probability. In Figure 128 we present all stands that met either more than two (orange) and three (red) objectives.

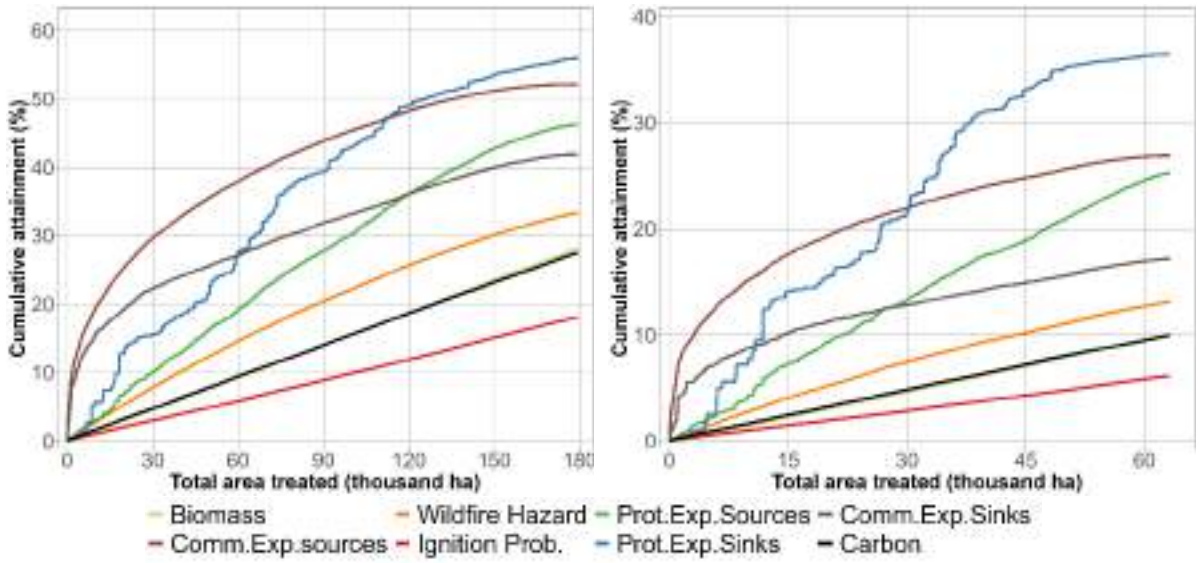

Figure 127 The attainment of the eight objectives analysed for the stands that were selected from the three runs of SET1 that a) meet two or more objectives (left) and b) meet three objectives (right). For graphing purposes, the stands selected first had the highest performance for the objective of community exposure sources.

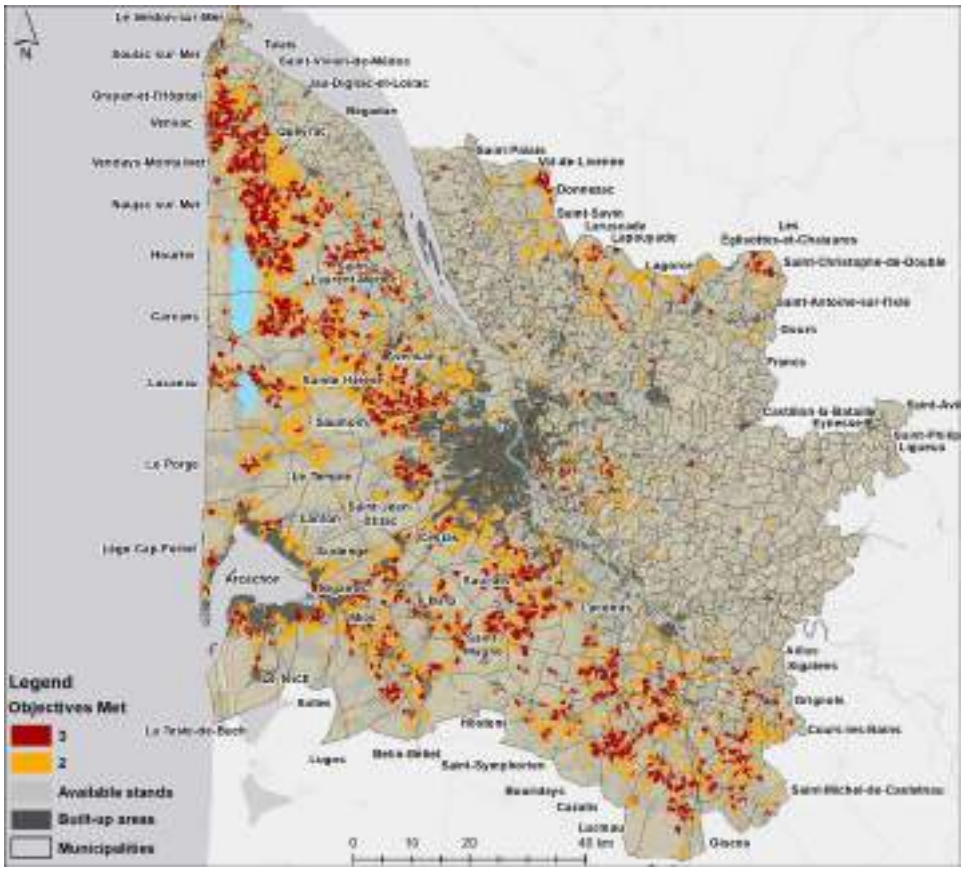

Figure 128 Allocation of stands that were selected from the three runs of SET1 that meet two or more objectives (orange) and three objectives (red).

4.4.3 SET2: Equity among planning areas

In this set of runs we chose to apply an equity approach among the different Municipalities, meaning that we requested the same number of projects for each district 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). Since this study area has so many Municipalities (>530), and given the fact that ForSys tries to find the same number of projects for all, we had to limit the number of requested projects to 20 since it would be impossible to find enough area to create 50 projects in Municipalities with very small area, as it was the case in the previous Living Labs analysed. Despite this, we can still see that in smaller Municipalities almost their entire available area was selected for treatments and create projects. We emphasize on those Municipalities (~30) which are large enough and have important forest resources and disregard the smaller ones.

In Figure 129 the attainment curve of community exposure sources can achieve up to ~55% when all the solution area is treated (198,500 ha), with protected areas exposure sources achieving a ~32% attainment. It is notable that even if we treat the best 75k ha, we can still achieve a 45% attainment for that objective. Biomass and Carbon are completely correlated and achieve a ~28% attainment, like the attainment of wildfire hazard. Community exposure sinks also are very effective and achieved a 45% attainment. with smaller achievements for the other four management objectives. Finally, the smaller attainment was achieved by the ignition probability objective (~20%).

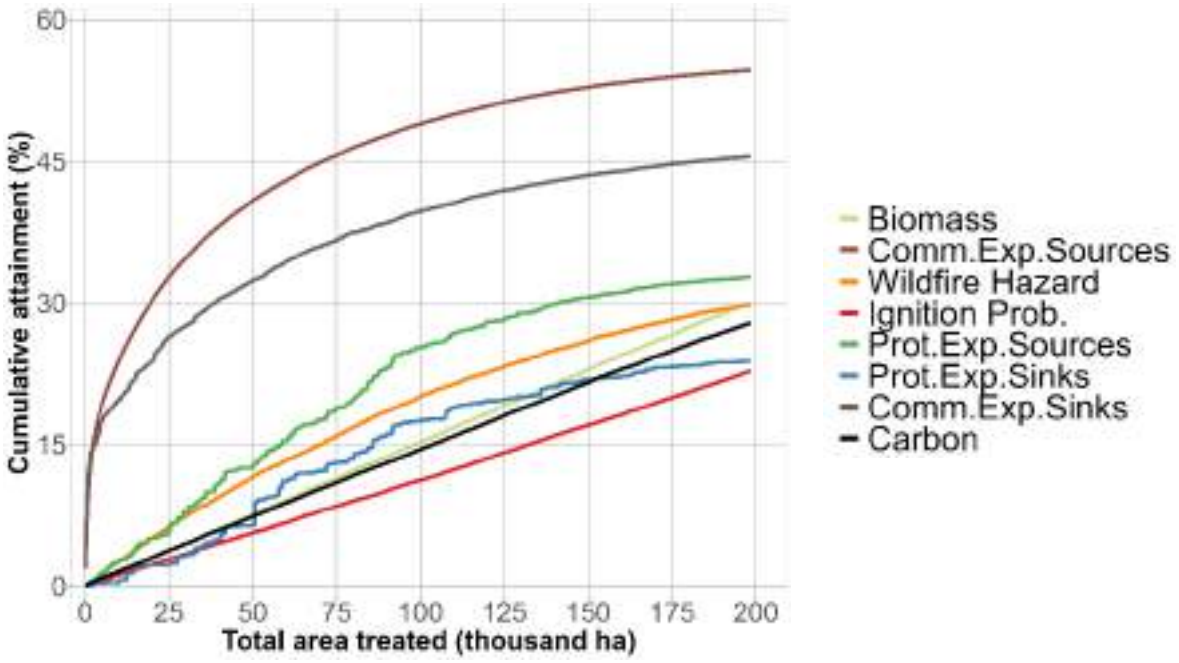

Figure 129 Area treated for all Municipalities and the level of attainment for all objectives after prioritizing for the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

In Figure 130 we mapped the 20 projects of each Municipality, with warmer colours applied to the best performing projects when prioritized for the objective of community exposure sources. The Municipality with the highest attainment for the main objective (community exposure sources) is Vendays-Montalivet with ~8% when 1940 ha are treated (achieving also a 8.5% for sinks), followed by Vensac with 4.2% and 1578 ha, Grayan-et-l'Hôpital (~4% and 1706 ha, with sinks achieving an impressive 6%), and Mios with 2.3% and 1928 ha, with the remaining Municipalities achieving <2% attainment (Figure 131). Except for the two objectives that deal with the protected areas, where we notice that some Municipalities are performing highly although not doing well with the main objective (Saint-Aubin-de-Médoc with 2.5%, Cabanac-et-Villagrains and Saint-Magne with 4%), all other management objectives achieved low attainment that is <1.5%.

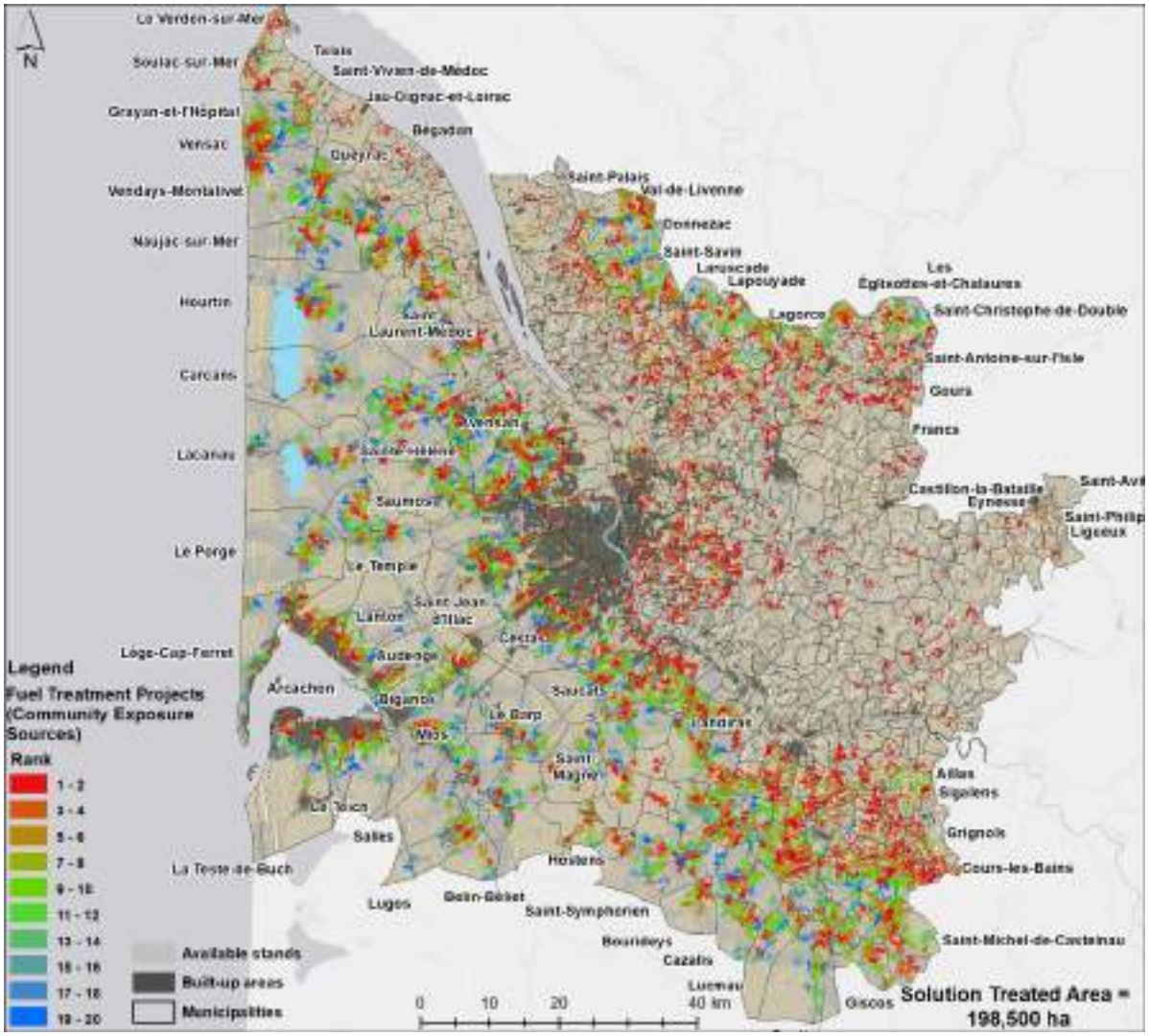

Figure 130 Map of the 20 best projects of each Municipality, ranked by the level of attainment they achieve, with the objective to reduce the exposure of developed areas from incoming wildfires (exposure sources).

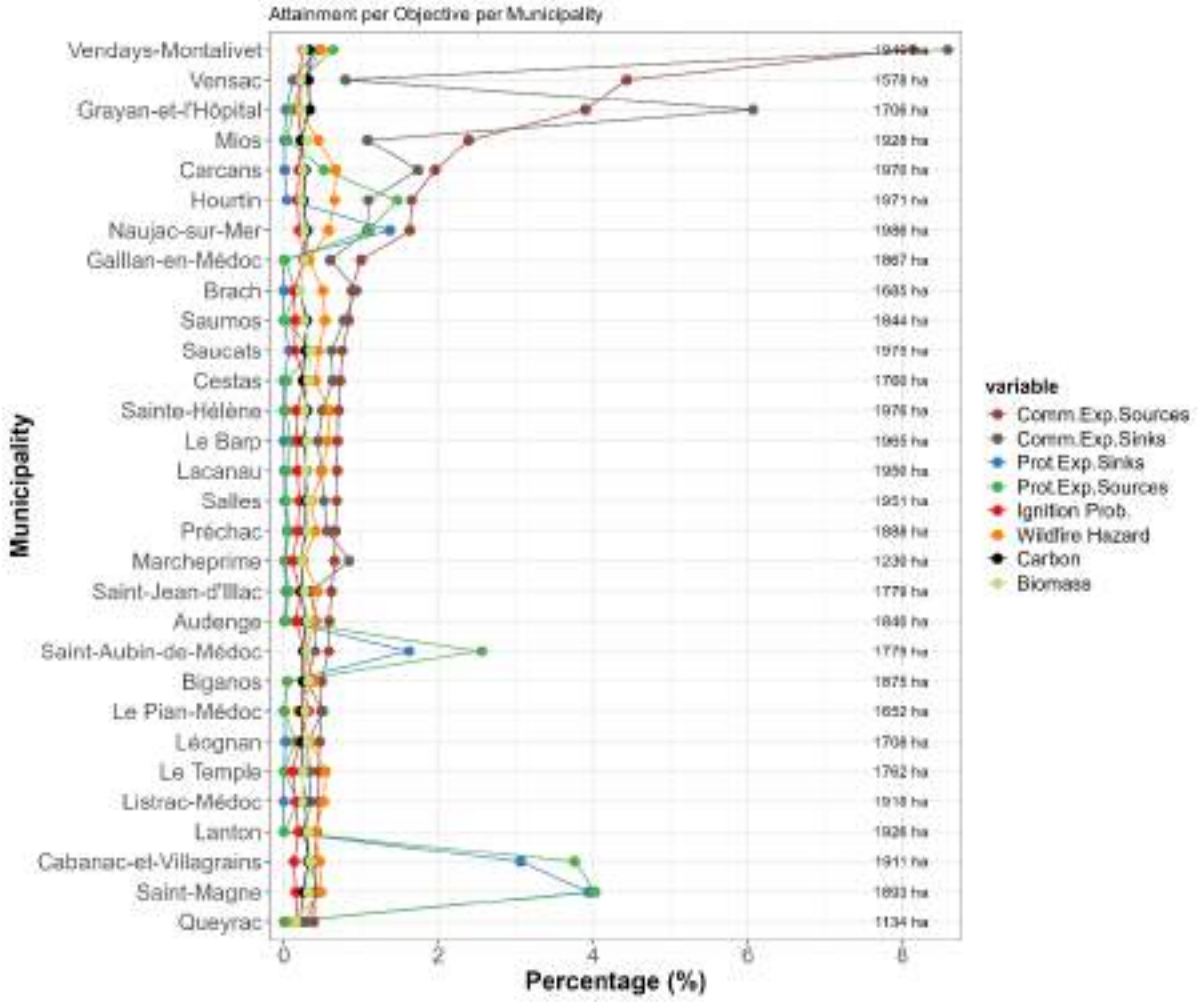

Figure 131 Attainment for each Municipality for the eight objectives when prioritized to reduce the exposure of developed areas from incoming wildfires (exposure sources).

The second run for this set prioritized fuel treatments for the management objective of limiting the exposure from the protected areas sources. In Figure 132 the attainment curve of the main objective can achieve up to ~46% when all the solution area is treated (112,000 ha), with protected areas sinks achieving a ~55% attainment and community exposure sources 30%. Very high attainment for the main objective is achieved even if we treat 40k ha (43%). All the other management objectives achieved attainments <17%. In Figure 133 we noticed that the projects are, as expected, clustered around the protected areas. Finally, in Figure 134 the Municipality of Hourtin achieved a high of ~5% for the main objective and an impressive 10% attainment for the protected areas exposure sinks by treating ~2k ha in 20 projects, followed by Cabanac-et-Villagrains with 4.8% with 1952 ha, Saint-Magne with 4.3% and 1845 ha and Saint-Médard-en-Jalles with 4.2% and 1812 ha. All other Municipalities achieved attainments <3% for the main objective. It is notable that for the Municipalities of Vendays-Montalivet, Vensac and Grayan-et-l'Hôpital, the objective of community exposure sources performed better than the main objective.

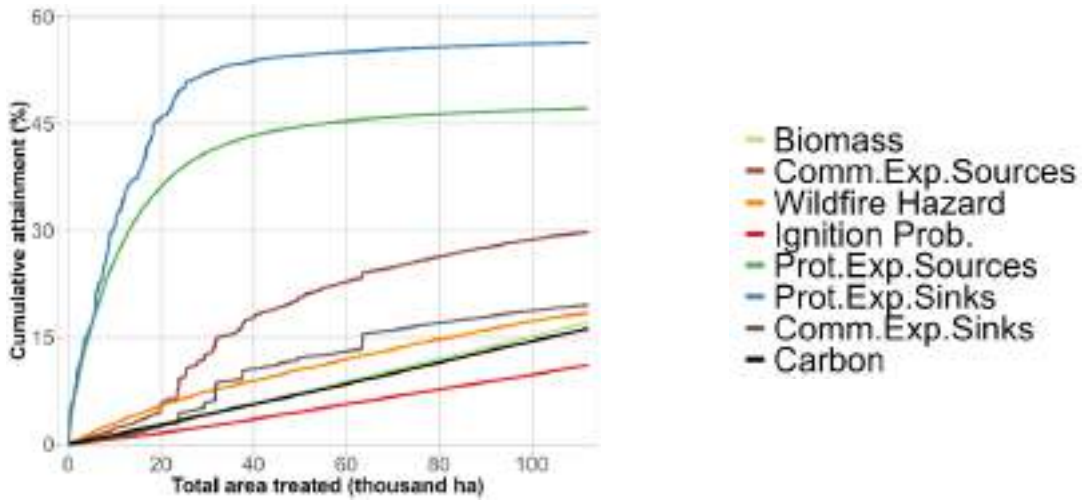

Figure 132. Area treated for all Municipalities and the level of attainment for all objectives after prioritizing for the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

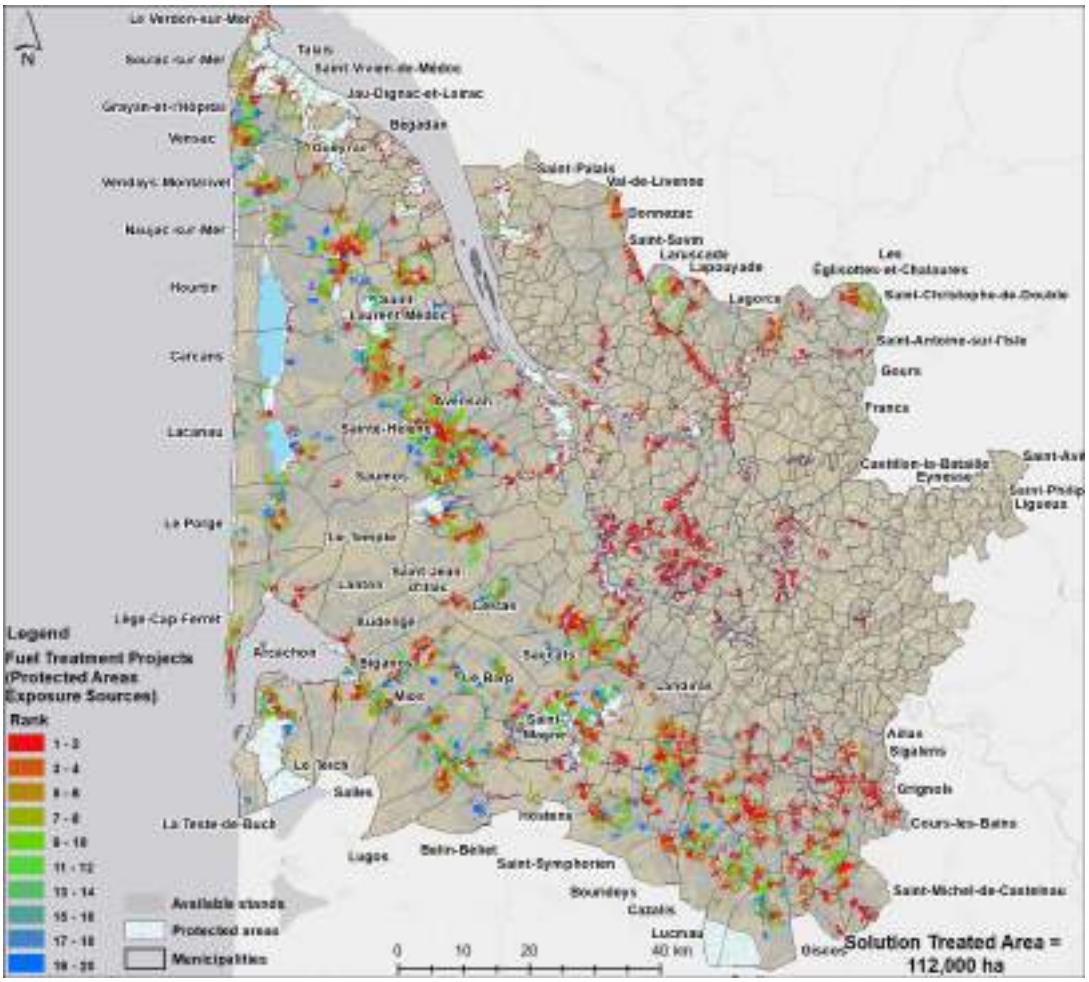

Figure 133 Map of the 20 best projects of each Municipality, ranked by the level of attainment they achieve, with the objective to reduce the exposure of protected areas from incoming wildfires (exposure sources).

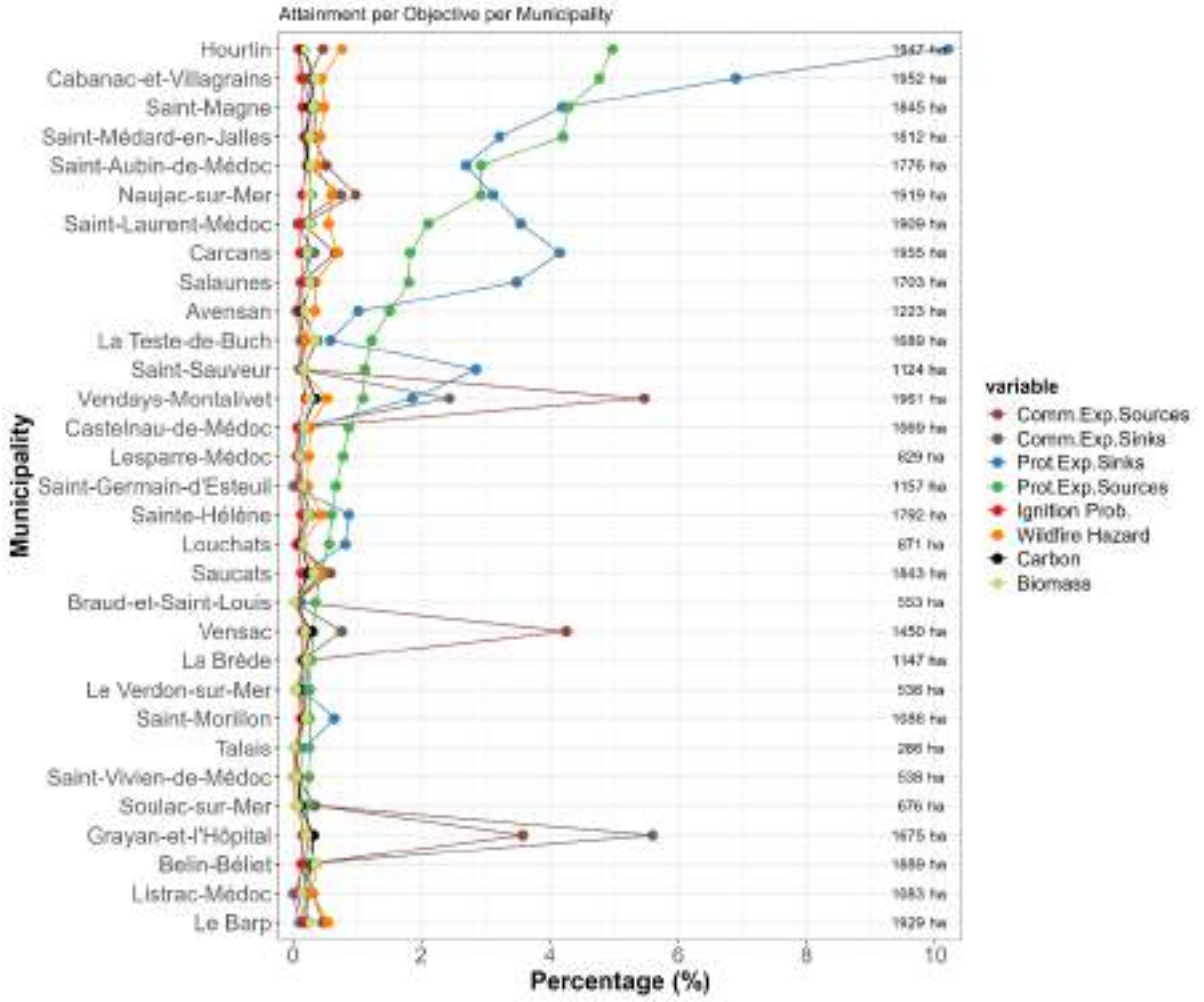

Figure 134 Attainment for each Municipality for the eight objectives when prioritized to reduce the exposure of protected areas from incoming wildfires (exposure sources).

The final run for this set prioritized fuel treatments for the management objective of limiting the ignition probability. In Figure 135 the attainment curve of the main objective (red line), although when starting and up to 40k ha is the second best performing, as the treated areas increases and up to 160k ha is fifth in terms of attainment and behind the community exposure sources and sinks, biomass and carbon, to end up achieving ~32% when all the solution area is treated (258,500 ha), ranked fifth and followed by wildfire hazard (29%), and protected areas exposure sources and sinks (~26% and ~23%, respectively). In Figure 136 we can notice a good distribution of projects across the landscape, since all of the available stands had an ignition probability value greater than zero, so, there were plenty to select and build the projects. Finally, in Figure 137 the range of performance among the Municipalities is low, as with the other Living Labs, with the highest performing (Le Pian-Médoc) achieving a ~0.4% and the lowest (Arsac) a ~0.2% attainment. The treated area among the districts was quite similar and approximately at 2,000 ha. Some Municipalities like Vendays-Montalivet and Vensac achieved high attainment for community exposure sources (due to their high population and building density), while others like Saint-Aubin-de-Médoc and Saint-Médard-en-Jalles were high performing for protected areas exposure sources.

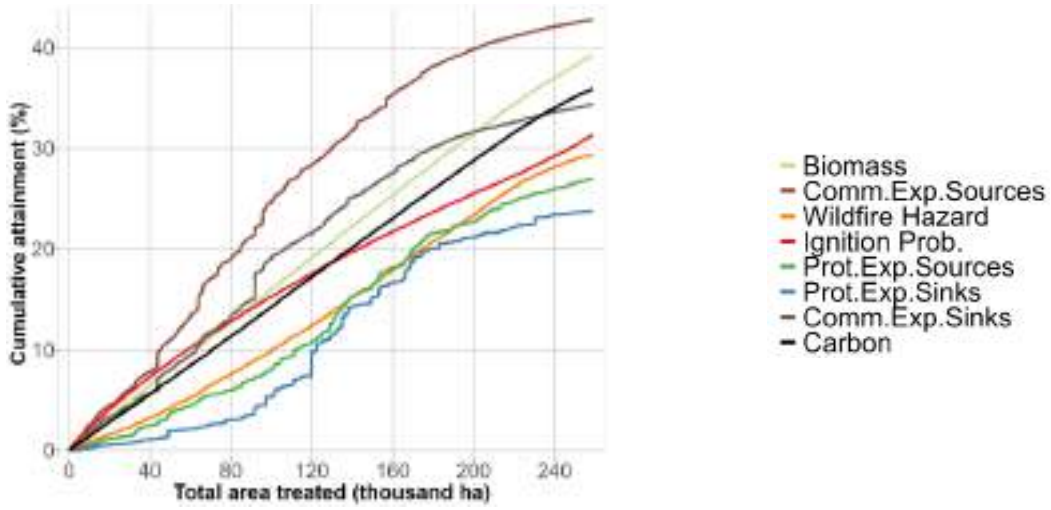

Figure 135 Area treated for all Municipalities and the level of attainment for all objectives after prioritizing for the objective to reduce new ignitions by treating in areas with high ignition probability.

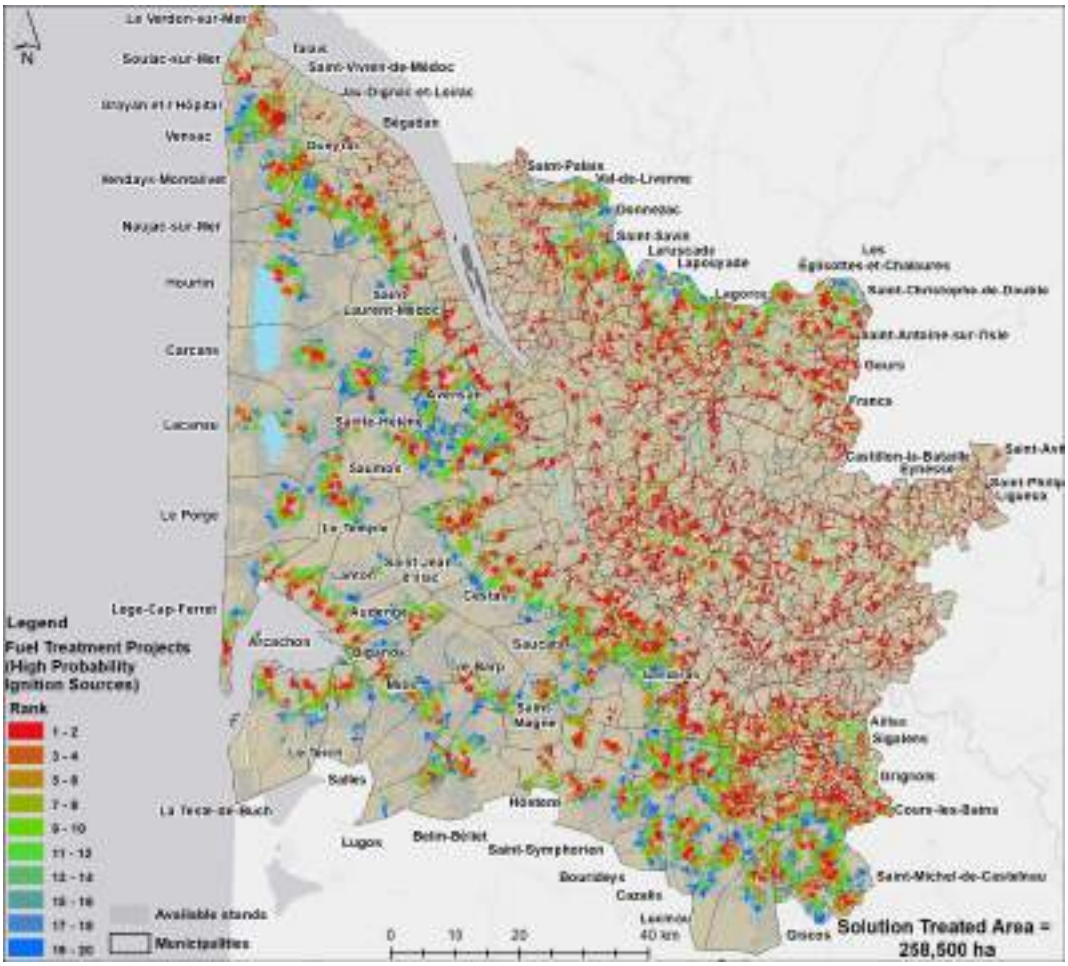

Figure 136 Map of the 20 best projects of each Municipality, ranked by the level of attainment they achieve, with the objective to reduce new ignitions by treating in areas with high ignition probability.

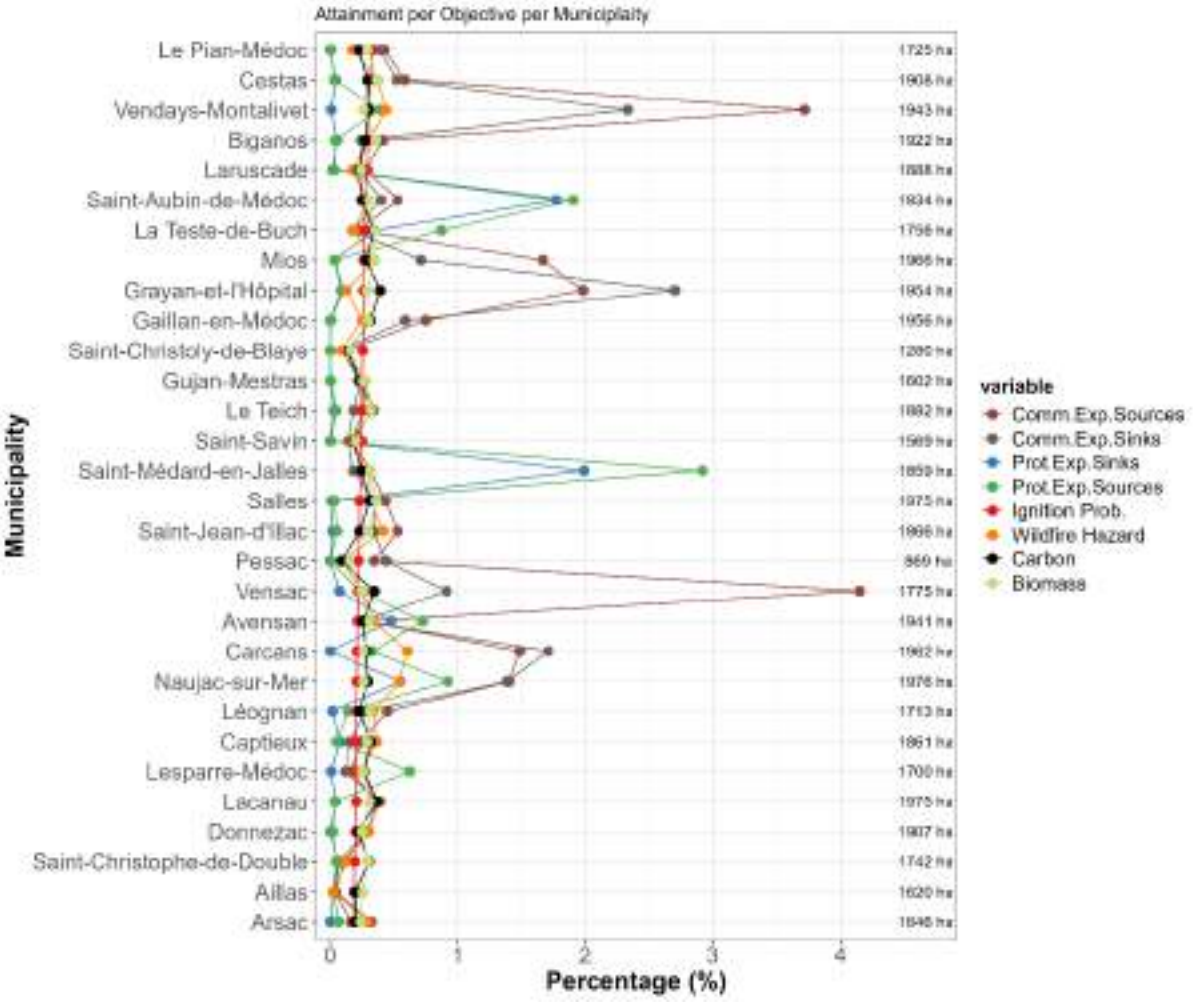

Figure 137 Attainment for each Municipality for the eight objectives when prioritized to reduce new ignitions by treated in areas with high ignition probability.

There are about 250k 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 138). 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 100k ha we can achieve a ~42% for that objective, ~25% for the protected areas exposure sources, and 11% for the ignition probability (Figure 138-left). By selecting with the same way, the stands that meet all three criteria, an attainment of community exposure sources of ~21% is achieved if we treat 60k ha, achieving a ~16.5% attainment for the protected areas sources and ~6.5% for the ignition probability. Overall, there were many more stands compared to the previously mentioned Living Labs that meet two or three criteria. This happened because a great number of stands came with the solution since, we assigned many planning areas (Municipalities) and ForSys returned project to most of the >530 Municipalities. In Figure 139 we present all stands that met either more than two (orange) and three (red) objectives.

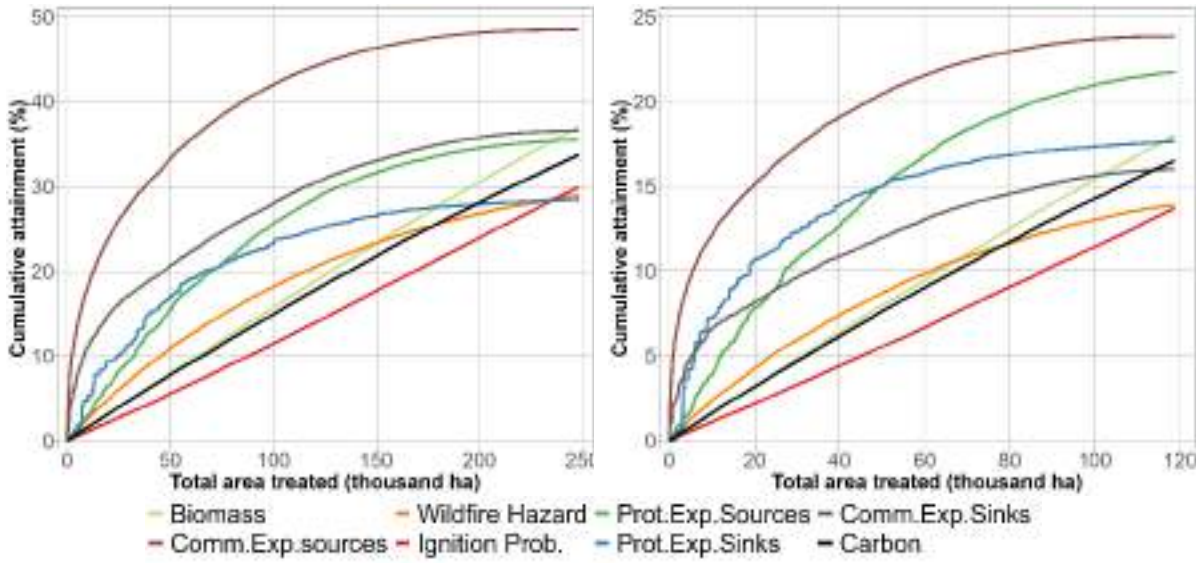

Figure 138 The attainment of the eight objectives analysed for the stands that were selected from the three runs of SET2 that a) meet two or more objectives (left) and b) meet three objectives (right). For graphing purposes, the stands selected first had the highest performance for the objective of community exposure sources.

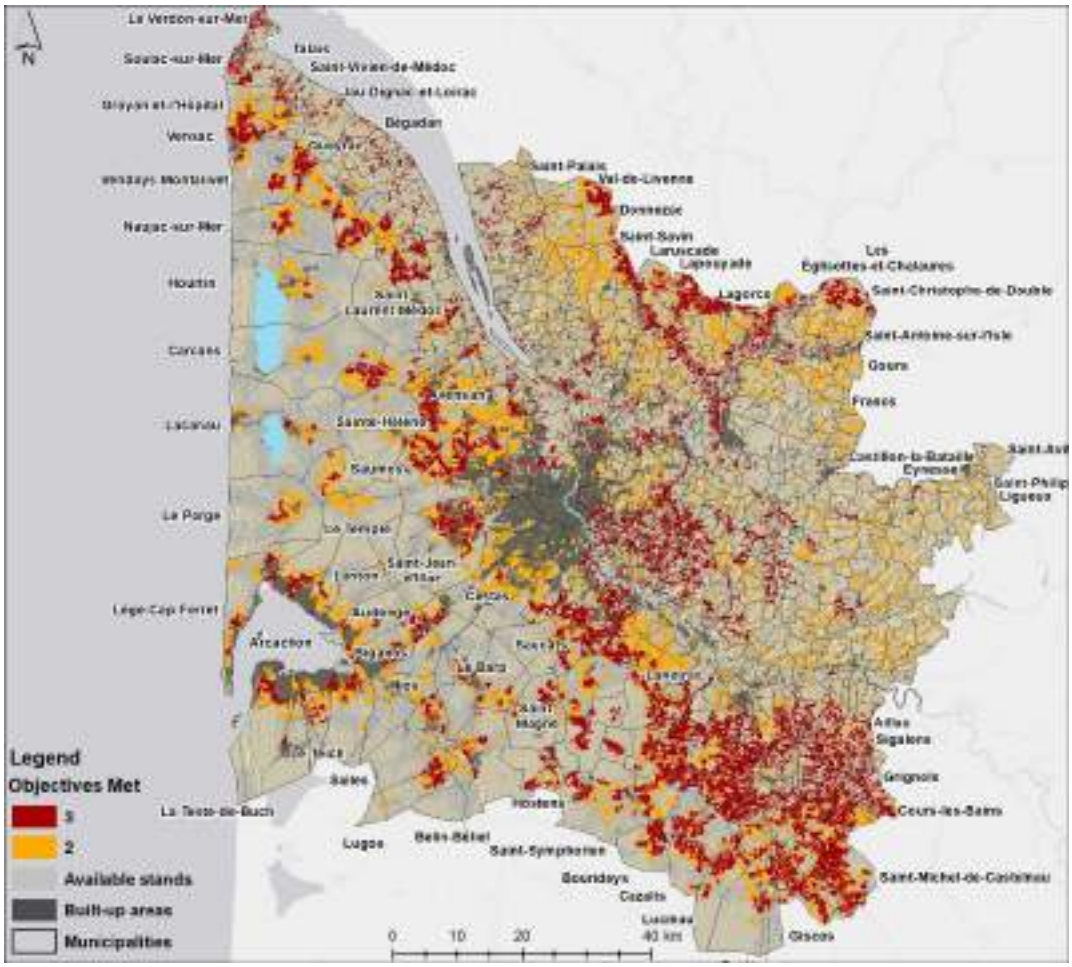

Figure 139 Allocation of stands that were selected from the three runs of SET2 that meet two or more objectives (orange) and three objectives (red).

4.4.4 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 Municipalities. In addition, although some Municipalities might show strong trade-offs, others might have none. The first couple examined the community exposure sources vs. the protected area sources, similarly to Greece and Portugal. The map in Figure 140 shows a solution of approximately 108,000 ha for the three examined weight combinations (equal, 10-3 and 3-10) and creates a maximum difference of 4% in the attainment of both the community exposure sources and protected areas exposure sources. 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.

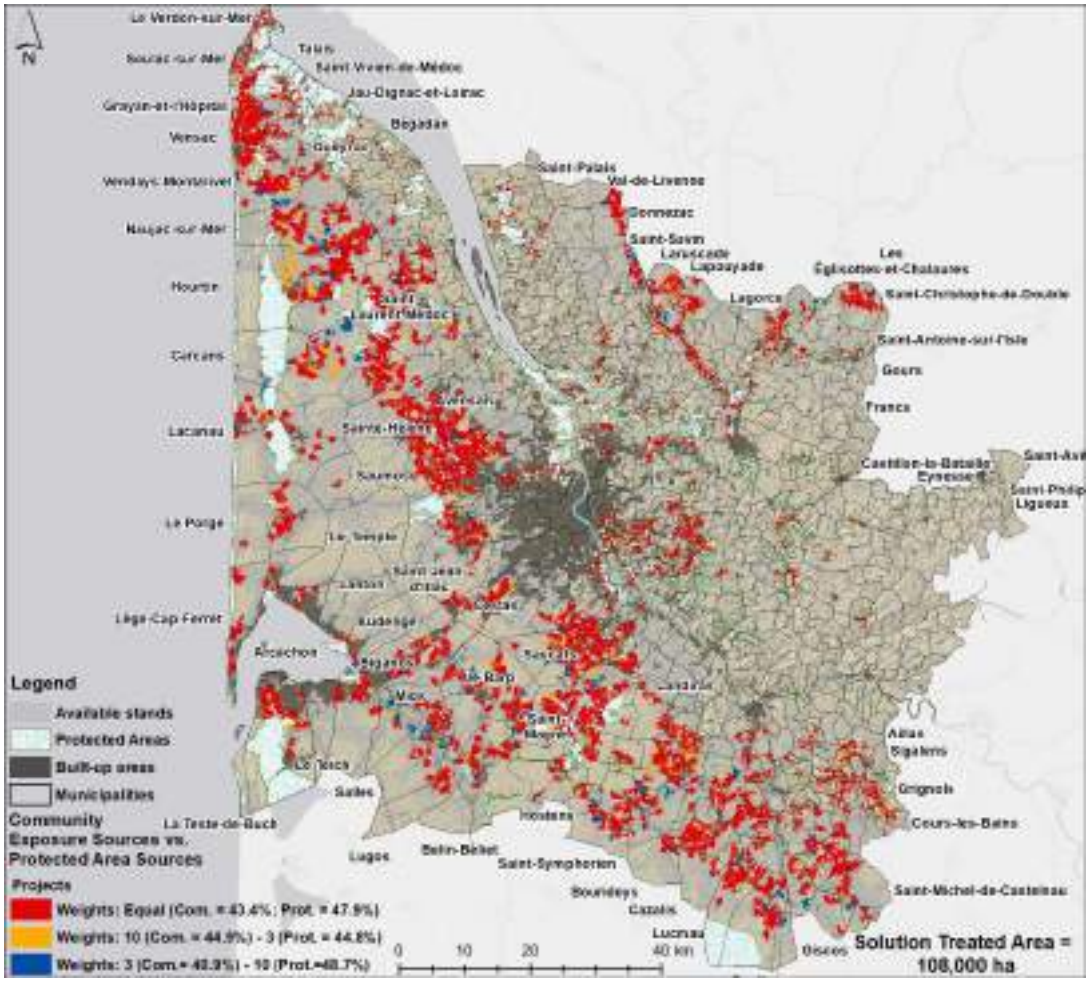

Figure 140 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and protected areas exposure sources set to low (3) (orange); c) Protected areas exposure sources objective weight maximized (10) and developed 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.

The overall attainment for the management objective of community exposure sources is approximately 42%, while for the protected areas approximately 47%. Most of the projects spatially coincide and only few differentiate at the Municipalities of Hourtin, Carcans, Balizac and Naujac-sur-Mer for the weight combination 10-3 (orange colour), and few in Mios, Vendays-Montalivet, Salles and Saint-Symphorien for the weight combination 3-10 (blue colour).

The trade-off graph in Figure 141 shows some shared differences in the Municipalities of Hourtin (i.e., the more the attainment of the community exposure source is increased, the more the protected areas exposure is decreased), Carcans and Naujac-sur-Mer. Most of the remaining Municipalities either show minor and insignificant changes in the attainment or were stable like the cases of Vendays-Montalivet and Mios where the attainment of protected area sources remained approximately at the same levels while the attainment of the community exposure was increasing.

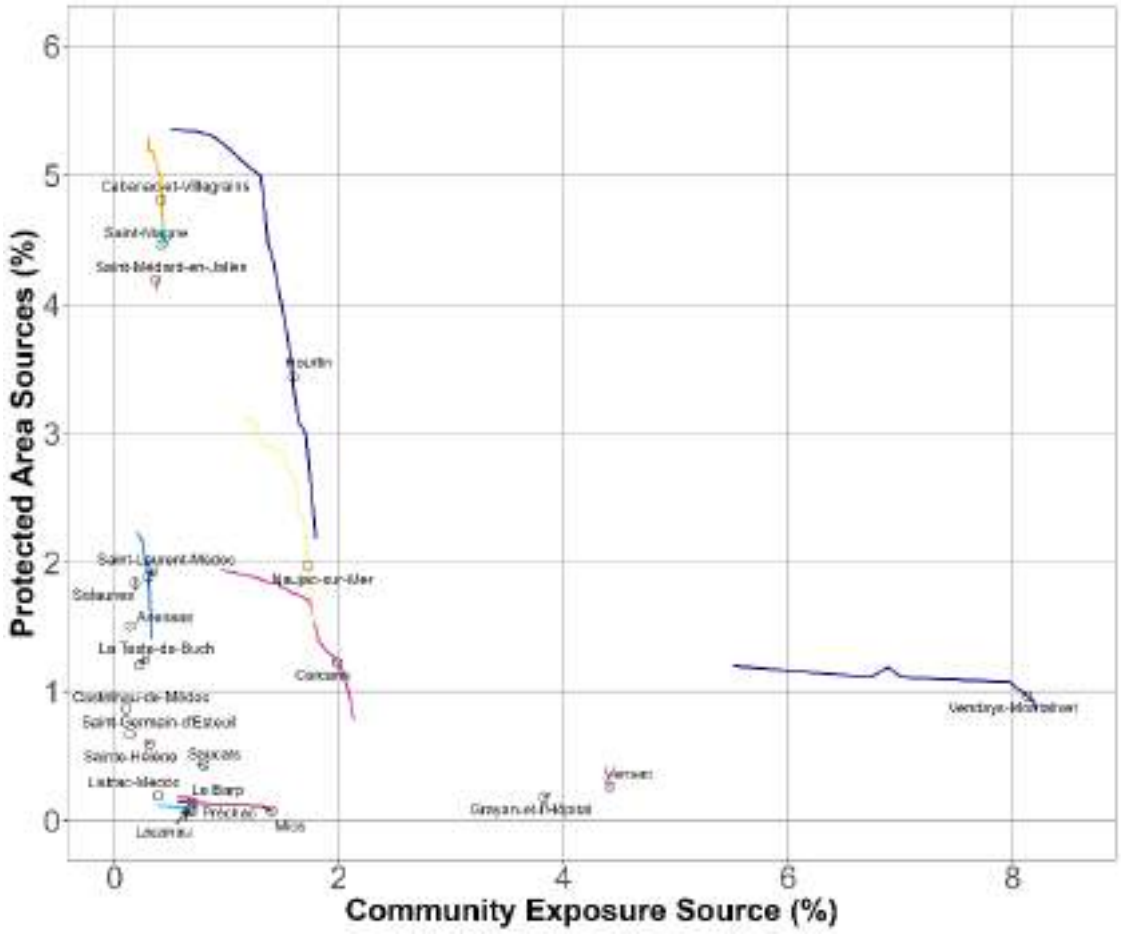

Figure 141 Trade-off production probability curves for each Municipality for the objectives of developed areas exposure sources vs. the protected areas sources. Axes show the level of attainment for each objective (%).

In Figure 142 we show the performance of each objective on each of the selected 30 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 Saint-Sauveur, Saint-Laurent-Médoc, Salaunes and Cabanac-et-Villagrains where protected areas sources exposure has a better performance (red dots at the right). Notable fluctuations in the attainment were recorded for the Municipalities of Naujac-sur-Mer, Vendays-Montalivet and Hourtin. Overall, in most cases the attainement for each objective remained at the same levels regardless of the weight combination.

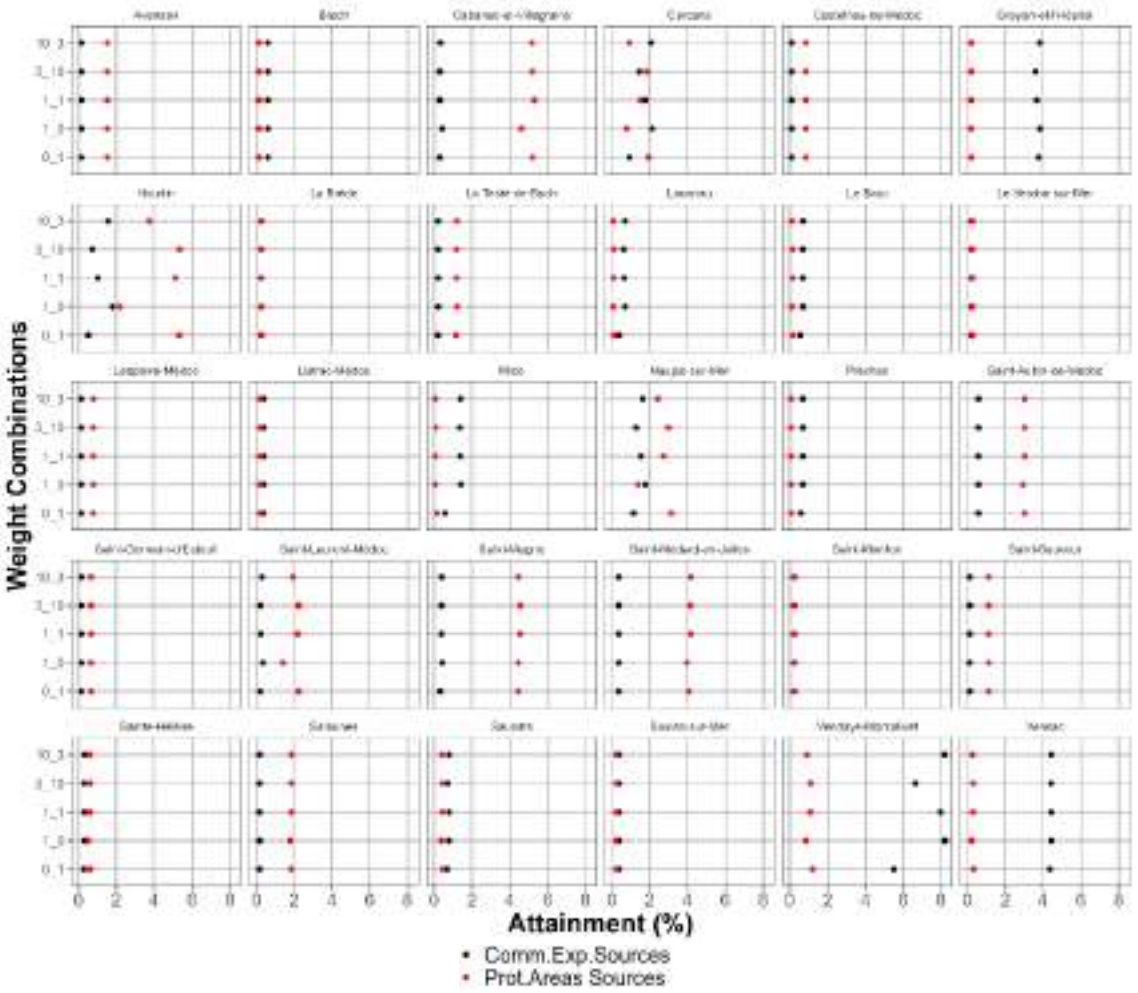

Figure 142 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: protected areas exposure sources) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The second couple examined was the community exposure sources vs. biomass. The map in Figure 143 shows a solution of approximately 220,000 ha for the three examined weight combinations and creates a substantial maximum difference of 4.5% in the attainment of the community exposure sources, and 0.7% for biomass. The overall attainment for the management objective of community exposure sources is approximately 55%, while for the biomass approximately 44%. While several of the proposed projects spatially coincide, there are some that differentiate at the

Municipalities of Belin-Béliet, Lacanau, Captieux, Listrac-Médoc, and Préchac, to name a few for the weight combination 10-3 (orange colour), and several in Le Barp, Naujac-sur-Mer, Vendays-Montalivet and Mios for the weight combination 3-10 (blue colour).

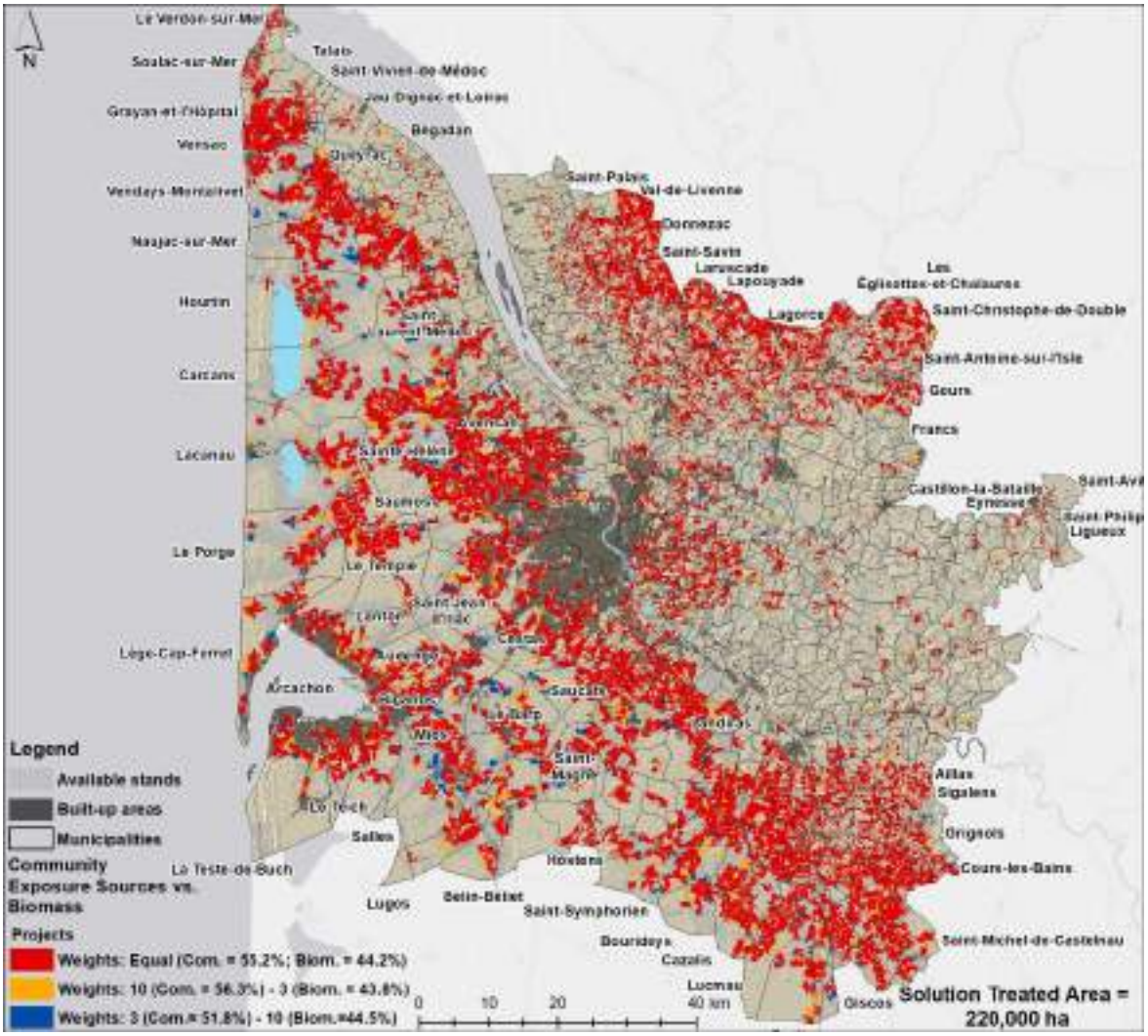

Figure 143 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and retrieved biomass set to low (3) (orange); c) retrieved biomass objective weight maximized (10) and developed areas exposure sources 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 144 shows sharp differences for most of the Municipalities, especially for Mios, Carcans and Hourtin Kynouria (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 high, since the highest performing Municipality like the Vendays-Montalivet can achieve a maximum of 8% attainment for the community exposure sources with approximately 0.35% for biomass, while the highest performing

curve for biomass is in the Municipality of Cabanac-et-Villagrains, with approximately 0.5% attainment (and 0.5% for community exposure). Note that most Municipalities achieve a high attainment for the Biomass objective, but they drop very rapidly in the attainment of community exposure sources, suggesting that there is no room for a joint optimality in project allocation. Some other Municipalities have a high increase in community exposure sources but a very low and gradual decrease in biomass, like in Vendays-Montalivet and Grayan-et-l'Hôpital.

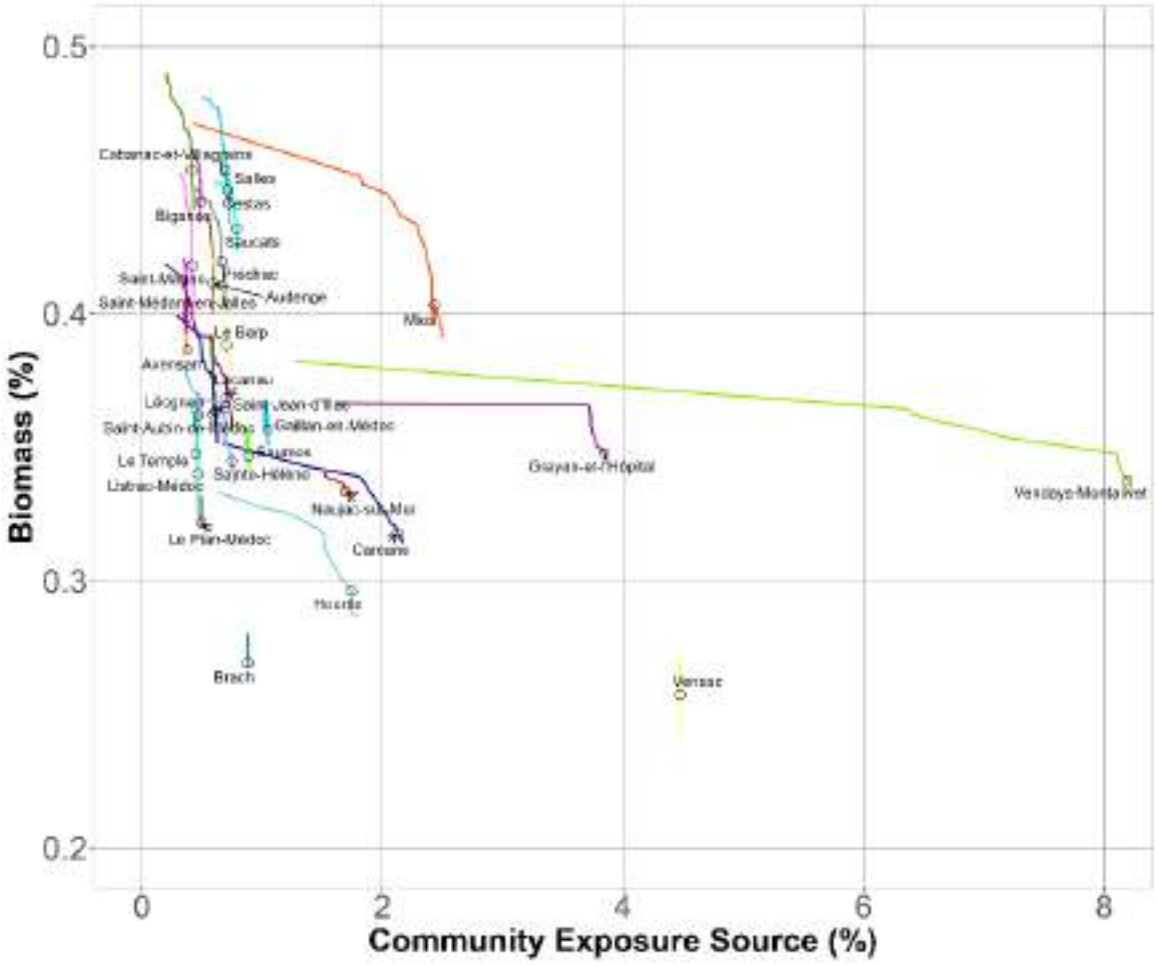

Figure 144 Trade-off production probability curves for each Municipality for the objectives of retrieved biomass vs. developed areas exposure sources. Axes show the level of attainment for each objective (%).

In Figure 145 we noticed very small fluctuations in the attainment of most Municipalities, and the only few that appear to have some sort of differences in their attainment value (thus suggesting the existence of potential trade-offs) are the Vendays-Montalivet, Hourtin, Mios and Carcans. Compared to the previous couple of objectives, this one has no evident trade-offs when the weighting scheme is changed, and the attainment of each objective is stable.

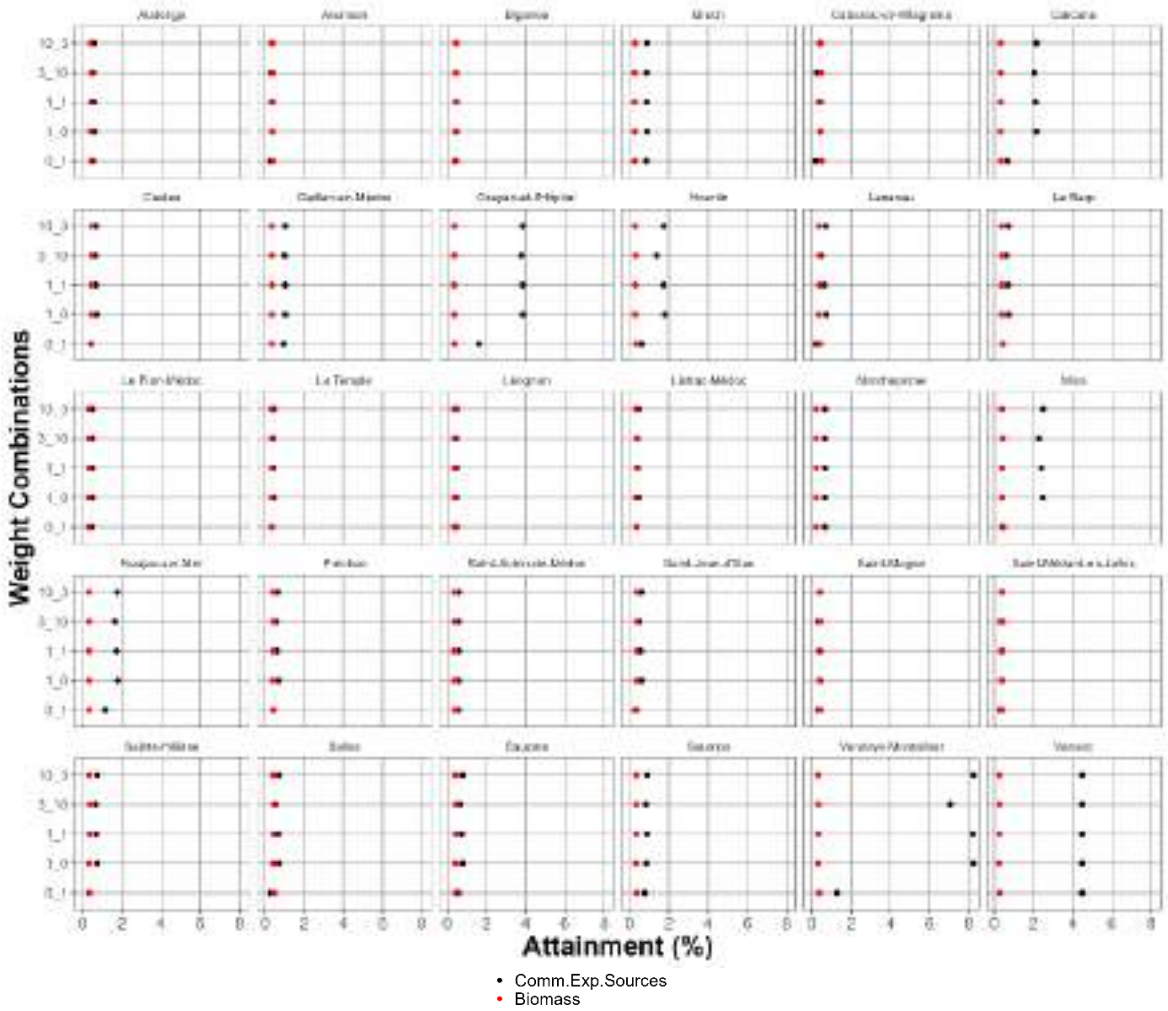

Figure 145 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: biomass retrieved) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The third couple examined the community exposure sources vs. sinks. The map Figure 146 shows a solution of approximately 194,000 ha for the three examined weight combinations and creates a small maximum difference of 1% in the attainment of the community exposure sources, and 4.5% for the sinks. The overall attainment for the management objective of community exposure sources is approximately 51%, while for the sinks approximately 53%. While several of the proposed projects spatially coincide, there are some that differentiate at the Municipalities of Le Temple, Saumos, Le Porge and Hourtin, among others, and for the weight combination 10-3 (orange colour), and several in Carcans, Naujac-sur-Mer, Salles and Captieux for the weight combination 3-10 (blue colour).

The trade-off graph in Figure 147 shows sharp differences for few Municipalities, especially for Carcans, Mios, Hourtin and Naujac-sur-Mer (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, since the highest performing Municipality like the Mios can achieve a maximum of 2.3% attainment for the community exposure sources with approximately 1.4% for sinks, while the highest

performing curve for community sinks is in the Municipality of Carcans, with approximately 2.6% attainment (and 1.7% for community exposure sources). All other Municipalities that appear with small lines in the graph show minor trade-off potential and low attainment for both objectives.

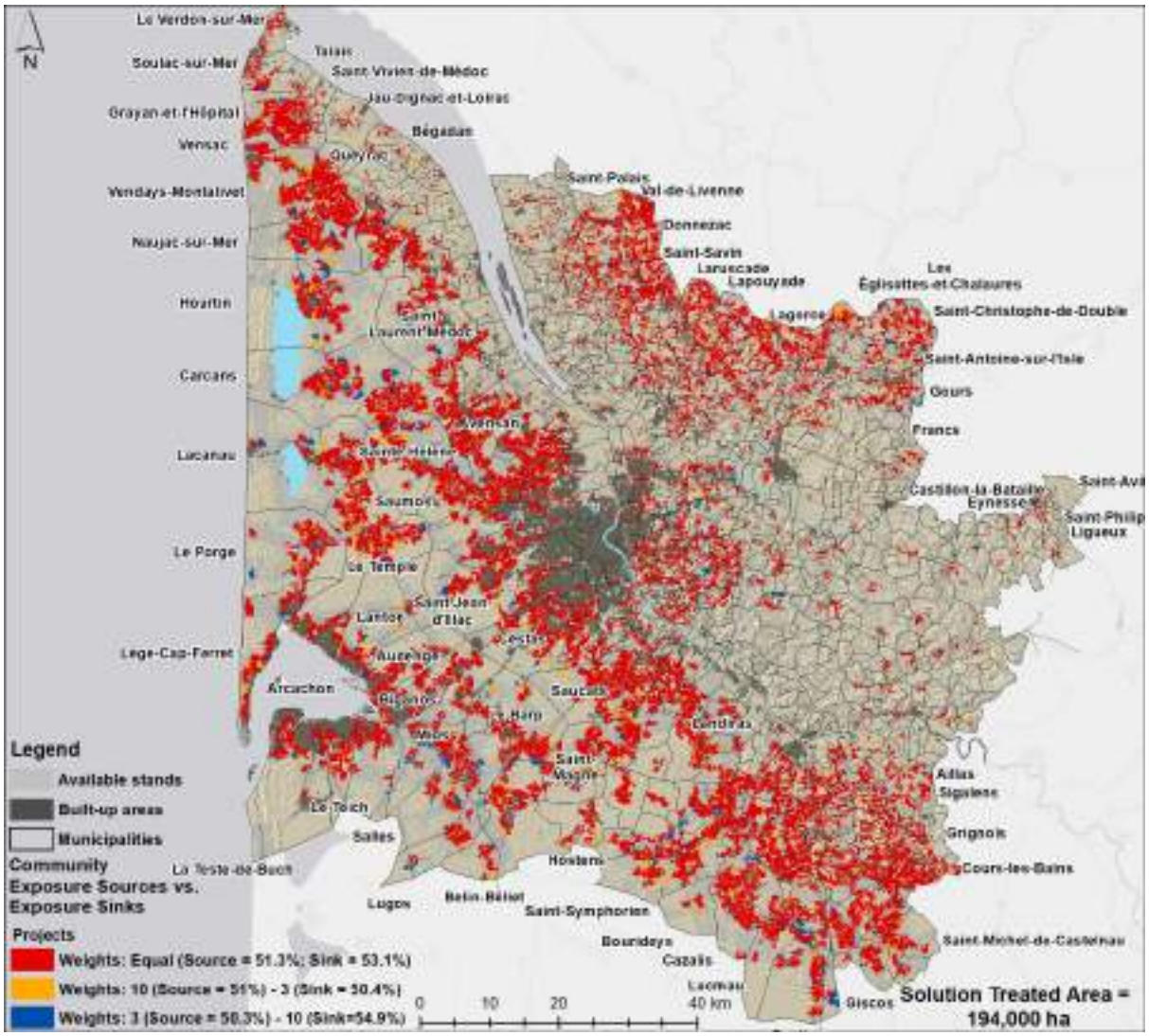

Figure 146 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Developed areas exposure sources objective weight maximized (10) and developed areas exposure sinks set to low (3) (orange); c) Developed areas exposure sinks objective weight maximized (10) and developed 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.

In Figure 148 we noticed small fluctuations in the attainment of very few Municipalities, like the Vendays-Montalivet, Naujac-sur-Mer, Carcans and Mios. In all other cases we noticed a stable attainment for both objectives, meaning that there are no trade-offs and the level of attainment is not influenced by the alteration of weights.

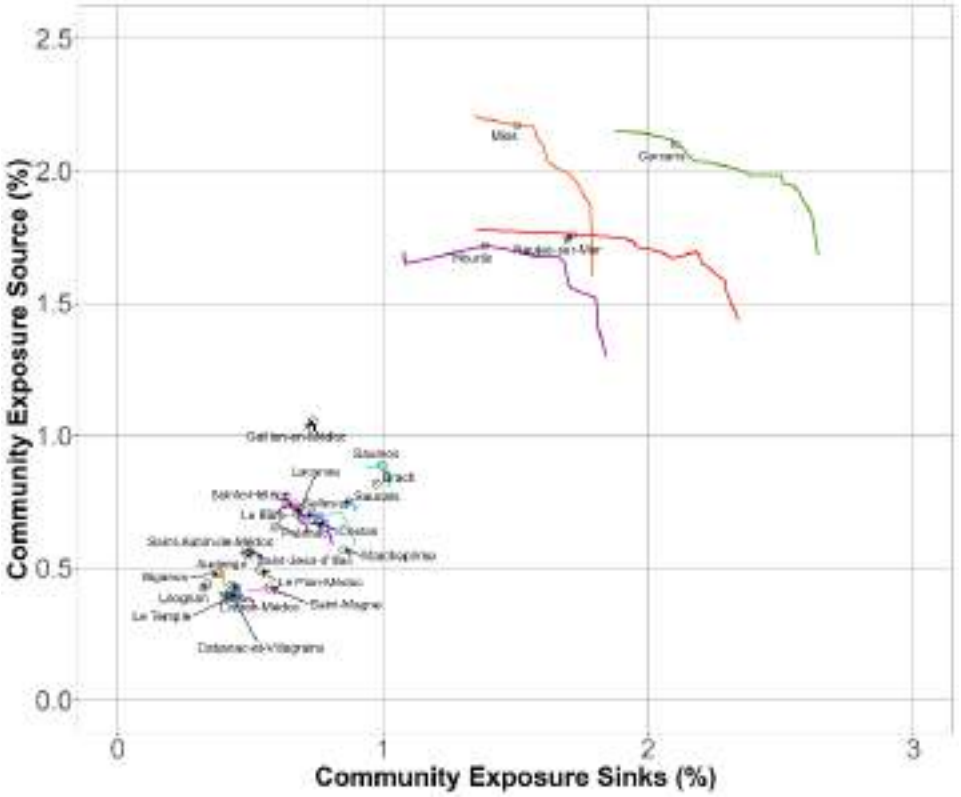

Figure 147 Trade-off production probability curves for each Municipality for the objectives of developed areas exposure sources vs. developed areas exposure sinks. Axes show the level of attainment for each objective (%).

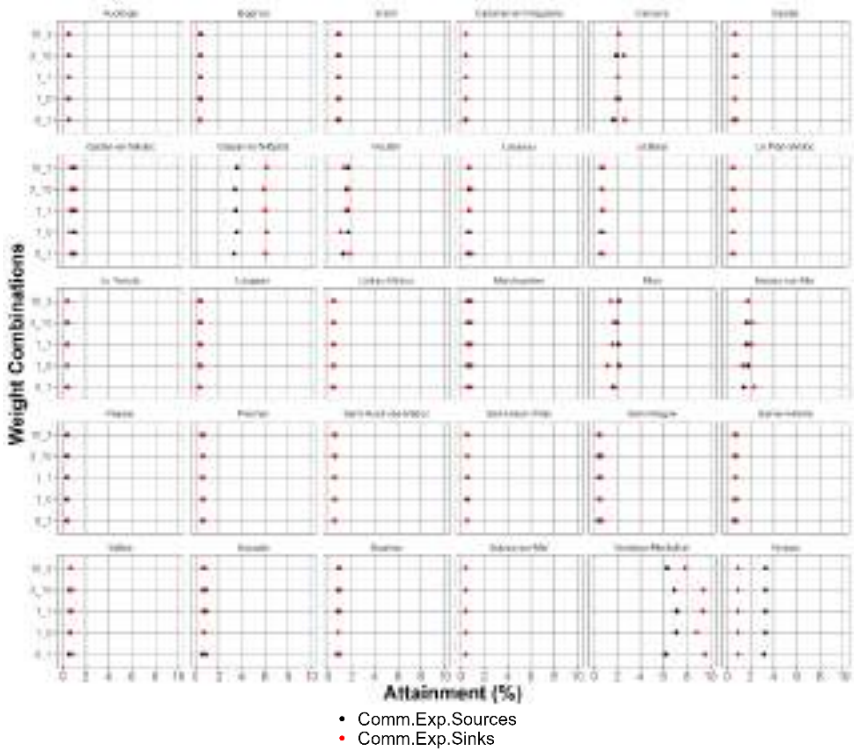

Figure 148 Each panel shows the attainment of each of the two objectives (black: developed areas exposure sources; red: developed areas exposure sinks) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Municipality.

The last couple of objectives examines whether it is better to apply fuel treatments on projects inside the protected areas (sinks) or where the fire risk originates (either inside or outside protected areas – sources). The map in Figure 149 shows a solution of 52,000 ha for the three examined weight combinations and creates a minor maximum difference of 0.2% in the attainment of the protected areas exposure sources, and 1.2% for the sinks. The overall attainment for the management objective of protected areas exposure sources is approximately 35%, while for the sinks approximately 66%. The total attainment for both objectives is considered high for the area selected for receiving fuel treatments. Almost all proposed projects spatially coincide, except for some projects inside the Municipalities of Hourtin, Vendays-Montalivet, Lucanau and Saint-Magne.

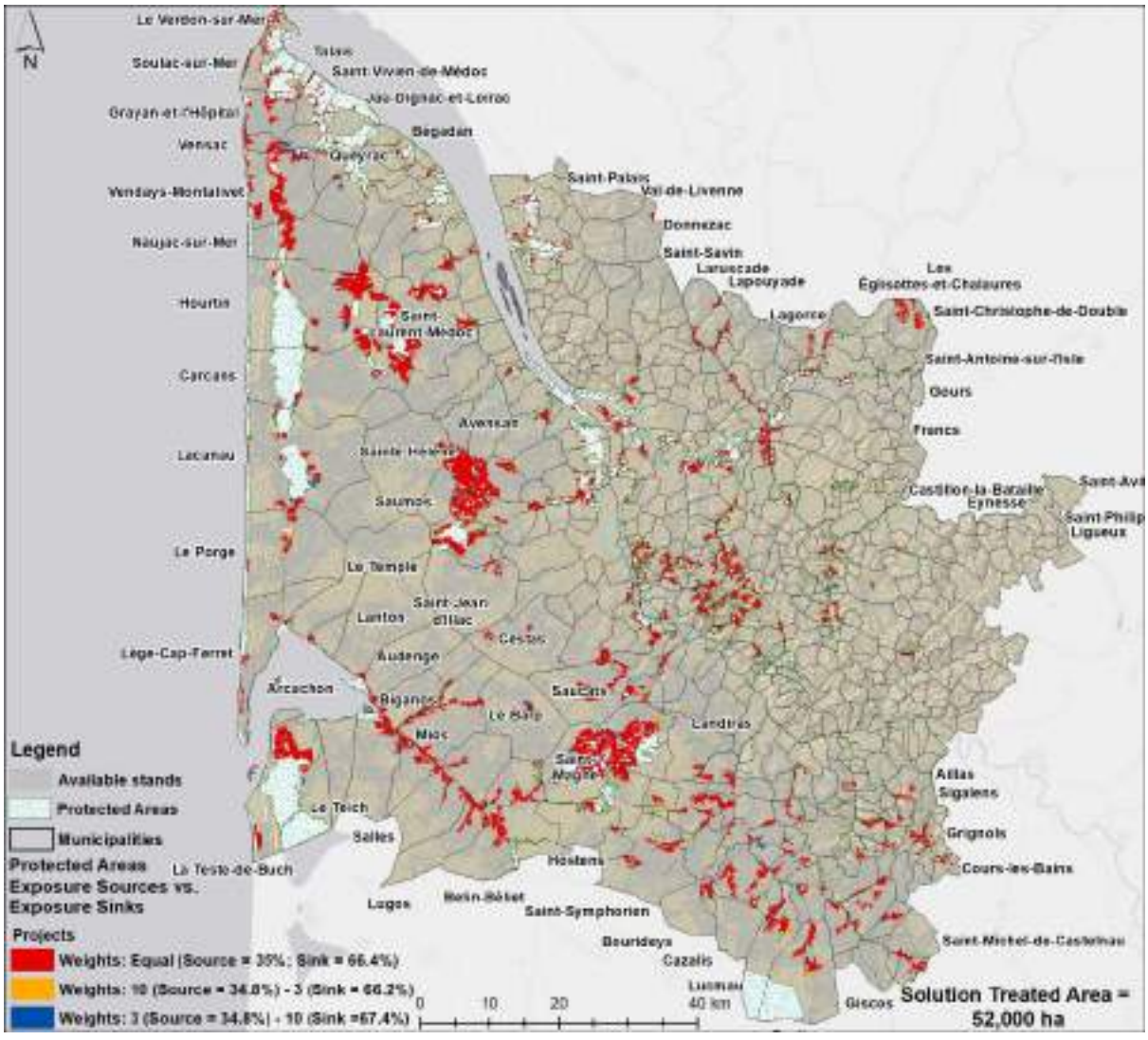

Figure 149 Trade-off scenario planning runs with three weighting schemes: a) equal weights (red); b) Protected areas exposure sources objective weight maximized (10) and protected areas exposure sinks set to low (3) (orange); c) Protected areas exposure sinks objective weight maximized (10) and protected 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.

In Figure 150 we notice only some minor fluctuations in the performance of the Municipalities of Cabanac-et-Villagrains and Saint-Magne, but without a clear trade-off curve or pattern. Almost all other Municipalities either have unchanged the attainment of one objective or no evident curves. No trade-offs or joint optimality exists for this couple. Finally, in Figure 151 we noticed stable patterns of attainment for each objective and for each Municipality with no important fluctuations found. This couple of objectives has no evident trade-offs when the weighting scheme is changed, i.e., no appearance of different colours on the map except for red, no curved shaped Municipality lines, and minor fluctuations in the dots of the attainment graph.

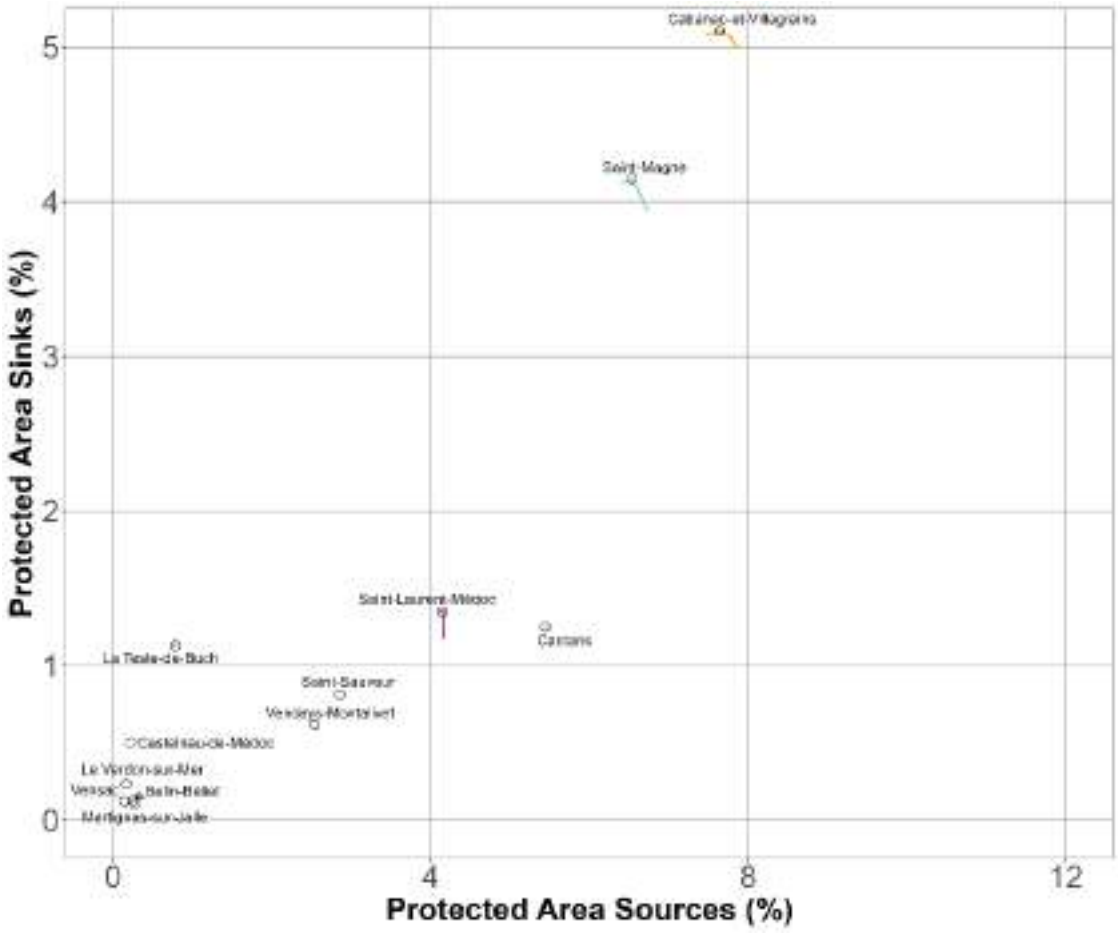

Figure 150 Trade-off production probability curves for each Municipality for the objectives of protected areas exposure sources vs. protected areas exposure sinks. Axes show the level of attainment for each objective (%).

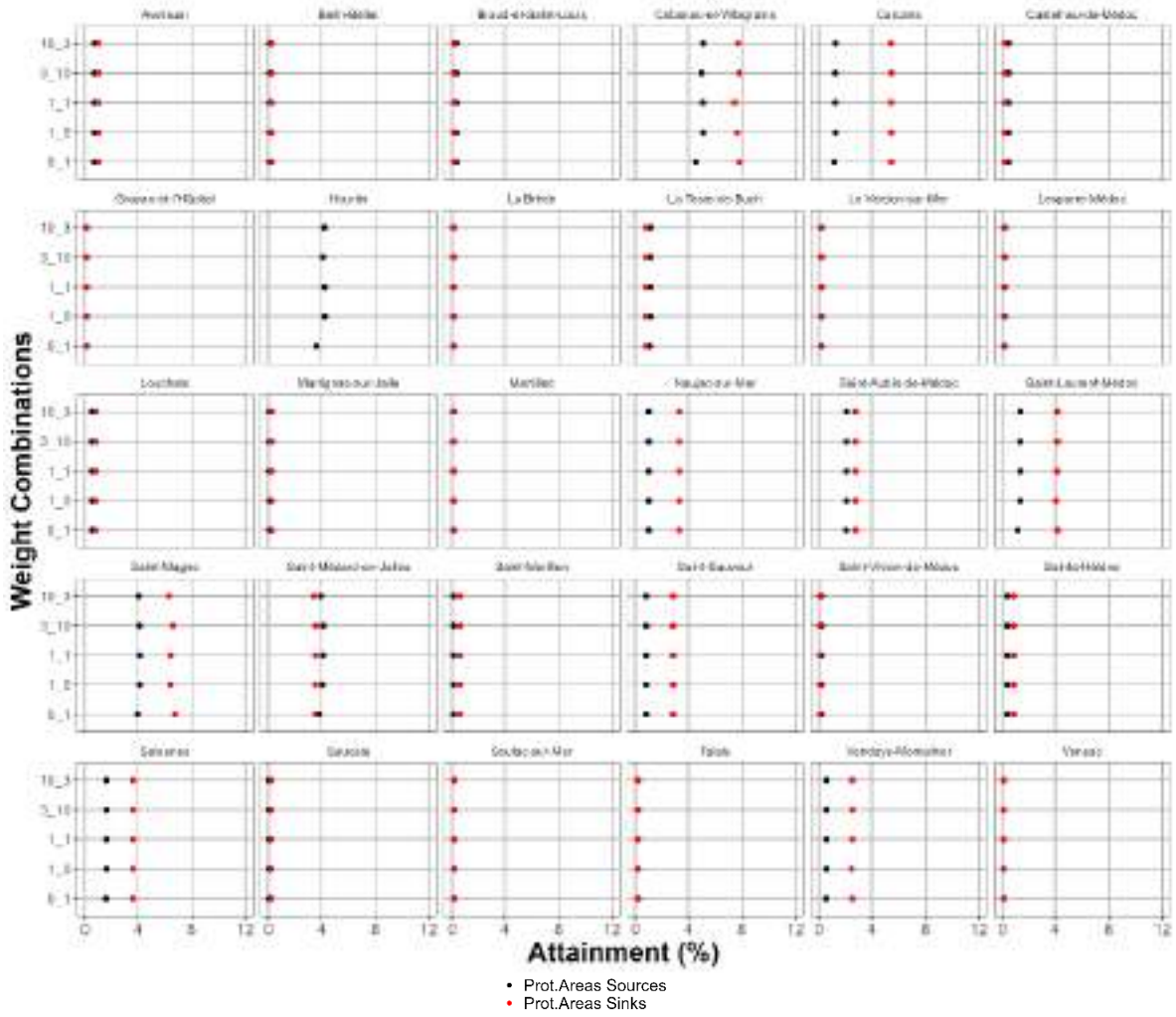

Figure 151 Each panel shows the attainment of each of the two objectives (black: protected areas exposure sources; red: protected areas exposure sinks) of five weighting combinations (10-3; 3-10; 1-1; 1-0; 0-1) for each Forest Service District.