The overall attainment for the management objective of community exposure sources is approximately 15.5%, while for the DPV approximately 11%. Most of the projects spatially coincide and only few differentiate at the Municipalities of Rio Lleulleu, Rio Andalien, Rio Culenco and Estero Quilacoya for the weight combination 10-3 (orange colour), and few in Rio Tirua, Estero Quilacoya, Rio Culenco and Rio Andalien for the weight combination 3-10 (blue colour).

The trade-off graph in Figure 176 shows a few curved lines that reveal shared differences (i.e., the more the attainment of the DPV is increased, the more the community exposure is decreased), in the Municipalities of Quilacoya, Rio Andalien1, Rio Lleulleu, Coihueco and Rio Culenco. Other Municipalities show a gradual decrease in one objective, and then a rapid increase or decrease for the other objective, e.g., Arriba, Rio Tirua, and Pangue, meaning that some projects that are added in a specific combination can have a sharp effect on the other objective, but the overall trend is for the line to resemble a curve (all end at lower values compared to the attainment they started. Most of the remaining Municipalities either show minor and insignificant changes in the attainment.

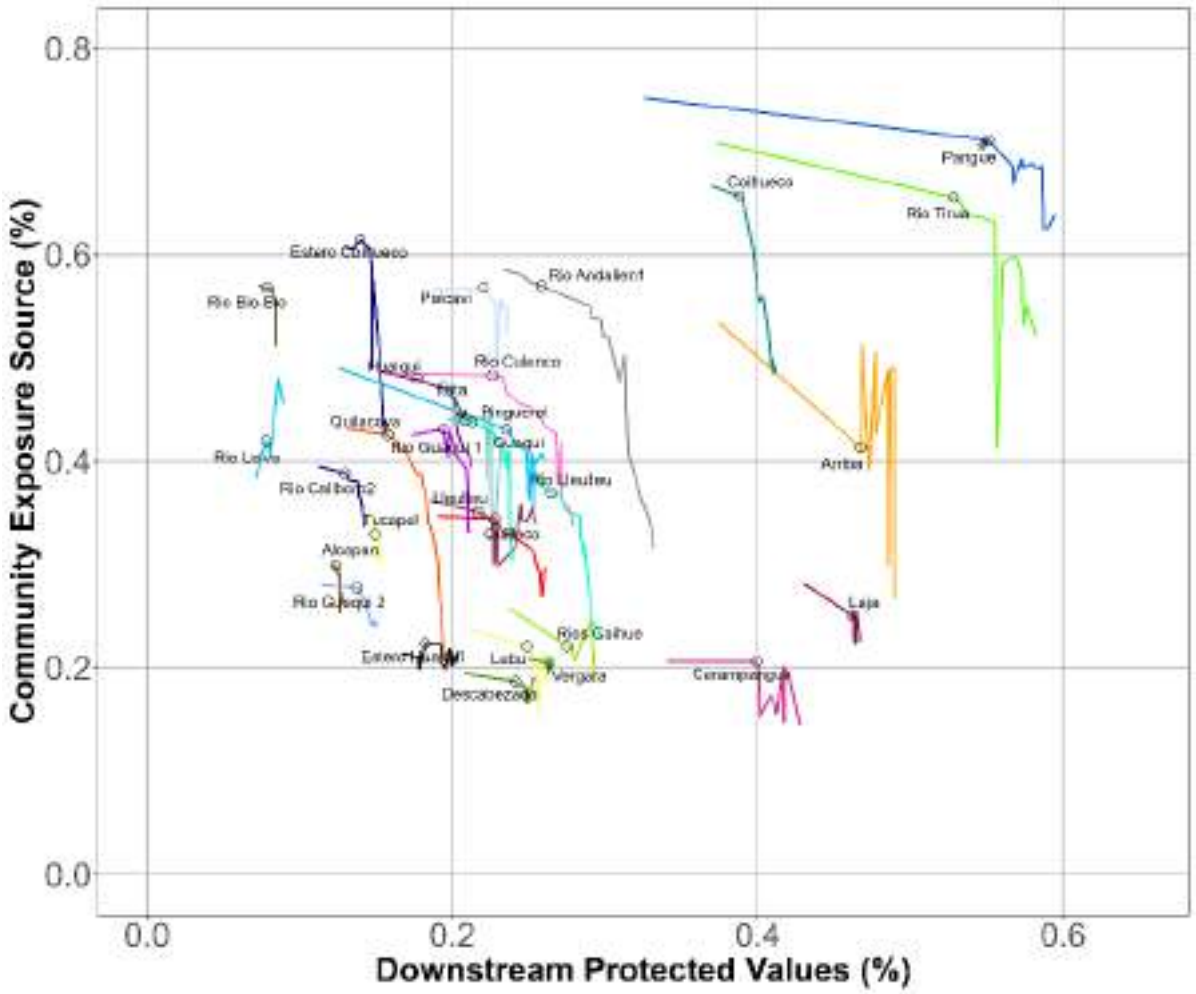

Figure 176 Trade-off production probability curves for each Municipality for the objectives of developed areas exposure sources vs. the downstream protected value. Axes show the level of attainment for each objective (%).

In Figure 177 we show the performance of each objective on each of the 30 selected Municipalities for five different weight combinations. If the red or black dots portray large fluctuations in their attainment this means that they are influenced when the weighting scheme is changed, while if they remain at the same levels of attainment, it means that same treated area has the same footprint on this objective no matter how they are arranged on the landscape. In most cases, the community exposure sources achieved higher attainment (black dots at the right), but there are some cases like the Municipalities of Carampangue, Vergana, and Rios Coihue where downstream protected has a better performance (red dots at the right). Notable fluctuations in the attainment, not only of the same objective but also how they changes between the two in some weight combinations (e.g.,Rio Tirua, where community exposure is higher and with an attainment of 0.6% for the 10-3 combination, and in the 0-1 combination it drops to 0.4% while DPV remains at 0.5%) were recorded for the Municipalities of Coihueco, Quilacoya, Pangue, Rio Andalien1 and Arriba, among others.

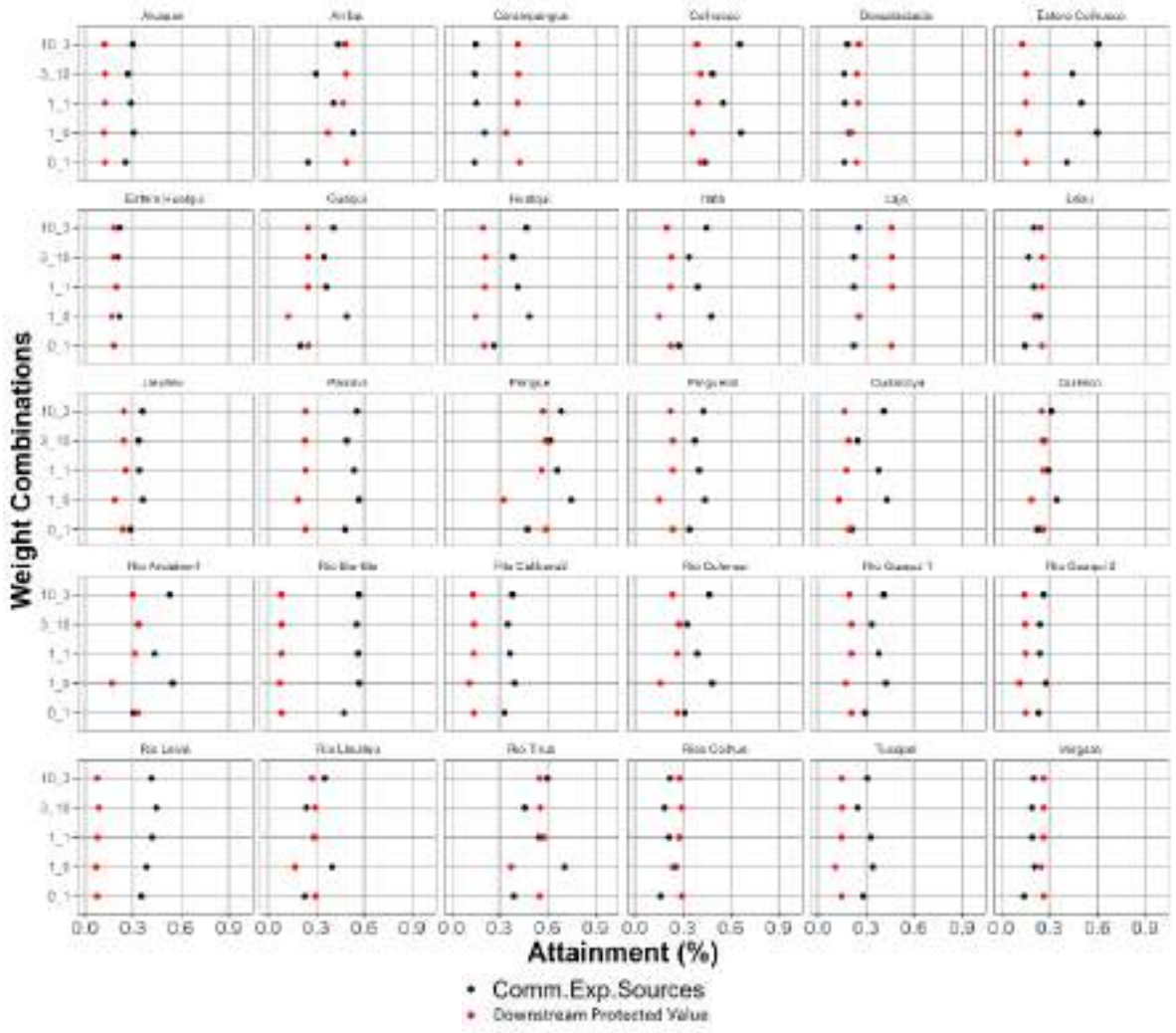

Figure 177 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: downstream protected value) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The second couple examined was the community exposure sources vs. biomass. The map in Figure 178 shows a solution of approximately 125,000 ha for the three examined weight combinations and creates a substantial maximum difference of 2.1% in the attainment of the community exposure sources, and just 0.1% for biomass. The overall attainment for the management objective of community exposure sources is approximately 12%, while for the biomass approximately 8.2%. While several of the proposed projects spatially coincide, there are some that differentiate at the Municipalities Tucapel, Rio Andalien1, Carampangue and Rio Guaqui 1 for the weight combination 10-3 (orange colour), but none is visible for the weight combination 3-10 (blue colour).

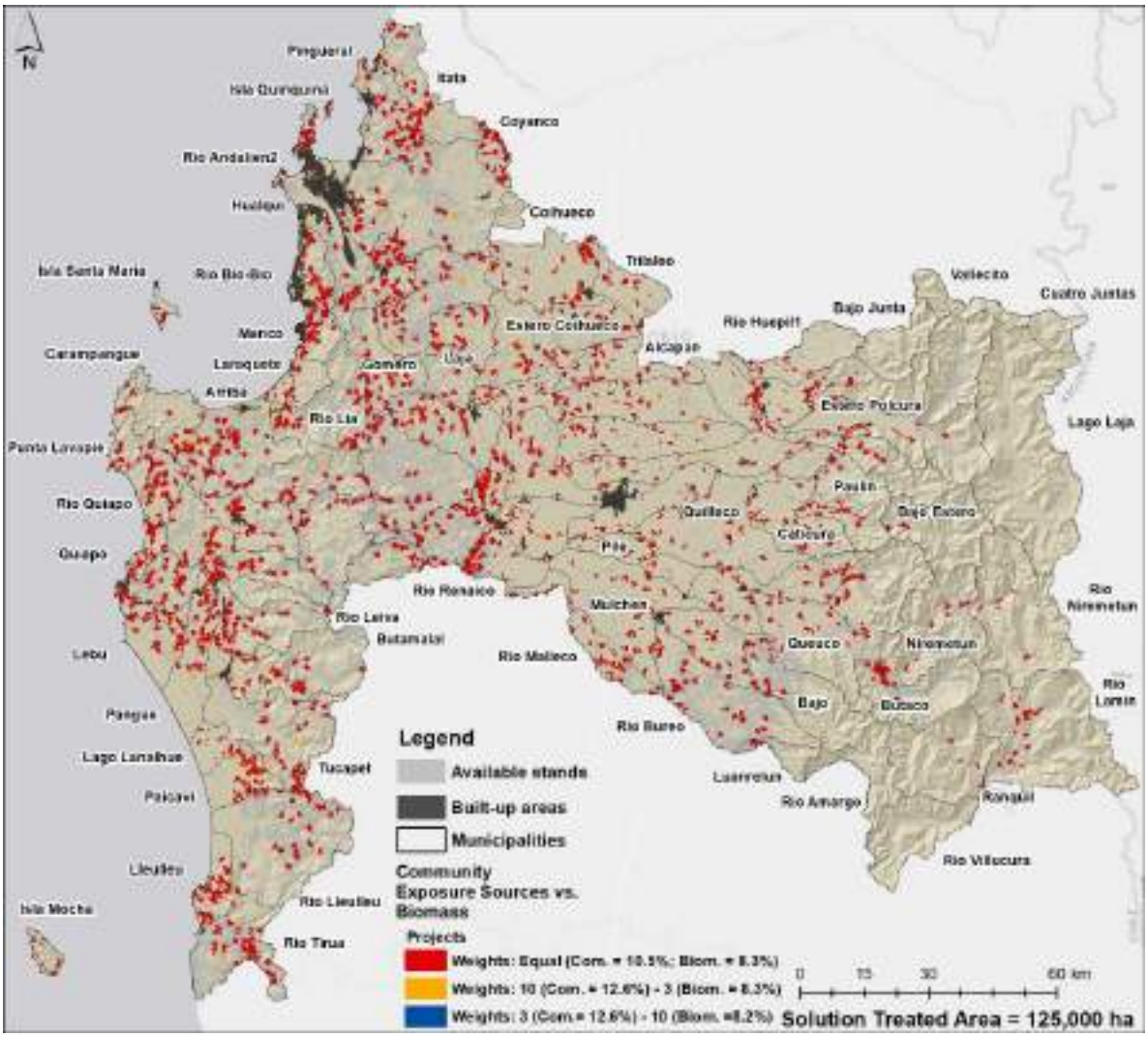

Figure 178 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and retrieved biomass set to low (3) (orange); c) retrieved biomass objective weight maximized (10) and developed areas exposure sources set to low (3) (blue). Blue- and orange-coloured projects that overlap with the equal weighing scheme are not visible, and they only appear where these projects were not selected by the other two weighting schemes.

The trade-off graph in Figure 179 shows sharp differences for most of the Municipalities, especially for Rio Andalien1, Rio Lleulleu, Pingueral and Rio Tirua (i.e., the more the attainment of the community exposure sources is increased, the more the biomass is decreased). These curves suggest that there are opportunities for a spatial allocation of projects (i.e., projects from a weight combination at the middle of each curve) that can achieve relatively high attainments for both management objectives. Overall, the attainment capacity of this objective combination is low, since the highest performing Municipality like the Pangue can achieve a maximum of 0.75% attainment for the community exposure sources with approximately 0.11% for biomass, while the highest performing curve for biomass is in the Municipality of Rio Andalien1, with approximately 0.23% attainment (and 0.21% for community exposure). Some Municipalities show a steady value for Biomass for several weight combinations, but with some that cause a decrease in one objective (biomass) and increase for the other (e.g., Rio Caliboro2).

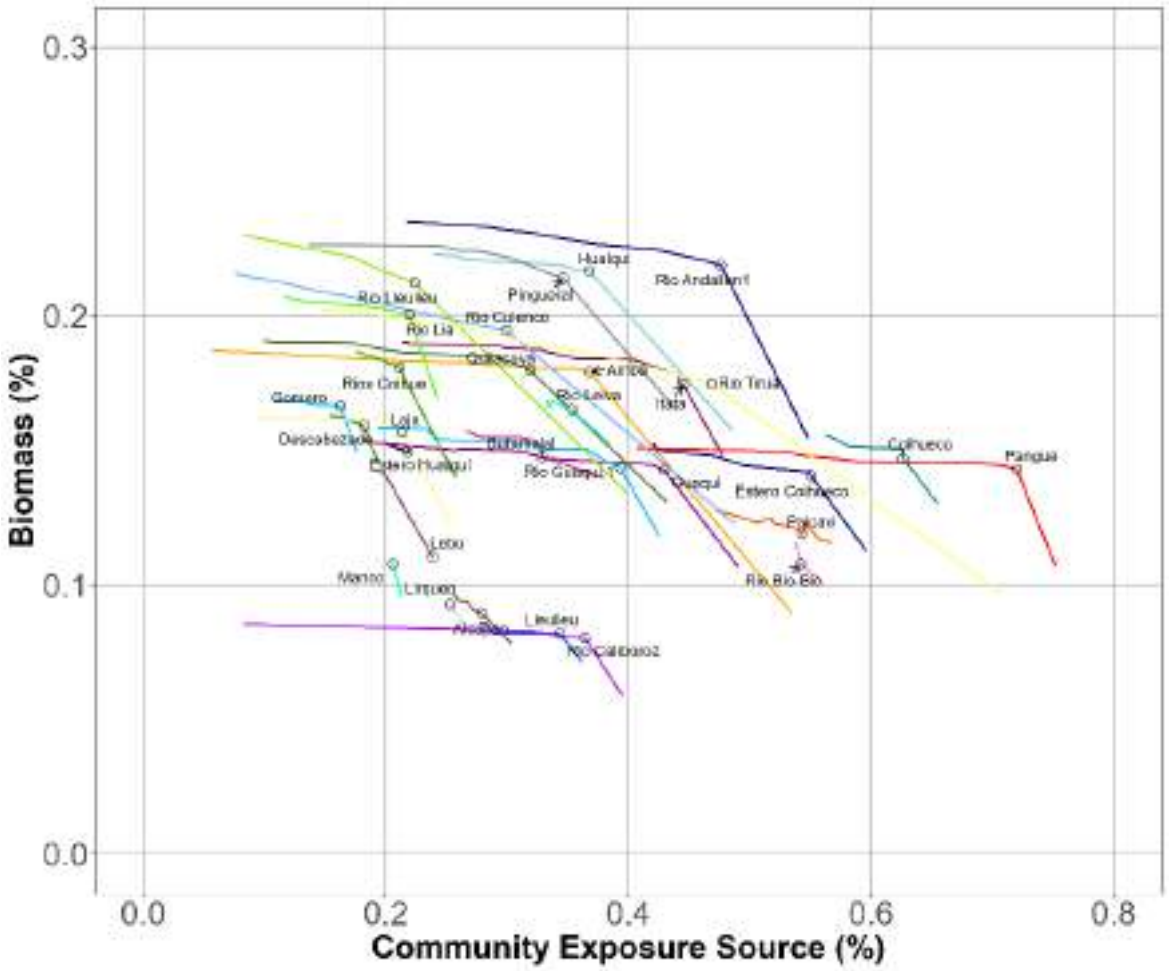

Figure 179 Trade-off production probability curves for each Municipality for the objectives of retrieved biomass vs. developed areas exposure sources. Axes show the level of attainment for each objective (%).

In Figure 180 we noticed large fluctuations in the attainment of the Municipalities of Paicavi, Estero Coihueco, Itata, Rio Bio-Bio and Pangue for the community exposure objective. The biomass objective has smaller fluctuations that is evident for some

Municipalities, like Arriba, Hualqui and Rio Guaqui 1, but their range in attainment is very small. In most cases, the community exposure sources achieved higher attainment (black dots at the right), but there are some cases like the Municipalities of Arriba, Rio Lia, Rio Culenco and Rio Lleulleu where biomass has a better performance (red dots at the right). This couple of objectives has some trade-offs when the weighting scheme is changed, while the curved shape of the Municipality lines and the large fluctuations in the dots of the attainment graph shows that there are weight combinations that can cause these trade-offs to appear.

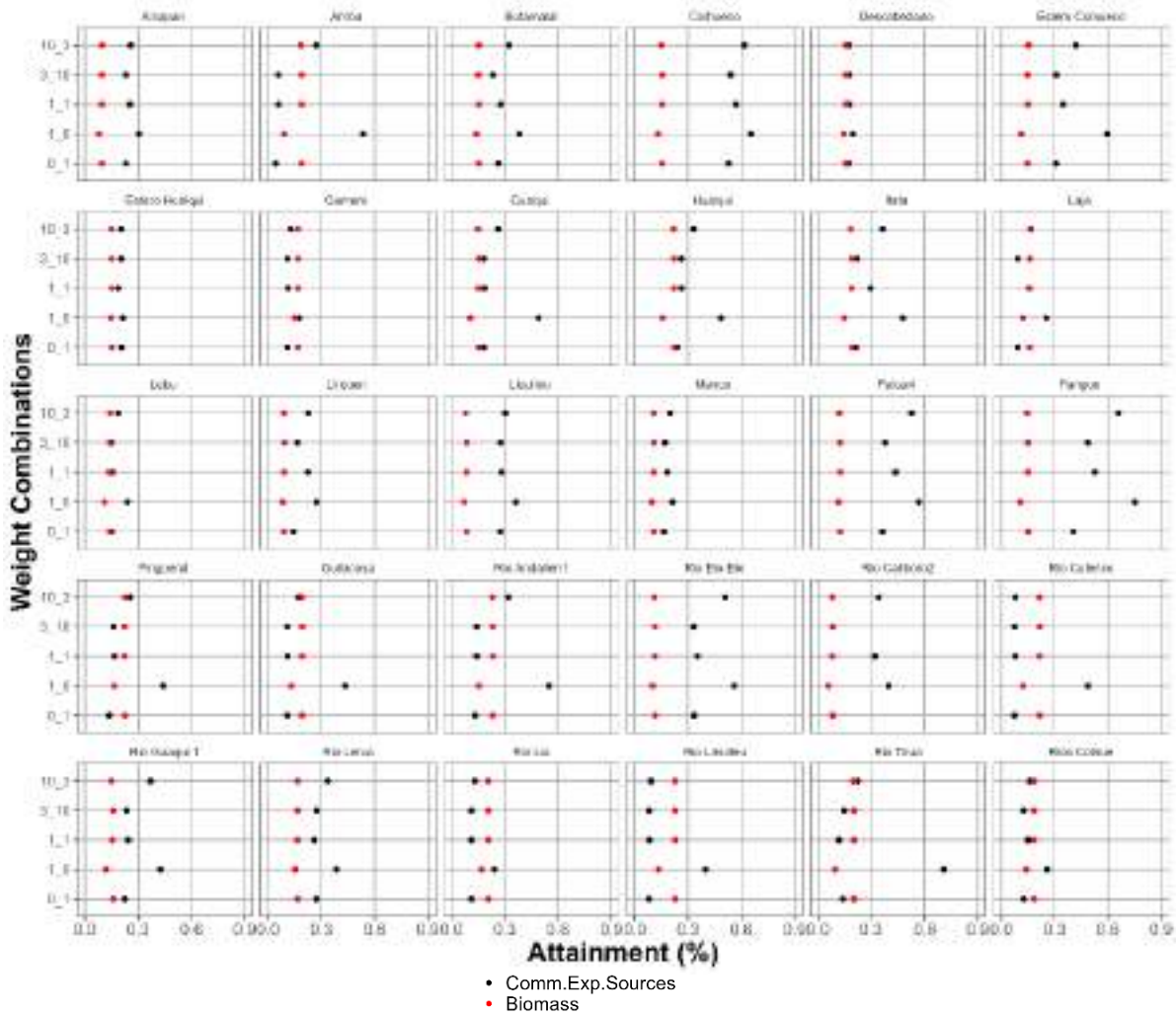

Figure 180 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: biomass retrieved) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The third couple examined the community exposure sources vs. sinks. The map in Figure 181 shows a solution of 107,000 ha for the three examined weight combinations and creates a small maximum difference of 1.8% in the attainment of the community exposure sources, and 0.8% for the sinks. The overall attainment for the management objective of community exposure sources is approximately 15%, while for the sinks approximately 10%. While several of the proposed projects spatially coincide, there is a large number that differentiate at the Municipalities of Rio Culenco, Arriba, Pingueral, Rio

Lleulleu and Carampangue for the weight combination 10-3 (orange colour), and several in Lebu, Rio Andalien1, Rio Culenco, Quilacoya, and Hualqui for the weight combination 3-10 (blue colour).

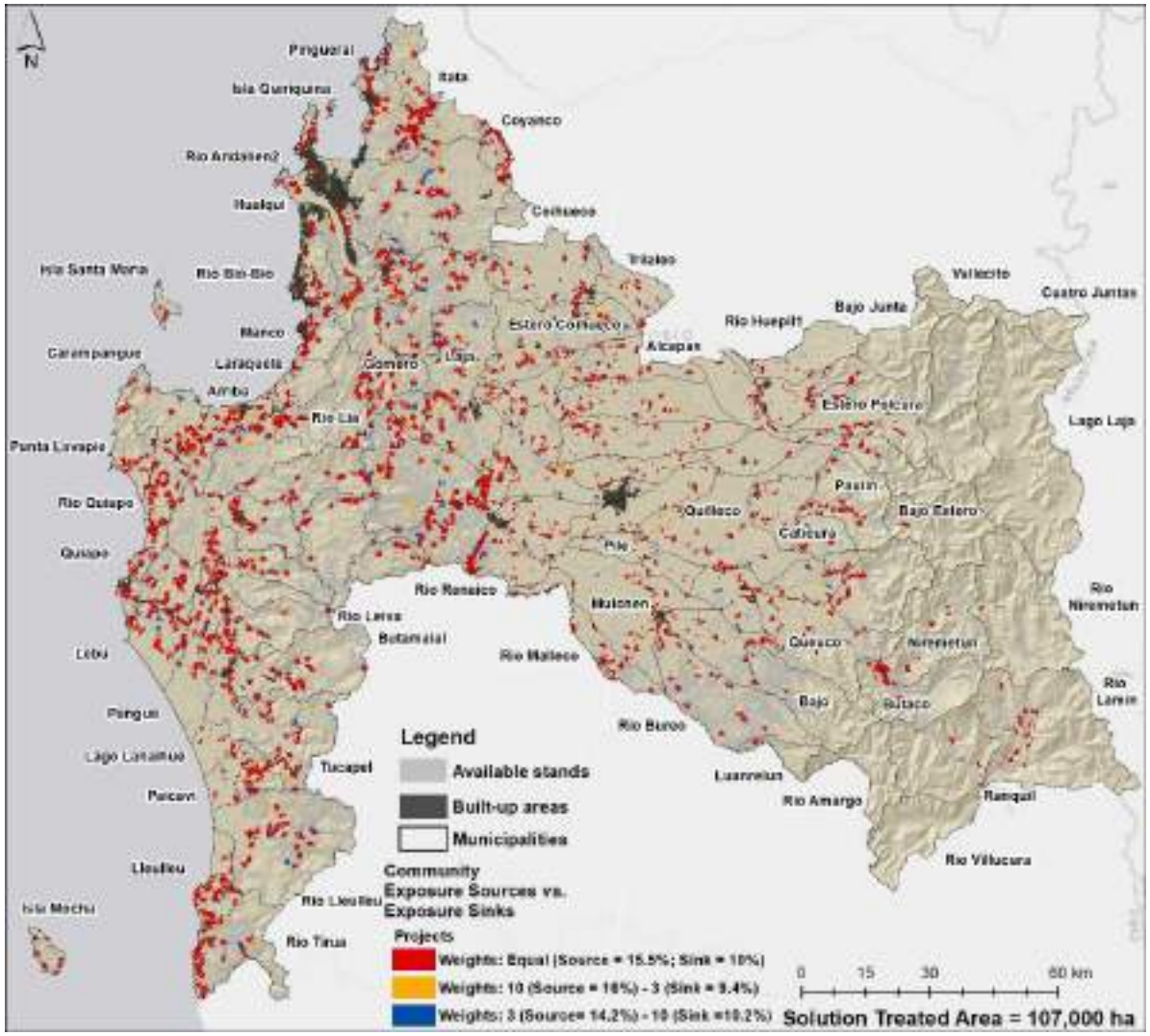

Figure 181 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and developed areas exposure sinks set to low (3) (orange); c) Developed areas exposure sinks objective weight maximized (10) and developed areas exposure sources set to low (3) (blue). Blue- and orange-coloured projects that overlap with the equal weighing scheme are not visible, and they only appear where these projects were not selected by the other two weighting schemes.

The trade-off graph in Figure 182 shows sharp differences for most of the Municipalities, especially for Rio Tirua, Rio Culenco, Rio Lleulleu and Rio Andalien1 (i.e., the more the attainment of the community sinks is increased, the more the sources is decreased). Overall, the attainment capacity of this objective combination is moderate, and the highest performing Municipality like the Rio Tirua can achieve a maximum of 0.7% attainment for the community exposure sources with approximately 0.45% for sinks, while the highest performing curve for community sinks apart from Rio Tirua is in the Municipality of Pingueral, with approximately 0.45% attainment (and 0.28% for

community exposure sources). Most of the Municipalities show a curved shaped line, for some of which sharp decline is noticed for the objective of community exposure sources with the change of weight combinations.

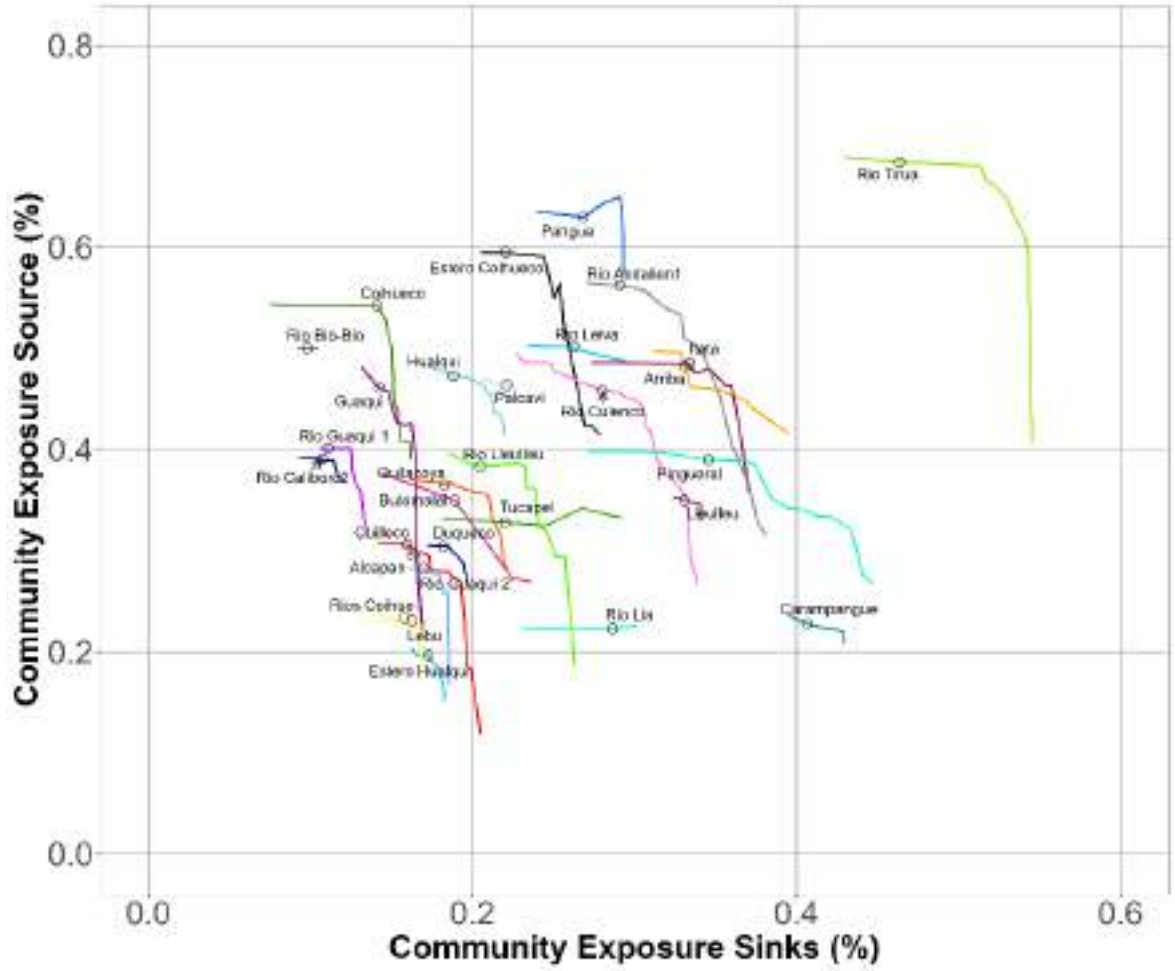

Figure 182 Trade-off production probability curves for each Municipality for the objectives of developed areas exposure sources vs. developed areas exposure sinks. Axes show the level of attainment for each objective (%).

In Figure 183 we noticed large fluctuations in the attainment of almost all the Municipalities, similar to other Living Labs. The most notable fluctuations were found in the Municipalities of Butamalal, Rio Culenco, Pingueral, Arriba and Lleulleu, i.e., change between the order of the two objectives with large difference range in the attainment values. These fluctuations cause in some weight combinations to alternate which objective achieves higher attainment. We also notice fluctuations in the attainment of each objective individually, for example, in Estero Coihueco the combination of 10-3 cause the sources to achieve 0.6% attainment and sinks 0.22%, while the combination 0-1 cause the sources to achieve 0.3% and the sinks 0.25%. Some Municipalities, like Carampangue, Alcapan, Rio Bio-Bio and Tucapel have a stable pattern of attainment for both the objectives across all weight combinations. Last, community exposure sinks achieved better attainment for the Municipalities of Carampangue, Pingueral and Rio Lia, meaning that there is more efficient to protect communities close or inside their

boundaries compared to the rest of Municipalities. Here again, this couple has evident trade-offs when the weighting scheme is changed, an evident fact from the appearance of different colours on the map (orange and blue instead of just red), the curved shape of the Municipality lines, and the large fluctuations in the dots of the attainment graph.

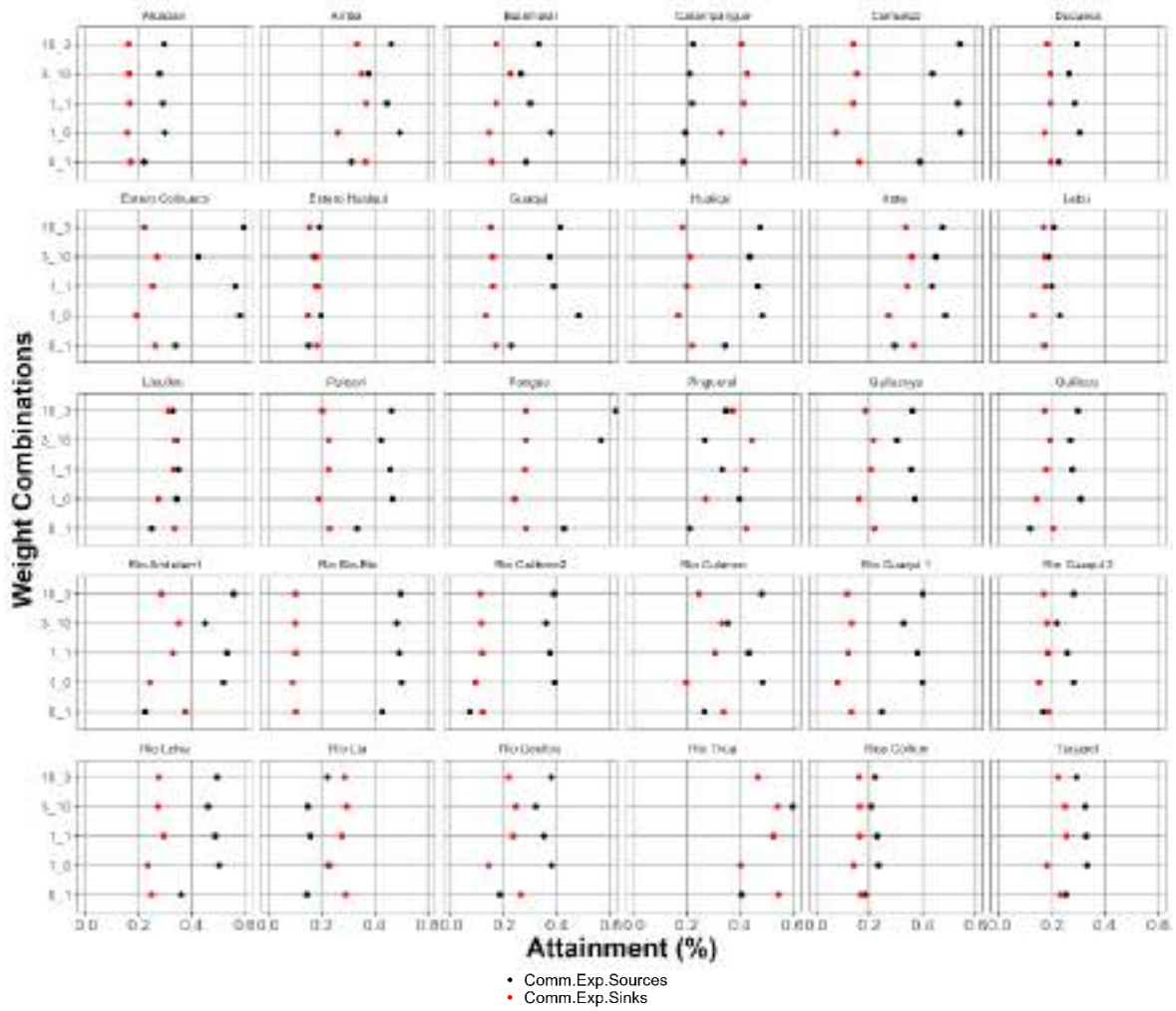

Figure 183 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: developed areas exposure sinks) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The last couple of objectives examines whether it is better to apply fuel treatments on projects area with high fire intensity or if it is better to apply it in high ignition probability areas. The map in Figure 184 shows a solution of approximately 170,000 ha for the three examined weight combinations and creates a minor maximum difference of 0.6% in the attainment of the ignition probability, and 2.1% for the fire intensity (CFL). The overall attainment for the management objective of fire intensity reduction is approximately 11%, while for the ignition probability approximately 10.5%. While several of the proposed projects spatially coincide, there is a very large number that differentiate at the Municipalities of Rios Coihue, Rio Culenco, Pingueral, Hualqui, Rio Bureo, Rio Tirua and Arriba, to mention a few, for the weight combination 10-3 (orange colour), and several in Arriba, Rio Culenco, Rio Tirua, Rio Lebu, and Quilacoya for the weight combination 3-10 (blue colour). In this couple, we noticed that differences were obvious at the eastern

Municipalities, and overall, it is one example where the difference in spatial allocation of the projects is obvious when weights are changed.

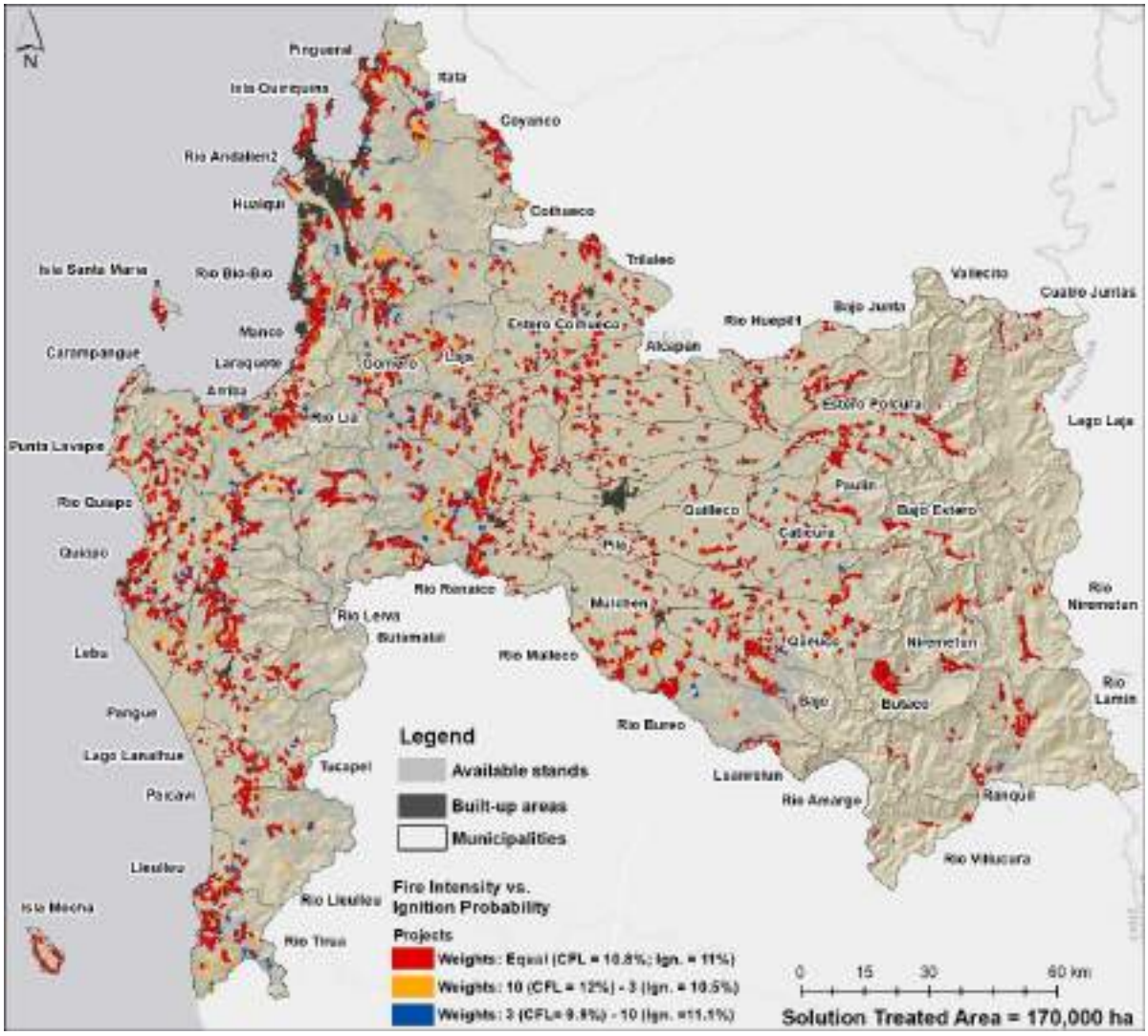

Figure 184 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Fire hazard objective weight maximized (10) and ignition probability set to low (3) (orange); c) Ignition probability objective weight maximized (10) and fire hazard set to low (3) (blue). Blue- and orange-coloured projects that overlap with the equal weighing scheme are not visible, and they only appear where these projects were not selected by the other two weighting schemes.

The trade-off graph in Figure 185 shows sharp differences and clear curved shaped lines for most of the Municipalities, especially for Pingueral, Rio Bureo, Rio Lleulleu, Rios Coihue and Rio Tirua (i.e., the more the attainment of the ignition probability is increased, the more the fire hazard is decreased). Overall, the attainment capacity of this objective combination is moderate, and the highest performing Municipality like the Rio Tirua can achieve a maximum of 0.42% attainment for the fire intensity with approximately 0.17% for ignition probability, while the highest performing curve for ignition probability is the Municipality of Pingueral, with approximately 0.27% attainment (and 0.19% for fire intensity). Most of the Municipalities show a curved shaped line, for some of which sharp

decline is noticed for the objective of fire intensity with the change of weight combinations.

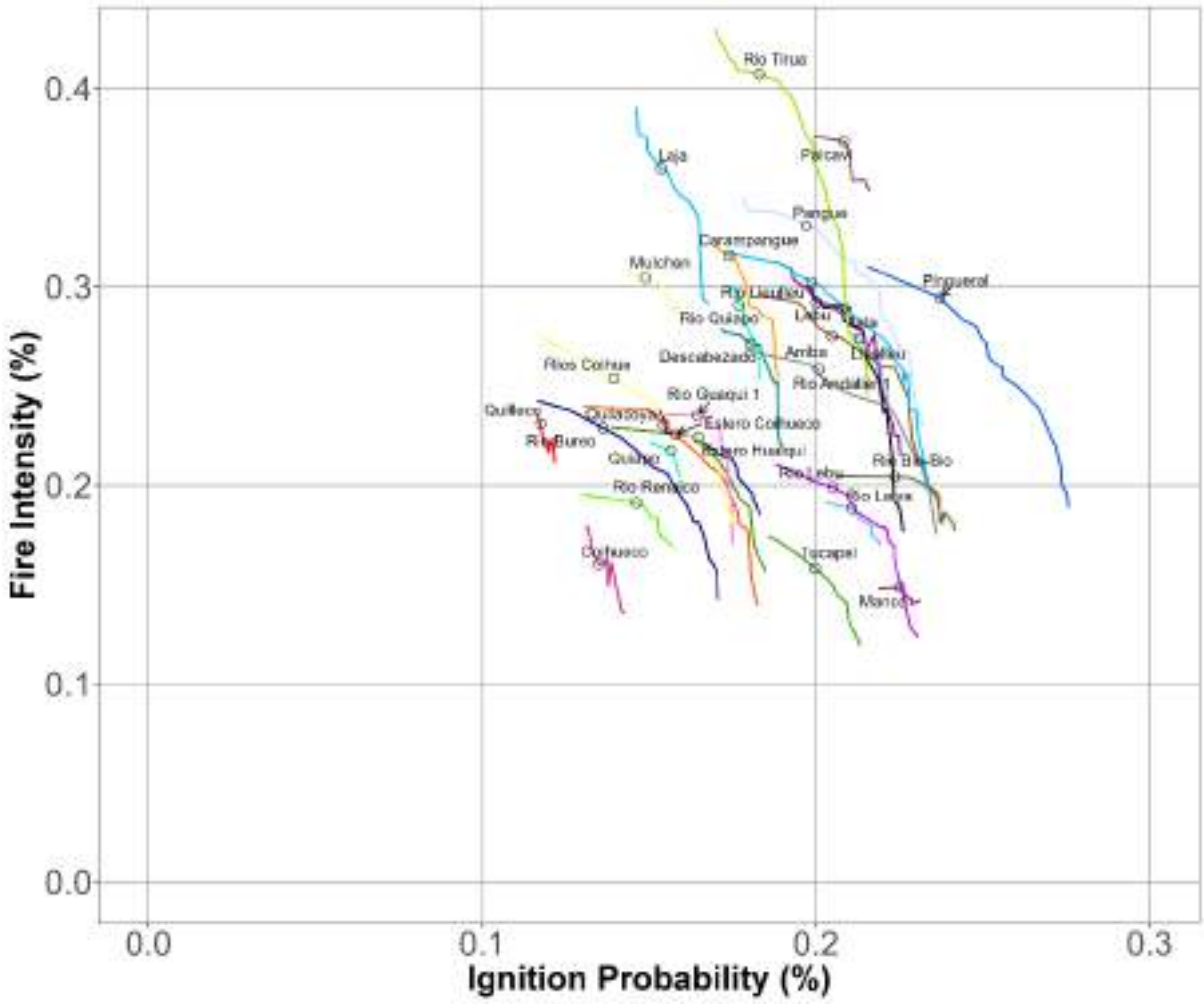

Figure 185 Trade-off production probability curves for each Municipality for the objectives of fire hazard vs. ignition probability. Axes show the level of attainment for each objective (%).

In Figure 186 we noticed large fluctuations in the attainment of almost all the 30 Municipalities examined in this graph. The most notable fluctuations between the two objectives were found in the Municipalities of Arriba, Rio Andalien1, Estero Coihueco, Pingueral, Rio Lleulleu and Itata, i.e., change between the order of the two objectives with large difference range in the attainment values. These fluctuations cause in some weight combinations to alternate which objective achieves higher attainment. We also notice fluctuations in the attainment of each objective individually, for example, in Rio Tirua the combination of 10-3 cause the fire hazard to achieve 0.4% attainment and ignition probability 0.19% (revealed also by the trade-off production probability curve), while the combination 0-1 cause the fire hazard to achieve 0.24% and the ignition probability 0.21%. Some Municipalities, like Manco, Quiapo, Rio Leiva and Paicavi have a stable pattern of attainment for both the objectives across all weight combinations (no large attainment differences for each objective). In most cases, the fire hazard objective achieved higher attainment, but we have the examples of the Municipalities of Manco, Tucapel, Rio Leiva,

and Rio Bio-Bio where ignition probability achieved higher attainment. Here again, this couple has evident trade-offs when the weighting scheme is changed, an evident fact from the appearance of different colours on the map (orange and blue instead of just red), the curved shape of the Municipality lines, and the large fluctuations in the dots of the attainment graph.

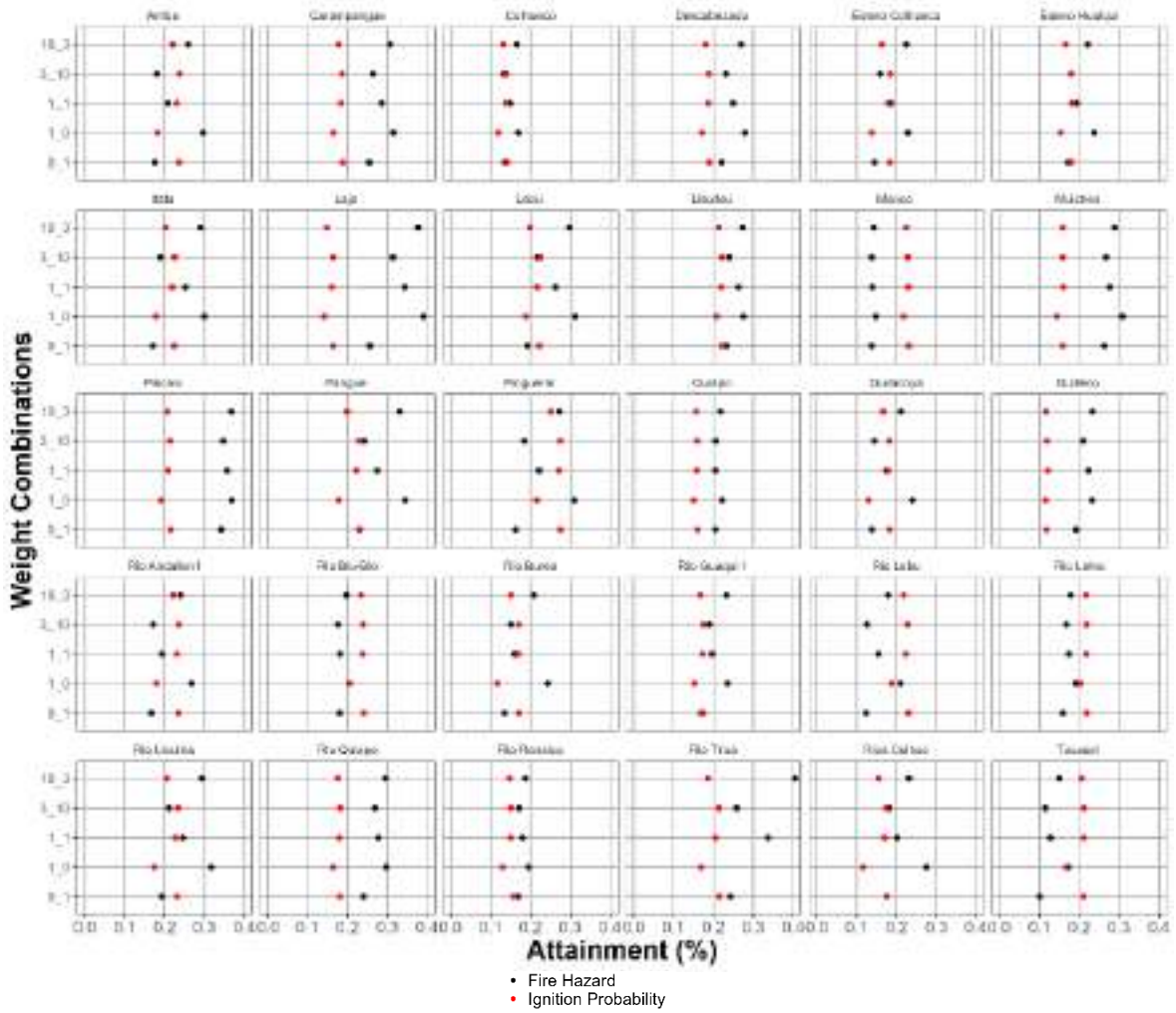

Figure 186 Each panel shows the attainment of each of the two objectives (black: fire hazard; red: ignition probability) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

5 A WebGIS tool for Dissemination & Communication

This ArcGIS Online application provides an interactive platform for analysing fire spread simulations with a focus on three key targets: 1. Efficiency, 2. Equity, and 3. Trade-offs. It allows users to explore fire simulation data and assess potential exposure risks using various thematic layers.

For the Efficiency and Equity projects, the app enables users to filter and analyse different vector data, including Community Exposure Sources, Protected Area Exposure Sources, and High-Probability Exposure Sources. These layers help stakeholders assess the impact of wildfires on communities and protected lands.

The Trade-offs section of the app introduces a comparative approach, allowing users to evaluate the relationships between Community Exposure Sources, Protected Area Exposure Sources, Biomass, Fire hazard and Exposure Sinks. By visualizing these interactions, users can make informed decisions on fire management and mitigation strategies.

5.1 Optimizing landscape fuel treatment allocation Web Portal, Web application

Upon entering the Web application, users are first introduced to the FIRE-RES Program, where they can access via link[1], a detailed information about its objectives and research efforts in wildfire risk mitigation in the FIRE-RES webpage. This section provides valuable context on the program's initiatives and the role of fire simulation data in decision-making. After reviewing the information about the program, users can proceed to select the regional web application they wish to explore. The web application offers simulation data for five different regions: 1. Peloponnese - Greece, 2. BioBio - Chile, 3. Vale do Sousa - Portugal, 4. Catalonia, and 5. Nouvelle Aquitaine - France. By selecting a region, users gain access to tailored fire spread analysis, including exposure sources and comparative assessments.

When users open any of the five regional web applications, they are presented with a brief tutorial explaining how to navigate and utilize the platform effectively. This introductory guide provides step-by-step instructions on interacting with the app's features, such as exploring fire simulation data, filtering exposure sources, and comparing different datasets. The tutorial ensures that users can quickly familiarize themselves with the interface and maximize the app's capabilities for wildfire analysis and decision-making (Figure 187).

[1] https://geography.aegean.gr/fire-res/

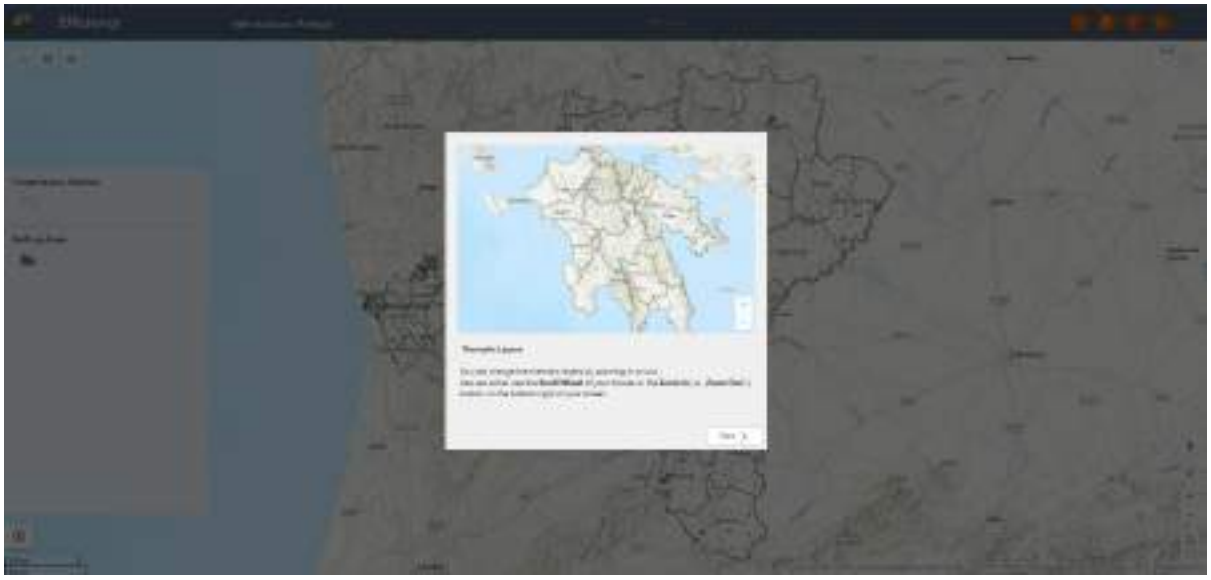

Figure 187 Initialization sequence to select the Living Lab

5.1.1 How-to use the web application

After completing the introductory tutorial, users can choose between three key objectives within the application: Efficiency, Equity, and Trade-offs on the top right of the screen. Each objective provides a different perspective on fire exposure visualization.

To navigate and utilize the Web Application effectively, users can access various tools and features (Figure 188):

- Measurement Tool: Located in the top-left corner of the screen, this tool allows users to measure distances and areas within the map.
- Basemap Selection: Adjacent to the Measurement Tool, users can change the Basemap according to their needs. This feature allows for customization of the map's background.
- Administrative Boundaries Button: In the top-right corner of the screen, users can access a button that displays Comarques, Forest Service Districts, or Municipalities. When a user selects a specific area, the map automatically zooms in and adjusts its cartographic scale to focus on the selected region, restricting the view to its boundaries for a more detailed analysis.

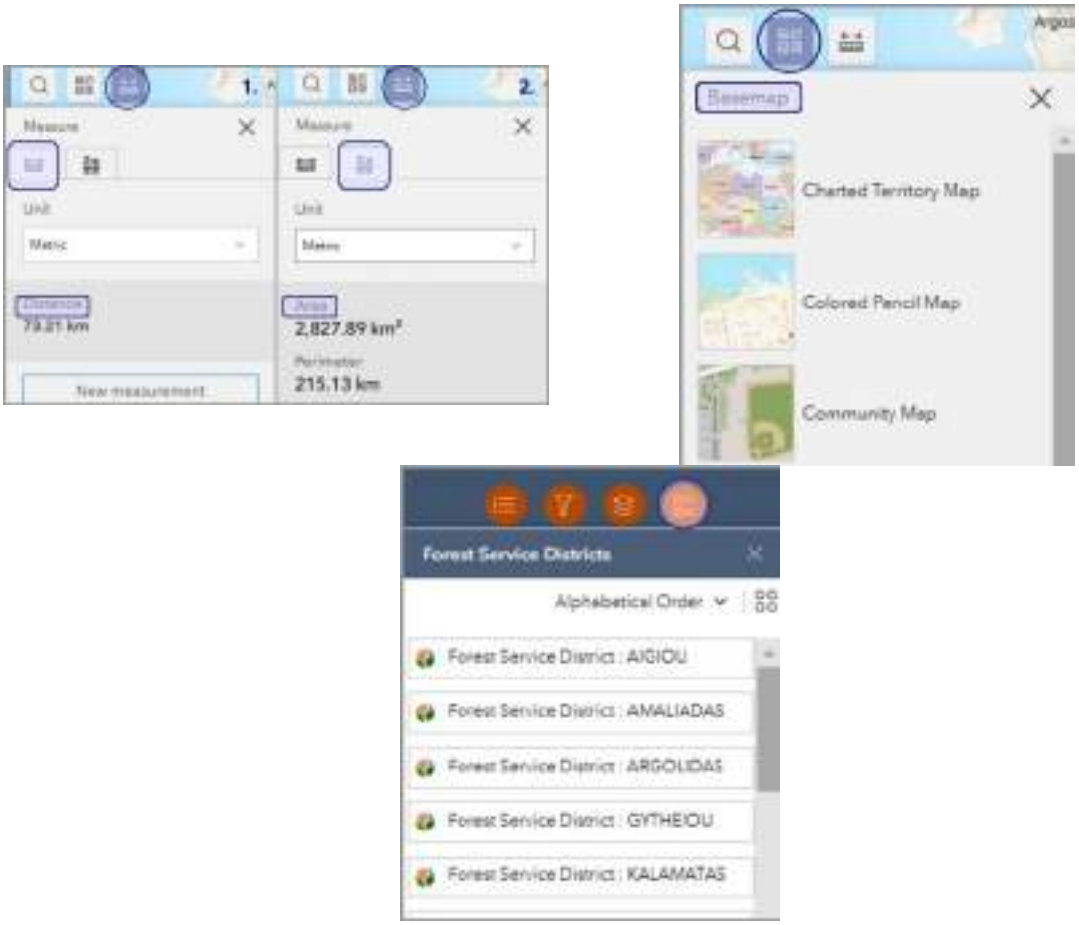

Figure 188 Left: Measurement Tool for measuring Distance and Areas within the Map. Right: Basemap selection. Bottom: Administrative Boundaries selection

5.1.2 Efficiency Outputs (SET1 results)

In the Efficiency set of runs, users must first select one of the three available map layers: Community Exposure Sources, Protected Area Exposure Sources and High Probability Ignition Sources. Once a map layer is selected, users proceed to the filtering options, where they can specify the Year of Implementation. This parameter ranges from 1 to 10. To ensure accurate data visualization, users must select the Year Filter that corresponds to the same Map Layer they have chosen. For example, if a user selects Community Exposure Sources as the map layer, they must also set the Year of Implementation filter for Community Exposure Sources (Figure 189). This alignment ensures that the displayed data reflects the correct exposure scenario for the selected timeframe, providing a more precise visualization of fire spread and its impacts (Figure 190).

Figure 189 Map Layer Selection for the community Exposure Sources and Filtering the Year of implementation from 1 to 10.

Figure 190 Visualization of the projects produced with ForSys for the Efficiency Set of Runs

5.1.3 Equity Outputs (SET2 results)

In the Equity set of runs, users follow the same process as in Efficiency but with a different filtering criterion. Instead of selecting a Year of Implementation, they must choose a Rank for each region ranging from 1 to 50 for all regions, except for Nouvelle-Aquitaine, where

the rank ranges from 1 to 20. To correctly visualize the data (Figure 191), users should first select one of the three Map Layers (Community Exposure Sources, Protected Area Exposure Sources, or High Probability Ignition Sources) and then apply the corresponding Rank Filter (Figure 192).

Figure 191 Map Layer Selection for the Protected Area Exposure Sources and Filtering the Rank per Forest Service District from 1 to 50.

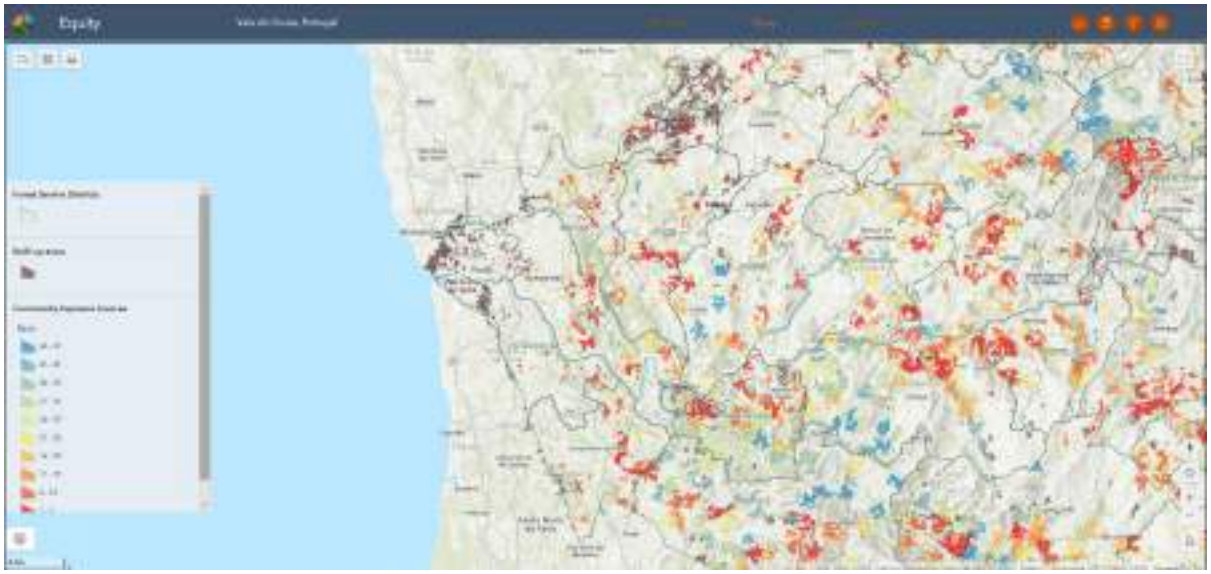

Figure 192 Visualization of the projects produced with ForSys for the Equity Set of Runs

5.1.4 Trade-off Outputs (SET3 results)

In the Trade-offs set of runs, users compare two different fire exposure scenarios by selecting a comparison layer. The web application allows users to rank one of these scenarios based on weighted criteria (Figure 193). Below are the steps to use the filter:

1. Select a Comparison Layer – Users must first choose a layer that compares two different scenarios and decide which of the two scenarios they want to rank.
2. Filter the Weight of the Objective – Users then select the Weight of the Objective, by selecting a value from 1 to 10.
3. Select a Weight Combination – Finally, users choose a valid combination of weights that aligns with the scenario they are ranking and press the "Apply" button.

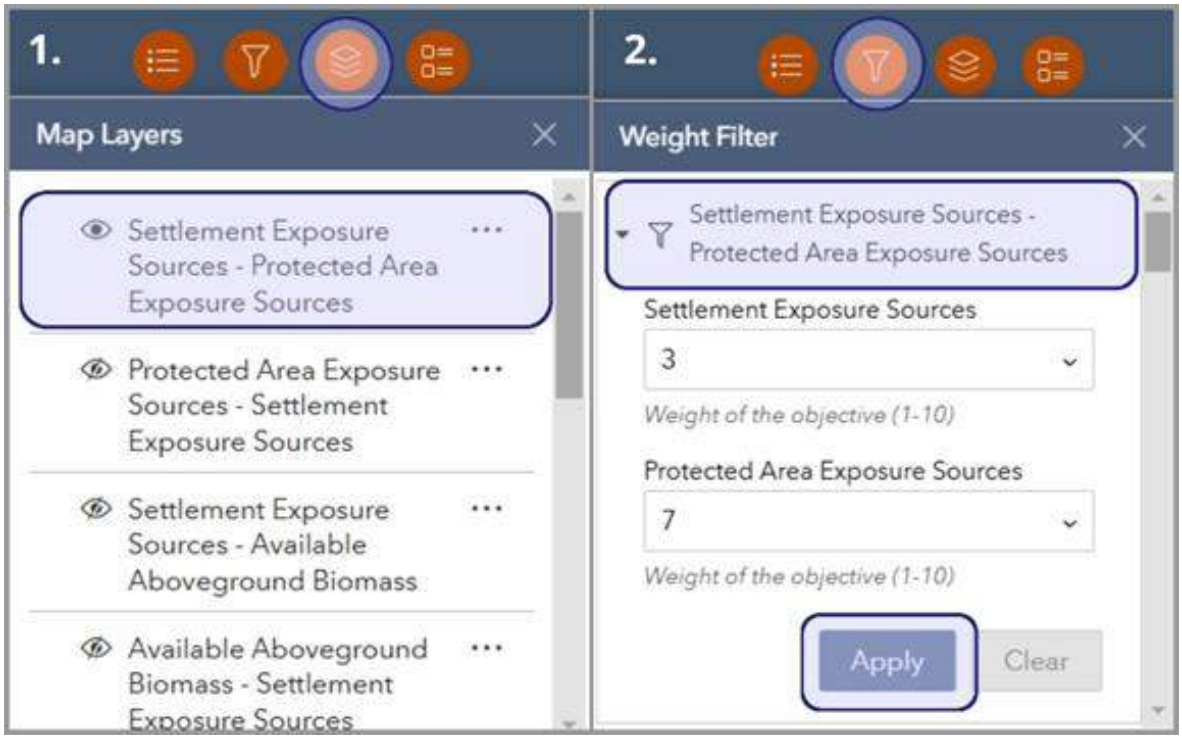

Figure 193 Map Layer Selection for the Settlement Exposure Sources vs. Protected Area Exposure Sources and Filtering the Weight of the objective from 1 to 10.

6 Validation of Scenario Planning with ForSys results with FlamMap fire simulations

FlamMap is a fire behaviour modelling and mapping software that is open-source and in the public domain. It is used to simulate and analyse potential wildfire behaviour across landscapes. Researchers, fire managers, and land planners widely use it to assess fire spread, intensity, and spotting potential under constant environmental conditions (weather and fuel moisture). FlamMap maintains constant environmental conditions, meaning it does not simulate temporal fire behaviour variations caused by weather changes or diurnal fluctuations. It also does not account for spatial variations from backing or flanking fire behaviour. However, the software is well-suited for landscape-level comparisons of fuel treatment effectiveness, as fuel is the only changing variable. These outputs help identify hazardous fuel and topography combinations, aiding in prioritizing fuel treatments. The FlamMap software can 1) Predict fire behaviour (rate of spread, flame length, fireline intensity, etc.) based on input fuel models, terrain, and weather conditions; 2) Simulate different fire scenarios (e.g., changes in vegetation management, wind conditions, or fuel treatments); 3) Work with GIS data to analyse fire risk over large areas; 4) Help in decision-making for wildfire prevention, suppression strategies, and fuel management planning.

For the Greek Living Lab, a Peloponnese LCP file is developed containing eight raster data with 30 m spatial resolution, describing fuels (fuel model, canopy cover, canopy height, crown base height, crown bulk density, stand height) and topography (elevation, slope, aspect) (refer to the description of the Fire Behaviour Modelling in the Methodology Section regarding FSim). Then, another two LCP files were created based on Peloponnese's Forest Management Plans and the following fuel model scenarios (Table 5):

1. Fuel model -Thinning: The managed areas were converted to fuel model TU1 (code 161), which represents a mixed dry-climate vegetation model with low fuel load. The primary fire carrier consists of low-load grasses and/or shrubs with litter. The rate of fire spread, and flame length are low.

2. Fuel model-Clearcut: The managed areas were converted to fuel model GR1 (code 101), representing sparse grassland vegetation in a dry climate with low fuel load. The primary fire carrier is discontinuous low grasses, with the possibility of small amounts of fine dead fuel. The rate of fire spread is expected to be low, as is the flame length compared to other grass- fuel models.

Table 5 Assumptions for each proposed fuel type/ scenario, considering the forest fuel characteristics.

	Canopy Cover	Crown Base Height	Crown Bulk Density	Stand Height	Fuel Models
Original Landscape	Continues as is	Continues as is	Continues as is	Continues as is	Continues as is
Thinning	Will decrease by 40%	Will increase to 5m for those pixels	Will decrease by 40%	Continues as is	161

Clearcut	is zeroed out	with a value lower than this is zeroed out	is zeroed out	is zeroed out	101

FlamMap v6 is utilized to simulate three wildfire scenarios for 30 large, populated settlements in the Peloponnese, using proposed fuel model scenarios. For a more representative wind speed and dominant wind direction, meteorological data were collected from 20 weather stations near the selected settlements from May to September between 2020 and 2024 through the online Meteo weather platform (http://meteo.gr) (Table 6). Also, data from another ten meteorological stations collected the same month period of the year 2024, due to lack of data the previous years. These stations are: Lagkadia, K Vlasia, Kalentzi, Kalavryta, Levidi, Andritsaina, Skala, Geraki, Amaliada, Lappas (Figure 194). Next, digital vector files (fire ignition) were generated with the frontal lines of each fire aligned with the prevailing wind direction.

Table 6 Meteorological data from May to September between 2020 and 2024.

	MEAN TEMP. (°C)	RAIN (mm)	AVG. WIND SPEED (km/h)	HIGH WIND SPEED (km/h)	DOM. DIR
PATRA	25.33	20.97	13.86	88.50	SW
KALAMATA	25.78	20.22	5.56	61.20	S
KORINTHOS	26.46	12.90	14.72	91.70	SE
TRIPOLI	20.80	32.96	3.34	66.00	E
PYRGOS	26.32	16.00	4.62	56.30	E
ARGOS	25.58	21.72	4.88	48.30	NW
AIGIO	27.36	6.32	5.78	48.30	NW
SPARTI	24.82	26.17	6.06	54.70	WNW
LOUTRAKI	26.76	14.14	5.04	70.80	E
KIATO	25.65	12.33	6.70	72.40	NE
K AXAIA	24.78	18.54	4.03	53.10	ESE
OMBRYA	25.57	19.64	5.25	67.60	ESE
RIO	25.14	21.35	11.18	78.90	SW
PARALIA	25.37	18.95	4.89	67.80	W
MEGALOPOLI	22.80	40.12	5.00	70.80	NE
KYPARISSIA	24.49	15.42	2.49	75.60	W
FILIATRA	24.36	17.29	4.22	87.60	NW
KRANIDI	26.08	22.95	6.98	62.80	SE
NEMEA	23.66	25.02	5.70	72.10	SE
KAVOMALIAS	25.58	14.59	10.61	96.60	N

The wind speed selected and applied for three fuel model scenarios is 55 km/h, with direction based on the prevailing wind. The Fuel Moisture Content for each fuel model in the study area, worst-case scenario, is as follows: 1hr: 3%, 10hr: 4%, 100hr: 5%, Live Herbaceous: 30%, Live Woody: 60%. The calculation of canopy fire parameters is based

on Finney (2004) equation. The Foliage Moisture Content of the tree canopy is set at 100%. In the Minimum Travel Time (MTT) model, the input simulation parameters were defined as presented in Figure 195.

Figure 194 Meteorological stations in Peloponnese.

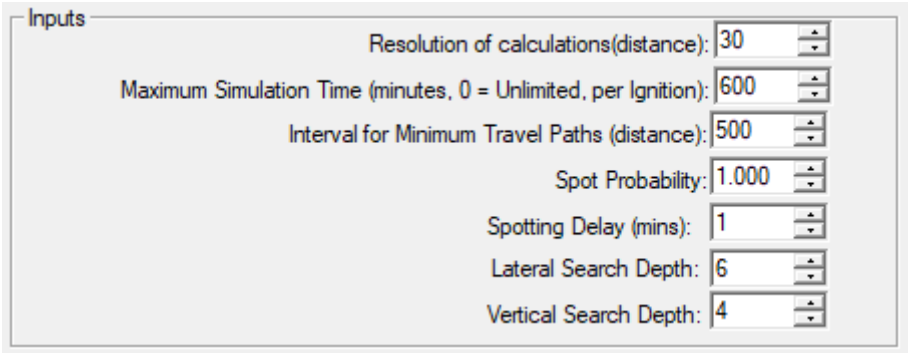

Figure 195 MTT input simulation parameters.

Based on FlamMap outcomes, the average of Rate of Spread (ROS) and Fireline Intensity (FI) was calculated for the settlements around each weather station taking into consideration the 90 forest fire simulations (Table 7).