (Scott and Burgan 2005) or other customized fuel types.

- **Data repository**

The data repository is the storage component which includes a database and a file system. Both the geospatial basis input data for the forest fire simulation engine core and the results of the executed simulations and effect relevance evaluations are stored in this container.

3.2.2 Base data

In order to run the simulations, FireSim needs specific base data to realistically model the fire behaviour outputs. To do this, the simulator makes use of geospatial data that gives the simulation engine information about the terrain's features so that it can run simulations and apply the topographic effect to other inputs like wind speed and direction.

This information is needed to process the fire simulation results, also considering the vegetation type and structure and the man-made and natural network infrastructures that influence how the fire spreads (such as roads, buildings, rivers, and water bodies). For the normal operation of the simulation engine, some of this geospatial data must be present, while other data may be contributed voluntarily. This supplementary data can be included to give the simulator more details about the vegetation or landscape, increasing the realism of the results that are produced.

The geospatial basis data has already been prepared and integrated into the fire simulator and is stored in the data repository component. This data is static and does not need to be updated on a regular basis, except for the fuel model layers after vegetation disturbances. The mandatory geospatial data layers are:

- **Digital Terrain Model (DTM)**: The digital terrain model provides the simulator with information about the characteristics of the terrain, namely the slope and the aspect of the terrain.
- **Vegetation fuel models**: The vegetation fuel models are one of the most important base information layers for the simulator. According to the existing type of vegetation, the fire behaves in a certain manner depending on specific parameters of each fuel model (e.g. fuel depth, fuel load, moisture of extinction, etc.). The fuel models layer developed in the FIRE-RES project frame was used for this purpose.

When available, additional base data, such as canopy cover, canopy height, canopy base height, and canopy bulk density, is used to model crown fires. Roads, rivers, and other firebreaks are already taken into account in the fuel model layer.

3.3 Fire simulation scenarios

3.3.1 Inputs

FireSim simulation scenario is composed of the base layers described in the previous section. In order to run a simulation, the simulator also needs two mandatory inputs: ignition point(s) and weather forecast data.

- **Ignition points**

Location of the ignition point(s) from which the simulation starts. For this study, and to obtain a general view of the fire risk across the territory, a regular grid of ignition points, spaced 400 m apart, was used.

- **Weather forecast data**

To run a simulation and calculate future fire behaviour, it is necessary to use a weather forecast model that provides the necessary information over the selected simulation duration (in hours). However, for this risk study, historical data was used to generate this meteorological scenario. These weather variables were extracted from reanalysis data provided by Google and Copernicus, specifically the ERA5-Land Daily Aggregated dataset (Muñoz 2019).

The variables used in the study included wind speed and direction, temperature, and relative humidity. The latter, which is not included in the ERA5 dataset, was calculated from its bands through the August-Roche-Magnus approximation. Dead and live fuel moisture content (FMC) were also estimated for the considered scenario. Dead FMC was computed following Nelson's (2000) method, using weather data as input, while live FMC was derived from the Normalized Difference Vegetation Index (NDVI). For a better understanding of the possible risks and a better adaptation to decision-making by the DSS, an unfavourable weather scenario was chosen by calculating the 2nd percentile for relative humidity and the 98th percentile for the rest of the variables in a time series from 1980 to 30 November 2023 (study cut-off date).

3.3.2 Simulation mode

In order to have a global vision of the potential risk in the territory, two different modes of simulations were performed:

Static (Basic Fire Behaviour, BFB) mode: this simulation mode uses static input conditions; that is, conditions from a snapshot in time and place. It then produces a snapshot of fire behaviour outputs for each cell given the specified scenario. This simplistic view removes the weather variability to evaluate differences in fire behaviour across the landscape that are driven by fuel and topography.

Dynamic mode: In this mode, fire spread simulations are run from each of the ignition points of the regular grid using the inputs of the considered scenario. This FireSim mode provides outputs within the considered simulation perimeter, defined by isochrones that represent the number of hours of the simulation. Hence, the respective outputs are calculated from the location(s) of the ignition point until reaching the maximum of the simulation hours that were defined. This means that each cell can be affected by different simulations coming from different ignition points.

3.4 Fire behaviour outcomes

The variables derived from the static simulations are the rate of spread (ROS), flame length (FL), fireline intensity (FI), crown type and spotting. These variables would represent the values of these fire behaviour layers for each pixel, considering the given scenario (unfavourable situation).

On the other hand, the variables calculated by running dynamic simulations were the burn probability (BP) and conditional flame length (CFL). Flame length probabilities (FL) are used to calculate the CFL. In this case, the value of the CFL is not the static value of each cell, but the average of the values obtained by all the simulations that reached that pixel. With this approach, it is not possible to know the maximum value of the variable at a single point. Instead, a more realistic value can be estimated by considering numerous simulations reaching that pixel from different areas and fire zones (e.g. front, flank, tail). The description and units of each variable can be found in the table below.

Table 1: Description of FireSim outcomes

Variable	Unit	Description
Rate of spread	km/h	The speed with which the fire is moving away from the site of origin under scenario conditions
Flame length	m	The distance measured from the average flame tip to the middle of the flaming zone at the base of the fire under scenario conditions
Fireline intensity	Kw/m	Expected fire front intensity under scenario conditions
Crown type	-	Expected type of crown fire under scenario conditions: 0-Surface Fire, 1-Passive Crown Fire (Torching), 2-Conditional Crown Fire, 3-Active Crown Fire
Spotting distance	m	Expected spotting distance from fire front under scenario conditions
Burn probability	%	Variable that represents the probability that a fire will burn a given pixel in a year under scenario conditions
Flame length probabilities	%	Variables that represent the probability distribution among six FL range classes that several (n) fires burned that pixel. FLP0 (0-0.61m). FLP1 (0.61-1.22m), FLP2 (1.22-1.52m), FLP3 (1.52-2.44m), FLP4 (2.44-3m) and FLP5 (>3m)
Conditional flame length	-	Estimator of the mean flame length (FL) of the n iterations that burned the pixel

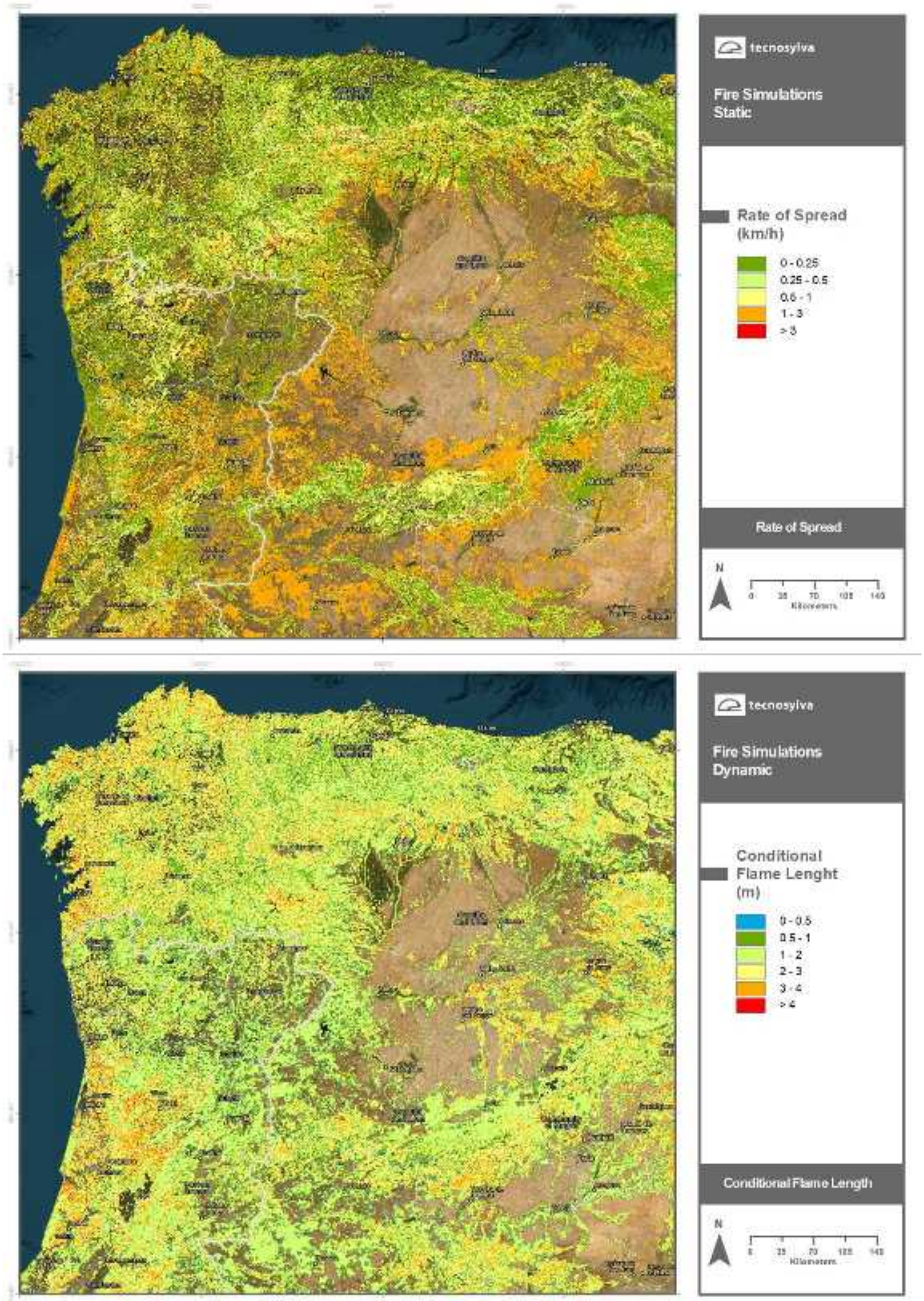


Figure 9: Example of FireSim outcomes for fire risk territory assessment, showing a detailed view of the Iberian Peninsula in the Galicia and Portugal Living Labs regions

4. Multicriteria prioritization system

A decision support system was implemented as QGIS plugins, comprised of 3 parts:

- **The user interface dialog**
- **The calculation backend**
- **The data provider backend**

This modular approach relies on QGIS, the leading open-source platform for GIS. Providing the best source for ready-to-use map interfaces, proven geographic algorithms and reliable user-interface design framework (QT). Also simplifying the distribution of the software via its plugin ecosystem.

All that is required is a computer with sufficient storage capacity to store the layers to be used. On the other hand, the processing time of the plugin will depend mainly on the processor to be used. It is necessary to take into consideration that processing time can be considerable in large study areas. Since the plugin makes use of GDAL tools that work with the data stored on the hard disk, it does not require a large amount of RAM memory.

4.1. What about the plug in does - functions (a summary of the user manual)

The plugin functionality can be summarized as "allowing users to define a study area, specify attributes with different units and ranges, and configure utility functions for each attribute, in order to summarize them in a resulting risk prioritization map".

In order to do all this, the plugin is modularized in three parts, which run in QGIS and detail the contribution of each module:

a) QGIS: is the platform that supports and coordinates all parts of the system. Specifically for this project, it provides a map visualization system with queries and exploring capabilities, a layer organization system in which each layer corresponds to an "attribute" (including visualization groups, ordering, colouring or rendering options), and a data management system that allows users to set up the data sources for each attribute or add custom ones locally on their computer.

b) The **Interface dialog**: is the main interface window which the user interacts with and adjusts all the system options. This part of the system can be accessed here. It is divided in four sections, arranged from top to bottom: (i) the attributes configuration or input rasters, (ii) the output configuration, (iii) a friendly graphical remainder of the multi-attribute utility functions parameters, and (iv) the bottom toolbox (Figure 10).

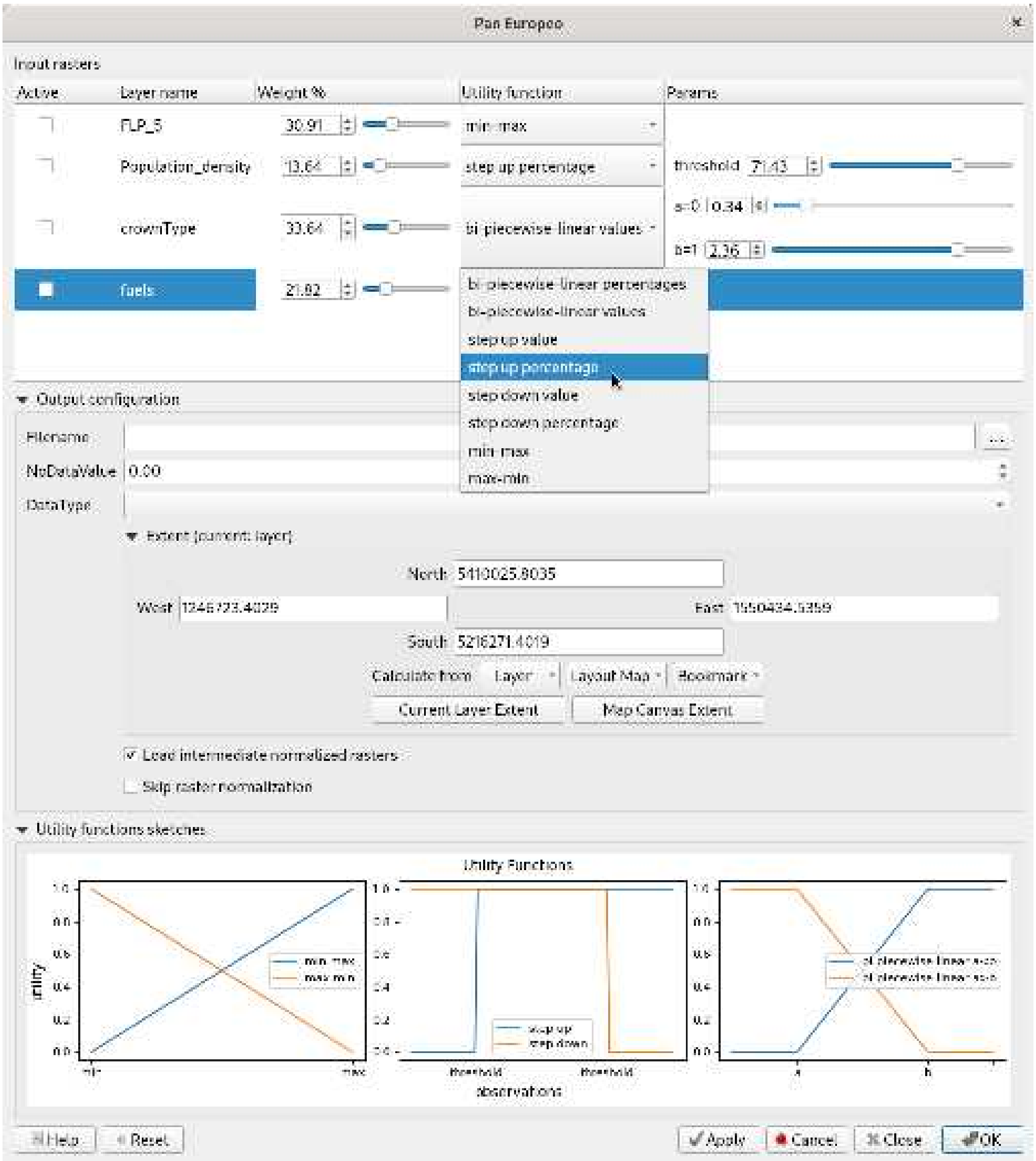


Figure 10: Interface plugin with its different sections: input rasters, the output configuration, utility functions sketches and the bottom toolbox

On **inputs section**:

- The user sees the layers displayed on the map. Any changes made to the raster layers – such as adding or deleting, or toggling their visibility via the active column- are automatically mirrored in the dialog in real time.

- In the weight column, the user can set the data ponderation in a coordinated fashion, as the apply button automatically adjusts all the active layers so the weights sum up to 100.
- The utility function dropdown combo box allows the user to select the data normalization utility function used, as shown opened for the “fuels” layer in the Figure 10. This causes the next column of parameters to adjust into the number of parameters required by the utility function definition with its corresponding range of values: real values or percentages.
- The adjustable parameters minimum and maximum range are automatically adjusted when the user changes the study area, whether selecting a polygon (for example the NUTS or LAU) or an extent. The minimum and maximum range parameters are also automatically adjusted when the user chooses between utility functions that use values or percentages.

The **output section** provides optional configurations that can usually be left unchanged, because the first three follow QGIS default values. And the extent group reflects the current study area (a NUT polygon selected by the user), although manual adjustment of the extent is also possible.

The **utility functions sketches** section is a friendly reminder of how to correctly configure the parameters of the utility functions . For example, when using the bi-piecewise-linear function, the observations on the tails (or outside the a-b range) are assigned values of 0 or 1, while a diagonal line represents the function within the central range. Furthermore, a user can click the “Help” button to access the full manual.

Finally, within the **button toolbox**, the “Ok” and “Cancel” buttons play a key role in managing background calculating tasks. Given the project’s European scope and the use of high-resolution rasters, some calculations may require significant computation time. To prevent the interface from becoming unresponsive, QGIS automatically handles these tasks in the background and displays a progress bar to inform the user of their statuts.

c) Although most users will not directly interact with the calculation backend, it provides a straightforward way to test each normalization strategy (namely utility function) and the ponderation capability. This component of the plugin can be accessed here. Implemented independently from the main dialog, it operates as a GDAL-type processing module rather than a standard QGIS processing plugin, allowing tasks to execute in the background without blocking the user interface. The interface includes a progress bar and cancel capabilities. The normalization dialog is shown in Figure 11.

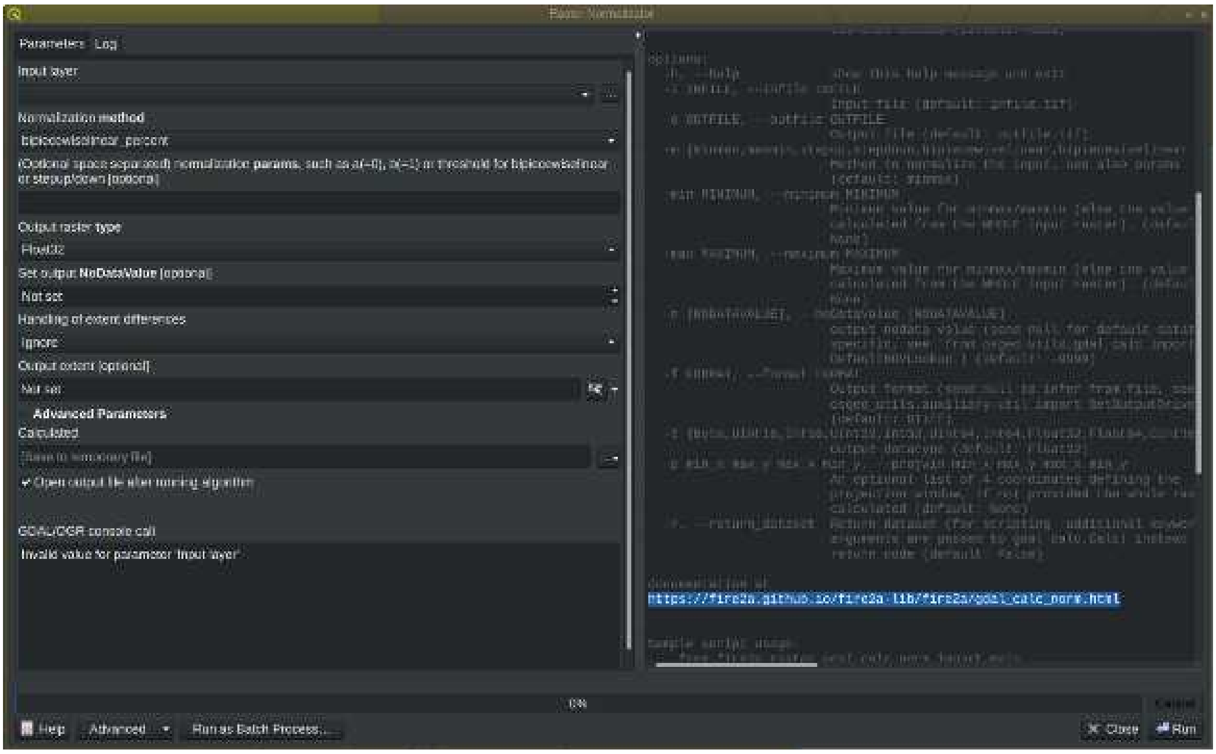


Figure 11: Normalization dialog interface

4.2. Programming of the QGIS plug in

The calculations needed for this project were implemented in a robust, visible and extensible way.

Robust, as is require handle computations over very large rasters (e.g., European-scale datasets), by processing data in chunks and writing intermediate results to disk rather than storing them entirely in memory. Visible, because the implementation of each utility functions should be easily reviewed for their implementation and accountability purposes. And extensible, since the utility functions are passed as literal string formulas to the widely used well-established tool gdal_calc. Consequently, the calculation backend is implemented as a QGIS GDAL processing plugin built on top of this tool.

The source code is public and located at: https://github.com/fire2a/qgis-pan-europeo/

4.3. User manual

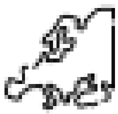
Comprehensive instructions, including video tutorials, are available on the plugin's documentation page: https://fire2a.github.io/qgis-pan-europeo/index.html. A concise textual summary is provided below.

4.3.1 Installation

The installation workflow begins within the QGIS Plugin Manager interface, where the "Pan Europeo" plugin can be identified among the available plugins. Detailed metadata, including version history, author credentials, usage statistics, and a functionality overview, is presented to guide the user's selection process, fostering transparency and trust in the software. The plugin is accessible to all QGIS users worldwide.

The installation steps are:

- Install QGIS (the latest desktop version on qgis.org).
- On the QGIS menu, go to "Plugins", then "Manage and Install Plugins".
- In the vertical tab on the left, select "All" and search for "Pan Europeo" in the top horizontal search bar.
- Select the plugin (checkbox) "Pan Europeo" and click "Install" (bottom right). Upon installation, the plugin system downloads and unpacks the core components. The process checks dynamically for necessary dependencies and opens the Plugin Dependencies Manager to facilitate the concurrent installation of the complementary "Pan Europeo Processing" plugin, which provides the calculation backend. This integration ensures that the plugin operates with full feature support, adhering to best practices in software deployment and package management.
- The plugin will be available on the "Plugins" section of the toolbar or on the "Plugins" menu, by clicking on the following icon:



Following a successful installation, the user returns to the QGIS environment, where the plugin interface is launched by clicking on the previous icon. This interface provides configuration options for input raster layers, including the ability to assign weights and select utility functions for each raster, highlighting the plugin's core functionality in handling multi-criteria spatial data analyses.

This comprehensive installation process exemplifies the commitment to delivering robust, user-friendly open-source geospatial tools that support Pan-European projects, with careful attention to dependency management and seamless integration within the QGIS ecosystem.

4.3.2 Project preparation

The preparation phase for using the "Pan Europeo" plugin in QGIS involves a thorough review and validation of the project's spatial datasets and settings to ensure a reliable analysis environment. The user begins by confirming that all required raster and vector layers are correctly loaded and visible in the Layers panel.