4.3 Living Lab Catalonia

The application for this component in the Living Lab of Catalonia-Spain is the whole region of Catalonia, a region that cover 3.21 million ha of which, 1.06 million ha are available for receiving fuel treatment projects. The analysis was performed at the level of Comarques (43 in total, including Val d' Aran, with an area ranging from 14,500 ha to 179,000 ha). We analysed the effects of fuel treatment projects at six management objectives: biomass retrieval, protection of carbon stocks, fire risk reduction at the community exposure sources, reduction of fire hazard (i.e., energy release) to facilitate better fire suppression, reduction of future ignitions in high ignition probability areas, and reduction of the exposure of protected areas from the sources of their exposure.

4.3.1 SET0: Control & Evaluation

In this set of fuel treatment scenario planning, we estimated the effect that spatial optimization has in three management objectives, namely community exposure sources, protected exposure sources and ignition probability, when we select to apply fuel treatments at 250,000 ha and we compared with a random and a proximity to roads allocation schemes. For comparison, for the previous two Living Labs the tested this set on only 50,000 ha, this is why in the case of Catalonia we achieved high attainment values. We found that both random and roads allocation have very low performance when compared with the optimized allocation (Figure 82). Random project allocation and proximate to road network allocation graphs (Figure 82) are similar with insignificant changes.

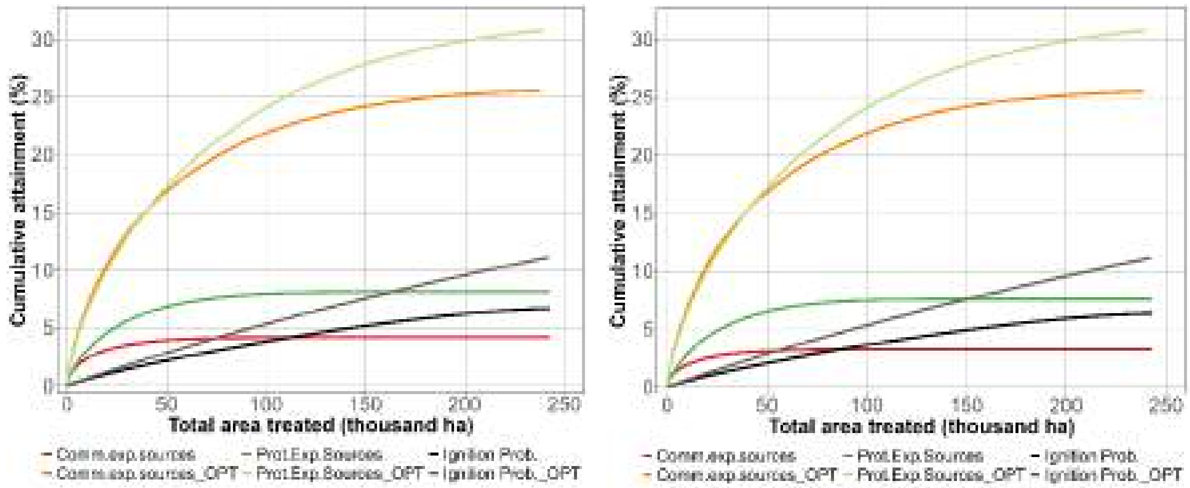

Figure 82 Left: Random project allocation; Right: Project allocation proximate to the road network. OPT: Results from the optimization runs. For comparison, similar colours with different intensity were used for the same objective.

In particular, the optimized allocation for protected areas exposure sources can achieve an attainment of up to 31% (i.e., a reduction of 31% in the total exposure that all protected areas has in the study area) compared to the 7-8% the non-optimized allocation achieved, the community exposure sources optimized allocation achieved approximately 25% vs. the 3-4% of the non-optimized allocation, and finally, we found smaller differences between the spatially optimized allocation of the reduction of ignition probability that achieved approximately 11% attainment vs. the 6-7% of the non-optimized allocations.

These results prove that the business-as-usual way of allocating fuel treatment projects (i.e., randomly or in proximity to roads) cannot provide substantial reduction to key management objectives like the protection of communities or risk reduction for protected areas and can have a similar impact only for the objective of reducing ignition probability.

4.3.2 SET1: Efficiency, with a 10-year implementation plan

The implementation of a 10-year plan to reduce the fire risk of the communities from the sources of their exposure by treating half (i.e., 268,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 537,000 ha), resulted to request the spatial optimization of 2680 projects (Figure 83). The total treated area returned from the spatial optimization solution is 255,419 ha. In this optimization run we did not consider any administrative boundary.

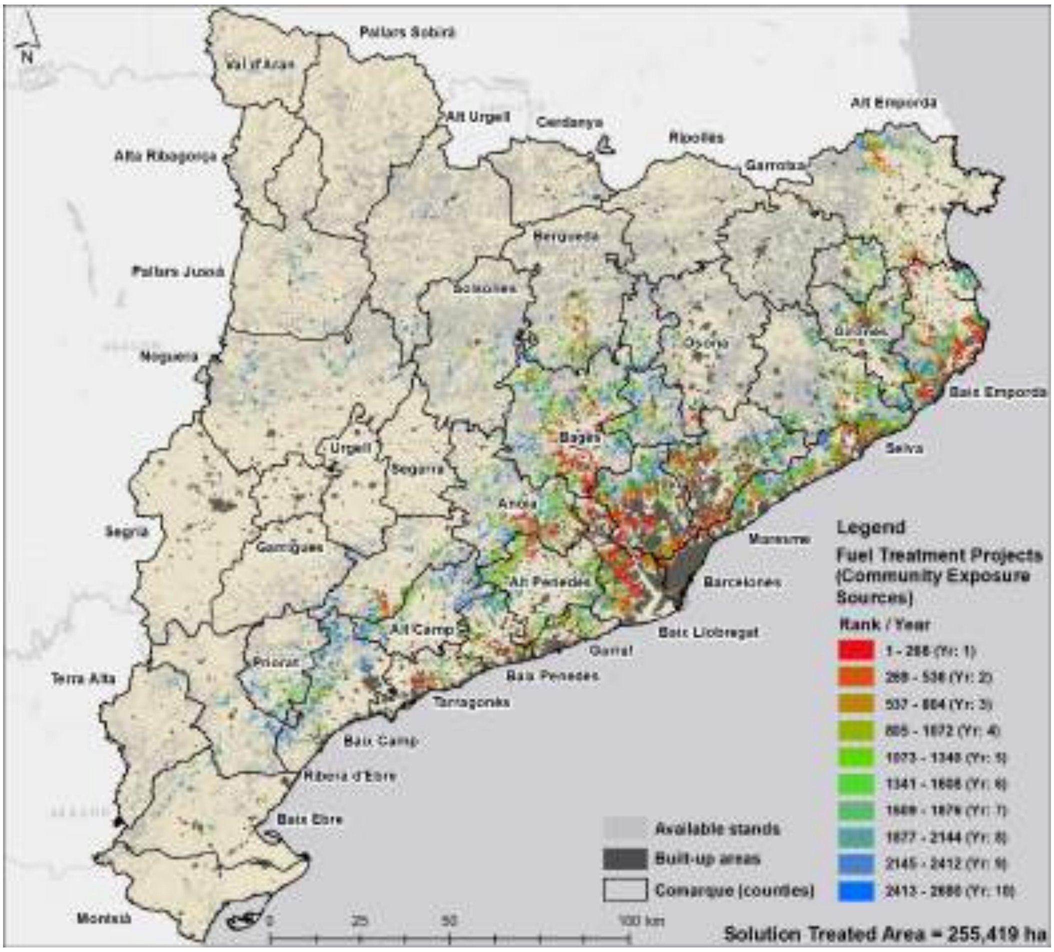

Figure 83 Map of the 2680 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

Each year, approximately 26,000 ha should be treated (Figure 84), and during the first year the main objective (i.e., community exposure sources) can reach an attainment of up to 12%. For the first five years, the attainment of the main objective can reach 24% by treating approximately 128,000 ha, with the attainment of the other objectives be low (between 4-7%) except for the protected areas exposure sources that is very effective and can reach up to 17% by the fifth year. After the fifth year, the attainment for the main objective is slightly increased to reach 25.5% by the tenth year, while the other objectives rise more sharply to reach an attainment of ~13% for carbon, 10% for the fire hazard and ignition probability and 8% for biomass.

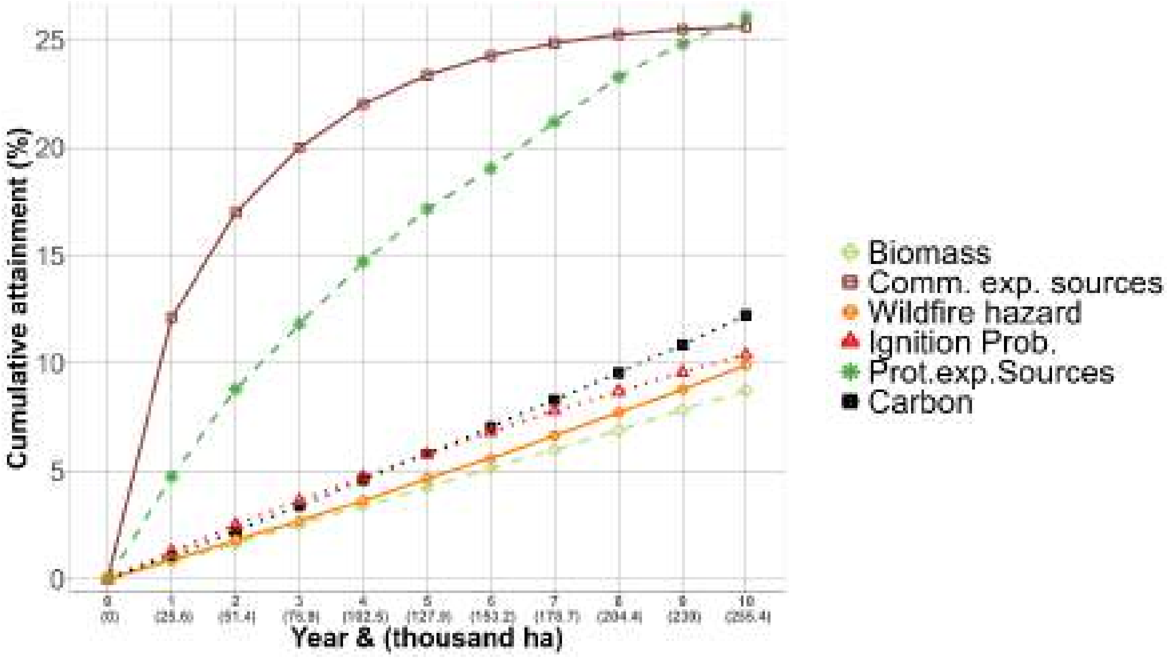

Figure 84 The 10-year implementation plan of fuel treatment with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

The bulk of the projects are in the Comarque of Bages (~26k ha), followed by Baix Empordà (20k ha), Vallès Occidental (18k ha), Anoia (16k ha) and Vallès Oriental (16k ha), with the rest Comarques receiving less than 15k ha of fuel treatments during the 10-year implementation plan (Figure 85-top). The highest attainment is achieved in the Comarque of Vallès Occidental (3.5%), followed by Baix Empordà (3.2%), Baix Llobregat and Bages (~3%), and Vallès Oriental (2.3%), with the remaining Comarques achieving less than 1.5% attainment during the 10-year implementation plan (Figure 85-bottom). It is notable that the projects planned to be implemented during the first year and are in the Comarques of Vallès Occidental, Baix Empordà, Baix Llobregat, Bages, Vallès Oriental, Osona and Barcelonès achieve at least half of their total attainment (Figure 85-right). This finding suggests that they should be among the first to receive fuel treatments to faster achieving the goals of the main objective.

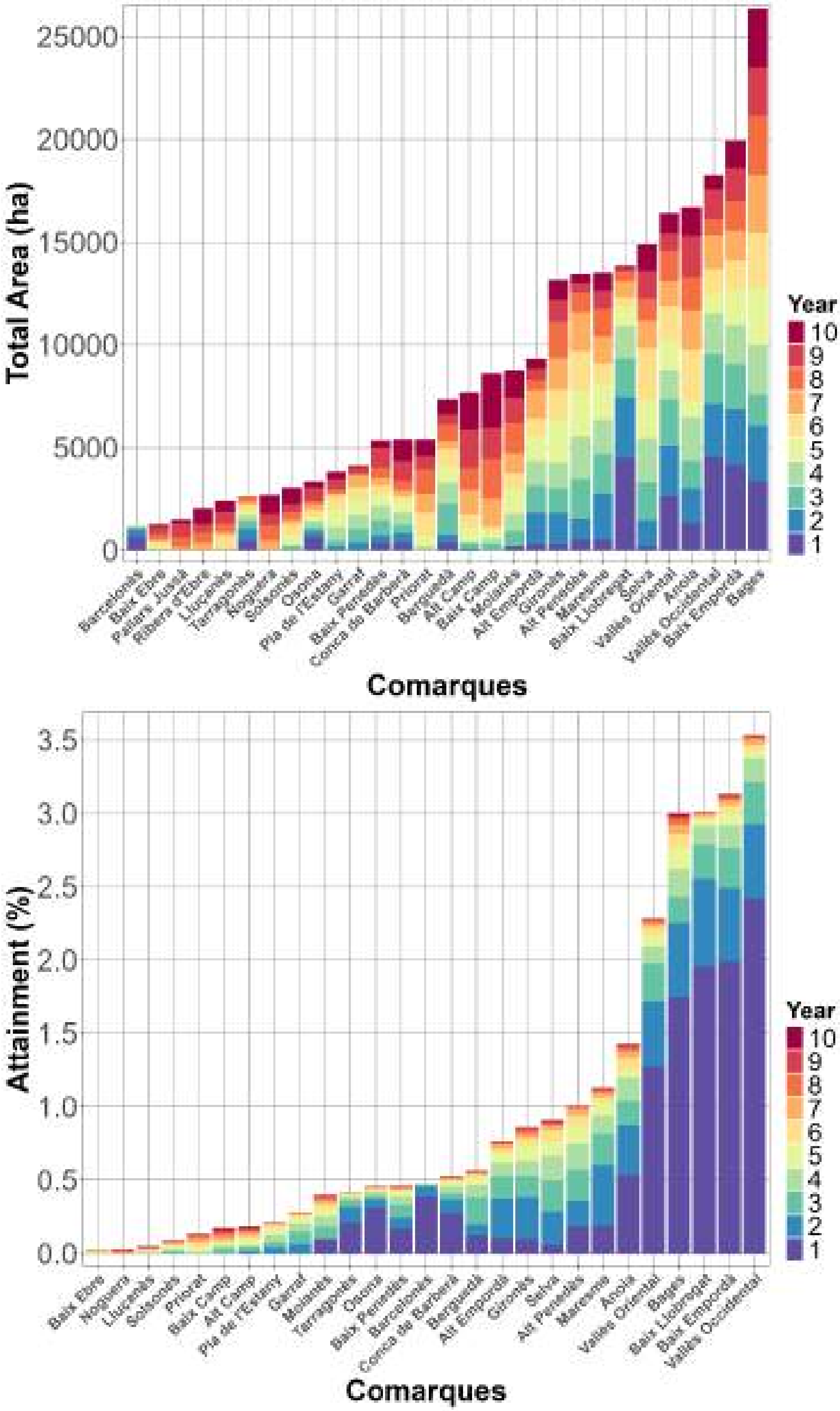

Figure 85 Top: area treated in ha for each Comarque by implementation year. Bottom: main prioritized objective attainment (%) for each Comarque by implementation year.

The implementation of a 10-year plan to reduce the fire risk of the protected areas from the sources of their exposure by treating half (i.e., 284,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 568,000 ha), resulted to request the spatial optimization of 2840 projects (Figure 86). The total treated area returned from the spatial optimization solution is 272,111 ha. In this optimization run we did not consider any administrative boundary.

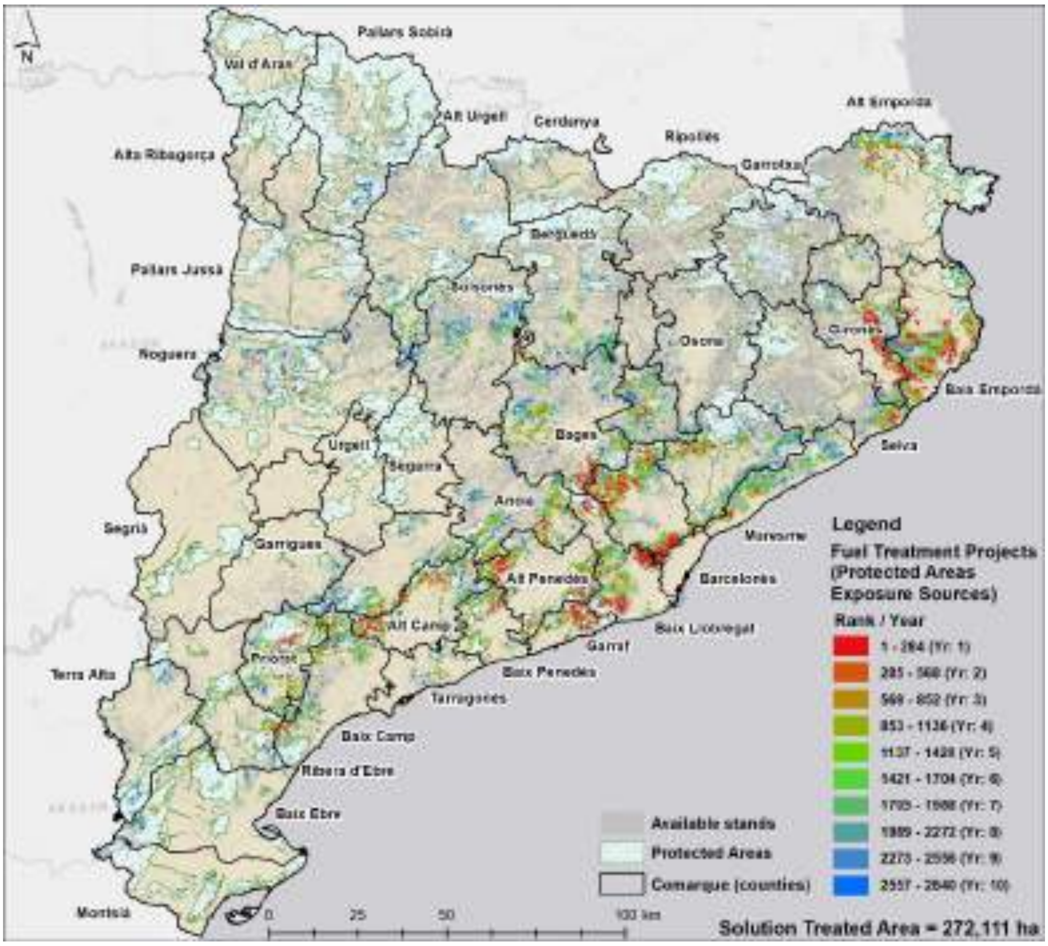

Figure 86 Map of the 2840 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

Each year, approximately 28,000 ha should be treated (Figure 87), and during the first year the main objective (i.e., protected areas exposure sources) can reach an attainment of up to 12%. For the first five years, the attainment of the main objective can reach 27% by treating approximately 137,000 ha, with the attainment of the other objectives be low (<7%) except for the community exposure sources that is effective and can reach up to 14% by the fifth year. After the fifth year, the attainment for the main objective is slightly increased to reach 30% by the tenth year, while the other objectives rise low to reach an attainment of ~14% for carbon, 12% for the fire hazard, and 10% for the biomass and ignition probability.

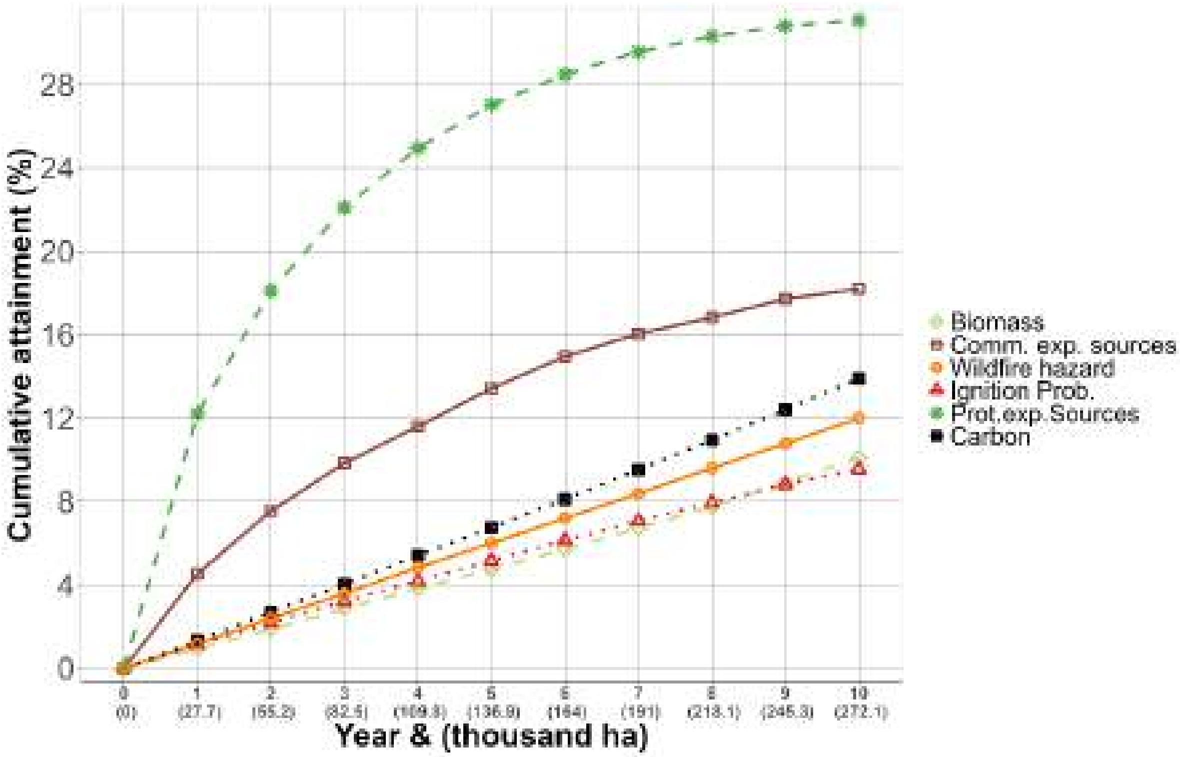

Figure 87 The 10-year implementation plan of fuel treatment with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

The bulk of the projects are in the Comarque of Baix Empordà (~23k ha), followed by Bages and Vallès Occidental (~18k ha), with the rest Comarques receiving less than 13k ha of fuel treatments during the 10-year implementation plan (Figure 88-top). The highest attainment is achieved in the Comarques of Baix Empordà (~4%) and Baix Llobregat (~3.2%), followed by Vallès Occidental and Gironès (~2.6%) although the total treated area for Gironès and Baix Llobregat is overall low (~13k ha) compared to the other Comarques, they achieve a high efficiency in their attainment (e.g., Bages with 18k ha achieves ~1.8%). It is notable that the projects planned to be implemented during the first year and are in the Comarques of Baix Empordà, Baix Llobregat, Gironès, Garraf and Barcelonès achieve more than half of their total attainment (Figure 88-right). This finding suggests that they should be among the first to receive fuel treatments to faster achieving the goals of the main objective.

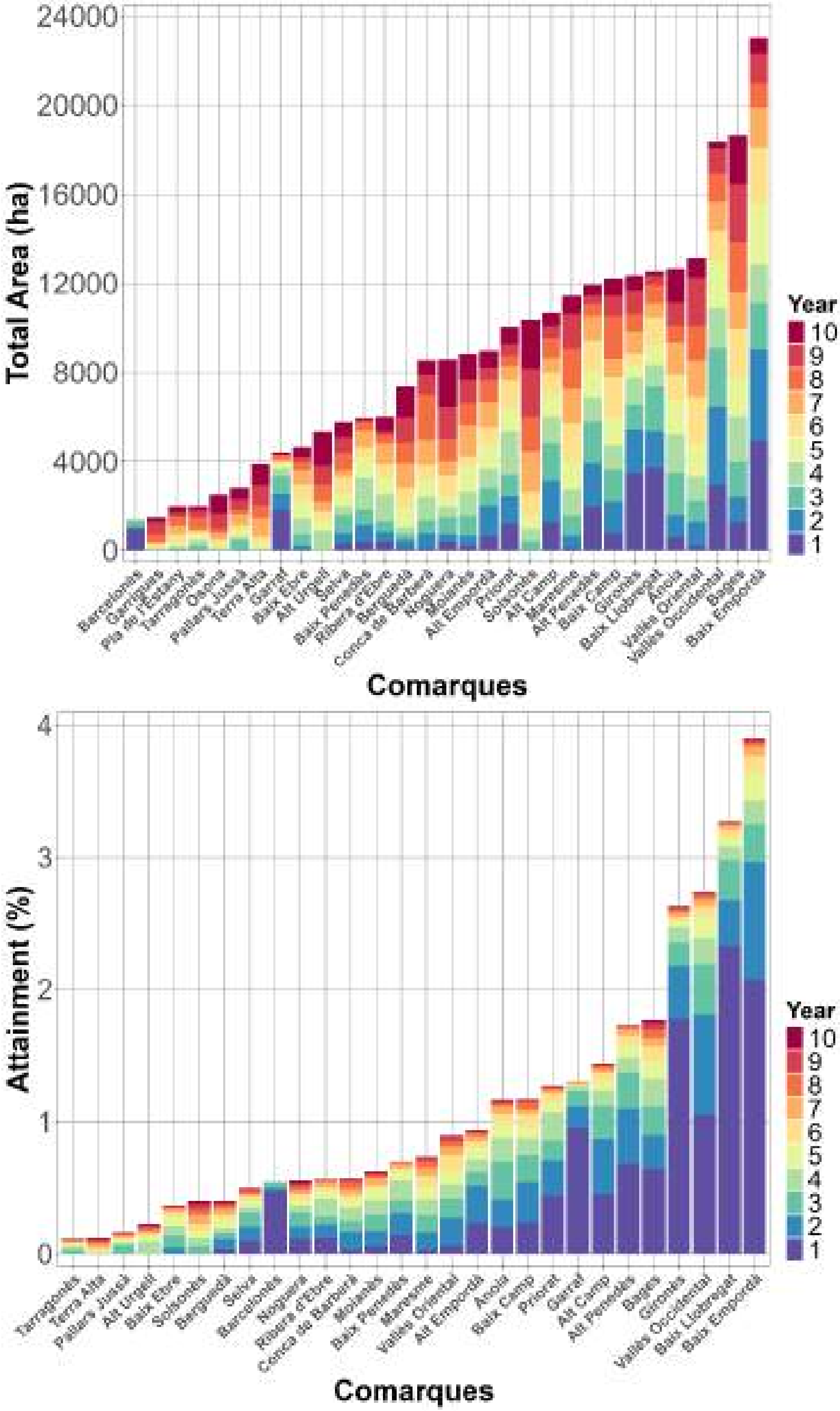

Figure 88 Top: area treated in ha for each Comarque by implementation year. Bottom: main prioritized objective attainment (%) for each Comarque by implementation year.

The implementation of a 10-year plan to reduce the ignition probability by treating half (i.e., 530,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 1,06 million ha), resulted to request the spatial optimization of 5300 projects (Figure 89). The total treated area returned from the spatial optimization solution is 511,154 ha. The proposed area for treatments is large since all the available stands had an ignition probability value attached that was greater than zero (the unavailable and non-burnable stands were already excluded). In this optimization run we did not consider any administrative boundary.

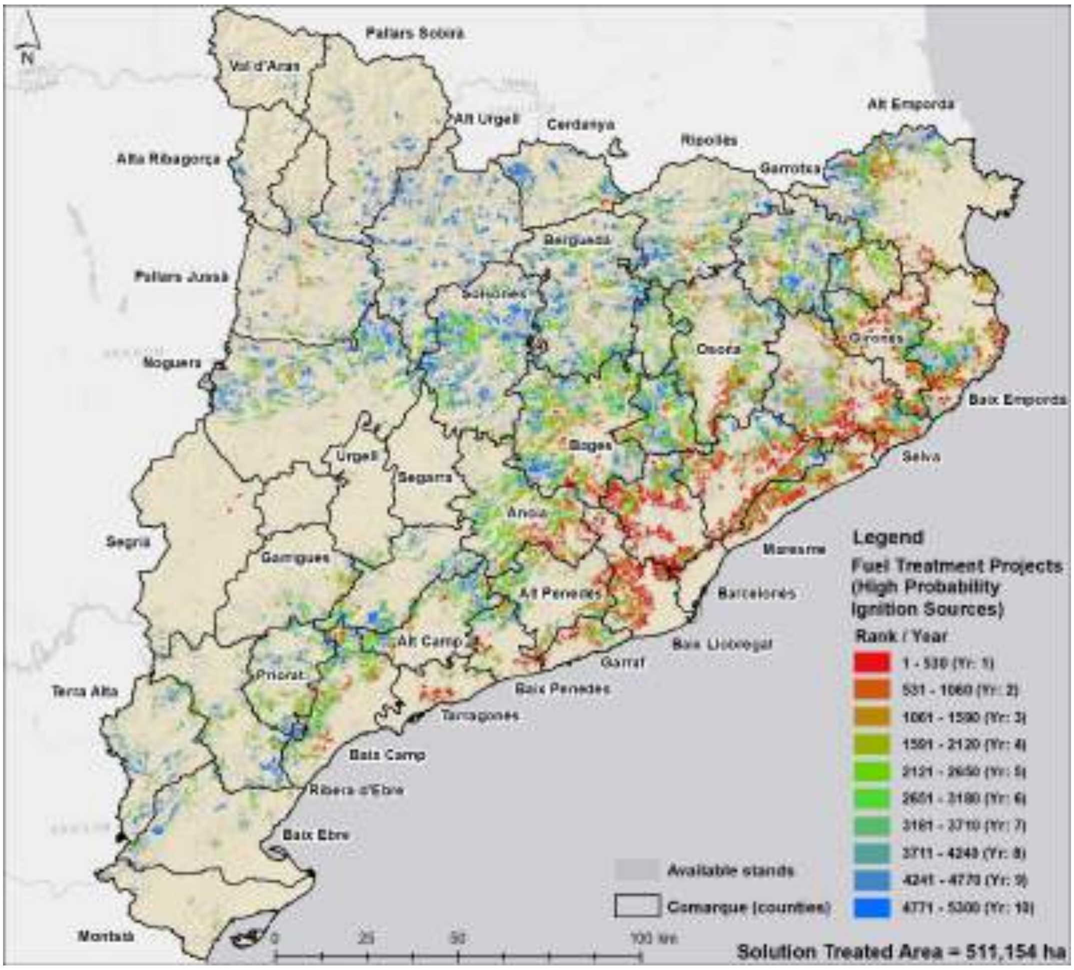

Figure 89 Map of the 5300 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce new ignitions by treated in areas with high ignition probability.

Each year, approximately 52,000 ha should be treated (Figure 90), and during the first year the main objective (i.e., reduction of ignition probability) can reach an attainment of up to 3%. For the first five years, the attainment of the main objective can reach ~12% by treating 257,000 ha, similar with the attainment of carbon (~12.5%), while the attainment of the other objectives is at higher levels (~16%) for community exposure sources and protected areas sources, and at lower levels (8-9%) for biomass and wildfire hazard. After the fifth year, the attainment for the main objective is moderately increased to reach ~18% by the tenth year, with a sharp increase for carbon that reaches an attainment of 27%. The community exposure sources have a slight increase from 17% to ~20% by the tenth year, while the protected areas exposure sources reach ~24% at the end of the period, but after treating a massive area that reaches 511k ha. Finally, wildfire hazard and biomass rise linearly from the ~9% to ~20% and ~22% attainment, respectively.

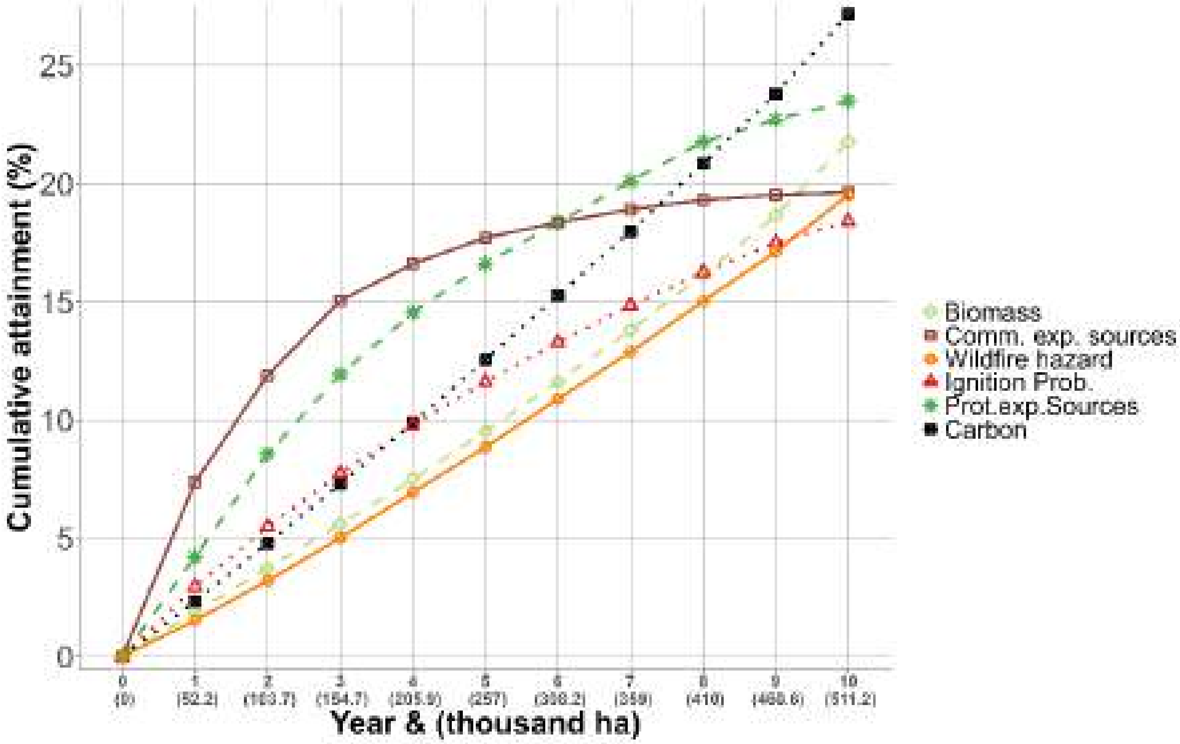

Figure 90 The 10-year implementation plan of fuel treatment with the objective to reduce new ignitions by treated in areas with high ignition probability.

The bulk of the projects are in the Comarque of Bages (~37k ha), followed by Selva (~27k ha) and Solsonès (~26k ha), with the rest Comarques receiving less than 24k ha of fuel treatments during the 10-year implementation plan (Figure 91-top). The by far highest attainment is achieved in the Comarque of Bages (~1.3%), that also receives a high load of treatments, followed by Selva (~1.2%) and Vallès Oriental (~1.1%) (Figure 91-bottom). All other Comarques achieved attainment <0.8%. The attainment per year is almost evenly distributed among the 10-year period, similarly to Greece and Portugal.

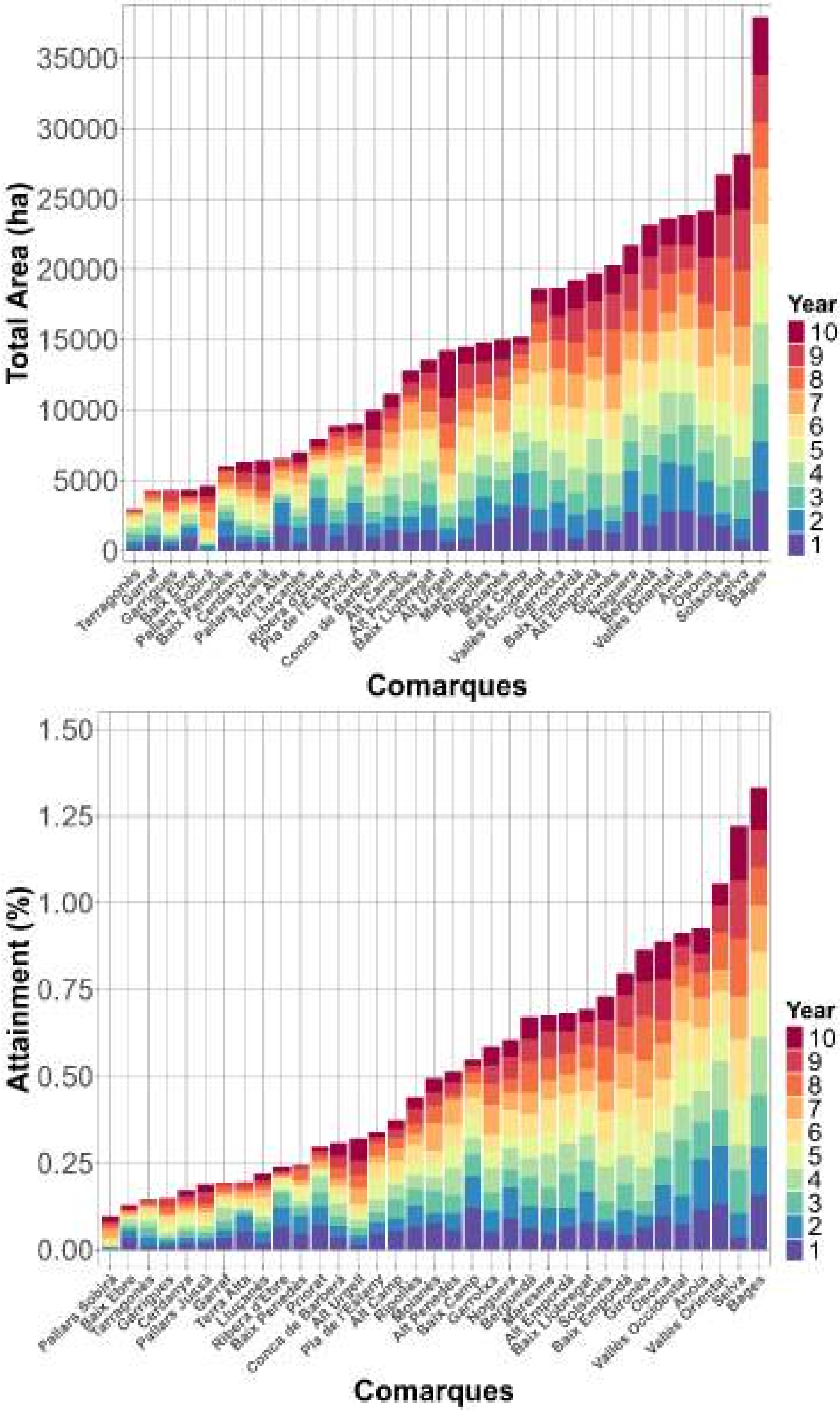

Figure 91 Top: area treated in ha for each Comarque by implementation year. Bottom: main prioritized objective attainment (%) for each Comarque by implementation year.

In Figure 92 we present all stands that met either more than two (orange) and three (red) objectives, but we do not suggest that spatial optimization allocation since the six out of eight objectives achieved very low attainments. There are about 300k ha of stands that meet at least two of the three main objectives examined above (community exposure sources, protected areas exposure sources and ignition probability), and 120k ha of stands that meet all three objectives (Figure 93). For the analysis, these stands are not grouped in projects.

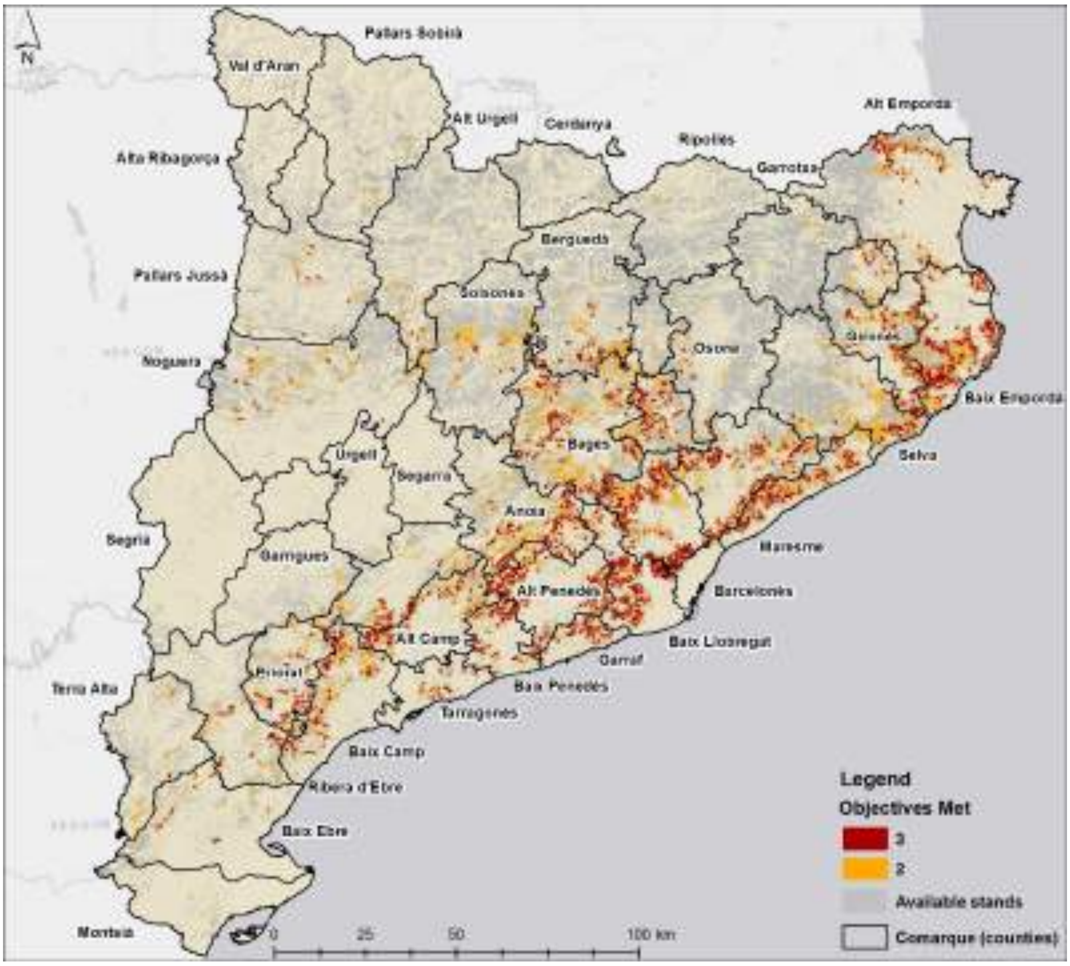

Figure 92 Allocation of stands that were selected from the three runs of SET1 that meet two or more objectives (orange) and three objectives (red).

When we start selecting these stands that were part of the ForSys solutions for the three main objectives based on the best available stands for the objective of community exposure sources, we notice that by treating approximately 100k ha we can achieve a 19% for that objective, 15% for the protected areas exposure sources, and less than 5% for the remaining objectives (Figure 93-left). By selecting with the same way, the stands that meet all three criteria, an attainment of community exposure sources of 9% is achieved if we treat 40k ha, achieving a ~8% attainment for the protected areas sources and <3% for the other objectives (Figure 93-right). By treating the same amount of area (40k ha), we achieve larger attainments in the relevant optimization runs, i.e., 9% vs. 16% for community exposure sources and 8% vs. 17% for protected areas exposure sources.

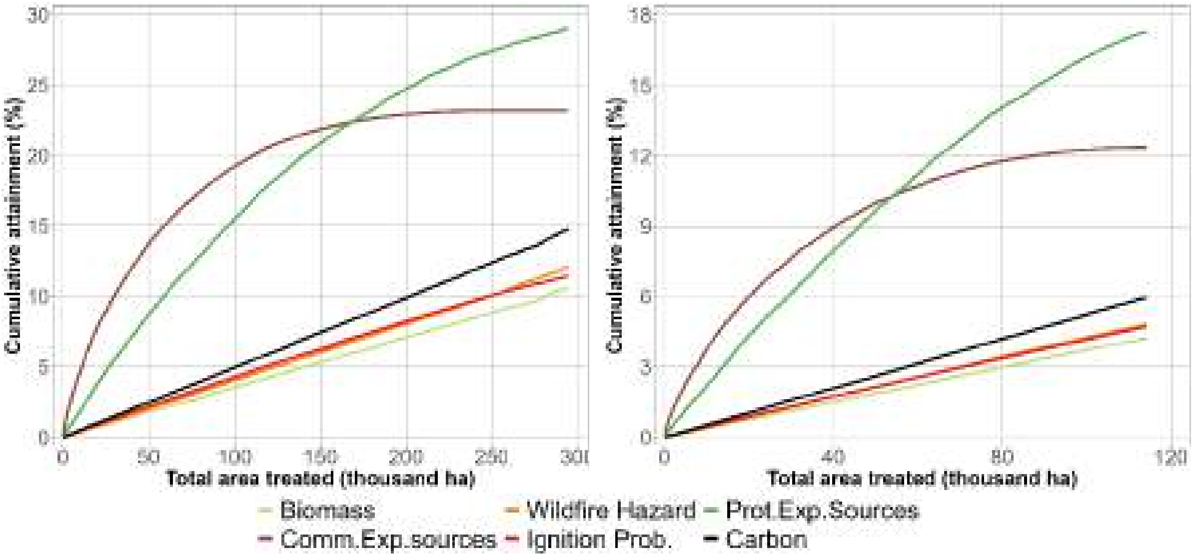

Figure 93 The attainment of the eight objectives analysed for the stands that were selected from the three runs of SET1 that a) meet two or more objectives (left) and b) meet three objectives (right). For graphing purposes, the stands selected first had the highest performance for the objective of community exposure sources.

4.3.3 SET2: Equity among planning areas

In this set of runs we chose to apply an equity approach among the different Comarques, meaning that we requested the same number of projects for each Comarque with the same treated area. This set does not offer a 10-year management plan. ForSys, given that there are enough available stands, will return what was requested regardless of the area of each district (a district with 50k ha can potentially receive the same projects and area treated as one with 10k ha area). In Figure 94 the attainment curve of community exposure sources can achieve up to ~18% when all the solution area is treated (148,621 ha), with protected areas exposure sources achieving a roughly ~16% attainment. Biomass and carbon are correlated and achieve a 5% and 7% attainment, respectively, with smaller achievements for ignition probability and wildfire hazard (~6% for both).

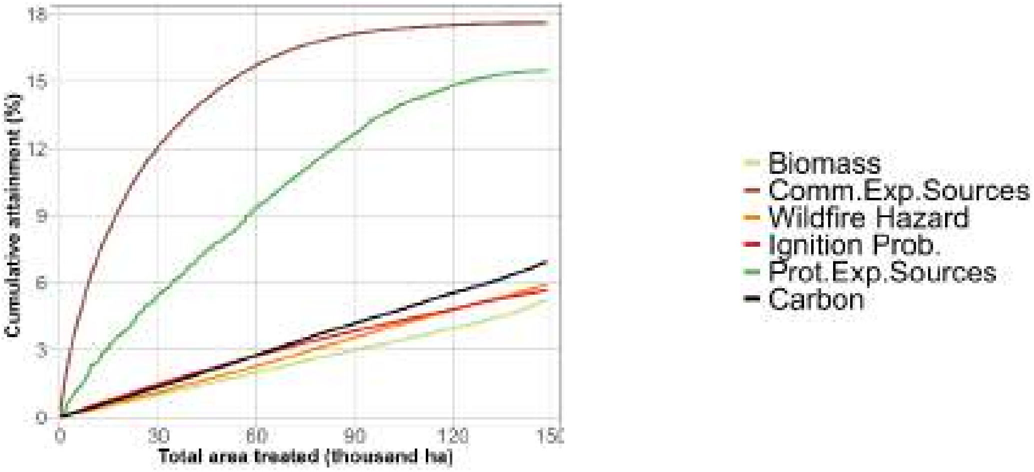

Figure 94 Area treated for all Comarques and the level of attainment for all objectives after prioritizing for the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

In Figure 95 we mapped the 50 projects of each Comarques, with warmer colours applied to the best performing projects when prioritized for the objective of community exposure sources.

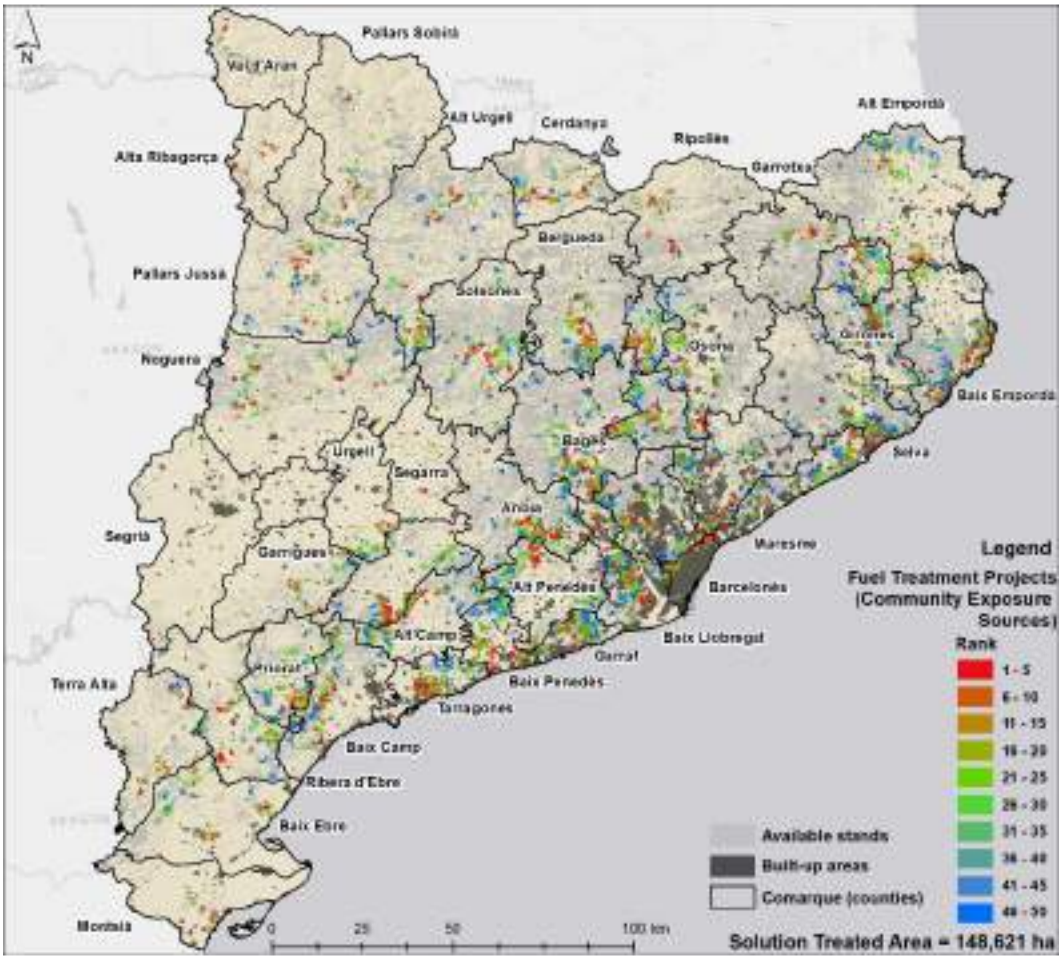

Figure 95 Map of the 50 best projects of each Comarques, ranked by the level of attainment they achieve, with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

The Comarque with the highest attainment for the main objective (community exposure sources) is Vallès Occidental with ~2.3%, followed by Baix Empordà (2%), Baix Llobregat (1,8%) and Bages (~1.6%), with the remaining Comarques achieving <1.4% attainment (Figure 96). Except for the objective of protected areas sources, where we notice that some Comarques are performing highly although not doing well with the main objective (e.g., Gironès with 1.4%, Garraf with 1.3% and Alt Penedès with 0.9%), all other management objectives achieved low attainment that is <0.3%.

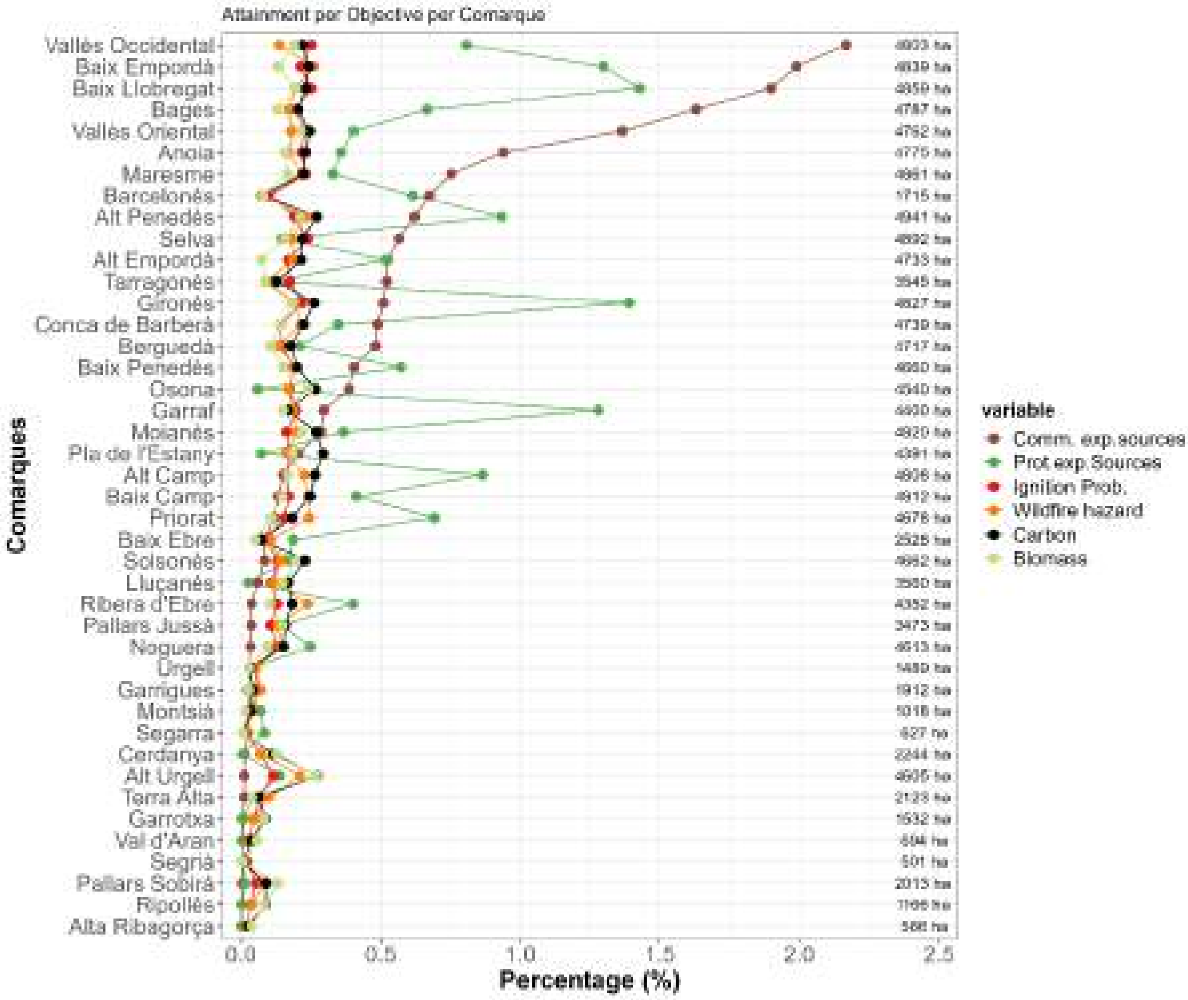

Figure 96 Attainment for each Comarques for the eight objectives when prioritized to reduce the exposure of developed areas from incoming wildfires (exposure sources).

The second run for this set prioritized fuel treatments for the management objective of limiting the exposure from the protected areas sources. In Figure 97 the attainment curve of the main objective can achieve up to ~23% when all the solution area is treated (159,390 ha), with community exposure sources achieving a roughly ~9% attainment. All the other management objectives achieved attainments <8% and were increasing linearly with the increase of treated area. In Figure 98 we noticed that the projects are clustered around the protected areas close to the coastal zone, with fewer projects allocated close to the protected areas of north and west. Most Comarques received the number of 50 projects, except for Val d'Aran (37 projects) and Barcelonès (40 projects). Finally, in Figure 99 the Comarque of Baix Llobregat achieved an impressive 2.4% attainment by treating ~4.8k ha in 50 projects, followed by Gironès with 2% with 4.8k ha and Baix Empordà with 1.8% and 4.9k ha. All other Comarques achieved attainments <1.5%. It is notable that for the Comarques of Barcelonès, Vallès Oriental, Tarragonès and Osona, the objective of community exposure sources performed better than the main objective.

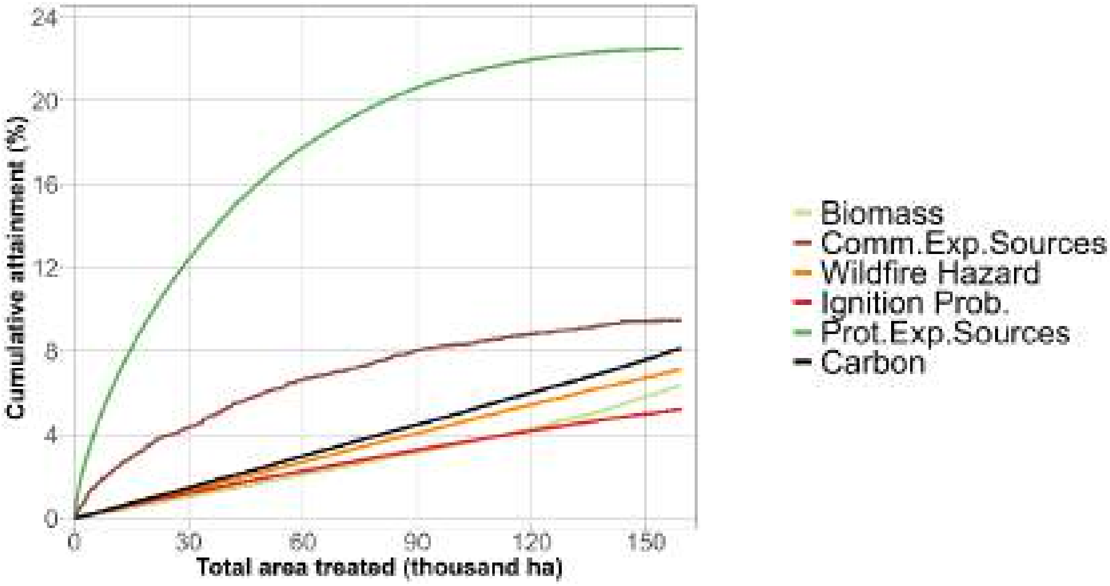

Figure 97 Area treated for all Comarques and the level of attainment for all objectives after prioritizing for the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

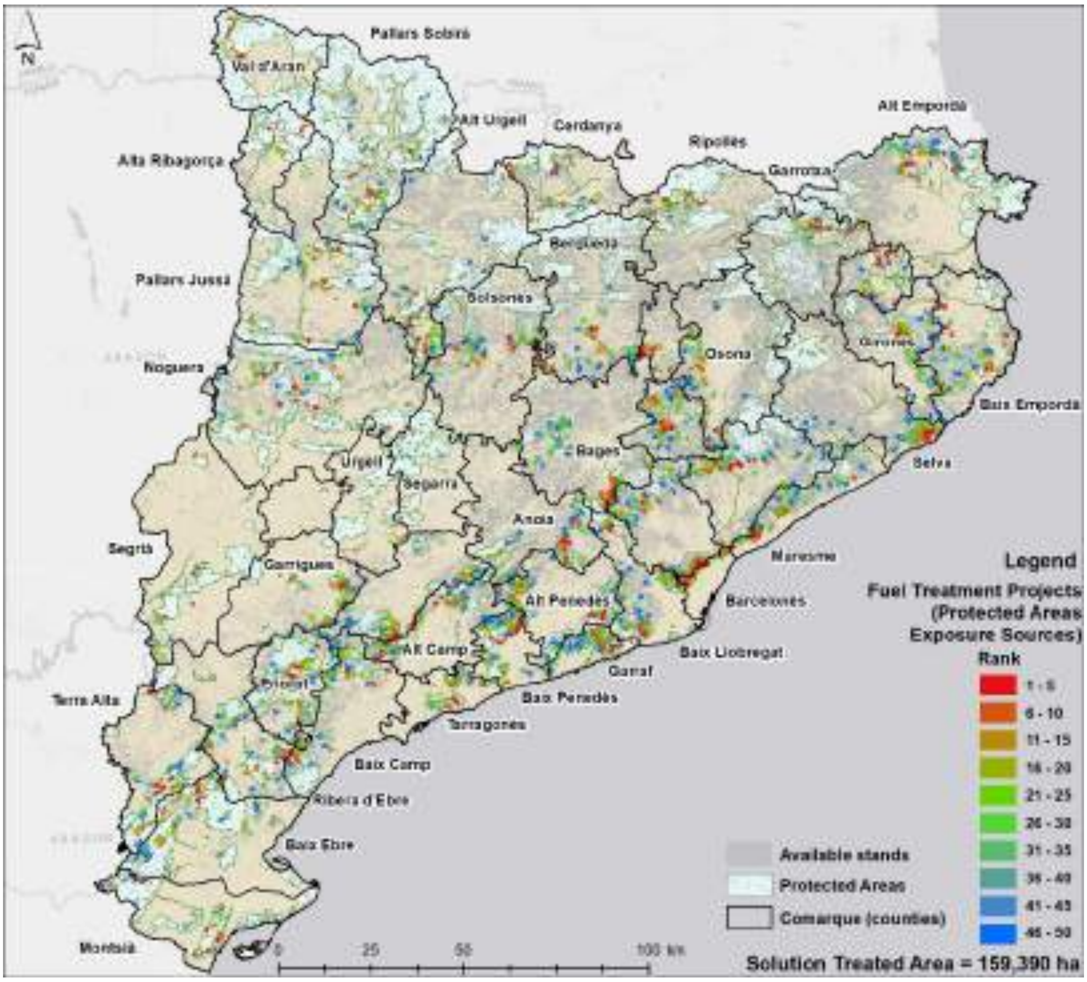

Figure 98 Map of the 50 best projects of each Comarque, ranked by the level of attainment they achieve, with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

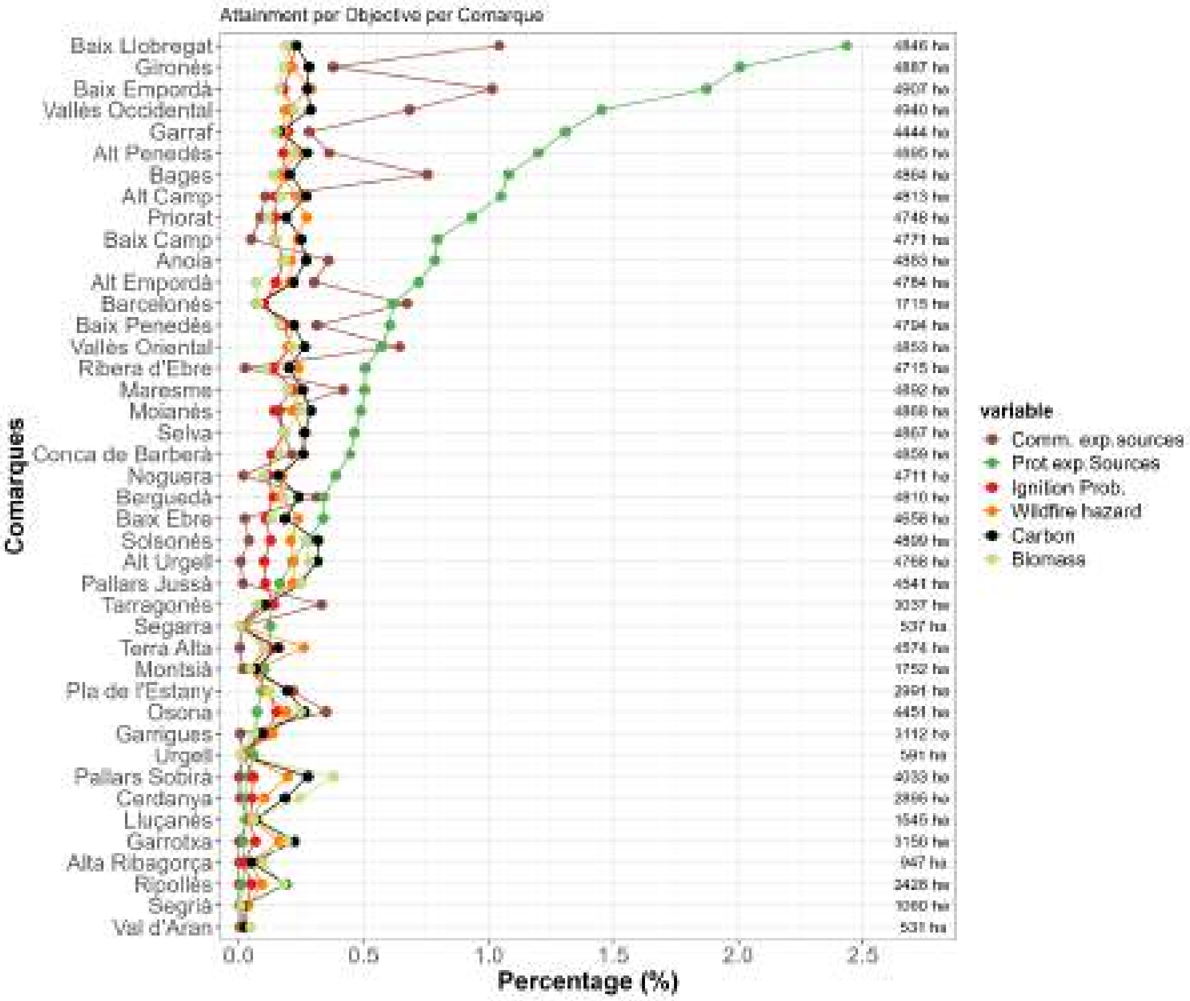

Figure 99 Attainment for each Comarque for the eight objectives when prioritized to reduce the exposure of protected areas from incoming wildfires (exposure sources).

The final run for this set prioritized fuel treatments for the management objective of limiting the ignition probability. In Figure 100 the attainment curve of the main objective (red line), although when starting and up to 30k ha is the third best performing objective, as the treated areas increases and up to 150k ha is the worst performing objective. Its increase has a linear form, with a steady rate of increase that reaches 7% when all the solution area is treated (184,188 ha). The highest performing objective is carbon, which also shows a linear increasing trend and achieves 10% attainment for the total area treated. A curved increase is noticed for the community exposure sources, showing a sharp increase until 60k ha (~5% attainment), and slower until the completion of the solution, while the curved increasing trend is prevalent in the protected area exposure sources that achieves up to 9% attainment. In Figure 101 we can notice a good distribution of projects across the landscape, except for some Comarques at the west like Urgell and Segrià.

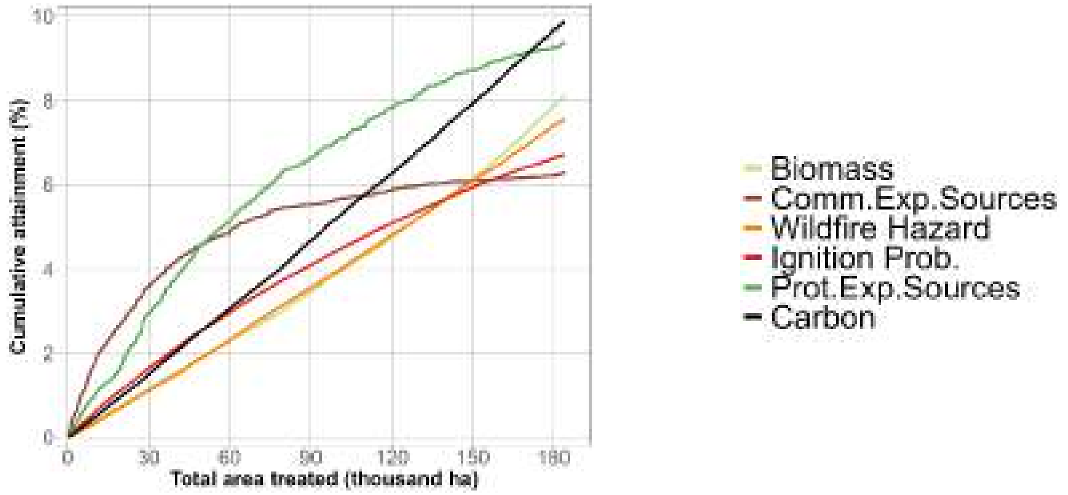

Figure 100 Area treated for all Comarques and the level of attainment for all objectives after prioritizing for the objective to reduce new ignitions by treating in areas with high ignition probability.

Figure 101 Map of the 50 best projects of each Comarques, ranked by the level of attainment they achieve, with the objective to reduce new ignitions by treating in areas with high ignition probability.

Finally, in Figure 102 the range of performance among the Comarques is low, with the highest performing (Baix Llobregat) achieving a ~0.25% and the lowest (Val d'Aran) a ~0.1% attainment. The treated area among the districts was quite similar and approximately at 4,500 ha. Some Comarques like Baix Llobregat and Baix Empordà achieved high attainment for community exposure sources (due to their high population and building density), while others like Gironès, Baix Llobregat and Baix Empordà were high performing for protected areas exposure sources.

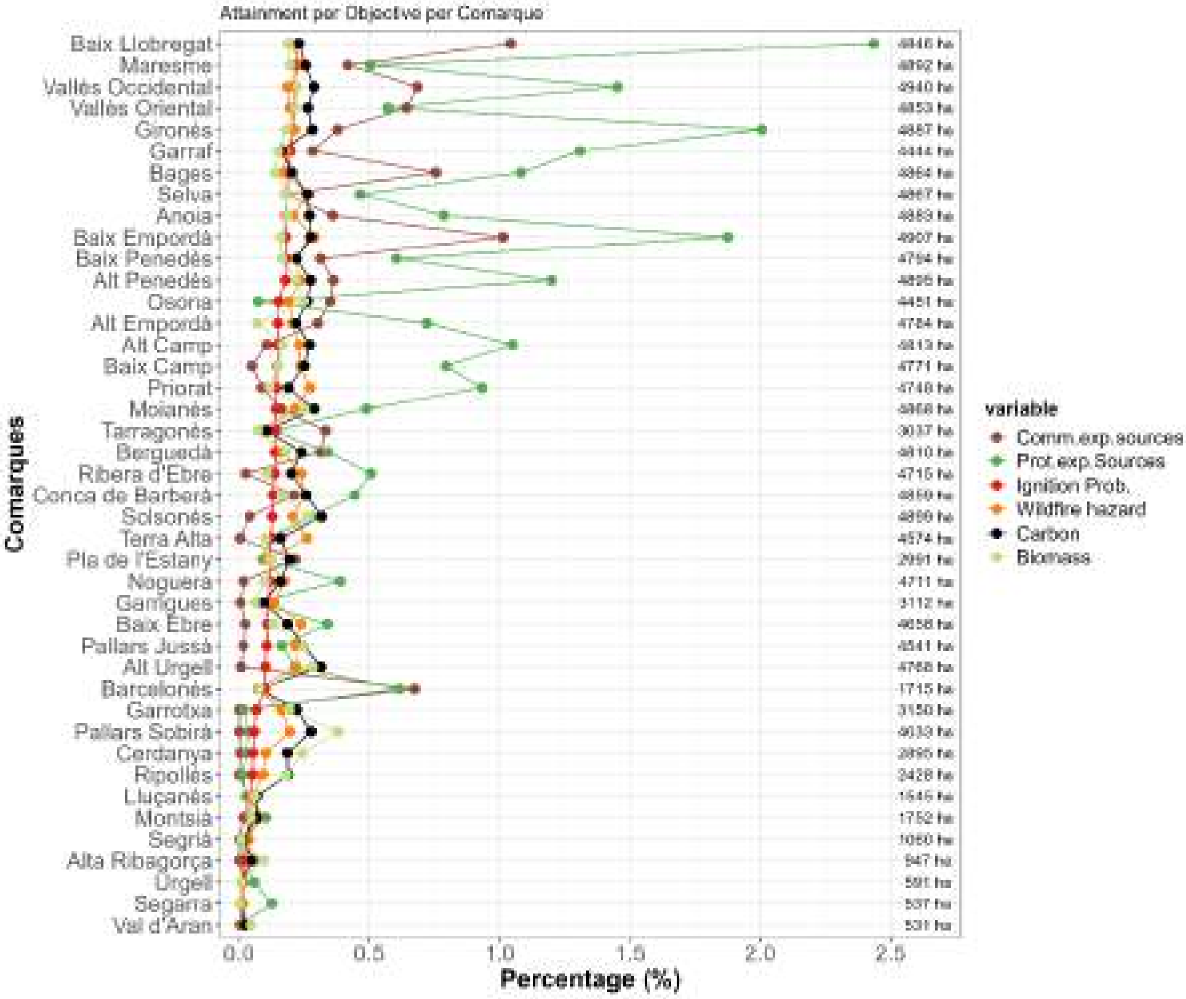

Figure 102 Attainment for each Comarque for the eight objectives when prioritized to reduce new ignitions by treated in areas with high ignition probability.

There are about 120k ha of stands that meet at least two of the three main objectives examined above (community exposure sources, protected areas exposure sources and ignition probability), and ~30k ha of stands that meet all three objectives (Figure 103). When we start selecting these stands based on the best available stands for the objective of community exposure sources, we notice that by treating approximately 60k ha we can achieve a ~10% for that objective, ~12% for the protected areas exposure sources, and less than 3% for the remaining objectives (Figure 103-left). By selecting with the same way, the stands that meet all three criteria, an attainment of community exposure sources of ~4.5% is achieved if we treat 40k ha, achieving a ~11% attainment for the protected areas sources and <2% for the other objectives. In Figure 104 we present all stands that met either more than two (orange) and three (red) objectives.

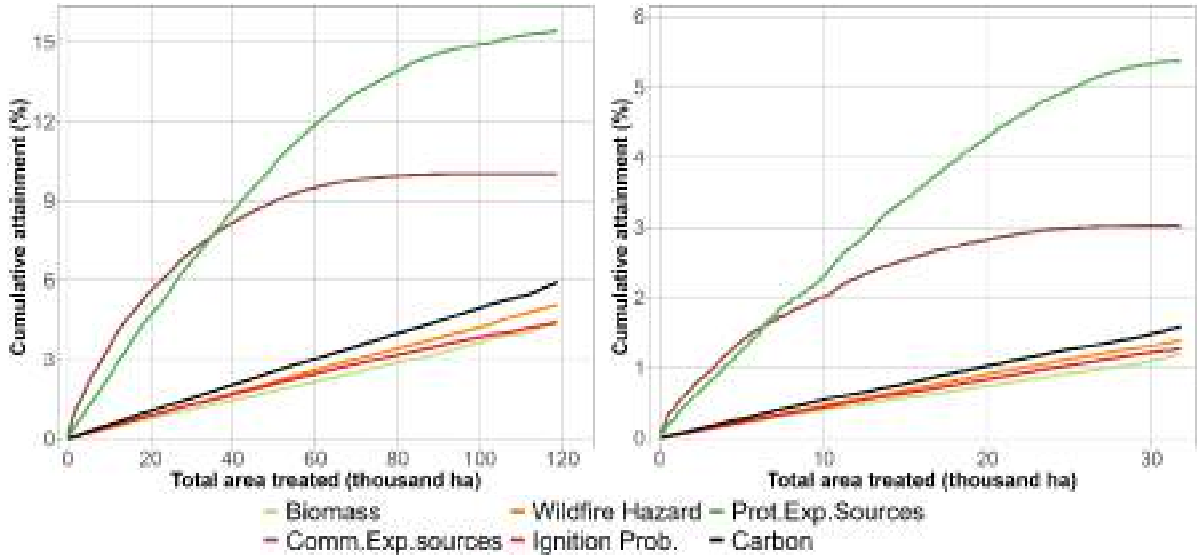

Figure 103 The attainment of the eight objectives analysed for the stands that were selected from the three runs of SET1 that a) meet two or more objectives (left) and b) meet three objectives (right). For graphing purposes, the stands selected first had the highest performance for the objective of community exposure sources.

Figure 104 Allocation of stands that were selected from the three runs of SET2 that meet two or more objectives (orange) and three objectives (red).

4.3.4 SET3: Trade-offs and joint optimality

This set of runs revealed the potential existence of trade-offs between different couples of management objectives and mapped the joint optimality on the spatial allocation of projects across each managing landscape. We note here that a couple of objectives do not necessarily mean the existence of trade-offs. These trade-offs were examined at the scale of Comarques. In addition, although some Comarques might show strong trade-offs, others might have none. The first couple examined the community exposure sources vs. the protected area sources. The map in Figure 105 shows a solution of approximately 77,500 ha for the three examined weight combinations (equal, 10-3 and 3-10) and creates a maximum difference of 2.5% in the attainment the community exposure sources and 3% for the protected areas exposure sources.

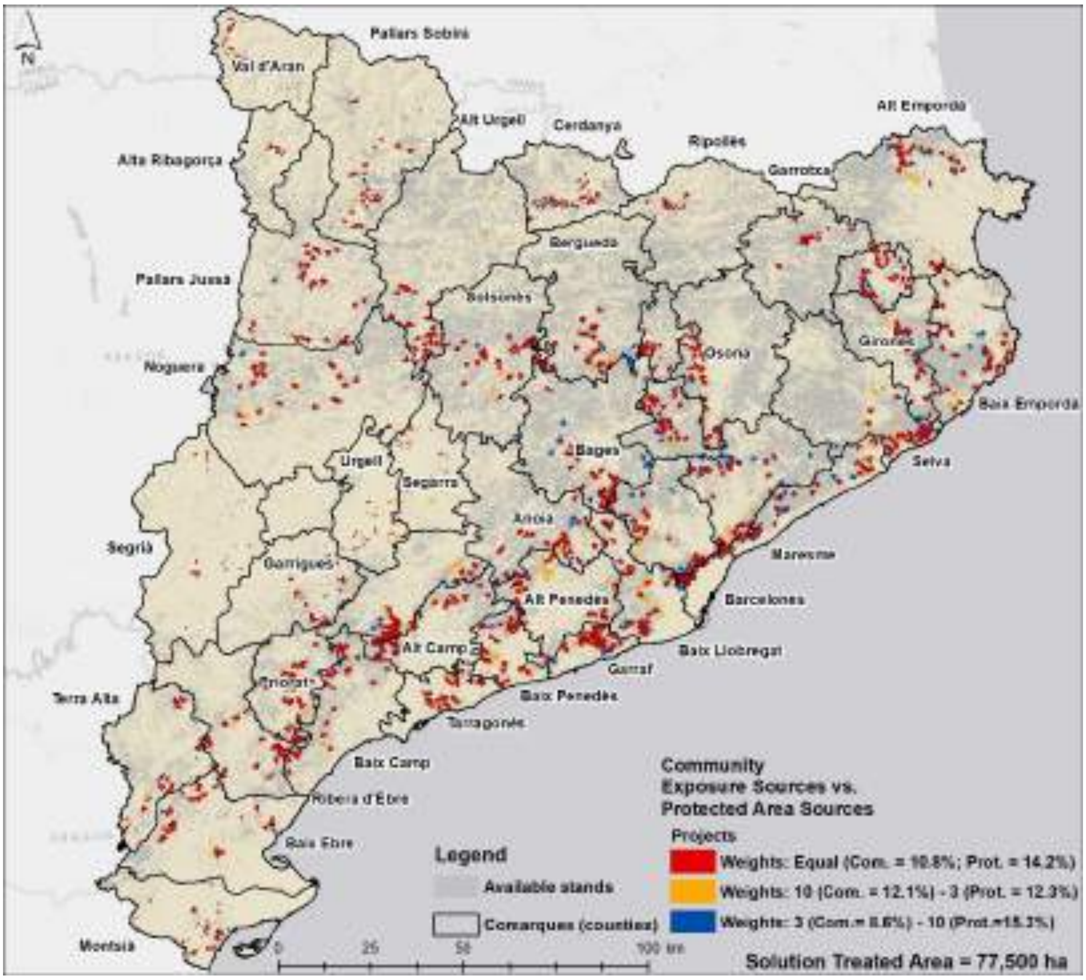

Figure 105 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and protected areas exposure sources set to low (3) (orange); c) Protected areas exposure sources objective weight maximized (10) and developed 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.

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 overall attainment for the management objective of community exposure sources is approximately 11%, while for the protected areas approximately 14%. Most of the projects spatially coincide and only few differentiate at the Comarques of Alt Penedès, Baix Llobregat, Selva and Vallès Occidental for the weight combination 10-3 (orange colour), and few in Berguedà, Bages, Vallès Oriental, Maresme and Selva for the weight combination 3-10 (blue colour).

The trade-off graph in Figure 106 shows some sharp trade-offs in the Comarques of Baix Llobregat (i.e., the more the attainment of the protected areas is increased, the more the community exposure is decreased), Baix Empordà, Vallès Occidental, Vallès Oriental, Alt Penedès and Bages. Most of the remaining Comarques show trade-offs but not as sharp and with large differences in the attainment of the two objectives as the previous mentioned. Some Comarques are stable like the cases of Baix Camp, Gironès and Priorat where the attainment of community exposure remained approximately at the same levels while the attainment of the protected areas was increasing.

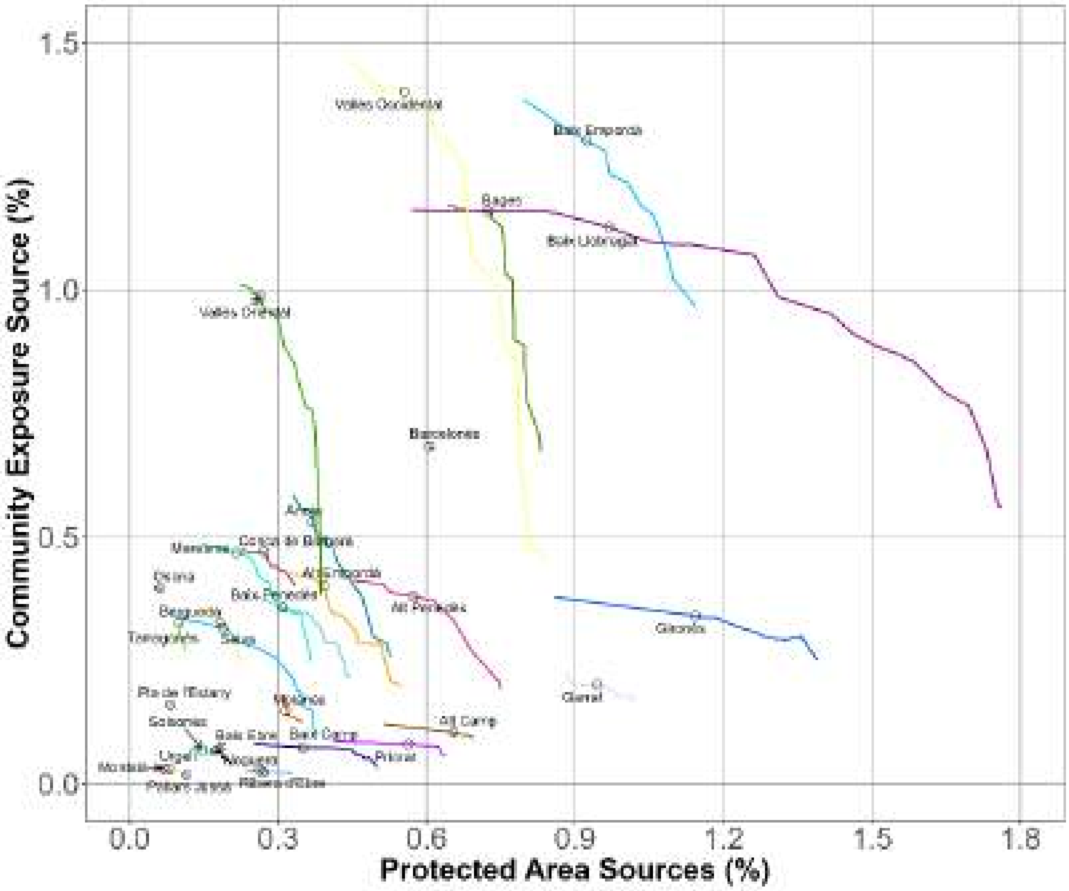

Figure 106 Trade-off production probability curves for each Comarque for the objectives of developed areas exposure sources vs. the protected areas sources. Axes show the level of attainment for each objective (%).

In Figure 107 we show the performance of each objective on each of the 30 Comarques with the most profound trade-offs 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 protected areas achieved higher attainment (red dots at the right), but there are some cases like the Comarques of Bages, Vallès Occidental, Vallès Oriental, Berguedà and Tarragonès where community exposure has a better performance (black dots at the right). Notable fluctuations in the attainment were recorded for the Comarques of Vallès Occidental, Vallès Oriental, Gironès, Alt Penedès and Bages for both objectives, with a profound effect of weighting scheme changes between the two objectives.

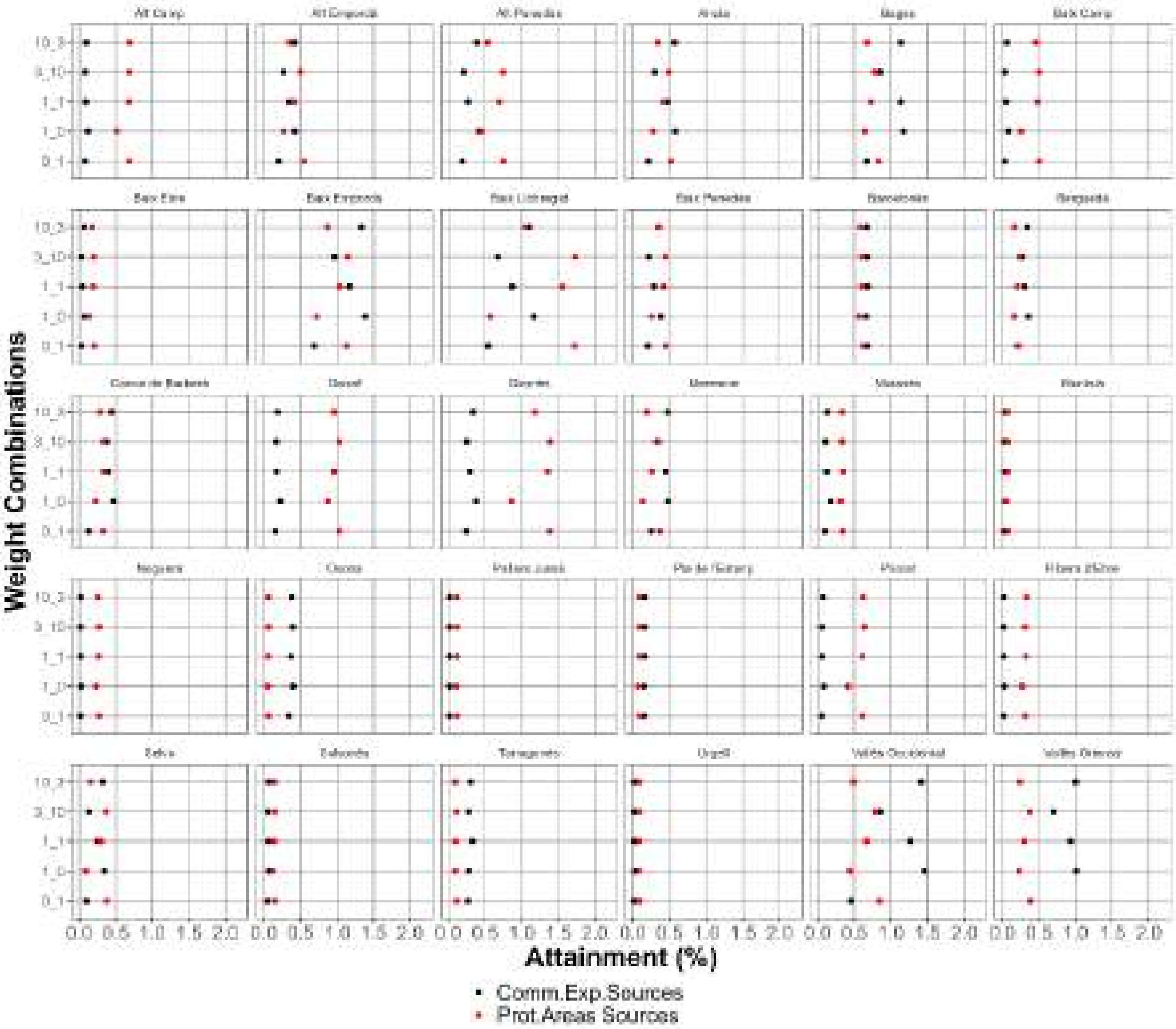

Figure 107 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: protected areas exposure sources) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Comarque.

The second couple examined was the community exposure sources vs. biomass. The map in Figure 108 shows a solution of approximately 85,000 ha for the three examined weight combinations and creates a substantial maximum difference of 2.3% in the attainment of the community exposure sources, and 0.5% for biomass. The overall attainment for the management objective of community exposure sources is approximately 12%, while for the biomass approximately 3.5%. While several of the proposed projects spatially coincide, there are some that differentiate at the Comarques Moianès, Solsonès, Noguera and Gironès for the weight combination 10-3 (orange colour), and several in Alt Camp, Maresme, Berguedà, Baix Camp and Selva for the weight combination 3-10 (blue colour).

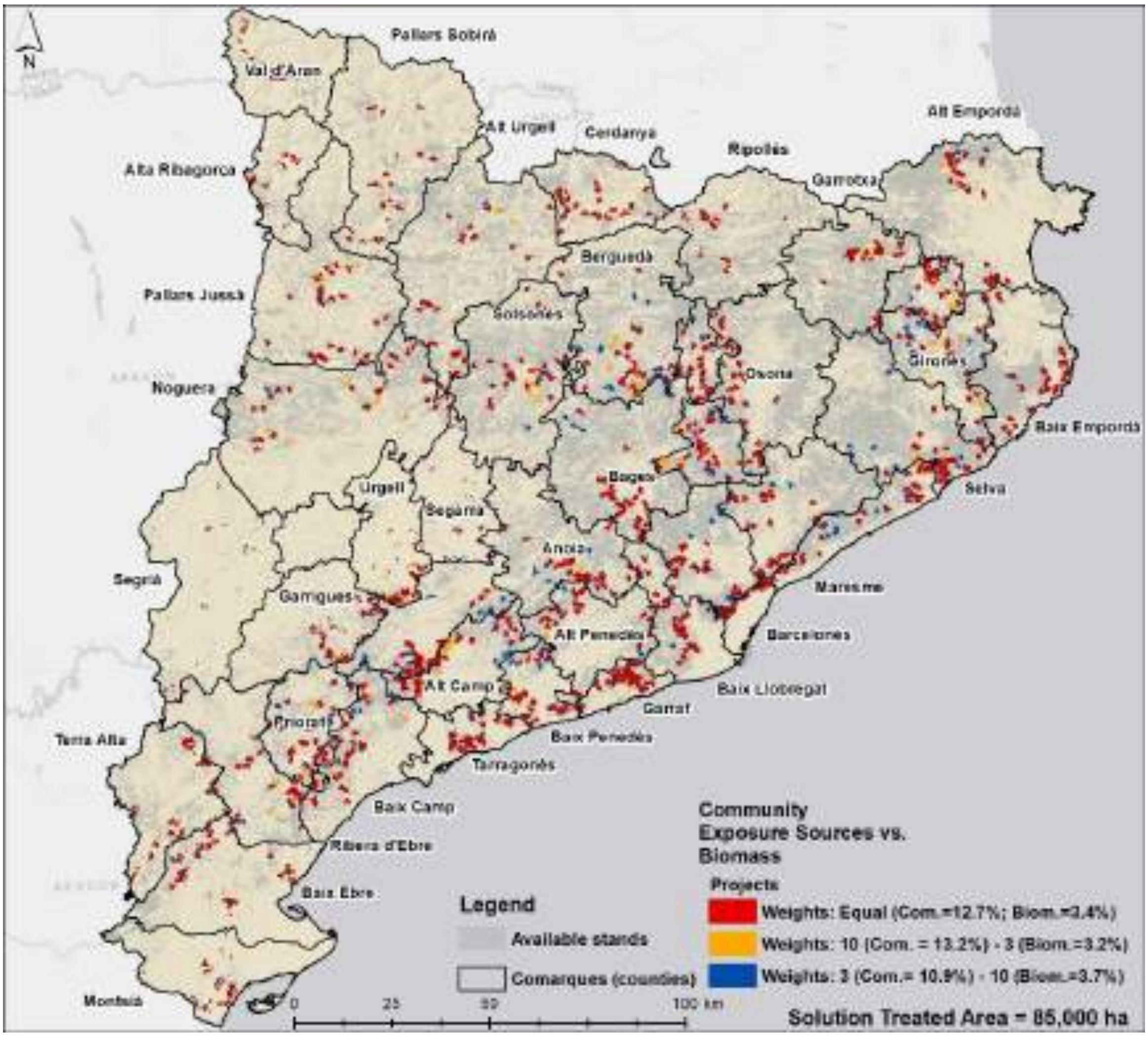

Figure 108 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and retrieved biomass set to low (3) (orange); c) retrieved biomass objective weight maximized (10) and developed areas exposure sources 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 109 shows sharp differences for most Comarques with a strong trade-off footprint, especially for Vallès Occidental, Bages, Osona, Gironès and Baix Llobregat (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 Comarque like the Vallès Occidental can achieve a maximum of 1.6% attainment for the community exposure sources with approximately 0.08% for biomass, while the highest performing curve for biomass is in the Comarques of Moianès, with approximately 0.15% attainment (and 0.25% for community exposure).

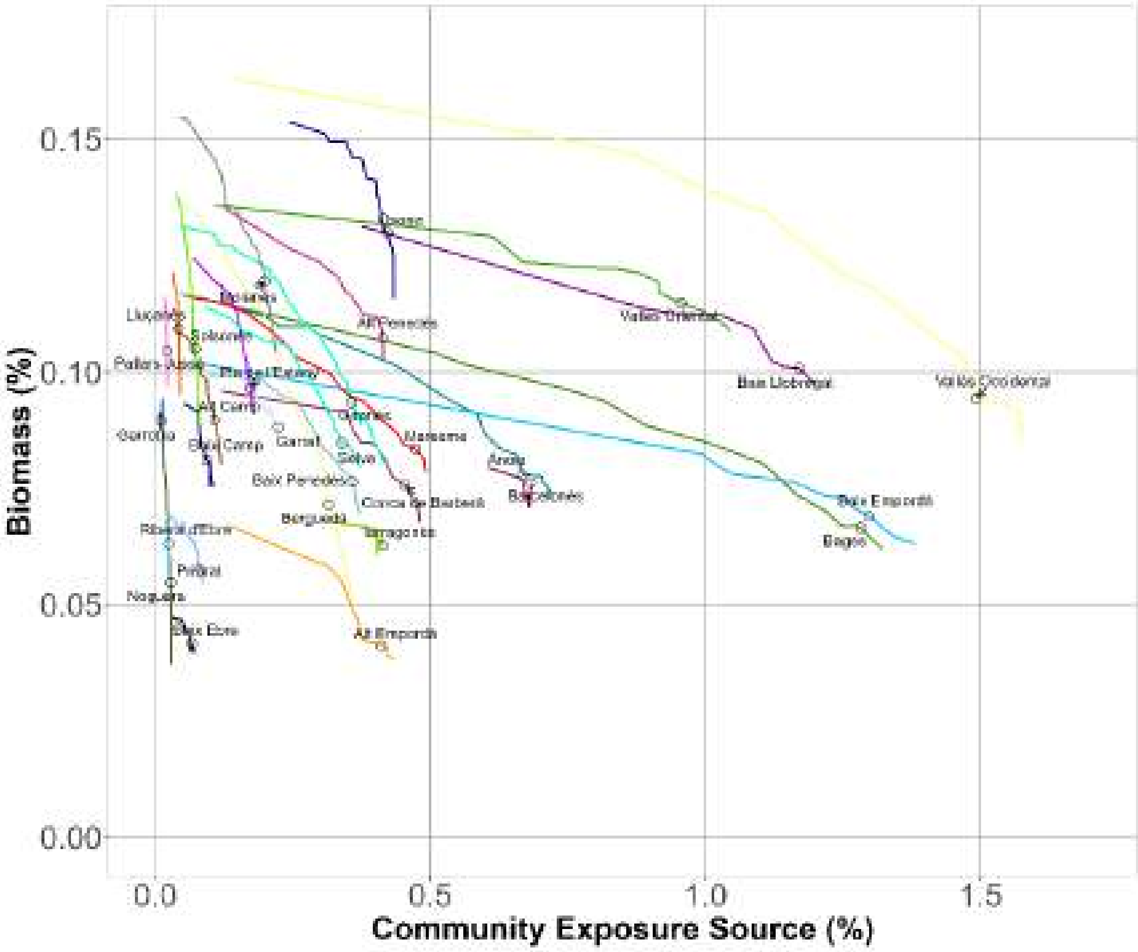

Figure 109 Trade-off production probability curves for each Comarques for the objectives of retrieved biomass vs. developed areas exposure sources. Axes show the level of attainment for each objective (%).

In Figure 110 we noticed large fluctuations in the attainment of the Comarques of Bages, Vallès Occidental, Vallès Oriental, Osona, Gironès, Anoia and Berguedà for the community exposure objective. The biomass objective has very small fluctuations for most Comarques, and 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 Comarques of Solsonès, Pallars Jussà and Lluçanès where biomass has a better performance (red dots at the right). Simiarly to the previous couple of objectives, this one 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 Comarques lines, and the large fluctuations in the dots of the attainment graph.

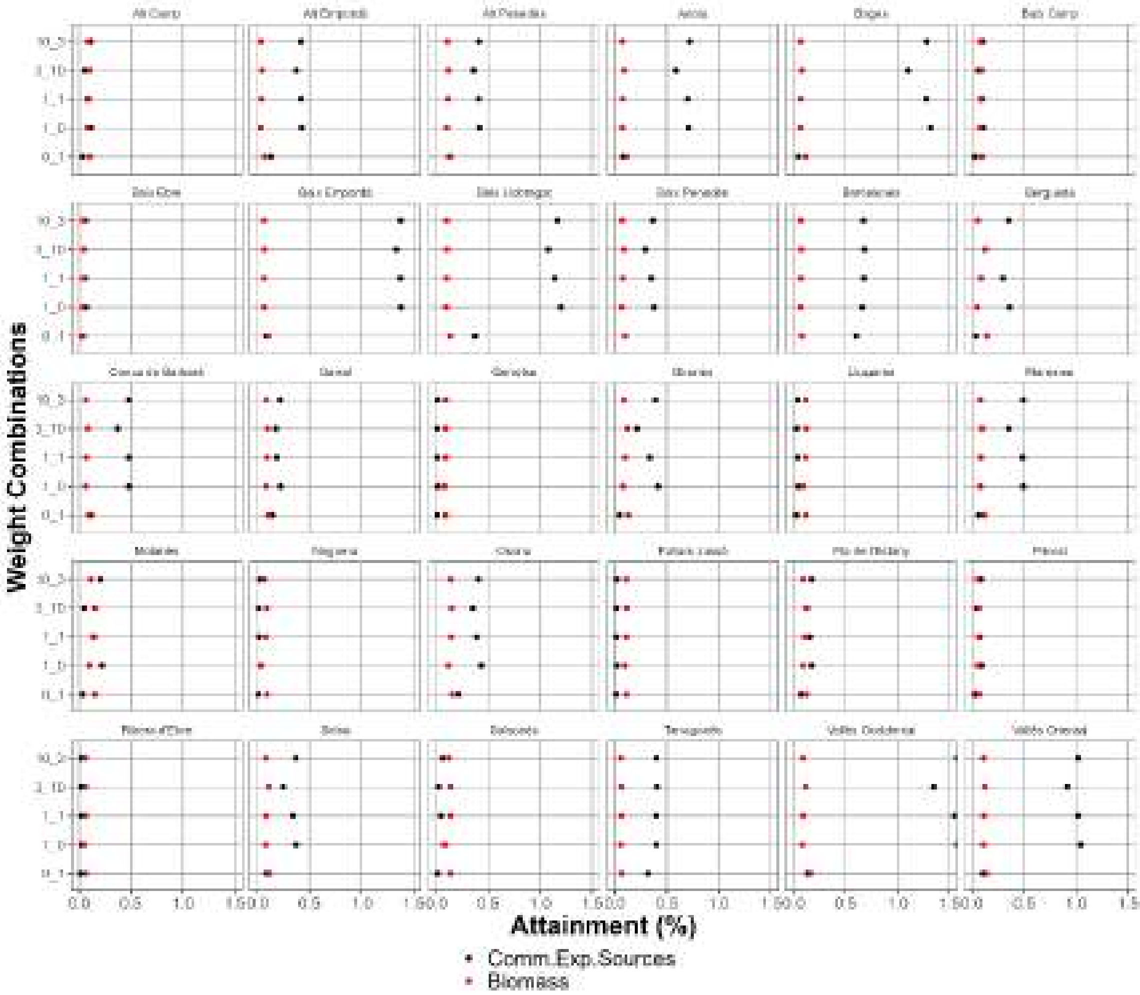

Figure 110 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: biomass retrieved) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Comarque.

The third couple examined the existence of trade-offs between wildfire hazard (i.e., CFL) and ignition probability. The map in Figure 111 shows a solution of approximately 98,000 ha for the three examined weight combinations and creates a small maximum difference of 1.5% in the attainment of wildfire hazard, and 0.7% for the ignition probability. The overall attainment for the management objective of wildfire hazard is approximately 5.5%, while for the ignition probability approximately 3.2%. While several of the proposed projects spatially coincide, there are many more that differentiate at the Comarques of Gironès, Baix Empordà, Maresme, Solsonès, Anoia, among several others, for the weight combination 10-3 (orange colour), and several in Baix Ebre, Noguera, Solsonès and Baix Camp for the weight combination 3-10 (blue colour).

The trade-off graph in Figure 112 shows sharp trade-offs for almost all Comarques, especially for Baix Empordà, Maresme, Gironès and Alt Empordà (i.e., the more the attainment of the ignition probability is increased, the more the wildfire hazard is decreased). Overall, the attainment capacity of this objective combination is low, since the highest performing Comarques like the Baix Empordà can achieve a maximum of 0.23% attainment for the wildfire hazard with approximately 0.07% for ignition probability, while the highest performing curve for the ignition probability is in the Comarques of Maresme and Baix Llobregat, with approximately 0.13% attainment (and 0.15% for wildfire hazard).

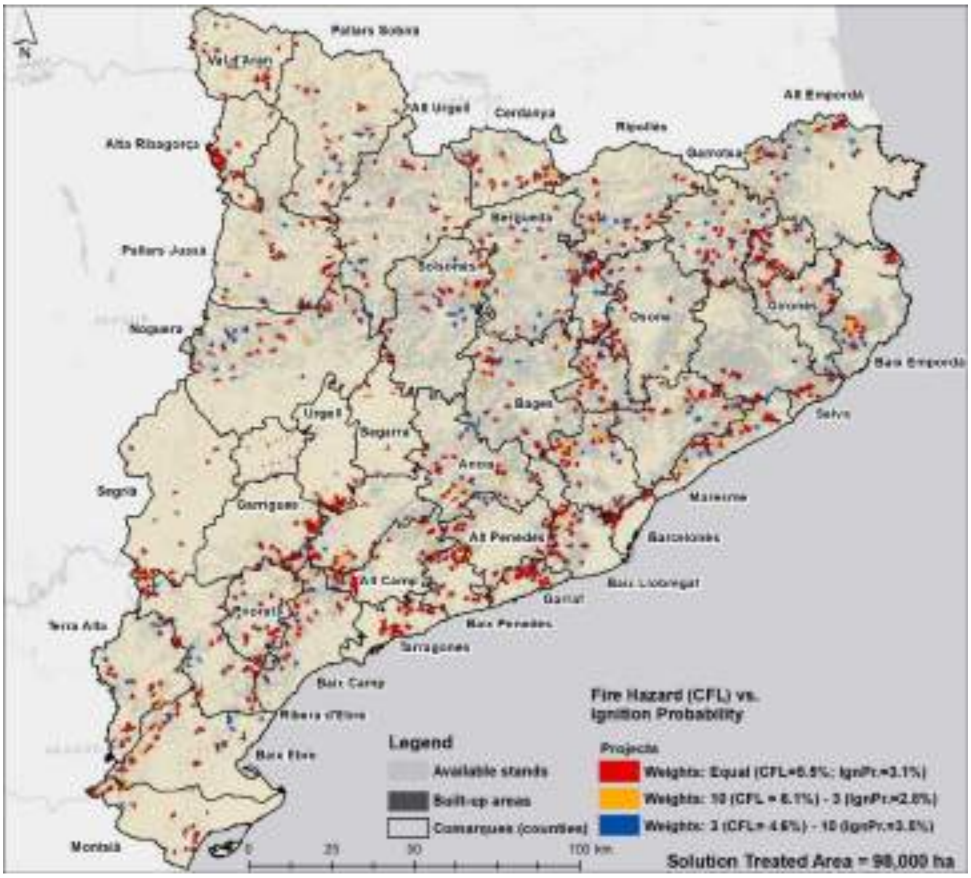

Figure 111 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Fire hazard objective weight maximized (10) and ignition probability set to low (3) (orange); c) Ignition probability objective weight maximized (10) and fire hazard set to low (3) (blue). Blue- and orange-coloured 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.

In Figure 113 we noticed small fluctuations in the attainment of almost all the Comarques, with most notable those of Vallès Oriental, Vallès Occidental, Solsonès, Alt Empordà and Maresme. 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 Maresme the combination of 10-3 cause the wildfire hazard to achieve 0.2% attainment and ignition probability 0.1%, while the combination 0-1 cause the wildfire hazard to achieve 0.05% and the ignition probability 0.1%. Most Comarques have a stable pattern of attainment for both the objectives across all weight combinations, with wildfire hazard achieving slightly higher attainment compared to ignition probability. 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) and the sharp decline curved shape of the Comarques lines, although the fluctuations in the dots of the attainment graph were small and with a similar pattern.

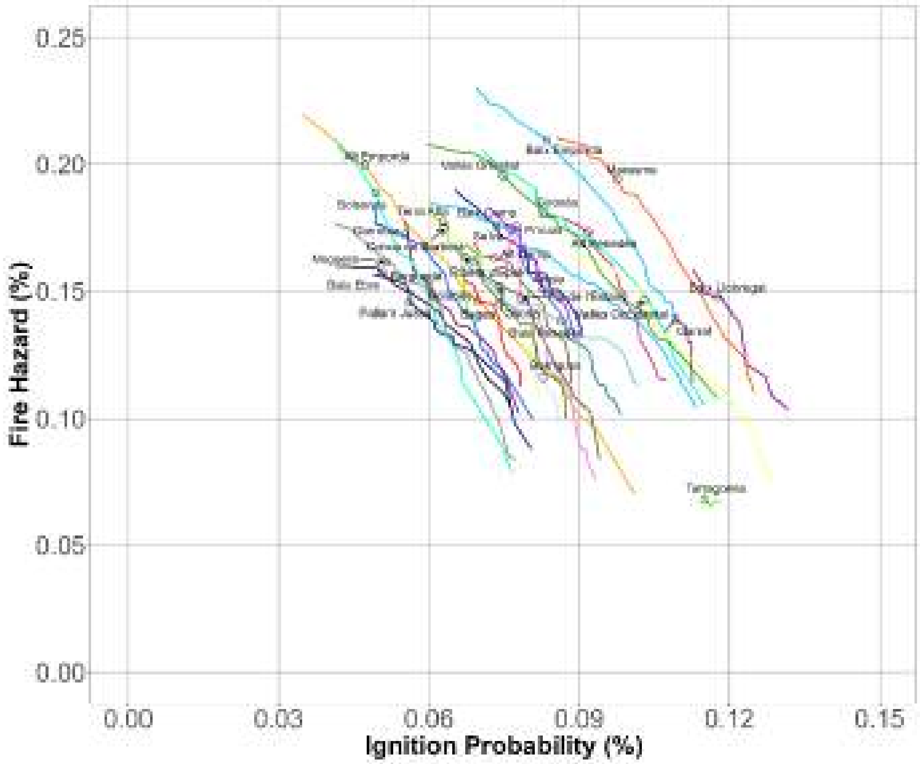

Figure 112 Trade-off production probability curves for each Comarque for the objectives of fire hazard (CFL) vs. ignition probability. Axes show the level of attainment for each objective (%).

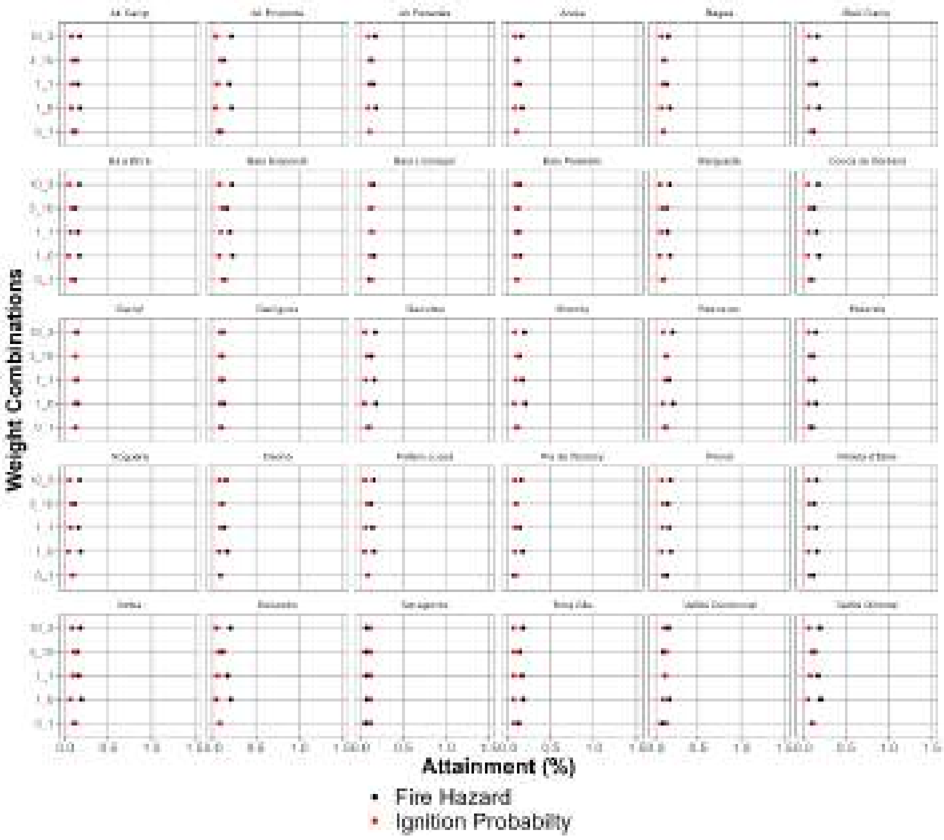

Figure 113 Each panel shows the attainment of each of the two objectives (black: Fire Hazard; red: Ignition Probability) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Comarque.

The last couple of objectives examines whether it is better to apply fuel treatments on projects in the areas of community exposure sources where the fire risk originates, or in areas where we anticipate high wildfire hazard (intensity levels). The map in Figure 114 shows a solution of approximately 173,000 ha for the three examined weight combinations and creates a very large maximum difference of 10% in the attainment of the community exposure sources, and 1.7% for the wildfire hazard objective. The overall attainment for the management objective of community exposure sources is approximately 19%, while for the sinks approximately 7.5%. Although a great number of projects spatially coincide, there is a substantial number of projects inside the Comarques of Urgell, Berguedà, Solsonès, Maresme and Alt Camp, among several others, for the weight combination 10-3 (orange colour), and several in Anoia, Baix Llobregat, Bages, Baix Empordà and Maresme for the weight combination 3-10 (blue colour).

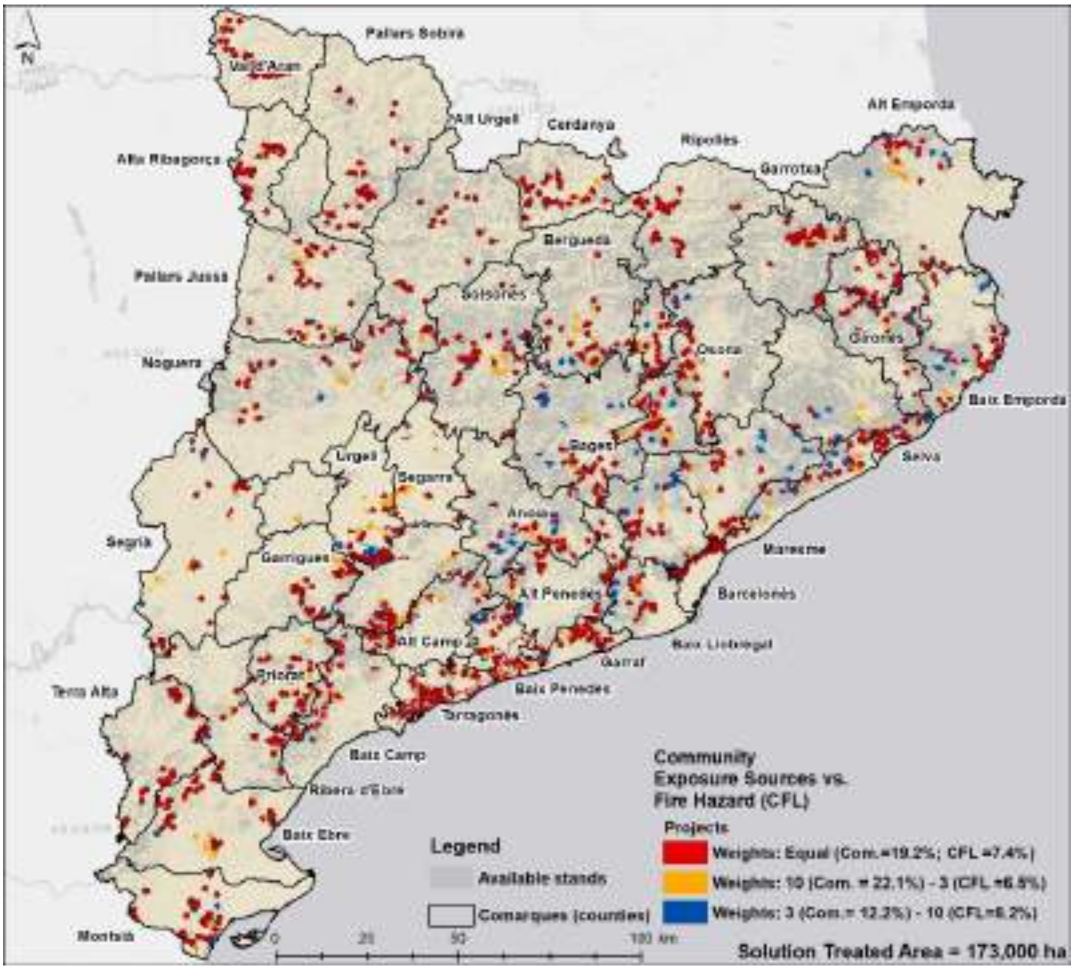

Figure 114 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and fire hazard set to low (3) (orange); c) Fire hazard objective weight maximized (10) and developed areas exposure sources set to low (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 115 shows sharp trade-offs for several Comarques, especially for Baix Empordà, Vallès Occidental, Bages, Baix Llobregat, Vallès Oriental and

Anoia (i.e., the more the attainment of the wildfire hazard is increased, the more the community exposure sources objective is decreased). Overall, the attainment capacity of this objective combination is moderate, since the highest performing Comarque like the Vallès Occidental can achieve a maximum of 1.5% attainment for the community exposure sources with approximately 0.07% for wildfire hazard, while the highest performing curve for the wildfire hazard is in the Comarque of Baix Empordà, with approximately 0.22% attainment (and 0.1% for community exposure sources).

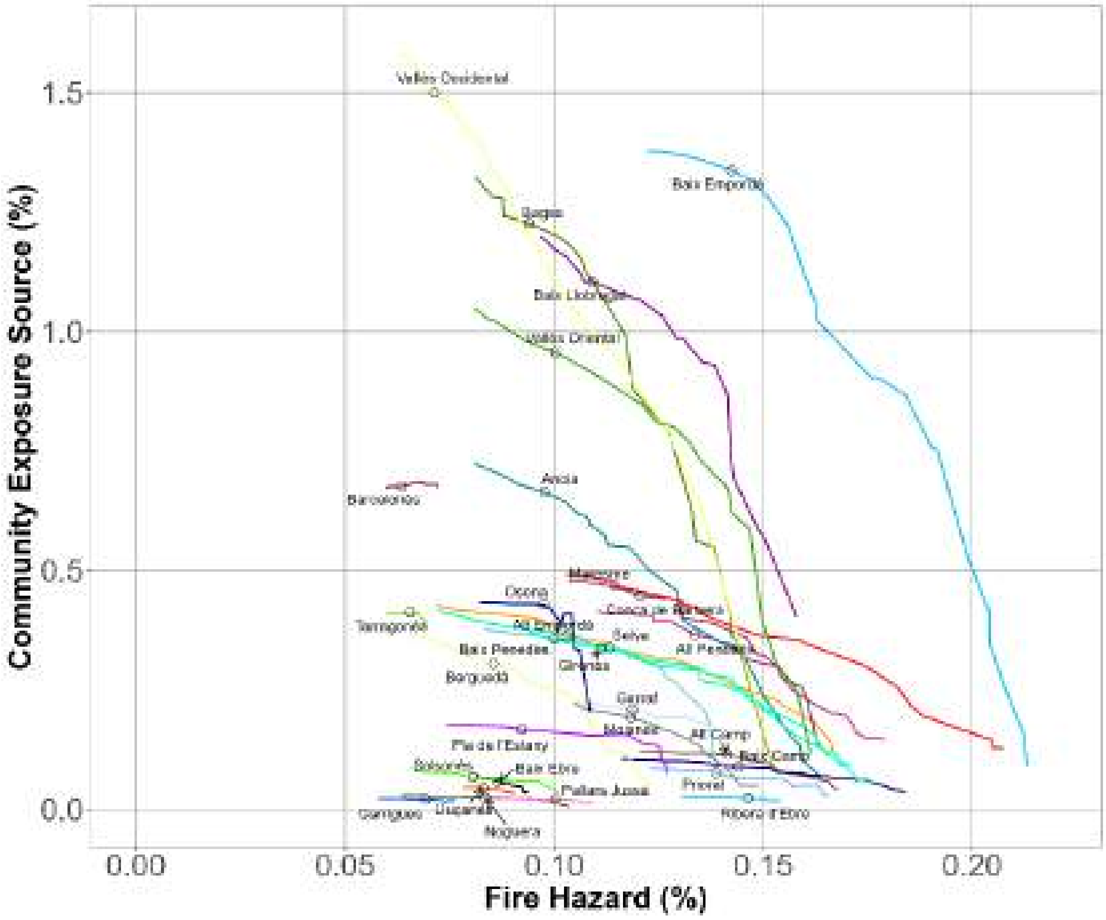

Figure 115 Trade-off production probability curves for each Comarque for the objectives of developed areas exposure sources vs. fire hazard (CFL). Axes show the level of attainment for each objective (%).

In Figure 116 we noticed the largest and most profound fluctuations in the attainment that each Comarque achieved when the weight combinations changed. In this case we noticed both fluctuations on the attainment of each objective separately, and the order of which of the two achieved the highest attainment for each combination. We examined the 30 Comarques with the most important differences and we found that Alt Empordà, Baix Penedès, Osona, Tarragonès, Conca de Barberà, Vallès Occidental, Vallès Oriental and Barcelonès had higher attainment for the community exposure objective (black dots at the right). The wildfire hazard objective has moderate fluctuations for a number Comarques, like Baix Camp, Priorat, Solsonès and Alt Camp (red dots at the right), but smaller compared to the community exposure sources. Similarly to the previous couples of objectives, this one 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 Comarques lines with sharp declines (trade-offs) when an objective is increasing, and the large fluctuations in the dots of the attainment graph.

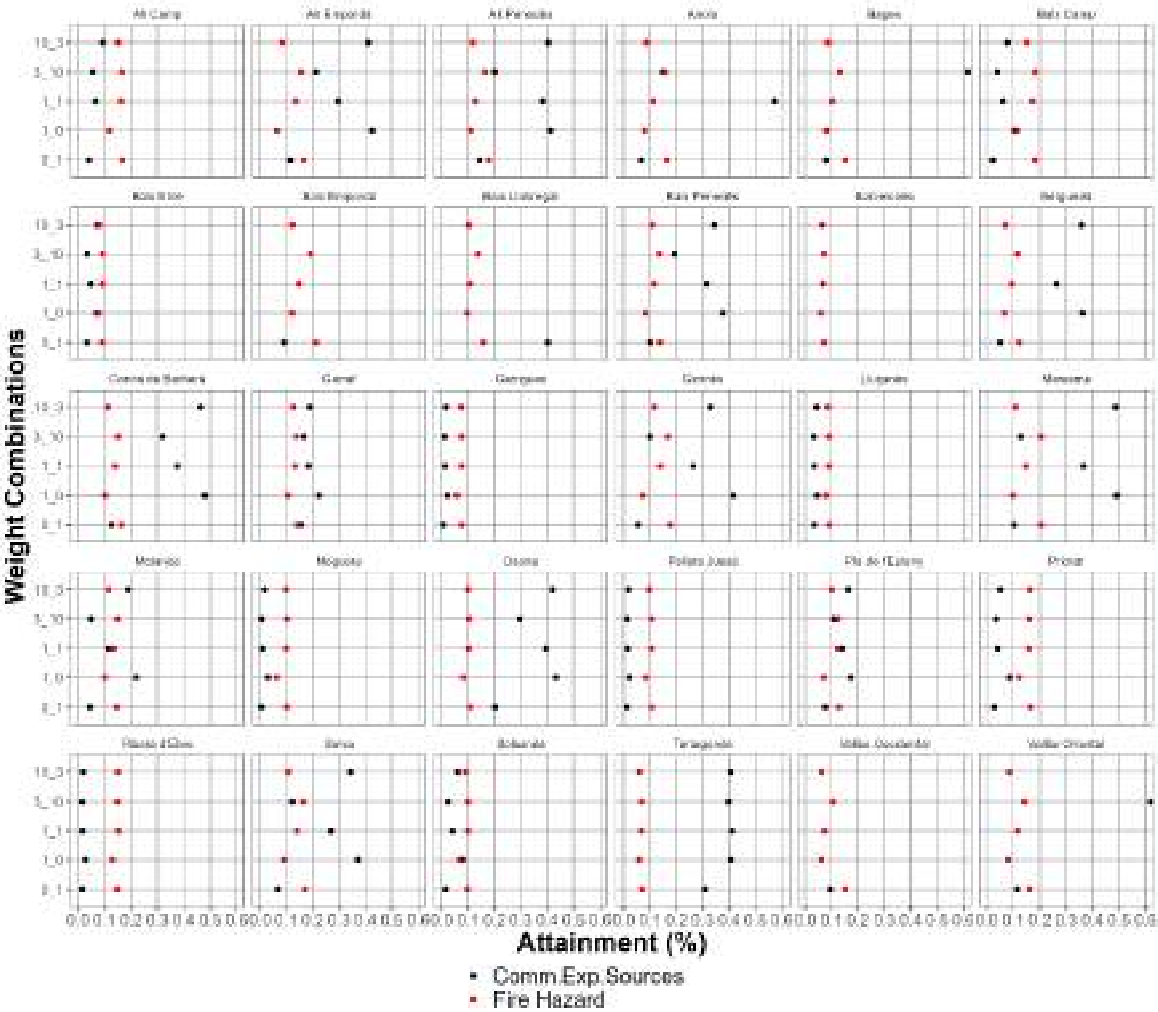

Figure 116 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: fire hazard) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Comarque.

4.4 Living Lab France (Nouvelle Aquitaine)

The region of application for this component in the Living Lab of France is the Nouvelle Aquitaine, a region that cover one million ha of which, 430,000 ha are available for receiving fuel treatment projects. The analysis was performed at the level of Municipalities (535 in total, with an area ranging from 150 ha to 22,250 ha – mean area is 1884 ha). This Living Lab, compared to the other, has many planning areas (Municipalities), most of which occupy a small area, while the larger ones are much smaller compared to the large planning areas we analysed for the other Living Labs. The interesting fact in this Living Lab is that almost all the eligible stands had a value while the non-eligible stands, usually had zero or very low values. To explain it simply, there were very few stands that contributed to the problem that were excluded based on topographic difficulties, distance to roads or had a disturbance in the previous years. Thus, the attainment of the objectives here is much higher compared to the other study areas. We analysed the effects of fuel treatment projects at eight management objectives: biomass retrieval, protection of carbon stocks, fire risk reduction at the community exposure sources, protection of community exposure sinks (parts of communities that receive the highest amounts of fire), reduction of fire hazard (i.e., energy release) to facilitate better fire suppression, reduction of future ignitions in high ignition probability areas, reduction of the exposure of protected areas from the sources of their exposure, and protection of the most exposed parts of protected areas (sinks).

4.4.1 SET0: Control & Evaluation

In this set of fuel treatment scenario planning, we estimated the effect that spatial optimization has in three management objectives, namely community exposure sources, protected exposure sources and ignition probability, when we select to apply fuel treatments at 140,000 ha and we compared with a random and a proximity to roads allocation schemes. We found that both random and roads allocation have very low performance when compared with the optimized allocation (Figure 117). In particular, the optimized allocation for protected areas exposure sources can achieve an attainment of up to 50% (i.e., a reduction of 55% in the total exposure that all protected areas has in the study area) compared to the 22% the non-optimized allocation achieved, the community exposure sources optimized allocation achieved approximately 55% vs. the ~22% of the non-optimized allocation, and finally, we found smaller differences between the spatially optimized allocation of the reduction of ignition probability that achieved approximately 19% attainment vs. the 10-12% of the non-optimized allocations. These results prove that the business-as-usual way of allocating fuel treatment projects (i.e., randomly or in proximity to roads) cannot provide substantial reduction to key management objectives like the protection of communities or risk reduction for protected areas and can have a similar impact only for the objective of reducing ignition probability.

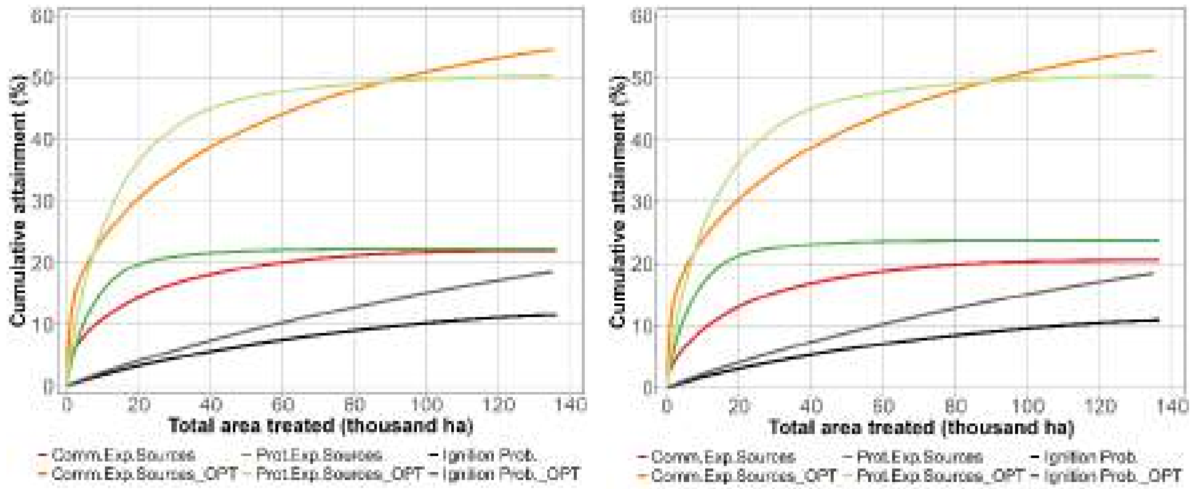

Figure 117 Left: Random project allocation; Right: Project allocation proximate to the road network. OPT: Results from the optimization runs. For comparison, similar colours with different intensity were used for the same objective.

4.4.2 SET1: Efficiency, with a 10-year implementation plan

The implementation of a 10-year plan to reduce the fire risk of the communities from the sources of their exposure by treating half (i.e., 205,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 410,000 ha), resulted to request the spatial optimization of 2050 projects, a similar allocation with the Greek Living Lab (Figure 118). The total treated area returned from the spatial optimization solution is 198,000 ha. In this optimization run we did not consider any administrative boundary.

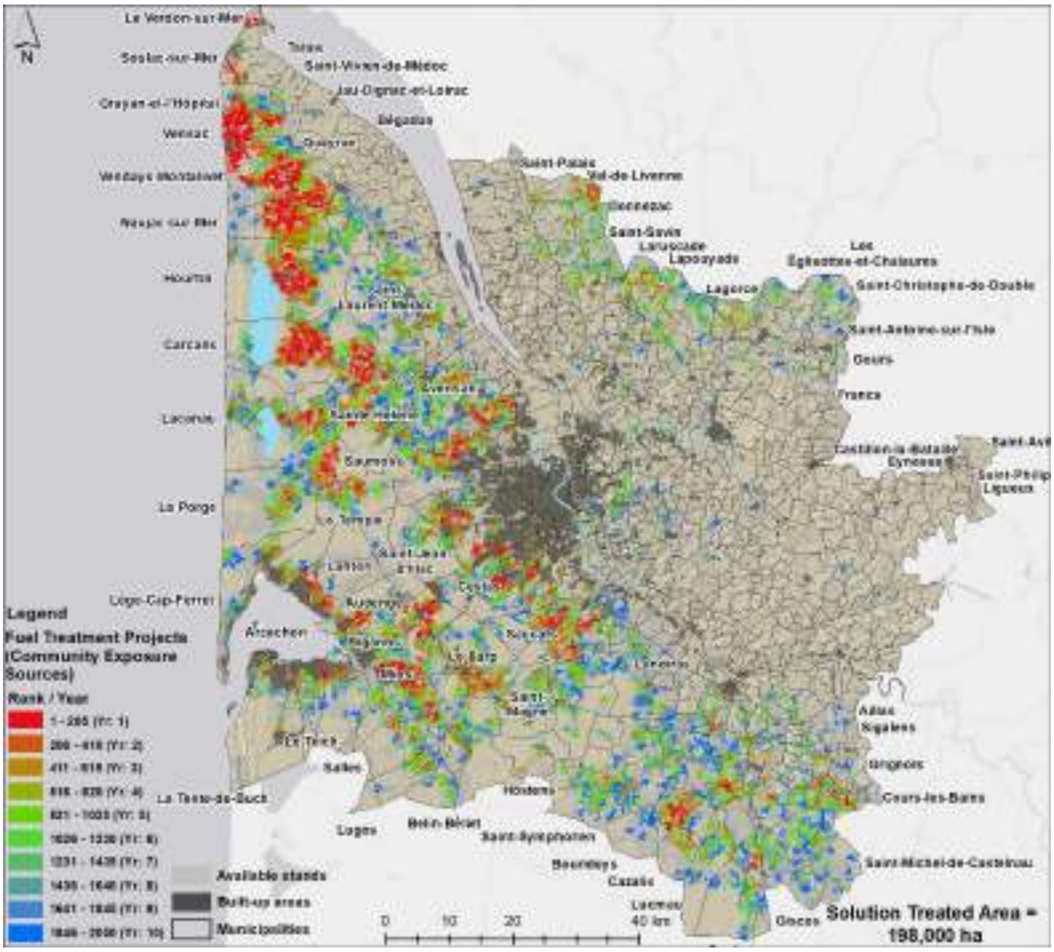

Figure 118 Map of the 2050 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

Each year, approximately 20,000 ha should be treated (Figure 119), and during the first year the main objective (i.e., community exposure sources), can reach an attainment of up to 30%, while for the first time in a Living Lab we notice a very high attainment of community exposure sinks, that can achieve up to 25% in the first year. For the first five years, the attainment of the main objective can reach 50% by treating approximately 99,800 ha, with the attainment of the other objectives be high as well (>10%). Very effective objectives were the community exposure sinks (41%), protected areas exposure sources (28%), wildfire hazard (22%) and protected areas exposure sources (19%), with the remaining objectives achieving attainments between 10% (ignition probability) and

15% (carbon and biomass). After the fifth year, the attainment for the main objective is slightly increased to reach 58% by the tenth year, while the other objectives rise more sharply to reach an attainment of ~30% for carbon and biomass, and 39% for the fire hazard, 20% for ignition probability, and 45% and 51% for the protected areas exposure sources and sinks, respectively.

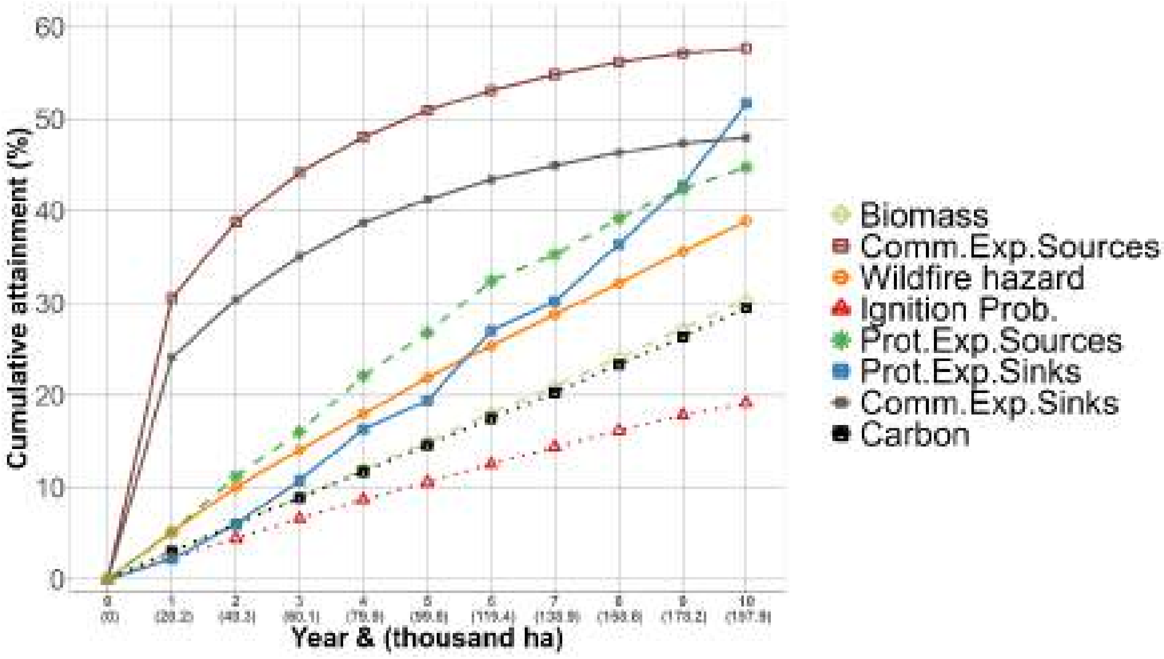

Figure 119 The 10-year implementation plan of fuel treatment with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

The bulk of the projects are in the Municipality of Carcans (~7k ha), followed by Lucanau and Hourtin (~6.5k ha), Sainte-Hélène (5.8k ha), Naujac-sur-Mer (5.5k ha) and Mios (5.2k ha), with the rest Municipalities receiving less than 5k ha of fuel treatments during the 10-year implementation plan (Figure 120-top). The highest attainment is achieved in the Municipalities of Vendays-Montalivet (9%) and Grayan-et-l'Hôpital (~4%), although the total treated area is much lower (~5k and 2.5k ha respectively) compared to the other Municipalities (e.g., Carcans with 7k ha achieves 3.2%). It is notable that the projects planned to be implemented during the first year and are in the six highest performing Municipalities (Vendays-Montalivet, Grayan-et-l'Hôpital, Carcans, Mios, Naujac-sur-Mer and Hourtin) achieve at least half of their total attainment, and for some, more than two-thirds (Figure 120-bottom). This finding suggests that they should be among the first to receive fuel treatments to faster achieving the goals of the main objective.

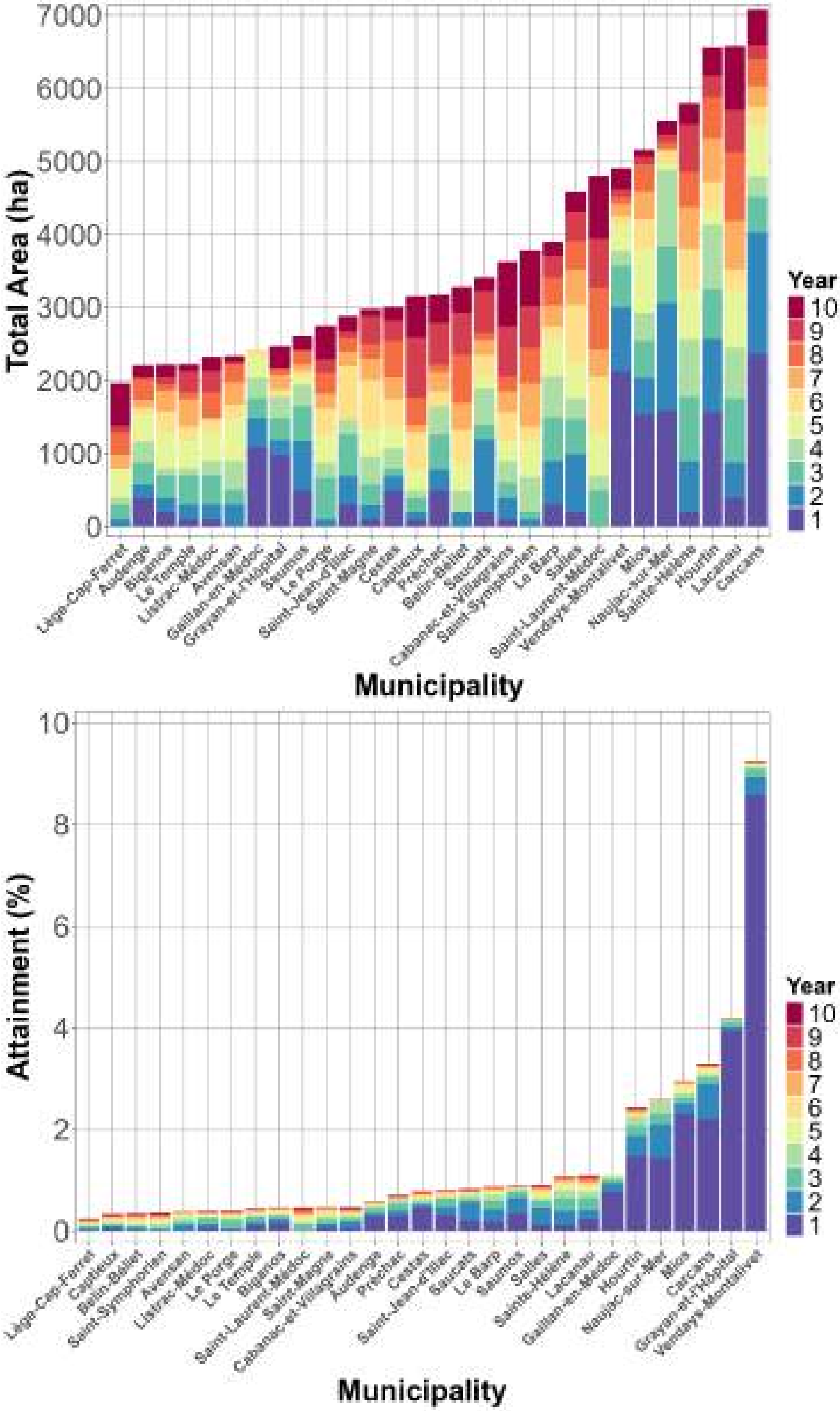

Figure 120 Top: area treated in ha for each Municipality by implementation year. Bottom: main prioritized objective attainment (%) for each Municipality by implementation year.

The implementation of a 10-year plan to reduce the fire risk of the protected areas from the sources of their exposure by treating half (i.e., 140,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 280,000 ha), resulted to request the spatial optimization of 1400 projects (Figure 121). The total treated area returned from the spatial optimization solution is 135,000 ha. In this optimization run we did not consider any administrative boundary.

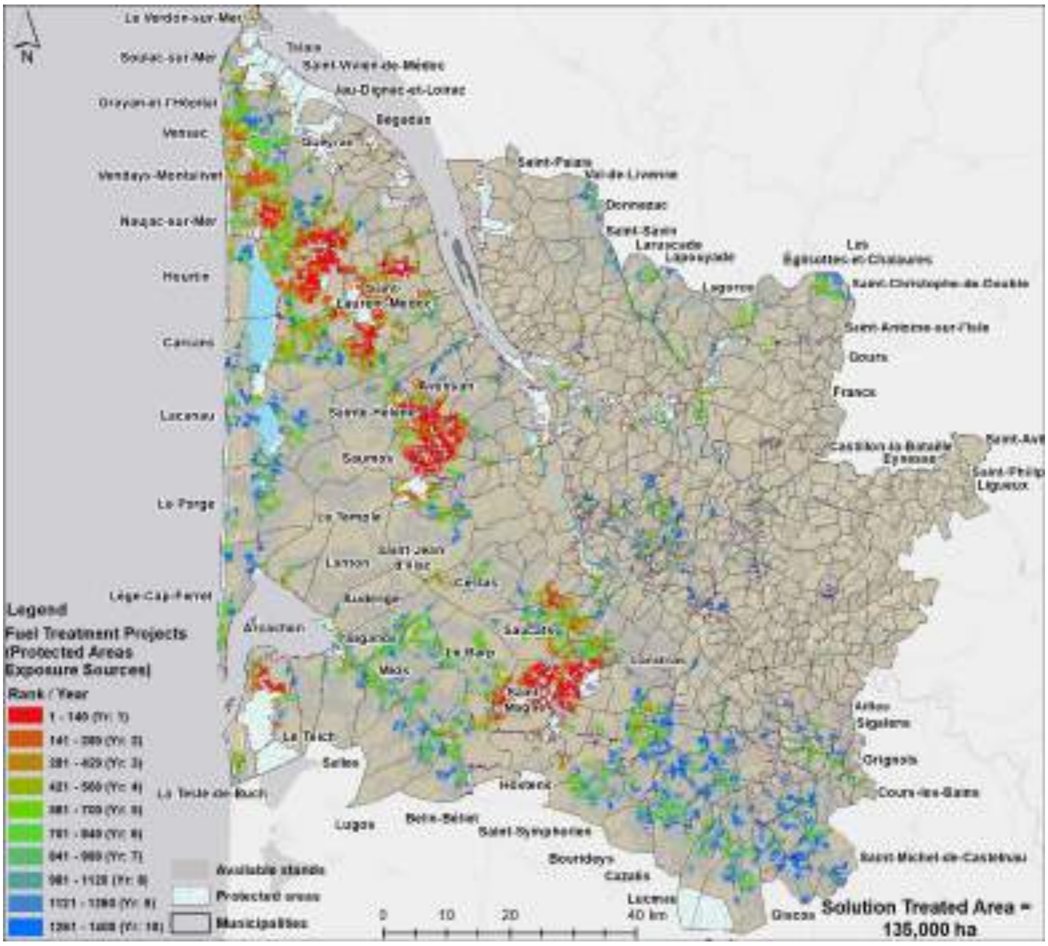

Figure 121 Map of the 1400 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

Each year, approximately 13,500 ha should be treated (Figure 122), and during the first year the main objective (i.e., protected areas exposure sources) can reach an attainment of up to 30%. It is notable that by treating the same areas, an impressive 52% attainment can be achieved also for the protected areas exposure sinks, much higher compared to the sources. For the first five years, the attainment of the main objective can reach 48% by treating approximately 67,500 ha, with the protected areas exposure sinks ascending up to 60%. The attainment of the other objectives is high for community exposure sources and sinks (28% and 22% respectively), moderate for the wildfire hazard (18%), and low for carbon and biomass which are totally correlated (11%), and very low for ignition probability (8%). After the fifth year, the attainment for the main objective and protected areas exposure sinks are slightly increased to reach 51% and 61% by the tenth year, respectively, while the other objectives rise gradually to reach an attainment of 38% and 30% for community exposure sources and sinks, respectively, 23% for wildfire hazard, 20% for carbon and biomass, and ~11% for the ignition probability. The lower attainment when optimizing for the reduction of the main objective is achieved for the community exposure sinks, that barely reaches 2% by the tenth year.

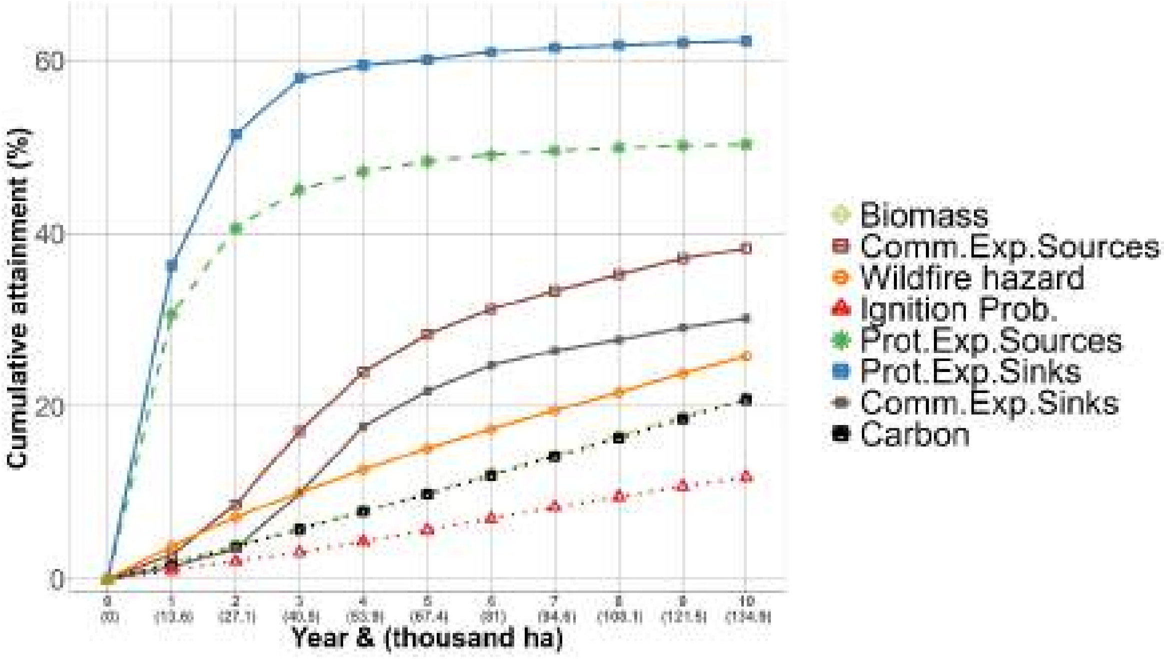

Figure 122 The 10-year implementation plan of fuel treatment with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

The bulk of the projects are in the Municipalities of Hourtin (~7.2k ha) and Carcans (~6.8k ha), followed by Naujac-sur-Mer (~5.8k ha), Vendays-Montalivet (~5.5k ha), Saint-Laurent-Médoc (~4.8k ha) and Cabanac-et-Villagrains (~4.2k ha), with the rest Municipalities receiving less than 4k ha of fuel treatments during the 10-year implementation plan (Figure 123-top). The highest attainment is achieved in the Municipalities of Hourtin (~6.5%) and Cabanac-et-Villagrains (~5.6%), Saint-Magne (5.3%), and Saint-Médard-en-Jalles (~4.3%), with the remaining Municipalities achieving attainment <4% (Figure 123-bottom). Saint-Magne and Saint-Médard-en-Jalles are ranked moderately in terms of area treated (3.5k ha and 2.6k ha, respectively), but they are very efficient when projects are allocated there. It is notable that the projects planned to be implemented during the first year and are in the six highest ranked Municipalities achieve more than two thirds of their total attainment (Figure 123-right). Also notable is that although 18 Municipalities can receive more than 2,000 ha of fuel treatments, only 11 achieve attainment >1% for that objective. This finding suggests that they should be among the first to receive fuel treatments to faster achieving the goals of the main objective and that most of the >500 Municipalities offer little to none in the achievement of this management objective.

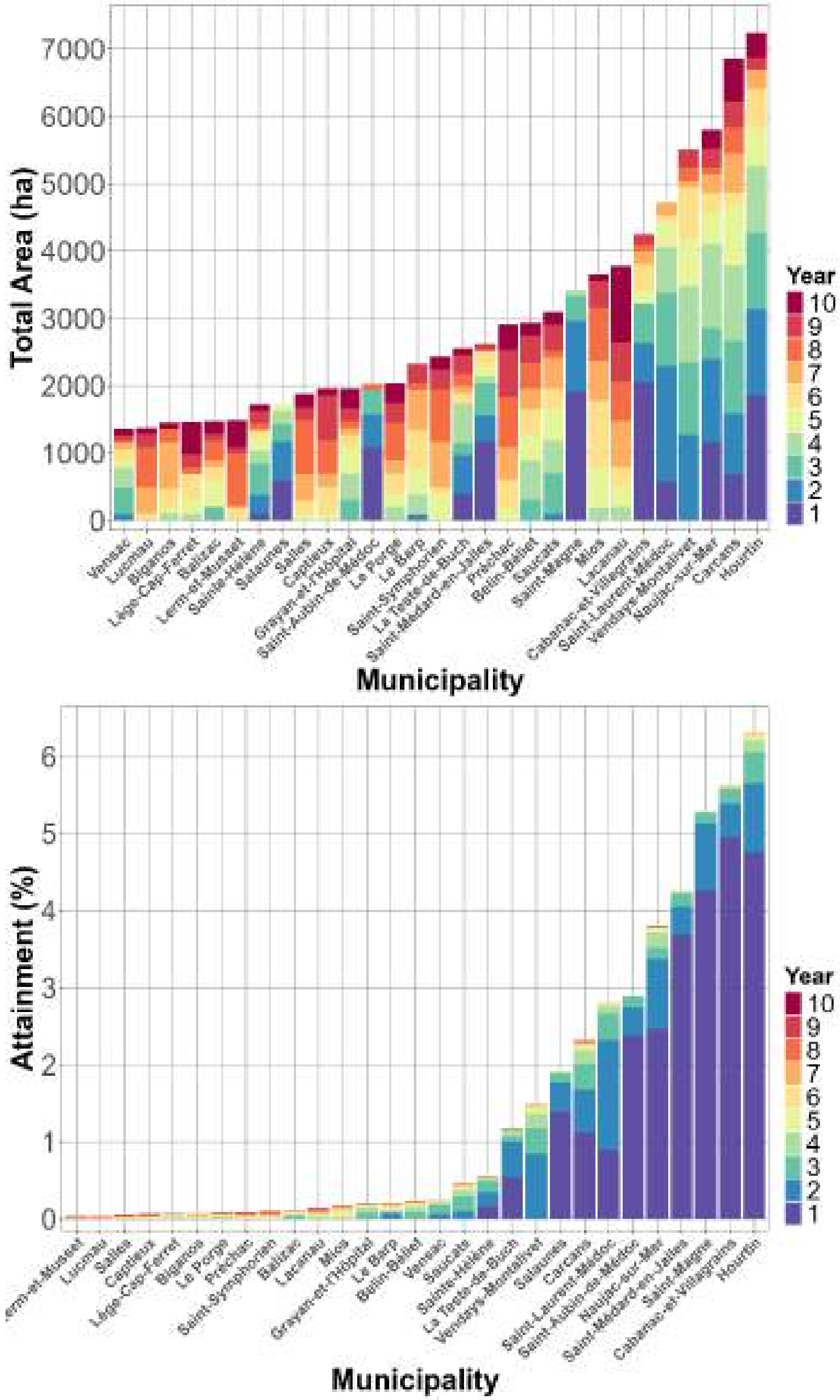

Figure 123 Top: area treated in ha for each Municipality by implementation year. Bottom: main prioritized objective attainment (%) for each Municipality by implementation year.

The implementation of a 10-year plan to reduce the ignition probability by treating half (i.e., 215,000 ha) of the lands that are available for treatment and has a value greater than zero for that objective (i.e., 430,000 ha), resulted to request the spatial optimization of 2150 projects (Figure 124). The total treated area returned from the spatial optimization solution is 208,000 ha. The proposed area for treatments is large since all the available stands had an ignition probability value attached that was greater than zero (the unavailable and non-burnable stands were already excluded). In this optimization run we did not consider any administrative boundary.

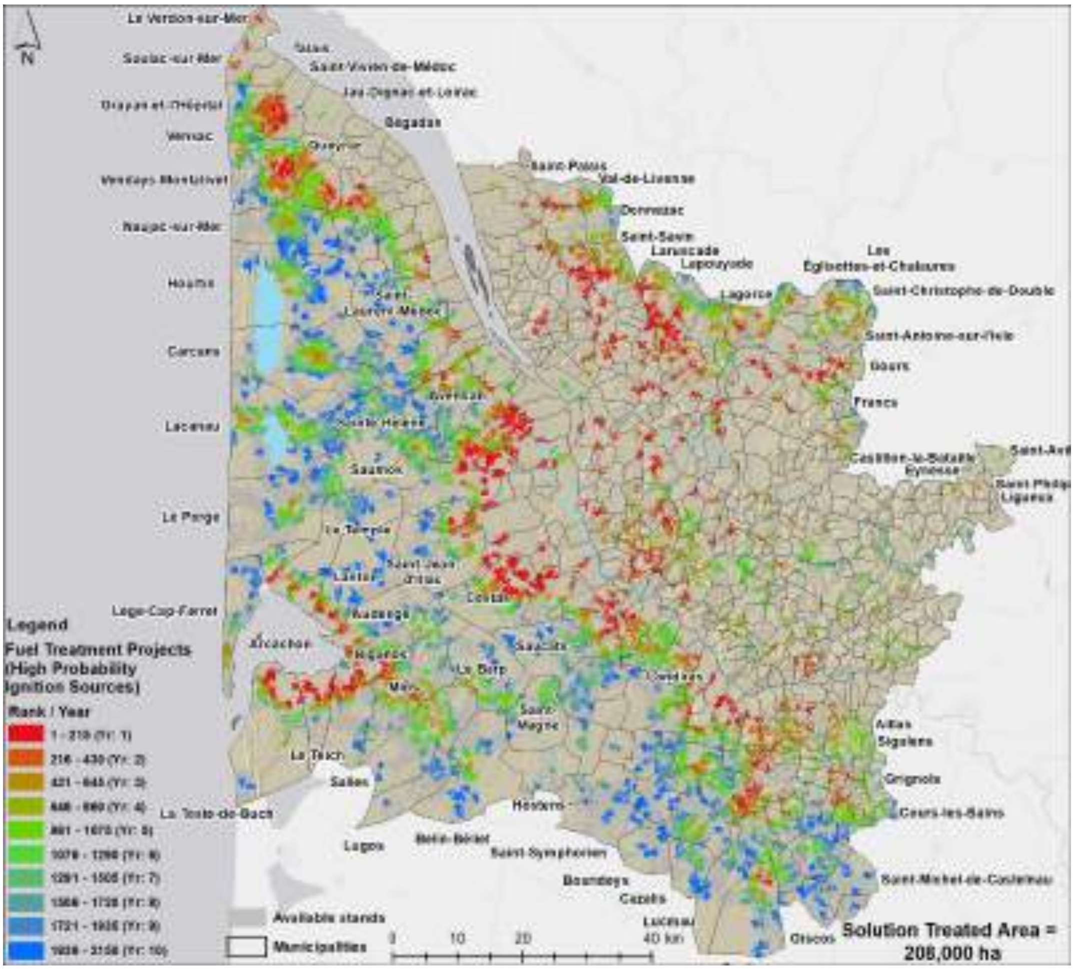

Figure 124 Map of the 2150 projects ranked by the level of attainment they achieve and distributed evenly across each year of the 10-year implementation plan of fuel treatment with the objective to reduce new ignitions by treated in areas with high ignition probability.

Each year, approximately 21,000 ha should be treated (Figure 125), and during the first year the main objective (i.e., reduction of ignition probability) can reach an attainment of up to 5%, similarly to the community exposure sources. For the first five years, the attainment of the main objective can reach ~15% by treating 103,500 ha, with the attainment of the objectives of carbon, biomass and community exposure sinks be at approximately the same levels, while community exposure sources reach a high of ~25%. In this optimization run, protected areas sources and sinks achieved a low attainment between 5-8%, while wildfire hazard achieved 10% attainment. After the fifth year, the attainment for the main objective is moderately increased to reach ~24%, ranked last compared to the attainment of all other objectives. Community exposure sources rise to a very high of 45% and sinks to 35%. Notable is the sharp increase in the two protected areas objectives, with sinks reaching 45% and sources 30%.

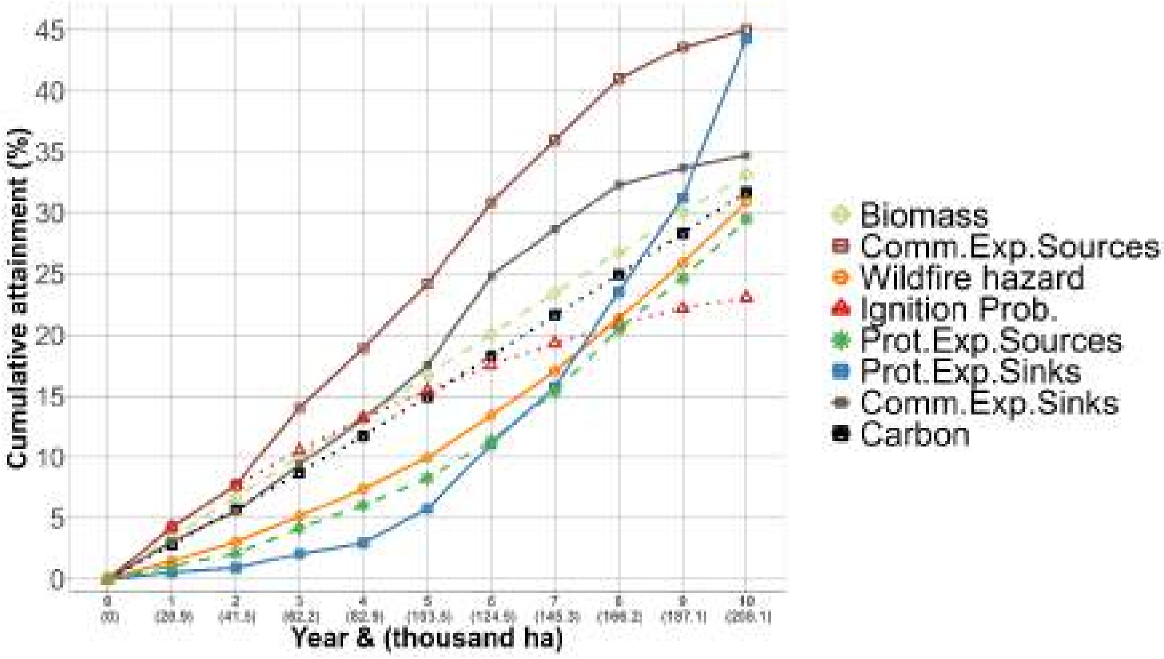

Figure 125 The 10-year implementation plan of fuel treatment with the objective to reduce new ignitions by treated in areas with high ignition probability.

The bulk of the projects are in the Municipalities of Lacanau (~6k ha), followed by Sainte-Hélène (~5k ha), Carcans (4.8k ha), Vendays-Montalivet (~4.5k ha), Hourtin (~4.3k ha), Mios (~4.2k ha) and Naujac-sur-Mer (~4.1k ha), with the rest Municipalities receiving less than 4k ha of fuel treatments during the 10-year implementation plan (Figure 126-top). The by far highest attainment is achieved in the Municipality of Vendays-Montalivet (~0.55%), that also receives a high load of treatments, followed by Mios and Lacanau (~0.46%), Cestas (0.42%) and Carcans (~0.4%) (Figure 126-bottom). All other Municipalities achieved attainment <0.4%. The attainment per year is almost evenly distributed among the 10-year period for most Municipalities.

There are about 180k ha of stands that meet at least two of the three main objectives examined above (community exposure sources, protected areas exposure sources and ignition probability), and 60k ha of stands that meet all three objectives (Figure 127). For the analysis, these stands are not grouped in projects. When we start selecting these stands that were part of the ForSys solutions for the three main objectives based on the best available stands for the objective of community exposure sources, we notice that by treating approximately 60k ha we can achieve a 39% for that objective and 28% for sinks, ~28% for the protected areas exposure sinks and 20% for sources, and less than 15% for the remaining objectives (Figure 127-left).

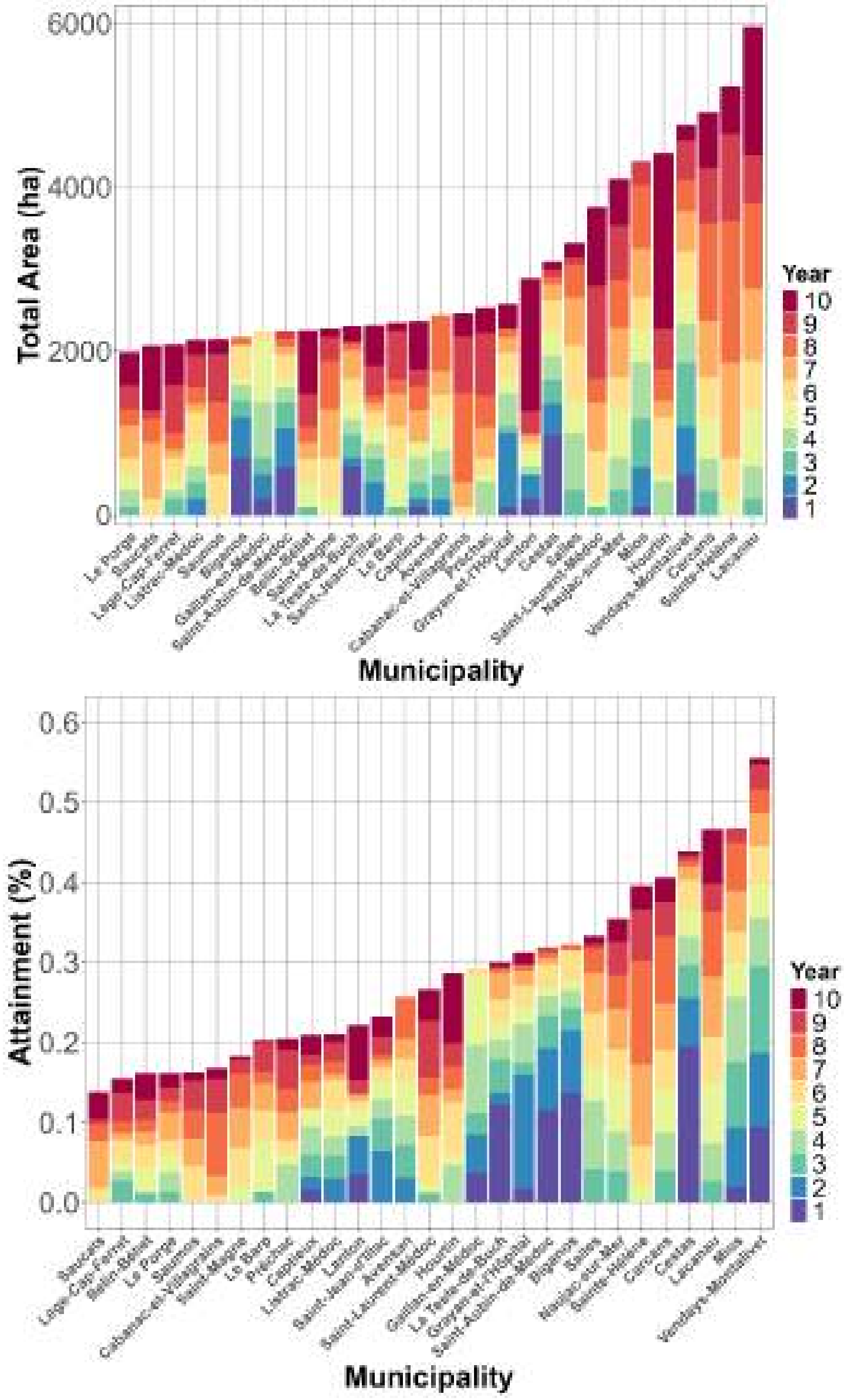

Figure 126 Top: area treated in ha for each Municipality by implementation year. Bottom: main prioritized objective attainment (%) for each Municipality by implementation year.

By treating the same amount of area (60k ha), we achieve larger attainments in the relevant optimization runs, i.e., 39% vs. 45% for community exposure sources and 49% vs. 20% for protected areas exposure sources. In Figure 127-right we show that treating to achieve all three objectives can lead to attainments of up to 27% for community exposure sources, 25% for protected areas exposure sources and 6% for ignition