FIRE-RES

Innovative technologies & socio-ecological-economic solutions for fire resilient territories in Europe

D1.3. PILOTING THE ADAPTATION OF METHODOLOGY OF FOREST FIRE POTENTIAL POLYGONS TO IMPROVE DECISION-MAKING ON EWE EVENTS

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Abstract: Fire potential polygons allow uncertainties in the decision-making process to be considered in a traceable and credible way. Fire potential polygons are a specific type of potential polygons that fit into a broader analysis that uses deconstruction, iteration and fractality. They are sized seeing changes in fire behaviour and opportunities for fire suppression efforts. The grouping of polygons and flows allows the identification of different scenarios of resolution. The adaptation of the methodology to Extreme Wildfire Events includes the extreme scenario from the beginning of the process by defining the expected scenario and considering its scales and behaviour.

Keywords: polygons of fire potential, decision-making, extreme wildfire events

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1. Introduction

1.1. Adaptation of the methodology of Polygons of Fire Potential into the living labs

Facing these EWE's means that responders themselves generate this knowledge directly. Organizations such as the Catalan Fire and Rescue Service have already faced situations where the methodology has been applied to EWE (example 6.5). As explained by the FIRE-IN project, '*emergencies are a source of knowledge and responders frequently need to be creative and innovate when facing new challenges coming from new emergencies*' (Miralles, et al., 2021). So it is a process of continuous testing, evolution and improvement.

The implementation of the IA 1.1 in the Living Labs of the FIRE-RES project requires the previous existence of the figure of wildfire analyst inside the response organization as well as previous work and knowledge on fire analysis (Castellnou, et al., 2021).

The methodology of Polygons of Fire Potential can be applied around the world because wildfires show patterns that are the same wherever they are. It will therefore be carried out in Catalonia and Portugal which have the fire analyst figure implemented for many years and the previous mentioned work already done.

Given that the D1.3 is delivered before the end of the project and it is not possible to know when and where EWE will take place in Catalonia and Portugal, at the end of the project the document will be updated to include the implementation cases that have been possible.

This deliverable has two parts. The first part of the D1.3 (sections 1 to 4) contains the translation of the guide published by GRAF unit from the Catalan Fire and Rescue Service (Bombers, 2023c) which brings together the knowledge developed by them in this area over the years. This knowledge has been acquired and implemented for 15 years (Section 6, examples 6.1 to 6.4).

The second part of the D1.3 (Section 5) covers the adaptation of the existing methodology to Extreme Wildfire Events (EWE) and reflects on how this methodology can be applied to them. The process of adaptation is described but it is important to note that it is an ongoing process. This is because response organizations are continuously generating knowledge as they have to adapt to these extreme forest fires in a novelty way.

1.2. The strategic reasoning in fire analysis

The strategic reasoning in fire analysis at Bombers was born in 1999 with the creation of the GRAF unit, and it implied a change in the model of extinction of forest fires in Catalonia. The rationale for analysing forest fires carried out by Bombers has evolved over the last 20 years. Currently, the aim of the analysis is to provide certainty in decision-making by isolating the sources of uncertainty in these complex and changing forest fires scenarios.

In recent years, fire services in Mediterranean Europe have been overwhelmed by extreme wildfire behaviour. As a consequence, fire management has moved to defensive strategies with a focus only on the known risks (the fear trap). In this region, wildfires can change rapidly, increasing the uncertainty and causing complex operational scenarios that impact society right from the initial hours. To address this challenge, proactive approaches are an alternative to defensive and reactive strategies (Castellnou, 2019).

As a scenario becomes more complex, the number of factors to monitor and the interactions between them multiply. There is too much **information** or too little and we fail to really identify the changing information that is key to understanding what is happening. We accumulate more and more information and decisions become more and more obscure and detached from reality (Bombers, 2023d).

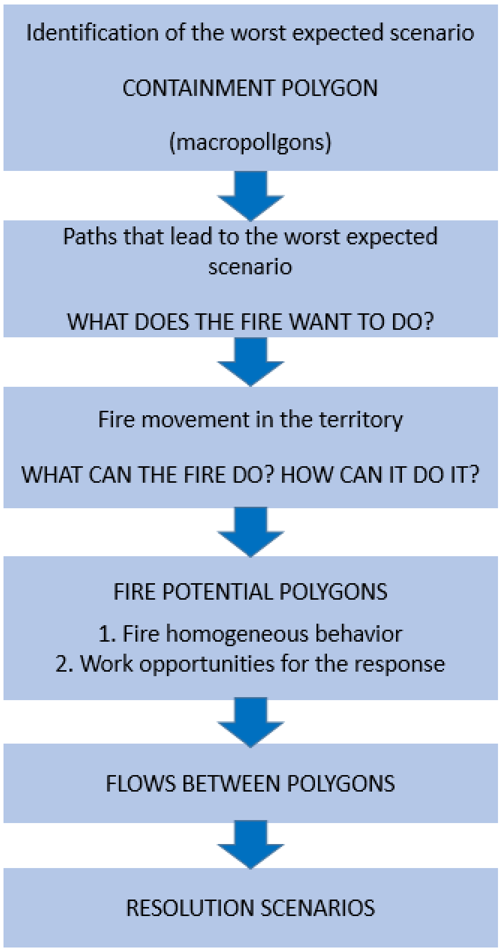
Situational awareness' collapses when there is a very voluminous amount of information exceeding the control stretches. (...) In this situation decision making will always come late; it focuses on information and risks that are certain and it is easy to lose sight of the uncertain ones. When there is enough certainty that there may be a change and what that may imply, it is often too late to change it (decision-lag). This can cause dangerous situations for responders, or in the best of cases it means not to be efficient in resolving the scenario. The objective is to achieve more resilient emergency systems and to avoid their collapse by analysing possible scenarios of resolution and the cost of opportunities (Bombers, 2023d).

Each decision has consequences that need to be assessed and included in the decision-making process, which is why it is necessary to use tools to trace the path that leads to each of the consequences. At the same time, traceability also facilitates to learn from the experiences.

The classic formula of lives, properties, environment includes the no-collapse value, which implies selecting the final strategic outcome using a common good approach and including ecology and future landscape resilience in decision making. This strategic decision fixes the tactical decision and priority manoeuvres to be made. Credibility is built between fire service and stakeholders (Castellnou, 2019), since what is explained and what happens converge.

Potential polygons are an operational tool to identify and manage uncertainty and provide an overview of the fire and explain what the fire can do, both for experts and non-experts. The polygons eliminate uncertainty and provide a clear and certain picture (Castellnou, 2019). Therefore, it is a way to trace decision making, communicate and increase credibility.

1.3. General Scheme



General scheme of the methodology:

1. Visualise what is to be avoided, this is the worst expected scenario, and define the macro-polygon that includes it (*containment polygon*).
2. Identify the multiple paths that lead to the expected scenario to be avoided ('*what does the fire want to do*?').
3. Identify how this fire that is moving in the specific territory will make this unique or multiple paths ('*what can this fire do*?'), that is to say, what will be the movement of the fire (flow or flows) in the fastest way. The flux is analysed from the end of the worst expected scenario (this is the end of the expected confinement polygon) to the beginning (the point where the fire is at the moment) so, starting from the place where the arrival of the fire needs to be avoided in the worst expected scene.
4. From this flow we observe at which points there are opportunities to hinder the flow (observing from large to small scale, analysing from the head of the fire to the ignition point). To do this, we use the *fire potential polygons* based on 2 elements simultaneously:
    a. Areas of homogenous fire behaviour
    b. Work opportunities for fire suppression

From this information, the polygons can be drawn to see if each of the steps of flow between each polygon are inside or outside the suppression capacity.

5. The colour of the arrows (*flows between polygons*) is determined at the end of the process, when it has been observed whether the response organization will have capacity and opportunity to work at that point. The colour refers to the existence of opportunity and determines whether the response organization has position and capacity (green) or none of them (red). Therefore, the colour explains the probability of the fire to cross that point.
6. Emergency management scenarios A, B, C are defined (A = desired, B = accepted as plan B, C = to be avoided).
7. Select one of the scenarios that will be the resolution scenario (based on values, common good, etc.) that will be implemented by the Incident Action Plan or as an objective in the wildfire prevention plan.

1.4. The origin of the polygons of fire potential

The idea of the Forest Fire Potential Polygons arises from the Torre de Fontaubella fire in Catalonia in 2007, when using the analysis, it was possible to anticipate the changes in the of the fire. By using the draw of polygons, it was possible to integrate the capacity to deploy resources in the territory and to prioritise objectives.

Figure 1. Smoke column of the fire broken at certain height in La Torre de Fontaubella municipality, the 6th of September of 2007. Source: Bombers.

The analysis and its expression in polygons made it easier to provide criteria for decision making, directly linking the decisions with the corresponding consequences.

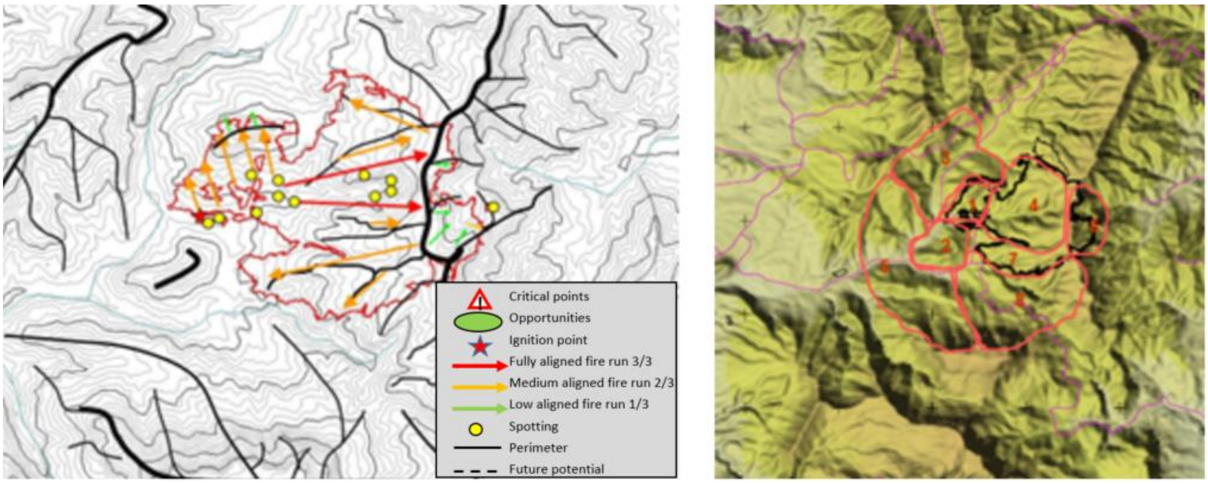


Image 2. Images with the diagrams of the report of La Torre de Fontaubella, the 6th of September of 2007. On the left, the perimeter with the fire runs and fire spotting depicted above topographic contours and the main slopes. On the right, perimeter and potential polygons on digital terrain model. Source: Bombers.

1.5. Fire potential polygons as a tool for fire analysis

The polygons of fire potential are a tool to include uncertainties in the decision-making process in a traceable and credible way. It is a way to plan to do what we want to do to achieve a resolution scenario. A scenario that is created by isolating the uncertainty and deconstructing the path that the fire can take to achieve what is to be avoided.

By isolating uncertainty, it is possible to explain what is being done so that the consequences of the decisions can be identified in the decision-making process, thus gaining credibility.

This credibility gives strength to the emergency management team in making decisions about the common good and the most important values without falling prey to the pressures that dominate these complex scenarios.

Therefore, in the use of the potential polygons as a tool for fire analysis, 4 premises must be taken into account:

- The deconstruction of the final scenario to be avoided in order to isolate the unknown factors of uncertainty.
- The traceability of decisions and their consequences.
- The constant iterative process of adapting the analysis to the complex scenario of emergencies.
- Fractal of the use of polygons in scenario analysis.

1.5.1. Deconstructing from the final scenario

The process of strategic reasoning is based on encapsulating the uncertainties inside the resolution scenario. To do this, it is necessary to start from visualizing the worst expected scenario and analysing what steps have to be taken to arrive at the scenario that is to be avoided.

We deconstruct because we do not know what will happen, but we can know what we do not want to happen and determine the steps that lead the fire to reach what needs to be avoided.

Therefore, the behaviour and movement of the fire in the territory is analysed from the end point to the point where we have the fire following the routes, or paths, previously identified as flows of the fire in the territory.

1.5.2. Traceability of the decisions and consequences

In order to make decisions about this scenario and communicate them, it is necessary to be able to explain what the consequences of these decisions are.

The methodology of polygons of fire potential is a good tool to show the consequences, in a visual way, and facilitates to trace the decisions or actions that have been carried out.

1.5.3. Iteration in the process of defining the polygons of fire potential

During decision making, both in planning and in fire management, the achievement of the initially set objectives allows adjust efforts, change priorities and move resources as the scenario is resolved. This is a common process in the management of emergencies that updates the scenario and the action plan in each operational period established. This process is described in the Operational Guide of the Action Plan for Firefighters' Intervention, 2019 (Bombers, 2019a).

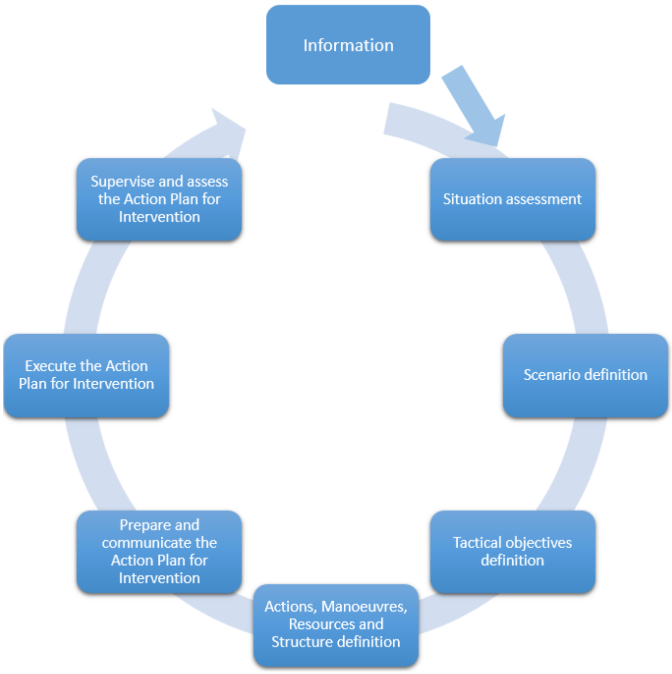


Image 2. Scheme of the sequential steps in the planning process of an intervention of Bombers of the Generalitat de Catalunya. Source: Bombers.

During this iteration process there are polygons that need to be re-evaluated and updated:

- The strategic polygons, such as the containment polygons that set the resolution scenario: they do NOT change, they are maintained as long as the strategy is maintained according to the evolution of the response scenario. Polygons that show the resolution scenario and transfer it to the territory must be maintained throughout the action plan.
- The tactical polygons, such as the potential polygons based on the behaviour of the fire and the opportunities for fire suppression: they CAN change, they are adjusted, unified or divided as the objectives are achieved. The tactical level polygons that relate the behaviour and work capacity of the deployed device have to be redrawn according to the objectives and the tactical deployment for each operational period.

1.5.4. Fractals in the drawing of polygons

The process of identifying and defining the polygons of the potential polygon methodology follows fractal patterns, since the same process is valid for the different scales to which fire analysis is applied.

As an example, in this guide, cases are applied for the delimitation of containment polygons, for the choice of emergency resolution scenarios or for the polygons of fire potential for planning tactical deployment adapted to the different types of landscape.

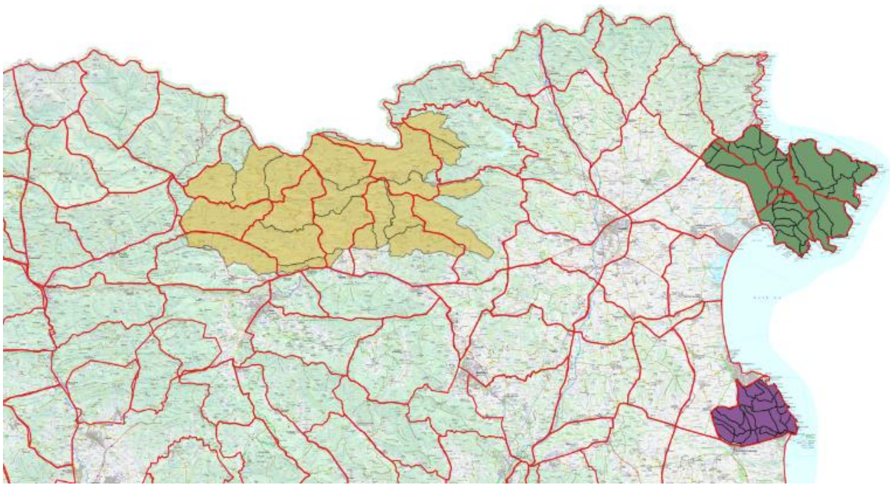


Image 3. Map with the large-scale confinement polygons of Catalonia (in red) and the polygons of fire potential for the massifs of Alta Garrotxa (green), Cap de Creus (green) and Montgrí (purple). Source: Bombers.

2. Definitions

There are several products that go by the name of polygon that need to be clearly differentiated:

Those used in strategic decision making:

- Containment polygons: these are macro-polygons that identify the consequences of decisions in order to establish large-scale priorities. They frame the resolution scenario, the territory where the incident is managed and focused on avoiding what we do not want to happen.
- Possible scenarios of resolution: these are the grouping of polygons of fire potential according to the possibilities of achieving the objectives set out in the strategy of the action plan. These polygons make it possible to identify the different possible scenario options according to the deployment and working capacity of the firefighting organization.

Those that apply at a tactical level:

- Polygons of fire potential: these include the behaviour of the fire and the opportunities of the response system.
- Polygons for manoeuvre: these are sub-polygons of the polygons of fire potential used to plan the execution of manoeuvres within the established polygon of fire potential and according to the identified opportunity.

Homogeneous fire behaviour polygons are also used in fire analysis and fire prevention planning (Bombers, 2011). These represent fire behaviour based on the interaction between meteorology, topography and fuel availability. The homogeneous fire behaviour polygons do NOT indicate the fire potential according to the planned response. They are polygons that identify the areas in which the fire spreads with a similar behaviour, which are comparable in terms of speed of spread and type of front/face of the fire, but also in terms of direction of the fire paths and intensity of the fire. They are usually delimited on the basis of the slopes of the orography, the hydrographic basins and the existing vegetation.

3.Defining the polygons of fire potential

This section describes how fire potential areas are used and defined when making decisions to resolve a forest fire.

3.1. Containment polygons

In front of uncertain and complex contexts, strategic reasoning seeks to visualise what it needs to be avoided, to identify the worst expected scenario that the fire could cause. This large-scale scenario is delimited by means of a macro-polygon, a boundary that must confine the fire within it: this is the containment polygon or confinement polygon.

The confinement polygon delimits the area where the emergency is managed. Within this area the scenario of resolution will be defined on the basis of the decision-making process.

3.2. Fire flows

Once the containment polygon is defined, the next step is to identify the multiple paths, the fire flows, that lead the fire to the place where it is to be prevented. Identifying the multiple paths is a process that is solved using the question of the analysis rationale *What does the fire want to do*? (Bombers, 2019c). The answer to this question defines the maximum potential of the fire. It is the way to understand and have a global vision of the scenario.

From this knowledge, the point where the fire is to be prevented is identified. The path of the flow is built from the end (the area at the end of the polygon of fire where it is to be prevented) to the beginning (the ignition point). It is important to draw the flow not starting from where the fire is (near the ignition point) but starting from the place where we want to prevent it from arriving.

This is a process to isolate the sources of uncertainty in the emergency scenario. The path is not built from the beginning. The path is deconstructed in order to find out where the key points are, and in order to know the point at where if the fire arrives, the scenario of resolution will be lost scenario.

In this step, lines of movement that identify this flow of light in the territory are obtained.

It is important to know the sequence of the steps that the fire follows to reach its maximum potential and determine how it will do so in order to make it possible to anticipate its movement and plan safe and effective operations and actions. This step facilitates the traceability between the decisions and the consequences and can be approached by using the question *What can the fire do?* (Bombers, 2019c). The answer to this question allows to identify which are the movements that the fire has to make to reach its maximum potential.

The final point in this process consists of choosing which of the multiple paths that the fire can follow in the territory are identified as the most probable according to its behaviour, speed and intensity.

3.3. Polygons of fire potential

The polygons of fire potential consider 2 simultaneous elements for their dimensioning: the fire behaviour and the work opportunities for firefighters.

The contour used to delimit the polygons of fire potential that have been dimensioned above depict an area of the territory where there will be changes in the fire behaviour, which at the same time are work opportunities for fire suppression:

- changes in behaviour according to the propagation pattern of the fire, based on the critical points of the type of fire, bottom of the valley, crests, limits of the upwind...
- the opportunities for fire suppression work when the capacity to deploy resources is available. In this case, the line that marks the contour of the polygon indicates an area to work. This area can be before or after the line and is where to carry out the manoeuvres, but it does not have to be the line itself.

These lines represent spaces, behavioural changes that are at the same time opportunities that can start before or after the line. The line shows a space according to the expected changes in the behaviour of the fire or the anchorages that the opportunity presents.

The numbering of the polygons facilitates their identification but is not an essential step to show the movement of the fire. It is useful to follow the order in accordance with the fastest evolution that the fire will follow, or in consonance with the sectoring of the device that is deployed according to the flanks of the fire.

3.3.1. Identify the behaviour and the reading distance of the fire

From the information observed about the fire behaviour monitored the key variables can be identified. The most relevant variables are the propagation velocity, the flame length, the spotting distance, the front of the fire analysis of each part of the perimeter and the intensity of the front of the fire.

The movement of the fire and its behaviour allows us to identify the *reading distance of the fire* over the territory (Bombers, 2011b). This *reading distance* determines the work opportunities that can be exploited. Therefore, it determines the size of the polygons and ensures that they are adjusted to the behaviour and movement over the territory and to the working capacities of the device.

3.3.2. Identification of work opportunities

To define the work opportunities for firefighters it is necessary to answer to the next questions:

What can I do? (Bombers, 2019c) This question helps to stablish the mission and define the idea of resolution of the incident.

What do I want to do? (Bombers, 2019c) This question allows to define the mission and to determine the idea of resolving the incident. It allows to establish the strategy to manage the fire based on:

- choosing a safe scenario
- maintaining a resilient operation
- integrating the common good into the decision-making process
- creativity to face uncertainties

What can I do? (Bombers, 2019c) This question helps to identify the position and capacity of the resources on-field to work.

3.4. Identify the probability of fire flow between polygons

In this phase it is necessary to describe the direction of the movement of the fire as it spreads and crosses from one polygon to another, so that the flows of the fire are represented.

This movement from one polygon to another can be quantified on the basis of a probability or a difficulty depending on if in the territory the response organization has the position and capacity to deploy resources to contain the fire and prevent it from passing to the next polygon.

It is possible to use the colour of the arrows according to the capacity of the firefighters' organization to take advantage of the opportunity at that point. The colour can indicate greater (green) or lesser (red) capacity, which can also be understood as a probability of the fire passing through that point (greater in red or lesser in green) according to the capacity of the organization of response.

This part helps to relate the connection between the potential polygons, to see each of the flows identified depending on if they are inside or outside the suppression capacity.

3.5. The possible scenarios of resolution

The potential polygons and the probability of crossing between them are grouped with the aim to obtain different scenarios. From these different scenarios the incident commander can establish objectives and priorities at the strategic level. This grouping makes it possible to identify the values and the impact on the territory of each one of them, in order to focus decision-making by assuming what will be lost and what will be saved in an objective manner in advance (Bombers, 2019c).

The different scenarios of resolution can be classified according to the ability to achieve them, for example: desirable, accepted or to be avoided. Choosing between these scenarios facilitates strategic and tactical decision-making and, above all, the dissemination to the actors involved about what are the reasons for deciding on some objectives and priorities.

4. Polygons of fire potential implementation on fire prevention planning

The measure proposed for planning must be justified under a specific response scenario and, therefore. This scenario should come from a methodological process similar to the process that is proposed to be applied during the response. For this reason, the methodology presented in this document can also be used in the planning process.

However, during the planning process there are different aspects regarding uncertainties and hypothesis of work than during the fire response process. These particularities are what the planner will have to take into account.

With reference to the response capacity, usually the planner does not know which is the real capacity that the response organization could achieve the day of the incident, so this capacity is assumed from a hypothesis as one of the conditions that will be used for the design of the project that is on development. But the planners that faces this uncertainty should not take as a solution the non-incorporation of capacity in the methodological process.

Table 1. Differences between fire response and planning for prevention.

	Certainties	Uncertainties
Fire response	The fire ignition point, or almost the initial area burning is known, and the movement of the fire is adjusted at what is observed in reality on-field.	The emergency evolution and the presence of not anticipated or forecasted elements that can appear.
Planning for prevention	The capacity of the response organization is considered from a known hypothesis.	It is necessary to consider different possible ignition points and to compare the alternatives.

If the planners do not include this element, unfortunately, there is a risk to fall into simplification because. If the planners do not know the capacity of the organization of response, the polygons of fire potential would consider only one of the two elements that define the polygons of fire potential (see section 3.3). If only one of the two elements are used these polygons will describe only the homogeneous fire behaviour, which is only part of the job. In this case, it is important to be aware that scenarios becoming from a process of analysis that only contemplate the fire behaviour will not consider the capacity to deploy the responders during the day.

5. Adaptation of the methodology of Polygons of Fire Potential to 6th Generation fires

Fires classified as 6th Generation (o *extreme wildfire events*, EWE, (Castellnou, et al., 2022b)) are those that generate extreme behaviour, uncertain scenarios and can lead to collapse the emergency management system. This new type of fire has been identified and recognised at international level since 2017, although it has subsequently been possible to recognise examples of this extreme type of fire in previous historical fires.

The knowledge about these fires on a global scale is still in its infancy, but emergency management systems and organisations dealing with them are already working to improve and innovate their knowledge. There is also an identified need to focus applied research on those variables most relevant to decision-making in the face of these 6th generation fires.

The methodology of polygons of fire potential is a tool to assist decision making in uncertain scenarios. Since 6th generation fires cause uncertain scenarios, the use of the methodology can facilitate decision-making in these scenarios as well.

These 6th generation fires are challenging in terms of the speed of the processes involved and the changes that occur, the multiplying factor of the processes, the behaviour of the fire with pyroconvection and the generation of Pyrocumulunimbus and also the great impact on the values of the landscape.

5.1. Adaptation of the methodology

The adaptation of the methodology involves including the extreme scenario in the initial definition of the expected scenario, taking into account its scales and behaviour.

In 6th generation scenarios we can also visualise the worst expected scenario, therefore, the way of starting the analysis process defined in the previous sections is still valid.

To apply the methodology to EWE it will be necessary to visualise the worst expected scenario (*macro-polygon*) taking into account the possibility of an extreme scenario, i.e., contemplating this option from the outset. This means determining *what needs to be avoided* and, therefore, where the fire is not wanted (confinement polygon), taking into account the scales of this type of phenomenon (Castellnou, et al., 2022b).

Although it is not currently possible to know when and where the extreme moment of a 6th generation fire will occur, it is possible to know approximately if the conditions that allow it to happen exist (Castellnou, et al., 2022a, Castellnou, et al., 2022b). And we are also sure that, given the uncertainty and safety problems they generate, this extreme scenario needs to be avoided.

As it has been observed during the fires, in order to prevent the fire from exceeding the containment area, efforts must be focused on preventing the fire from having the capacity to spread to extremes. Some actions to achieve this are aimed at managing the fire before the optimum conditions for an extreme wildfire event are met at atmospheric level, or to avoid the fire spread to areas where it can involve enough vegetation to start the pyroconvective processes using the available energy in these fuels.

Therefore, when it is clear what is the '*worst scenario expected*', it is then possible to define a containment polygon and apply the deconstruction process (sections 1.4 and 3). The analysis of the flows, of the existing opportunities and the definition of the polygons of fire potential will allow the identification of those 2 or 3 possible resolution scenarios. These will allow the selection of the one that avoids reaching the situation that favours the extreme scenario.

5.2. Existing uncertainties associated with EWE and future challenges

One of the important elements of the polygons of fire potential is the inclusion of fire behaviour, both by observing it on the ground during response and the behaviour of the fire considered in the process of planning. For 6th generation fires, although progress is being made in understanding their behaviour (Castellnou, et al., 2022a) and there are observations on the ground that have allowed some definitions to be reached (Castellnou, et al., 2022b; Tedim, et al., 2018), this is not yet fully understood.
Some of the elements that generate uncertainty about the phenomenon are:

1. At the moment, it is not possible to predict when and where a fire with extreme behaviour will occur, although it is possible to approximate whether the conditions exist for this phenomenon to occur by observing certain atmospheric parameters.
2. The effect of the multiplying factor of the variables of the behaviour of the fire (Castellnou, et al., 2022a).
3. The exact processes that generate this extreme behaviour are not known, although it has been observed that there is a coupling between the fire and the atmosphere that generates a change in behaviour (Castellnou, et al., 2022a). However, we do not yet know the mechanisms that generate the coupling and uncoupling with the atmosphere, nor at what point the influence of one over the other (fire-atmosphere) dominates.

Therefore, the adaptation of the polygons of fire potential to extreme scenarios makes it possible to use a proven existing tool for the traceability of actions and decisions in uncertain situations created by EWE. In the future, once more information is available on the behaviour of this type of fire, the methodology can be better adjusted to be adapted to take into account new knowledge.

6. Examples of the use of polygons of fire potential

In this section some examples are described to show the applied use of the methodology of polygons. Cases of fire flows in the territory, schemes of possible resolution scenarios and how they adapt to 6th generation fires (Bombers, 2020) (extreme wildfire events, EWE (Castellnou, et al., 2022)) are depicted.

6.1. Containment polygons of the Tivissa's fire (2014)

The forest fire that occurred in Tivissa municipality (Catalonia, 2014) (Bombers, 2014) had the pattern of a wind-driven fire with subsidence. During the process of explaining the strategy and establishing the objectives according to the different scenarios during the day (with a sea-breeze from S-SE-E) and at night (with NW wind called *Mestral* locally), containment polygons were established in the large existing opportunities. It was also calculated the potential affected area associated with the cross of the fire through each of these large axes.

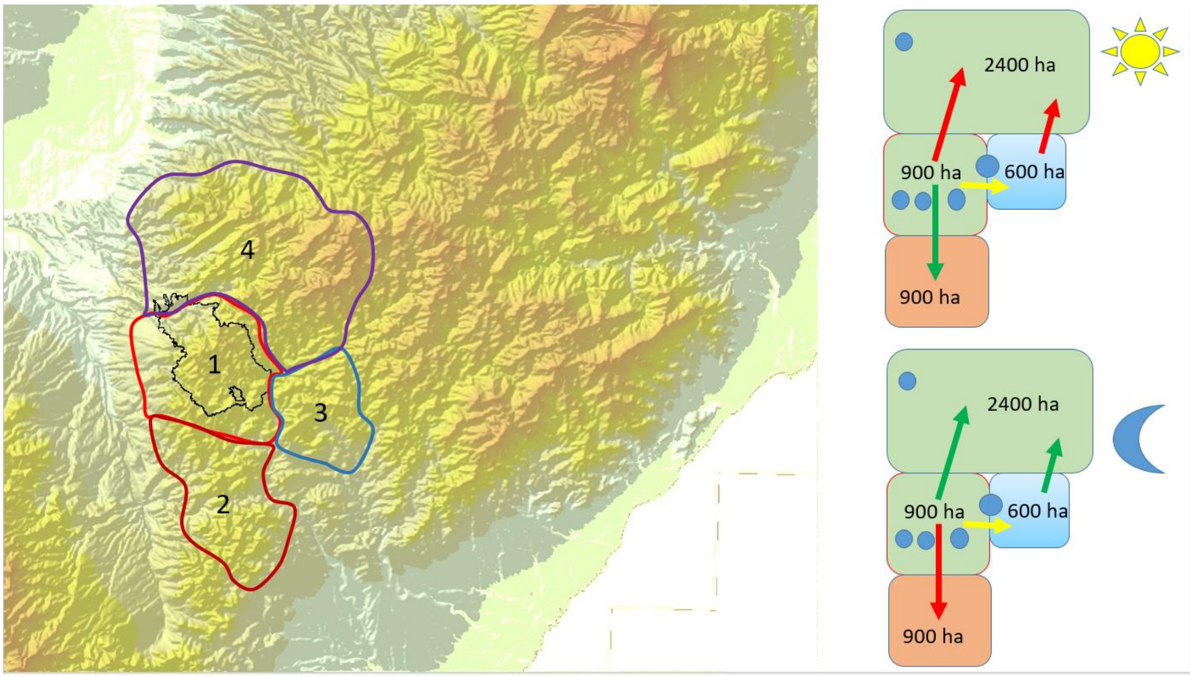


Image 4. Image of the diagram of the areas contained in the confinement lines defined for the Tivissa's fire of the 15th of June of 2014 and the day and night flows. Source: Bombers

6.2. Polygons of fire potential of the Òdena's fire (2015)

An example of the use of fire polygons in the analysis to facilitate the decision making of a forest fire is the case of the Òdena's fire (Catalonia, 2015) (Bombers, 2015) that affected the counties of Anoia and Bages. Below are images of the behaviour and information obtained from the polygons of fire potential and the fluxes of the fire used during the analysis of the fire.

Image 5. Image of the right flank of the Òdena's fire the 26th of July of 2015 (Bombers, 2011b), which affected 1,300 ha of the centre of Catalonia. In this fire, the management of the emergency considered different scenarios for the decision-making: the impact on the inhabited areas with wildland-urban interface (WUI) of the right flank, the arrival of the fire to the Natural Park of Montserrat and the entrance of the left flank to the great forest massif of Bages impacting on the socio-economic activity of the territory. Source: Bombers.

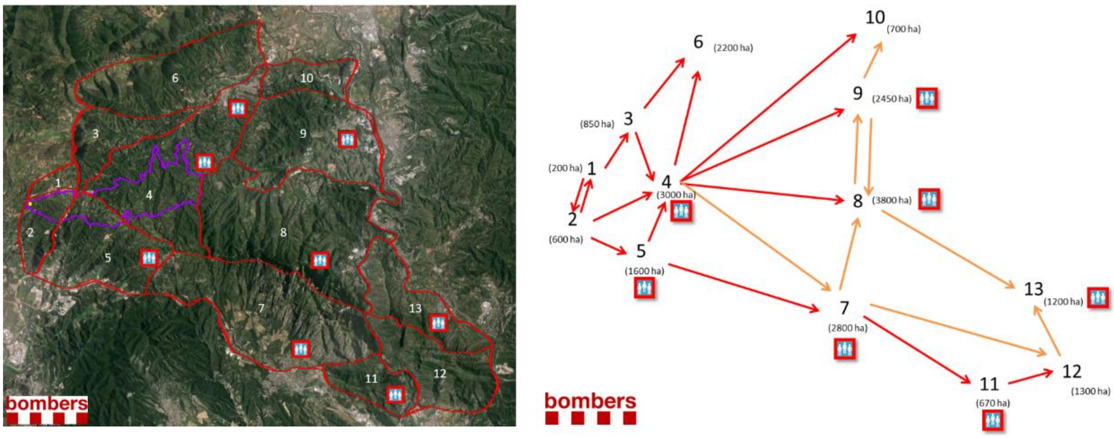


Image 6. Images of the analysis and planning of the Òdena's fire of the 26th of July of 2015. On the left, image with potential burned areas (red) identified by numbers, the final perimeter of the fire (purple) and the icons of the areas where there is an urban-wildland interface (WUI) zone. On the right, diagram of the flows and probability of the fire flowing between polygons, with the associated surface area of each polygon and the icons with urban-wildland interface (WUI) zones. Source: Bombers.

6.3. Scenarios of resolution in the El Perelló's fire (2019)

The fire that occurred in El Perelló (Terres de l'Ebre, Catalonia, 2019) (Bombers, 2019b) showed a situation under the interaction and evolution of the strong NW wind (named *Mestral* locally) and accompanied by the possible arrival of the fire in a forest area with very difficult access to resources. These generated a stage in which it was necessary to choose the scenario of resolution by applying criteria and traceability to the decisions and their consequences.

The 4 possible scenarios identified were:

- Scenario A: IDEAL, this is the scenario that responders were looking to achieve, it meant assuming that the polygons 1 and 7 would burn.
- Scenario B: PREFERABLE, if the wind opened the right flank quickly, it meant accepting that polygon 4 would also be affected.
- Scenario C: TO BE AVOIDED, the planning of the objectives had to focus on avoiding the flow to polygons 3 and 5, assuming that polygons 1 and 7 were already lost (this should be accepted in this scenario), and after that, the idea was to save polygon 4.
- Scenario D: FATALISTIC, situation if the established objectives failed and the first flanking actions from the back of the fire to prevent flow to polygons 2 and 6 did not initially contain the fire.

The decision-making process when choosing the scenario was based on different actions. First, it consisted of closing the back of the fire to avoid that the fire could relocate its position from the back (this was the move of the flow to polygon 6). Secondly, it involved assuming that the fire would reach the area of agricultural fields on the flat area (polygon 7) and thus allocating resources to prevent the opening of the left flank towards the forest massif (polygons 3 and 5). Finally, it required making a flanking manoeuvre at the right flank to prevent the opening of the fire towards the village of El Perelló (polygons 2 and 4).

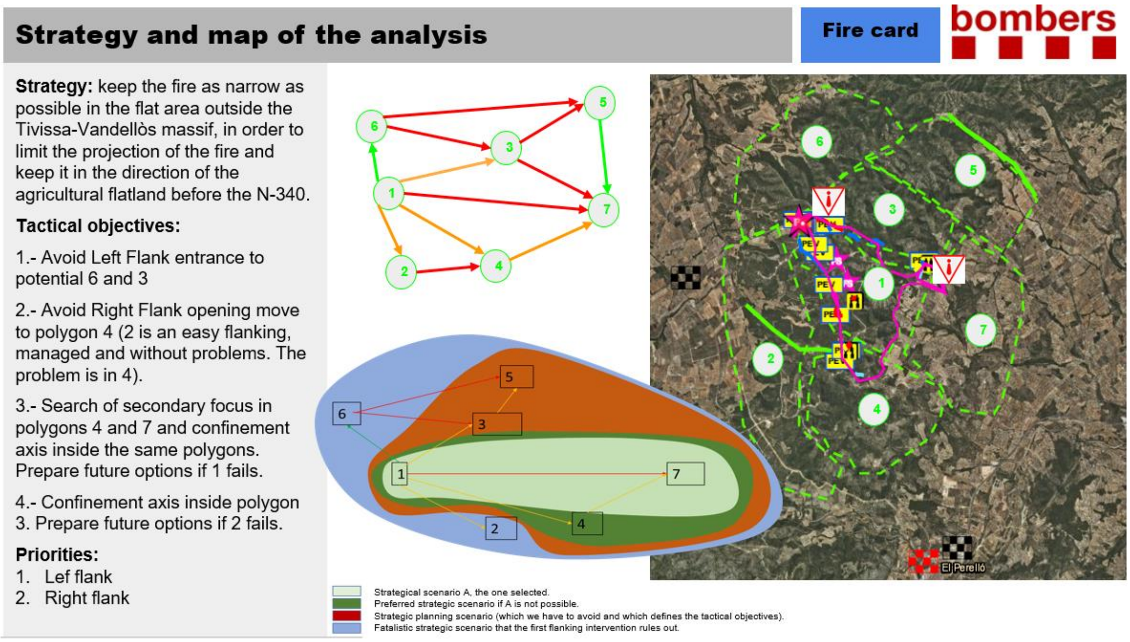


Image 7. Image of one of the sections of the El Perelló fire report of the 10th of June of 2019 (Bombers, 2019b), describing the strategy, tactical objectives, priorities, polygons of fire potential using the ArcGis platform, fire flows with movement inside or outside the firefighters' suppression capacity for each polygon and scenario of resolution. Source: Bombers.

6.4. Polygons of fire potential in planning for prevention of forest fires in the Prades massif

The Prades massif, in the Catalan pre-coastal mountain range between Tarragona and Lleida, has an orography consisting of many small and interconnected ravines. It has several fires of design that create a complex risk scenario, and it also has a well-studied history of past fires.

The massif does not have a very marked structure of axes or lines from which the different scenarios of fire propagation can be clearly differentiated. Therefore, in this massif, planning was based on a matrix of potential polygons showing the small basins. This made it possible to add values and therefore accumulate the priorities, comparing different basins and establishing priorities.

In this case, the fire flow diagram facilitates to compare scenarios and to decide which are the priorities and what impact they have on the future decisions of territorial and possible fire management.

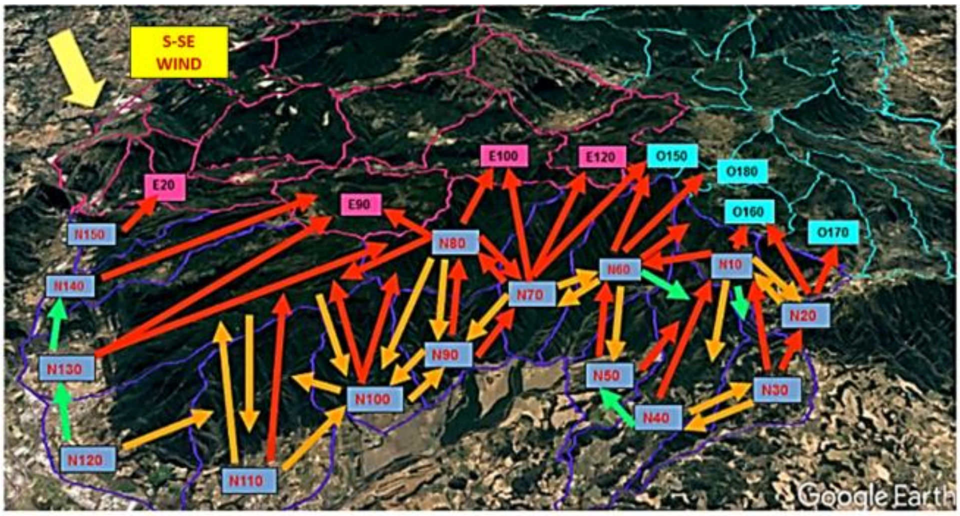


Image 8. Image with the potential polygons (purple colour) of the northern sector of the massif of Prades (Catalonia) and the probability of passing between polygons (coloured arrows). The green arrow is low probability of passing from one polygon to another, the orange arrow is probable, and the red arrow is high probability. Source: Bombers.

6.5. Polygons of fire potential in Santa Coloma de Queralt's fire (2021)

Santa Coloma de Queralt's fire (2021) is one of the first cases identified as EWE in Catalonia and to which the methodology of the polygons of fire potential was applied considering the new uncertainty scenario. On the second day of the fire, the pyrocumulus (PyCu) transitioned to pyrocumulonimbus (PyCb). It did it in the late afternoon and spread the fire in the new direction of the fall of the column.

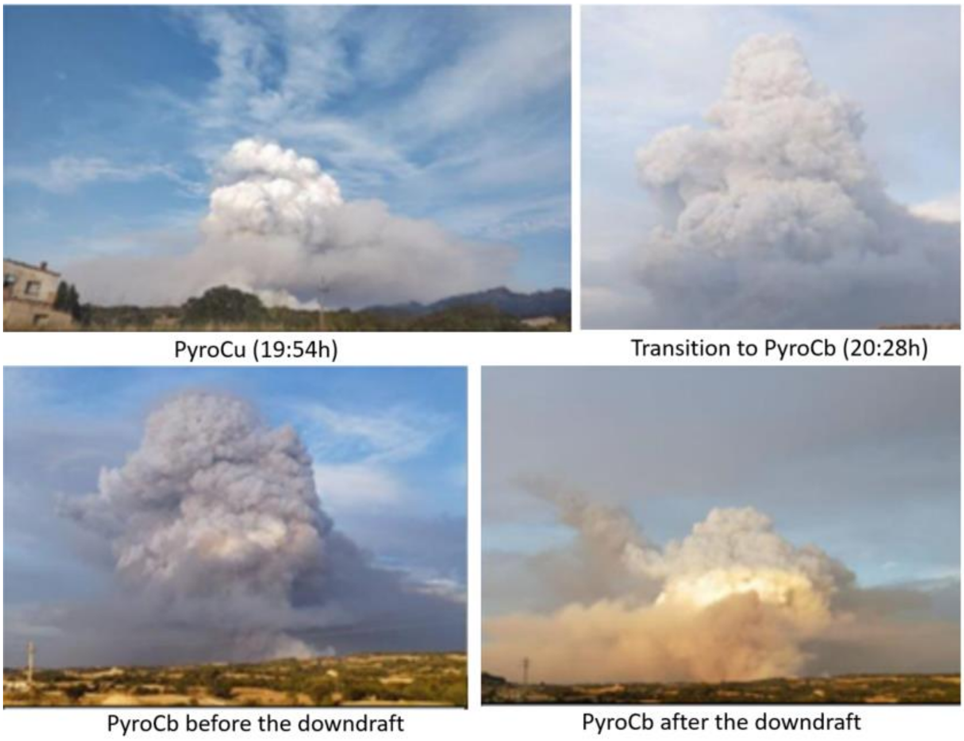


Image 9. Images from the report of the Santa Coloma de Queralt's fire of the 24th of July of 2021 (Bombers, 2021) with the evolution of the pyroconvection generated by the fire and the transition from PyCu to PyCb on the 25th. Source: Bombers.

The scenario of resolution changed due to the uncertainty linked to where the pyroconvection process will take the fire propagation axis. Once the transition was over and the dynamics stabilised again, the potentials were readjusted according to the new scenario and the new strategy.

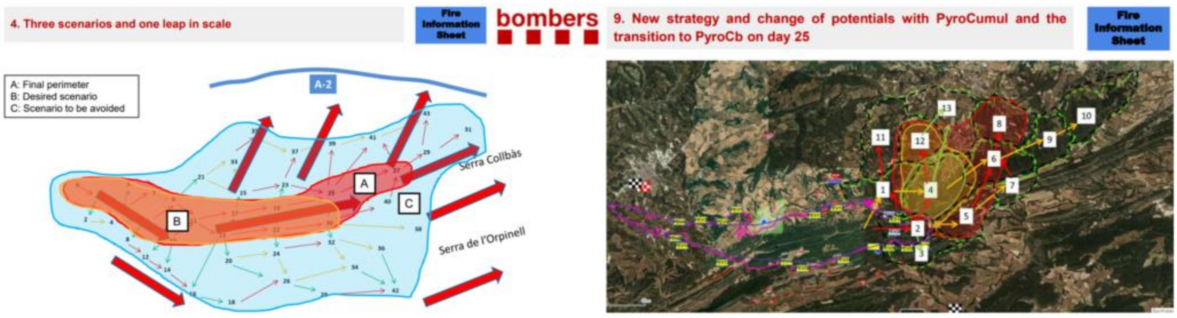


Image 11. Images from the Santa Coloma de Queralt's fire of the 24th of July of 2021 report (Bombers, 2021) with the different possible scenarios of resolution in front of the uncertainty of the transition from PyCu to PyCb on the second day, and the adjustment of the new potential polygons with the fire fluxes. Source: Bombers.

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