Operational tools for improving efficiency in wildfire risk reduction in EU landscapes FIREfficient

Wildfire risk mitigation: Protocol for a cost effective assessment on fuel treatments at landscape level

Action A3.1
"Developing a set of procedures, tools and methodologies for enhancing planning capabilities to mitigate large wildfire risk"

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Building a culture of prevention is not easy. While the costs of prevention have to be paid in the present, its benefits lie in a distant future. Moreover, the benefits are not tangible; they are the disasters that did NOT happen.
(Kofi Annan 1999)

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Deliverable 14. Wildfire risk mitigation: Protocol for a cost effective assessment on fuel treatments at the landscape level

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1. Introduction

Forest fires have been positioned as one of the most important threats to forest in Europe with 65.000 incidents per year with the consequent burning area (on average) of around 500.000ha of forest lands (European Commission 2013). The natural amount of burn area alternates with no clear trend and dramatic fire seasons, especially in the Mediterranean regions where the 1% of fires incidents is responsible for as much as 98% of burnt area (Strauss et al. 1989). Even if fire is historically an integral component of, among others, the Mediterranean ecosystems (Dubar et al. 1995) dominated by pine and oaks species well adapted to fire (pyrophytes species) and depending in part on it, nevertheless the increasing frequency and severity degree of this extreme fires, is one of the leading causes of forest degradation (EEA 2007). Furthermore, since 1960 the burnt are in Europe has quadrupled, therefore, it is not surprising that during the last decade forest fires have attracted more public interest and increased concern about their negative environmental and economic consequences and the loss of human lives. In this sense, the annual cost average of forest fires in Europe has been quantified around 2 billion Euros, with major incidence in Spain, Portugal, France, Italy and Greece, who accumulate approximately the 85% of EU burnt area (*FAO "State of Mediterranean Forest" 2013*) and even worse, the highest fatalities rate, due in part to the expansion phenomena of wildland urban interface areas (WUI), experimented during the last decades, and occupying mainly marginal abandoned agricultural lands surrounded by forest.

This situation in fire prone areas, promotes the likelihood of fire ignitions due to human's activities, which represent the 95% of fire occurrence causes (Catry et al. 2010). Furthermore, taking all into account under the near future expected climate conditions; worst meteorological scenarios and therefore wider fire episodes (Montero et al. 2004), we are facing an increasing wildfire hazard exposition all along Europe, even in unusual areas, which will need of policy and wildfire risk management measures at different levels to minimize the negative socio-economic impacts. The implementation of such measures requires substantial investment of financial, human and organisational resources, which should be justifiable and efficient. To estimate whether investments in forest fire related measures (e.g. prevention) are justified, and to choose the optimal amongst several alternatives (e.g. the combination of investments in fire prevention, fire fighting and amount of wildfire), reliable data and experiences are required on the economic efficiency of fire management alternative within a risk culture approach.

In this report, the cost-effectiveness assessment of wildfire risk management as a tool for decision making is discussed and crucial issues of the wildfire phenomenon that affects the implementation of a cost-benefit assessment are identified.

2. Understanding the economy of wildfire risk

2.1. Wildfire impacts, a unique accountability?

Environmental, economic and social impacts from wildfires in the European Union and especially Mediterranean basin have been steadily raising over the past decade, culminating with several large and costly fires during 2000, 2003 and 2005 (E.C. 2007). Since those events, the social and political awareness and concern of wildfire's negative environmental and economic consequences, and particularly, the loss of human lives, has increased at the EU level (McCaffrey 2008), as evidenced by the increasing number of research projects funded to better understand and address this problem (e.g. Eufirelab, Fire Paradox, Flame, WUI watch, eFIRECOM, Firesmart, Forfires and Pharos among others).

The cost assessment within a natural hazard context, might looks to provide a basis and support for better decision making and improving risk management (WB and UN 2012, IPCC 2012), despite the fact that cost estimates will always be uncertain and imprecise to some degree. (Downton and Pielke 2005). Beyond the forest vegetation consumption and loss of forest products (goods/services) production, high severity wildfire effect impacts adversely on wildlife habitat, aesthetical landscape values, tourism and recreation, water quality and supply, and society infrastructures or community facilities.

Until now, public administrations wildfire's responsible are still calculating and evaluating just some post-fire data such as burn surface, extinction costs or structure loss in order to feed their annual fire statistic, but in this approach a lot of important information about fire affectation is lost. However, these impacts, such as restoration costs, alteration of wildlife habitat, loss of tourism revenue, effects in forest services or human health effects, are important components of risk assessment and wildfire management. On this sense, an estimation of "total" and "real" wildfire effects costs, becomes necessary to evaluate the fire losses dimension and its affectation, and makes possible a wildfire management economic assessment from a global point of view. The main objective of these policies and management measures is to minimize the non-desirable environmental, economic and social impacts of extreme wildfire (EU 2005), and are supported by financial, human and organizational resources, which should be justifiable and efficient.

The understanding and assessment of socio-economic impacts (both positive and negative) of wildfire (as a function of the severity degree) should be considered as an essential part of the wildfire risk assessment, development of wildfire risk related policies, as well as planning and implementation of management practices (Morton et al. 2003).

Box 1 Potential wildfire impacts on forest goods and services

Forest goods and services*	Impact of fire	
Direct Use Value	**Low intensity fire**	**High intensity fire**
Wooded forest products (WFF): wood and firewood	Non-relevant negative effects with heat resistant barks. Potential positive effects in tree growth and health	Potential death of trees and disappearance of the stock. In some cases depreciation of the value (when selling wood by weight)
Non wooded forest products (NWFF): cork	Depreciation because of the black colour of the bark	Depreciation because of the black colour of the bark. Potential death of trees
NWFF: Resins	Non-relevant negative effects. Potential positive effects in tree growth and health	Potential death of trees and disappearance of the stock
NWFF: Wild aromatic and medicine plants	Temporal disappearance of the stock	Temporal disappearance of the stock
NWFF: Forest seeds and fruits	For those at the crown, non-relevant effects	Potential death of trees and disappearance of the stock
NWFF: Truffles and mushrooms	Non-relevant effects or temporary disappearance of the stock	Potential death of truffles trees and disappearance of the stock. Change of forest habitat (from wooded to non wooded land)
NWFF: Honey	Temporary disappearance of the flowers	Medium term disappearance of the flowers
Pastures	Temporal disappearance of the stock and regrowth of the pastures	Temporal disappearance of the stock, elimination of wooded vegetation and regrowth of the pastures
Hunting	Positive effects opening areas and access to forest	Death of animals and potential change of fauna species (from wooded to non wooded habitats)
Continental fishing	Non-relevant negative effects	Potential contamination of the water
Outdoor commercial recreational and cultural activities	Non-relevant negative effects. Positive effects opening areas and access to forest	Negative effects in those activities related with the wooded lanscape
Employment in forest sector	Non-relevant negative effects	Potential increase of employment for restoration. Medium-long term decrease of employment for those forest goods and services affected
Indirect Use Value	**Low intensity fire**	**High intensity fire**
Watersheds protection (soil conservation and movement) and water quality	Non-relevant negative effects. In some cases, positive for avalanche prevention	Increase of the potential of soil erosion, floods and avalanches. Potential decrease of percolation, decrease of water quality and aquifers replacement
Wildfire prevention	Positive effects with the fuel load reduction at sand level	Positive effects with the fuel load reduction at landscape level (mosaic landscape) level
Landscape quality and recreation	Non-relevant negative effects. Potential improve of landscape quality with the reduction of fuel loads	Temporal burnt landscape and usually negative perceived changes from wooded to non wooded landscapes
Micro-climatic regulation and carbon sequestration	Temporal smoke emission but non-relevant negative effects	Temporal smoke emission, loss of carbon stock and loss of forest cover climatic regulation
Local ecosystem conservation and potential source of unknown biodiversity	Functional effects related with the vegetation cover disappearance (high sensitive sites) and landscape change	Functional effects related with the vegetation cover disappearance and landscape change
Potential source of energy and materials, and profit of non-used landscape resources	Non-relevant negative effects	Functional effects related with the forest cover disappearance and landscape change

In this sense is important to point the **fire affectation on forest's goods and services according to fire intensity degree** (box 1) because it does not always have the same response to the perturbation in terms of intensity and recurrence, furthermore could be in some cases a benefit or advantage with regards at the no fire occurrence situation. This is well documented and known as *the two faces of fire* (Myers 2006), based on the natural interdependency between the ecosystem and fire, as a natural disturbance proper of the historic coevolution of both elements. According to this and depending on the fire ecology of the ecosystem, forest could deal with low to medium intensity fires, meanwhile high intensity fire represent a treat to its continuity and maintenance without experimenting a degradation phase. Even in some cases, high intensity fires are inside the natural cycle of the forest ecosystem, and from a natural point of view non loss should be associated to the disturbance. Fire can strongly affects other ecosystem functions as flood or avalanche protection with potential losses (e.g, a small plot affected by a fire in alpine landscapes can have a big impact in losses because of a future avalanche) and those scenarios on the ecosystem functionality affection should be integrated in the accountability. An illustrative example of this interactions between natural disturbance and its related costs were reported at the Alpine mountain level by Olschewski et al. (2011), confronting the snow avalanche effect's costs with and without a pre-existing disturbance (win throw); figuring out an important increase of the potential damages costs when win throw takes place (affecting 1 ha).

Finally, fire recurrence directly affects the ecosystem response and for instance, to events in a resilient and non-resilient plot, ecosystem or landscape can have opposite results (e.g., reinforcing the resilience in low intensity fires with the fuel reduction versus collapsing the forest regeneration capacity and starting soil degradation). Therefore, fire impact and consequently cost of wildfire on the ecosystem goods and services are strongly influenced by the fire severity and the fire ecology as well as the ecosystem resilience.

On the other hand, **not all fire impacts are easily calculated by means of traditional cost (monetary) estimation methodologies**. Cost are easily calculated when impacts are affecting elements with a direct market price (e.g, price of a house) or indirect (e.g estimation of customers in a rural tourism site in a burnt area market price or increase of avalanche defensive measures in a mountain, due to the loss of protection forest); but are not so easily to, in the case of environmental and social services (no tangibles market price). Non market valuation methods can be applied to value these goods and services by means of revealed preference techniques or the stated preference techniques (Morrison 2009). Even though these methods have improved considerably in the last years, they still have limitations, which should be considered when used; such as the difficulty to extrapolated the estimated value. Although the set of methods available from the environmental economics approach (hedonic price, travel cost, contingent valuation, etc.), up to what extend their results are integrated in the decision making process should be considered. In some cases as the forest carbon and carbon offsets are currently marketed but disaster risk reduction benefits extend beyond carbon uptake. In fact, according to Shreve and Kelman (2014) this point is a major concern about using quantifiable ecosystem services in conjunction with CBA: that the focus might end up on a small number of services without being comprehensive.

Other considerations regarding the **short-long term effects**, as well as the **spatial and cross-sectoral dimension** of the impacts should be taking into account in a wildfire impact assessment. Some impacts are compensated in a short period, as those related with annual crop production. In forest products exploitation, estimation on the wood and other forest products price at long term is not always easy. At spatial level, losses in a plot can be assumed as a benefit at landscape level for future fire event as the plot is providing a mosaic and increase the suppression opportunities (especially while vegetative growth is low).The provision of big amounts of wood after a fire in a market (for instance, the sawmill industry capacities to absorb the pine wood oversupply) can distort both local and international wood markets. From a cross-sectoral perspective, the mobilisation of the "stock" (as fire allow to cut all the trees affected) is offering an extra mobilisation of funds for the property (who before the fire, only was extracting the forest's "interests"; e.g. annual forest growth) which allows it to invest this extra funds in other productive sectors of the farm with higher revenues (for instance, from forest to intensive cattle production or rural tourism) increasing the net value of the farm.

Finally, **the "property" of the cost** has to be considered properly in case of a cost benefit assessment. Losses in wood production for instance, correspond to the forest owner. Impacts in forest services is affecting as well to society. Cost of suppression even prevention measures, in most cases, are covered by the administrations.

In sum, there is not a unique accountability for forest fires impacts;

- The understanding of how each fire severity is affecting (positive or negative) the ecosystem functionality is crucial to identify properly the impacts (positive and negatives).
- Social perceived impacts should be distinguished from those inside the natural cycle of the ecosystems (which can assume not only low but also high severities).
- Not all impacts can be calculated from the monitory point of view, at least, to support decision making processes.
- The negative impacts should be balanced with the positive one in terms of cost considering each timeline, spatial and cross-sectoral dimension.
- The assessment should be done from each cost "property" perspective.

2.2. Interaction between the components of wildfire risk management

The United Nations Office for Disaster Risk Reductions (UNISDIR), defines the natural disaster risk as the exposure or chance of loss (of fatalities/injuries, property, livelihoods, economic activity disturb or environmental damaged) due to a particular hazard **for a given area** and **reference period**.

Traditionally, a distinction between risk and uncertainty concepts is made. In the beginning there is just uncertainty, but this can be transformed into risk with an assessment of probability distributions indicating the likelihood of occurrence, taking the value "1" under full certainty that a prediction will be confirmed, and "0" value when do not be confirmed.

Wildfire effects estimation has an important role at the policy makers and land managers levels, if it's treated like another natural risk enclosed to our landscapes dynamic and not just as an isolate emergency event. This approach will allow and promote the integrative risk assessment and analysis as a systematic cycle composed by the preparedness (reducing vulnerability), the response (limiting extent of damage) and the recovery (learnt lessons capitalization to improve future mitigation levels) phases. This operative feedback cycle aims at optimised allocation of financial resources by reducing de social, economical and environmental values risk exposure.

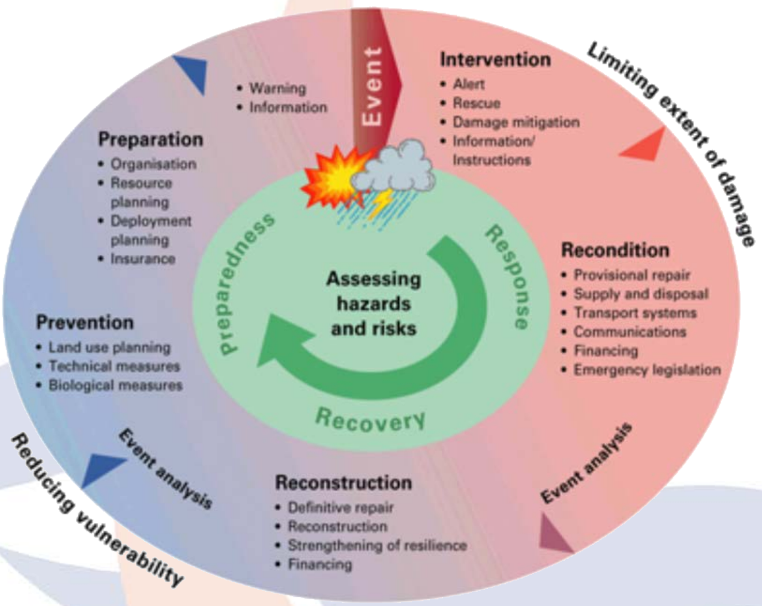


Figure 1: Risk cycle. Author: National platform for natural hazards (PLANAT 2011)

All efforts done in reducing vulnerability have a direct effect in the efficiency of the fire event suppression and emergency management as citizens and infrastructures protection is the priority. This shows how every risk phase is strongly related with others and the improvement in one element will rebound with different degree in the others. In this sense, there is a correlation between the cash flow of every risk component; for instance investing in the capitalization of lessons learned allows getting an efficient management of future events.

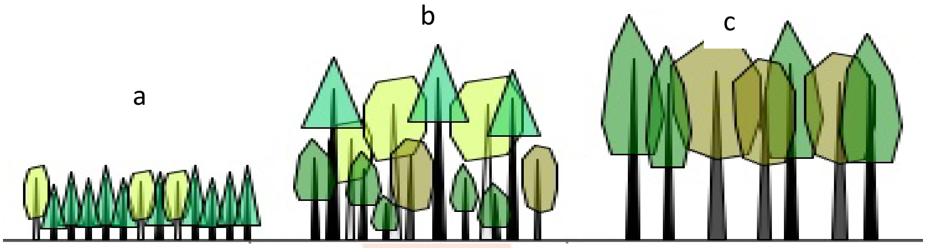
Traditionally, cost-effectiveness assessment in fuel treatment focus the attention in up to what extends this fuel reduction is limiting the fire spread and total burnt area. Beyond the simple "confrontation" among prevention and extinction investments (basically because the investment in suppression media is done with or without fire event in the end) how the relationships between the components works (response – recovery – preparedness) can offer a better argument to identify the best investments for an efficient wildfire risk management. This chapter put the attention in the preparedness step (prevention + preparation) as a way for reducing the landscape vulnerability and discuss the cost-effectiveness assessment of fuel treatments along a territory and its spatial and temporal planning and impacts as a tool to justify its budget allocation.

2.3. Wildfire risk reduction through fuel management

2.3.1. Fuel treatment effects and types

Concerning all the variability and complex interaction between the elements composing the fire behaviour's tetrahedron (Topography, Weather, Fuel and Fire environment), **fuel** is the only edge where managers can intervene and get a role to attempt successfully the reduction of fire propagation along the landscape. In this sense, many research have shown that physical setting, fuel, and weather combine to influence wildfire intensity (fuel consumption rate) and severity (fire effects on vegetation, soil, human infrastructures …) (Russell et al. 2004). According to the three main fuel characteristics; fuel type (fine or heavy), fuel moisture and fuel arrangement and continuity, the spatial distribution is the most influential element in terms of fire behaviour modification. This is the horizontal and vertical arrangement of the vegetation and how this enables different fire types (crown fire, surface fire, spot fires…) and therefore fire impact and forest vulnerability (Box 2). Fuel treatments may modify a fire regime that is linked to a forest stand through altering stand structure, i.e. accelerating processes at the most vulnerable development stages and maintaining those structures least vulnerable to fire over time. The frequency and type of silvicultural treatments in any stand structure may mitigate its vulnerability or maintain its resistance, depending on the characteristics it shares with the fire regime that defines it.

Box 2. Forest stand structures and fire vulnerability



a) Dense forest stand with high vertical and horizontal fuel continuity which cause a high vulnerability in front fires
b) Dense structure with some vertical discontinuity difficult the crown fire transfers from lower fuel layers. Medium level of vulnerability in front a fire.
c) Long turn forest stand without understory or far from the crowns (no vertical continuity), low vulnerability.

Into a hedonic situation, all forest resources will be managed under the sustainable criteria to promote its potential multi-function (protection, production, leisure…) according to the natural hazards which they are subject; ensuring its continuity for future generations. Beyond the defensive strategies, ideally, the best way to avoid large wildfire events should be reducing fuel loads at landscape level. This was made by the rural activities for years, through the wood and firewood extraction and grazing the understory. Commonly, once these fuel reduction activities have been abandoned forest become unmanaged and unstructured and therefore landscape becomes vulnerable to large and extreme wildfires. This points the dilemma in fire-prone landscapes about how to reintroduce the fuel elimination and reorganization (from dense and fuel layers scaled stands to less and bigger trees in fewer dense stands) from the perspective of the economic feasibility.

In this sense, fuel treatments are seen as a pro-active way to reduce wildfire risk through promoting forest structures (at stand and or landscape level) and fuel characteristics that reduce the likelihood that wildfires will cause large and irreversible changes in environmental condition, while also fire behaviour is sufficiently modified to make fire suppression easier and safer (Russell et al. 2004).

Some basic **fuels treatment benefits on high risk stands** could be listed as follow (Kline 2004): Fire fighting costs avoided; fatalities avoided; facility losses avoided; timber, biomass, non-timber forest products losses avoided; regeneration and rehabilitation costs avoided; community value of fire risk reduction; increased water yield and watershed protection; regional economic benefits and Carbon sequestration among others.

The combination of fuel treatment type and forest condition is also important in determining the wildfire regime (intensity, severity and scale), so fuel management can be applied to a specific target fuel layer in order to disrupt the vertical progression of fire and the horizontal spread (especially the canopy's one). Depending on the layers characteristics and managed surface, different fuel treatment methods are well accepted at different spatial and economic levels:

1- Prescribed burns; Applicable at small or large areas. High variability of costs depending on the surface. Difficulties in terms of social acceptability, health and smoke, and security (Cleaves et al. 2000; Gonzales-Caban 1997)
2- Mechanical thinning: Basically applied in small areas. High variability of costs depending on the fuel type and fuel treatment (U.S. Dep. Int. 2004).
3- Mastication and mulching. Applicable in small areas. High variability of costs depending on the fuel type and orography.
4- Grazing: Traditional way of fuel reduction linked to agrarian activities. For new implementation, a pre-treatment opening the vegetation is necessary. Costs depend on the market conditions (subside dependent sector). For new implementation, extra cost in management infrastructures is needed. (Plana et al. 2007)

The implementation of one or many of them is basically based on the ecology and post-treatment response of vegetation, the knowledge and expertise of forest operators realizing the treatment (e.g. prescribed burns) and especially depends on the planning scale; treating at the landscape level or local level (for instance WUI areas). Operational (possibility of mechanization or not, legal use of fire, etc..), economic (costs assessment) and social (acceptability, health, etc.) issues are also considered.

Furthermore, fuel treatments should integrate ecological, aesthetic, economic, and social values with respect to reduction of fire hazard and values at risk.

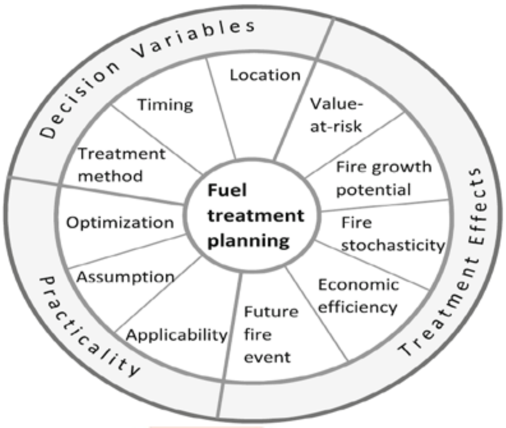


Figure 2: Examples of decision variables in fuel treatment planning (Source: Extract form Chung 2015)

In all cases, both implantation and maintenance cost should be considered and are also influenced by the fuel treatment intensity (opening the forest stand increases fire prevention and also the understory regrowth controlled by the canopy shadow). As much as traditional fuel management linked to wood, firewood and biomass extraction or grazing activities can be integrated in the wildfire risk management, more cost-efficient will be the system, as employment and other rural development issues are combined all together.

Nevertheless, to integrate effectively the agrarian activities in the fuel management strategies some key points have to be considered as follow:

- Only sawmill industry that promotes high diameters trees in even-aged stand will have a relevant impact in terms of wildfire risk reduction
- In Mediterranean pine forest, both together logging and understory grazing have significant effects in fuel loads reduction to prevent wildfires. Only logging or firewood extraction is not necessarily creating the fuel layers discontinuity needed. This is more crucial in uneven-aged stands adapted to the sawmill industry, which is demanding medium diameters; typically for instance for pallet and other small sawmill pieces.
- Landscape mosaic is effective only if forest cover is not dense enough to allow spot fires crossing crops or fuel discontinuities.
- As more dependant are these activities from subsides more difficult is to integrate them in wildfire risk management strategies. Showing the economic benefits in terms of wildfire prevention (avoided costs) with together social (employment) and other cross-sectoral territorial benefits could help the decision making process. Unfortunately, the cash-flow between the rural development and wildfire prevention is not usually recognised.

- A strong institutional and public-private coordination is needed as well as a harmonisation of the rural development and risk management policies.

2.3.2. Spatial distribution and strategies of risk mitigation

The spatial patterns of fuel treatment at the landscape level will most likely determine their effectiveness in modifying wildfire behaviour (Hessburg et al. 2000, Loehle 2004), because of the spatial variability of forest stands and fuel condition. Treating small or isolate stands without assessing the broader landscape will most likely be ineffective in reducing wildfire extent and severity; therefore, a post analysis is required to ensure the optimal function and performance of the treatment. Physically setting (topography) will determine the spatial location strategy or design approach, as an example, into wide and continuous forestlands a multiple patches dispersed arranged pattern, containing fuels that burn slower, could disrupt the forward progress of the fire and create variability in the intensity of fire as it move across the landscape (Finney 2001). Evidence that mosaic patterns reduce fire spread, comes from natural fire patterns that have fragmented fuels along landscape. Another interesting approach is the strategic area treatment (Finney 2001), allow creating landscape fuel patterns that collectively slow fire growth and modify behaviour while minimizing the amount of treated area required. A real case on this approach is found in Catalonia (Spain), where the fuel treatment location is based on the natural fire's spread potential within a watershed and for a determined synoptic condition (defined as a "forest types"). The objective is to treat just those strategic places (Strategic Management Points) that will interrupt or difficult fire's progression to next basin, facilitating the contention of fire propagation (Castellnou et al. 2009, Costa et al. 2011). This approach has been exported all along Europe and is being applied in recent years on other sites as, for instance in the Mourne Mountains of North Ireland[1].

The spatial dimension of fuel treatments is also a crucial issues regarding cost-effectiveness. As more intensive is the treatment more intensive will be the effects over the fire behaviour and this can be economically justified depending on the value endangered or at risk. High intensity fuel treatments are common, for instance, in the prevention of wildland urban interface (WUI), protecting houses from the fire radiation. At landscape level, a mix of treatments intensities looking for different objectives can coexist, as follow:

1) High intensity fuel treatments in buffer zones or strategic management points.
2) Medium intensity fuel treatments in planned areas aiming to decrease the spotting distance.
3) Low intensity fuel treatments in large forest areas, through silvicultural systems looking for forest structures able to avoid high intensity fire behaviours at large areas level.

Therefore, from a defensive perspective, fuel treatments could seek for;

a) Defence: to exclude fire as much as possible for protecting people and infrastructures to fire (WUI areas, levels 1-2 of fuel treatment intensity),

[1] For further information see: http://www.climatenorthernireland.org.uk/cmsfiles/CaseStudies/Climate-NI_Mournes-Fires_NI-Water-v2-190213.pdf

b) Pre-extinction: to prepare the landscape to help suppression system in case of fire (strategic management points, level 1-2 of intensity), and/or
c) Tolerance: to slow down the fire spread and extreme fire behaviour which burns out of suppression capacity and carries huge negative effects reducing the capacity of the landscape to “sustain” a high intensity fire (acting over the fuel at landscape level, levels 2-3 of intensity).

In all cases the distance of the spot fires seems to be crucial, so acting in the forest cover, even between the crops in a mosaic landscape, is a condition (without doing so and reducing forest density, spotting fires jumps the crops or the buffer zones and the mosaic and lineal fuel discontinuities are not recognised by the fire).

Therefore in each scenario a different fuel treatment would be applied in different degree, according to the value and asset to be protected (forest *VS* houses). Taking all into account, the main expectation is that fuel treatment over long term should result in less fire suppression budget, lower personal and property damages and in major socio-economical and environmental benefits as well as in creating resilient landscapes to future wildfire events. Consequently, fuel management planning has to be based on several questions such as where, when and how to perform the treatment to mitigate current and future wildfires risk (Chung 2015). In this sense, two main issues can help to address the cost-benefit assessment of the fuel treatments from the market price conditions;

- Estimation of the avoided costs in damage of properties and infrastructures.
- Estimation of the avoided cost in loss of forest ecosystems functionality, as flood or avalanche protection, soil stabilisation, landscaping provision for tourism activities and others when a direct affect in monetary terms can be quantified.

Embarking on one particular management and policy alternative necessarily carries costs associated with other opportunities that are forgone, because all management actions that we conduct today have the potential to affect future forest conditions and wildfire regimes, as well as our range of management choice in future years. Although fuel treatments undoubtedly can be used to alter forest structure and modify wildfire behaviour and severity (Graham et al. 2004), to date there has been little scientific evidence on the cash-flow between the prevention efforts and suppression and emergency management avoided cost. Land managers who need to make decisions about what, where, when and how to perform fuel treatment to mitigate current and future fire risk, must to run multiple models in order to analyse and develop effective fuel treatment plans, depending on the incremental change in annual net benefit it could be expected by conducing the treatment type and according on the likelihood, intensity, scale and severity of the designed wildfire.

3. Economic evaluation of wildfire risk management strategies; tools and considerations

3.1. Cost benefit and Cost-effectiveness analysis; definition and concepts

Into a risk management framework, a common economical and financial evaluation tool to support the decisions in term of public budget allocation is the cost-benefit analysis (CBA) (Kopp et al. 1997, Wethli 2014). CBA provides a structured approach to organize data, present costs and benefits, and finally estimate the cost-efficiency of projects or policies intervention. CBA measures the change with and without the specific action to be implemented, comparing the costs of the planned project with its benefits (commonly calculated in terms of avoided costs in the case of risk management) and allows to decide the adoption or refusal of the action assessing whether or not the policy is likely to result in overall benefits to the society and economy. Although different levels of complexity to CBA exist, box 3 lists some general features of CBA. Box 4 summarizes the common stages to be done for carrying out a CBA.

Box 3. Main principles of CBA (Mechler 2005):

With and without-approach: CBA compares the situation with and without the project/investment, not the situation before and after.

Focus on selection of "best-option": CBA is used to single out the best option rather than calculating the desirability to undertake a project per se.

Societal point of view: CBA takes a social welfare approach. The benefits to society have to outweigh the costs in order to make a project desirable. The question addressed is whether a specific project or policy adds value to all of society, not to a few individuals or business sector.

Clearly define boundaries of analysis: Count only losses within the geographical boundaries in the specified community/area/region/country defined at the outset. Impacts or offsets outside these geographical boundaries should not be considered.

Box 4. Stages of a Cost-Benefit Analysis[2]

1.- Set the framework for the analysis: Definition of the program or policy change and the current status quo as well as the state of the world before implementation compared to after. This includes the definition of the study area; where the majority of the effects of the project are considered, and the time frame; which starts with the first project expenditures and extends through the useful life of the project which should be consistent for all alternatives and long enough to capture the majority of costs and benefits.

2.- Identify the relevant project impacts: Identify whose costs benefits should be recognized. The geographic scope of the analysis needs to be determined in order to limit the groups impacted by the policy. It is important to label costs and benefits as direct (intended costs/benefits)/indirect (unintended costs/benefits), tangible (easy to measure and quantify)/intangible (hard to identify and measure), and real (anything that contributes to the bottom line net-benefits)/transfer (money changing hands) in order to include the effects of each cost and benefit.

The analysis is based on incremental benefits and cost according the *additionally*, which means that only extra cost and benefits as a result of undertaking the project should be considered.

[2] Decription partially coming from the "Written protocol on how to proceed for the private and social evaluation" of FIREPARADOX project (Deliverable 4.5-1). The project also include a software program to estimate the economic impact of wildfires for European countries (www.fireparadox.org).

3.- Quantification and monetize cost and benefits: Assess how costs and benefits will change each year. Make sure to place all costs and benefits in the same unit. Whenever environmental externalities are difficult to quantify, a list of them should be included in the CBA in order to offer the decision maker a wider perspective on the project's impacts (step 7).
4.- Discount costs and benefits: Convert future costs and benefits into present value (also known as the social discount rate, or the rate at which society makes tradeoffs over time). It generally ranges between 2-7%. A common solution is to use the market rate of interest as a social discount rate. With discount rates, the more distant the costs and the closer the benefits are in time, the better a project will be evaluated.
5.- Calculate the CBA performance indicators: Compute net present values and other indicators. This is done by subtracting costs from benefits. The policy is considered efficient if a positive result is produced; however, it is important to think about the policy's feasibility and social justice.
6.- Perform sensitivity analysis: Allows to check the accuracy of the estimates and assumptions. This is normally done by altering the social discount rate utilized, by increasing it and decreasing it. This also includes *variable-by-variable analysis* (isolating the effect of a change in one variable on the performance indicators) and *scenario analysis* when factors affecting cost-benefit flows do not operate independently. The purpose of the sensitivity analysis is to determine critical variables and parameters of the model, that is, those to which the net present value outcome is most sensitive.
7.- Make a recommendation: Assess all results and account for other qualitative and context considerations.

The CBA can be conducted from the perspective of *Private*; considering the costs and benefits of the analyzed project which are imposed onto or accrue to a private individual or firm, or *Social*; considering the costs and benefits which accrue to the society as a whole. In terms of wildfire risk, fire suppression costs are typically assumed by the public agencies and should not be considered as an input in a private assessment. Neither environmental services (also called externalities) which are not typically perceived by the forest owner.

The main performance indicators for the CBA are:

- ***Net present value (NPV):*** compares if the projected earnings generated by a project or investment (in present money) exceeds the anticipated costs (also in present money). Generally, an investment with a positive NPV will be a profitable one, meanwhile a negative NPV will result in a net loss. This concept is the basis for the Net Present Value Rule, which dictates that the only investments that should be made are those with positive NPV values.
- ***Benefit-cost ratio (BCR):*** is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. All benefits and costs should be expressed in discounted present values. BCR takes into account the amount of monetary gain realized by performing a project versus the amount it costs to execute the project. The higher the BCR the better the investment. General rule of thumb is that if the benefit is higher than the cost the project is a good investment. BCR differs from NPV because is insensitive to the magnitude of net benefits, therefore, may favor alternatives with smaller costs and benefits over those with higher net benefits.
- ***Internal rate of return (IRR):*** evaluate the desirability of investments or projects calculating the profitability at the end of an investment (e.g. 10% of gains). The higher a project's IRR, the more desirable it is to undertake the project. Assuming all projects require the same amount of up-front investment, the project with the highest IRR would be considered the best and undertaken first.

- ***Payback period:*** indicates how long it does take for the accumulated benefits to exceed the accumulated costs. The first year in which the accumulated benefits exceed the accumulated costs is the called the payback period.

With the costs and benefits estimations in monetary terms, it is necessary to convert them into a common metric to render current and future effects comparable. Discount can be done by computing the net value of benefits minus costs for each time period (each year), and discounting each of these annual net benefit flows through the lifespan of the treatment. The discount rate used in CBA is the social one which attempt to reflect the social view on how future benefits and costs should be value against present ones. As higher is the discount rate, as greater preference is given to the present consumption, reason why the European Commission suggest a discount rate of 4 to 5% meanwhile World Bank adopt rates around 10%. It is important that discount rate is consistent with the inflation; if future costs and benefits follow the common practice of being expressed in terms of real (constant) monetary units, then discount rate should be the real interest rate which excludes the effect of inflation.

CBA allows performing a **sensitivity analysis** to examine how the outcomes of the CBA changes with input variations, such as discount rate, physical quantities and qualities of inputs and outputs (different types of fuel treatment) or the project life span

In the case of having difficulties of measuring the benefits in monetary terms, an alternative is the **Cost-effectiveness analysis** which shows how to achieve a given benefit, measured in physical terms, at the lowest cost measured in monetary terms (discounted). In principle, using CEA or CBA largely depends on the purpose of the analysis and questions to be solved; usually, CBA is a more general evaluation of the project implementation sense (for instance, doing or not fuel treatment for wildfire prevention), meanwhile CEA could be used for comparing the relative effectiveness of different alternatives in achieving a given objective (if yes, using prescribed burning vs. mechanical thinning). Thus, CEA is a good alternative when each alternative has the same annual benefits expressed in monetary terms or is not possible to assign a monetary value to the benefits, for instance, when dealing with non-marketed benefits. Due to the similarities between CBA and CEA, most of the stages to run a CBA (box 4) are also applicable to the CEA.

An alternative is using the Multi-Criteria Anlaysis (MCA, not discussed in this report) to address the qualitative variables, such as social and environmental benefits, of a project as a subset within the CBA which is used to address the quantitative variables (Shreve and Kelman 2014). MCA utilizes expert opinion to select the criteria and the rating options for the model offering more flexibility for a greater range of awareness and involvement actors scales, although adds complexity and subjectivity.

3.2. CBA and CEA application in wildfire risk management: elements to be discussed

3.2.1. Background; applying CBA in natural hazards and wildfire risk

Many real examples of CBA risk management implementation could be listed across Europe natural hazard context, especially concerning the risk mitigation measures of floods (see the EU project funded: "*Floods CBA - a common framework of flood risk management cost benefit analysis features" 2012-2014*), snow avalanches (Fuchs et al. 2007) or landslides (see a relevant example of the Seventh Framework Programme: "*SafeLand*").

Among all risks, CBA on flood risk reduction is the most commonly reported although there is no clear consensus on the minimum criteria necessary for conducting a comprehensive CBA for disaster risk reduction (Shreve and Kelman 2014). For instance, there is no standard or systematic approach detailing which variables need to be assessed to represent vulnerability, disaster consequences, or even the appropriate spatial and temporal scales for determining CBA.

Overall, the CBA studies tend to generalize vulnerability into four board categories (Shreve and Kelman 2014). While all four categories are recognized as important, social and environmental impacts are more qualitative in nature and therefore the focus of CBA for disaster risk reduction tends to be on the quantitative economic and physical impacts:

- Economic: financial capacity to return to a previous path after a disaster.
- Environmental: a function of factors such as land and water use, biodiversity and ecosystem stability.
- Physical: related to susceptibility of damage to engineered structures such as houses, damns, and roads.
- Social: ability to cope with disaster at the individual level as well as capacity of institutions to cope and respond.

The parts of a CBA of disaster risk management are comprised of (Mechler 2005):
1. Risk analysis: risk in terms of potential impacts without risk management has to be estimated. This entails estimating and combining hazard(s) and vulnerability.
2. Identification of risk management measures and associated costs: based on the assessment of risk, potential risk management projects and alternatives can be identified. The costs in a CBA are the specific costs of conducting a project, which consist of investment and maintenance costs. There are the financial costs, the monetary amount that has to be spent for the project. However of more interest are the so-called opportunity costs which are the benefits foregone from not being able to use these funds for other important objectives.
3. Analysis of risk reduction: next, the benefits of reducing risk are estimated. Whereas in a conventional CBA of investment projects, the benefits are the additional outcomes generated by the

project compared to the situation without the project, in natural disasters risk management benefits arise due to the savings in terms of avoided direct, indirect and macroeconomic costs as well as due to the reduction in variability of project outcomes. Only those costs and benefits that can be measured likewise are included. Often, an attempt is made to monetize those costs or benefits that are not given in such a metric, such as loss of life, environmental impacts etc. Generally, some effects and benefits will be left out of the analysis due to estimation problems.

4. Calculation of economic efficiency: Finally, economic efficiency is assessed by comparing benefits and costs to assess whether benefits exceed costs. The costs of risk management project are the one-time investment costs and maintenance costs that arise over the lifetime of the project. Benefits of such project arise due to the savings in terms of direct and indirect damages avoided such as avoidance of loss of life and property in the affected area.

Therefore, cost and benefit definition and calculation are the baseline of the CBA and a special care has to be taken **defining costs and benefits**. All benefits of alternative risk mitigation options are related to their costs in order to identify the course of action with the highest net benefit, compared to a baseline option; hence the importance of precise costs and benefits determination is highlighted.

The EU project "Costs of Natural Hazard" (CONHAZ 2010-2012) propose a **cost** types classification for disasters risk management as follow:

1. *Direct costs*: damages to property due to direct physical contact with the hazard. They are considered as a good indicator for the severity of the event and quantified by means of the susceptibility functions, market valuation techniques or integrated assessment analysis (Bubeck and Kreibich 2011). The typical direct cost of wildfire is the loss of saw-wood quality and quantity, but also loss of houses and infrastructures…
2. *Business interruption costs*: occurring into areas directly affected by the hazard where the socio-economical activities are interrupted by the phenomena (Bubeck and Kreibich 2011). For instance leisure activities (trekking business, biking business, roads temporarily closed…).
3. *Indirect costs*: are those induced by the losses on the production by suppliers and customers of companies directly affected by wildfire; the most relevant example is the tourism loss after a fire (Przyluski and Hallegtte 2011).
4. *Intangible costs*: are referred to damages on goods and services which aren't measurable (not easier) in monetary terms because they aren't traded on a market; such as environmental impacts, health impacts or cultural heritage impacts (Markantonis et al. 2011).
5. Risk mitigation costs: all the costs coming from the implementation of measures and action to improve risk reduction: prevention operations (fuel treatment) or suppression (extinction tasks) (Bouwer et al. 2011).

The calculation of **benefits** for a proposed mitigation project entails estimating the present value of the sum of expected annual damages over the useful life. In forestry, benefits are determined by socially desired outputs produced from existing forest conditions, and the values society places on those outputs. Therefore, an important factor affecting whether the benefits of fuel treatment outweigh their costs is the degree to which fuel treatment incrementally reduce the likelihood of severe intense wildfires as well as the reduction of high intensity affected surface.

In the context of disaster risk, **benefits are probabilistic and arise only in case of events occurring** (a part of those indirect benefits coming from having the area safety, figure 3). Thus the viability of such a project is tied very closely to the occurrence probability of disasters. For disasters happening relatively rarely (eg. earthquakes) it may be more difficult to secure investment funds than for more frequent events such as flooding. This poses additional challenges for including disaster risk into economic appraisals **as the occurrence needs to be captured**. This involves a solid risk assessment in terms of **recurrence** and **severity** as the basis for assessment of benefits.

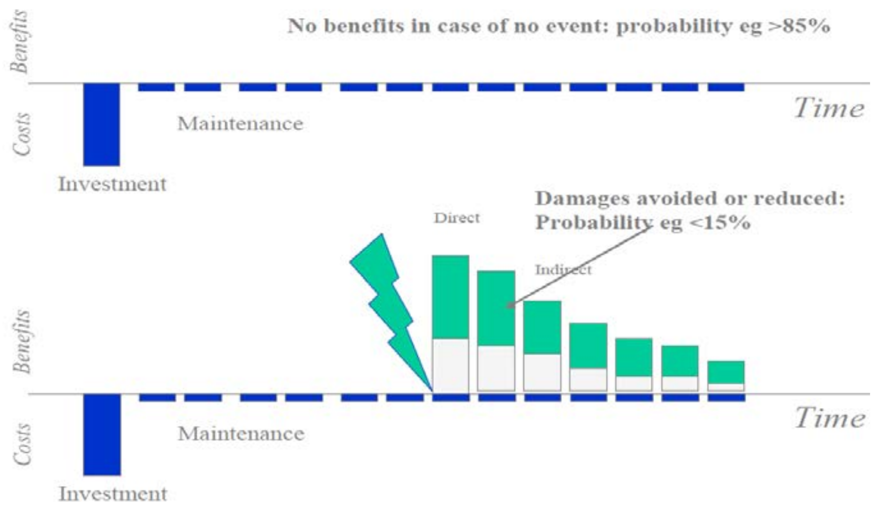


Figure 3: Representation of the CBA performance in case of non hazard occurrence (up) and if hazard strikes at a determined moment (down) (Source: extracted from Mechler 2005)

Shreve and Kelman (2014) distinguish among 'structural' (e.g. measures such as installing dykes) and "non-structural' (e.g. measures such as developing an evacuation plan or training), and show how most studies reported difficulty with valuing certain components of non-structural ones which often require valuing social and environmental aspects that do not have a market value (e.g. sense of security, peace of mind and avoided property damage). Similarly, thought direct costs are somewhat easier to estimate for structural measures (e.g. cost of constructions materials), indirect costs and benefits are rarely included. This also happen when dealing with 'ecosystem-based disaster risk reduction' which include the ecosystem restoration (and/or, resilient ecosystems to the natural perturbations) as forestation, forest management to get resistant stands to natural hazards, agroforestry technics, etc. In this case, cross-sectoral issues and indirect cost and benefits (employment, territorial development, etc.) are adding complexity to the assessment, but in the context of risk mitigation, it would be advantageous to have a more substantive understanding of CBA.

Additionally, there are alternate approaches to evaluation the costs and benefits without reporting a CB ratio such as Cutter et al. 2003, who has utilized country-level socioeconomic and demographic data to generate an index of social vulnerability to environmental hazards (called the 'Social Vulnerability Index', SoVI).

According to Wethli 2014, cost-effectiveness studies are most common in categories where the risk-management interventions in question are very specific, and the groups of people who benefit are relatively easy to define. The same author, comparing several examples (not any case of wildfires), shows three grouped conclusions on benefit-cost ratios for various risk management interventions:

- **The range of values in each area[3] is very large**, which is strongly related with the underlying probabilities of shocks occurring.
- **The minimum value is very low** in the case for large structural investments aimed at reducing damage from some natural hazards, where damages if a hazard event takes place can be high but the probability of such an event occurring may be low (such as earthquakes and flooding… could be the same for wildfires?).
- **Risk management appears cost-effective** in all categories… once the event occurs!

Shreve and Kelman (2014) show how certain hazards, such as floods, droughts, and earthquakes are more commonly reported in CBA case studies. Part of the bias is likely to be the ease of calculating costs and benefits of measures to reduce risk and the same inertia of the existing literature what inspires others to pursue similar work. But also because structural flood defences costs are easily valuated, as are the property and possessions (and potentially lives) which are 'protected'. In this case the CBA is not independent of the disaster risk reduction measure itself which influences the situation when people gain a false sense of security due to the visibility and hardness of the measures, leading them to build and settle in areas 'protected' by the flood defences, without taking adequate mitigation measures.

A common challenge for the CBA on natural hazard is the **uncertainty** related with the climate change. Variability in the accuracy and precision of climate data, difficulty associated with projecting and predicting hazards occurrence, and challenges in incorporating future social behavior and policies, contribute to the uncertainty of future climate impacts. Understanding the hazard and vulnerability changes is much more challenging with larger uncertainties (Shreve and Kelman 2014), including those coming from the land-use changes.

In the cases of **wildfire risk**, few experience and applied examples are found with such robustness and detail as for the others natural hazards previously commented, although the issues regarding the evaluation of costs and benefits of fuel treatments and other measures to reduce wildfire risk is present enough in the literature and more and more in the agenda (Kline 2004, Ingalsbee 2010, AFE et al. 2015). CBA should focus on the evaluation between the variation on the forest vulnerability (affection on forest

[3] The comparative include examples on Early warning systems, Structural measures to limit damage from earthquakes, floods and tropical storms, Improved water & sanitation, Vaccines, Nutritional interventions

goods and services) and fire emergency operations (preparedness, response and recovery phases), in term to justify the land planners decision making. Some example of it is Finney 2001 (comparing fire propagation and suppression efforts with or without prevention fuel treatments) and Plana et al. 2007 (comparing fire impacts in different landscape management scenarios).

While Finney (2001) is comparing intensive fuel treatment in planned strategic sites, Plana et al. (2007) develop an 'ecosystem-based disaster risk reduction' CBA providing a more resilient landscape to wildfires from the fire ecology perspective of the forest species through traditional logging and grazing (although strategic points management is also included) in two forest landscapes of Catalonia (NE Spain). In Plana et al. (2007) the initial scenario (current situation) is compared with three situations: nothing is done and land use is abandoned, current low intensity land management is maintained and the target scenario where silviculture and grazing oriented to get more resilient forest to wildfires are promoted. In all cases all added cost of interventions are calculated and compared with the fire simulated impact costs. Several compared assessments are done for all the landscape transformation period (in the case study, a 40 years period is estimated as necessary to move from initial to wildfire resistant target scenarios). In all situations fires are simulated and total affected area and fire intensity is calculated. CBA compares the cost of scenario implementation with the fire impact costs. Scenario alternatives are compared between them in terms of avoided costs. The study shows how in the local traditional farm areas the logging and grazing integration looking for wildfire resistant forest stands are justified from a cost-benefit perspective.

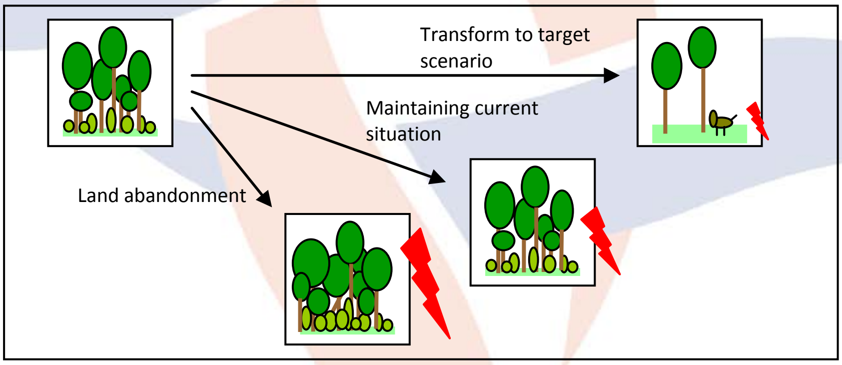


Figure 4. Scenario comparison for a CBA on fuel treatments and wildfire impacts (Source: From Plana et al. 2007)

These studies show some specific considerations regarding wildfire characteristics different than other natural hazards that should be taken into account in a CBA. Some of become a real constrains to integrate the CBA on wildfire risk management into decision making process. Next chapter discuss some important methodological considerations to run a CBA in case of wildfire risk management alternatives.

3.2.2. Elements to be discussed regarding wildfire risk management

3.2.2.1. - Spatial definition of wildfire intensity and affected area

In contrast with other natural risks as floods or snow avalanches, wildfire location and its affectation area is a complex task due to the uncertainty about where it will start (ignition point) and where it will spread (fire could run everywhere with available fuel) and how (under which specific synoptic conditions and how those will affect at local level the fire intensity).

Fire starting point depends basically on human ignition causes or human risk (Merrill and Alexander 1987) representing the 95% of wildfire occurrence and has basically a random distribution pattern. Until now any theoretical model has shown adequate results to simulate it with enough spatial and temporal resolution and accuracy. However, some research have figured out different approximations in order to shed some light in, such as the *logit* and *probit* modelling to predict the human risk of fire occurrence (Vega Garcia et al. 1995, González-Olabarria et al. 2015) or even the spotting process (Koo et al. 2010), but they are still far from getting the reliability to include them in a predictable way. This issue is discussed in deliverable 12 of the FIREfficient project (Protocol for ignition risk assessment).

Regarding the fire's affectation surface, some concrete simulations can be done according the specific synoptic conditions and the fire behaviour patterns knowledge (this last is not usually available in most areas. A relevant case is the Catalonian Fire Service in NE Spain, where 9 patterns have been identified in the territory (Castellnou et al. 2009, Costa et al. 2011). It has to be taken into account that the two main drivers of fire behaviour, weather conditions and fuel distribution, are under evolution with the global change, and some level of unpredictability with unrecorded new extreme fire behaviours with long distance spotting, blow up, plume collapse, rolling burning materials, etc. has to be assumed.

Although all possible estimations or simulations, areal and intensity degree of affectation concretion is far from those in the case of floods (basically depending on the water level) and avalanches (easy estimated by the recurrent surface affected).

3.2.2.2.-Temporal delimitation of wildfire events

The return period of the extreme wildfire (in term of probability) is something that will determine the temporal horizon of the CBA. In the European context, this issue is not clear because of the historical relationship between human activities and landscapes evolution, as opposed as other natural ecosystems less anthropogenic such as the *Pinus ponderosa* forests of the USA (Kernan and Hessel 2010), where the natural role of wildfire is well understood allowing the establishment of the natural wildfire regime, in term of recurrence and intensity. Mediterranean landscape has suffered constant modification as a result of the society necessities and demands during the last centuries, erasing with it the natural role of wildfire.

To attempt to solve this gap, sometime is used the fire frequency (even not be the natural one) relying on the ignition and surface statistics. But, should be used the statistics as a reference? Some arguments to take care of it are:

- Burnt area is related with the fire service results which are under evolution in terms of capacities and efficiency.
- Fuel distribution is changing over time which also changes the potential of a territory of suffering a wildfire.
- The mosaic of large burnt areas from the past, could offer a period of non-large fire in recent years, which makes difficult to estimate any average along time.

All together make really difficult to estimate the return period of a wildfire event in a concrete site. Some qualitative estimation for a region could be assumed, but far from the concretion of the static return period in the case of floods and even avalanches (the same event records include information in terms of frequency and intensity). This issue is totally relevant in the case of CBA, as if none wildfire strike during the life time of the treatment implemented, no benefit will be generate by the measure and only costs will be involved and accounted.

3.2.2.3.- Fire severity and ecosystem functionality

Beyond the surface, is also important the intensity as, how chapter 2.1 shows, this has different impacts on forest land goods and services. Again, according the specific synoptic conditions and the terrain and fuel conditions, fire intensity will change. Campbell Prediction System (CPS) (Campbell 2005) for instance, offers an easy way to estimate how intense will be the fire, but again this should be calculated considering case by case.

This means that the same fuel distribution could show different fire intensities with different synoptic conditions. This is quite crucial assuming that some forest stands can react in an opposite way if they are affected by high or low intensity fires (box 1), even some species show high sensitiveness to low intensity fires. As well as forest land functionality (soil and avalanche protection, biodiversity, landscape, production…) can be heavily affected or, by contrast, enhanced, according the fire intensity. In all cases the extension of the areas affected by different intensities is also important. For instance it could have important effects in the forest regrowth of species that need the seed dispersion from mature forests if the gap of forest cover disappearance is big enough, or be insignificant in the case of small gaps with mature forest surrounding them. Do not have the same effect high intensity fires in the upper zone of a watershed than in the bottom.

The risk assessment should include the potential interaction with other natural hazards linked with the forest ecosystem functionality which is strongly linked with the fire severity and its distribution inside the burnt area. This is very visible in all those effects related with the loose of forest cover and protection function (floods, avalanches, etc.) and some studies has been done at this level, for instance, assessing the wildfire impact on water supplies (Emelko and Chi Ho Sham 2014).

Adding some more difficulties, the recurrence of several events should be considered to evaluate the forest ecosystem resilience to each fire type. In fire-prone areas, some forest stands have the capacity to self-protect in high recurrent low intensity fires. Other stands needs the high intensity fire to regenerate and this is inside the natural cycle, but too often events can break the equilibrium with the perturbation.

4. Protocol for a cost-effectiveness analysis on fuel treatments at landscape level

In this chapter the common steps of a CBA (box 4) are followed including the specific considerations to undertake a CBA on wildfire risk management and fuel treatments at landscape level.

Step 1.- Set the framework for the analysis

Objective:

Definition of the program or policy change and the current status quo as well as the state of the world before implementation compared to after.

Considerations for the wildfire risk management:

Defining the base case and the proposed alternative: Several different options appear for the implementations of a CBA on fuel treatments. Two fundamental approaches are identified. Option 1 need the fire event meanwhile option 2, the question “in case of wildfire event (and kind of), which alternative is better” can be developed:

<u>Option 1. To justify the fuel treatment done in a delimitated area</u>: Here the initial scenario without fuel treatment is compared with the fire simulated scenario with the fuel treatment. Benefits understood as avoided costs (damages plus extinction) are compared with the cost of fuel treatment. This is the most basic approach, and it assumes that the fire event exists. The suppression capacity of the fire service should be simulated as well. CBA evaluates the losses caused by a forest fire with or without fuel treatment.

<u>Option 2. To discuss different strategies of wildfire risk management at landscape level (region or massif)</u>: The fuel distribution scenarios coming from different strategies of risk management (Defence, Pre-extinction, Tolerance, see chapter 2.3.2) are compared; investing in houses protection and defence, investing in fuel treatments in strategic points, investing in fuel management at landscape level and restoring the natural fire ecology in the landscape, mix of. In this option, the efficiency on wildfire risk

mitigation measured in terms of surface or severity is compared in case of a fire event. Here the consequence of applying a certain fire risk management strategy of forest management scenario is evaluated.

In both options, CBA will be affected by assessment **variables** as;

- cost of fuel treatment type implemented and maintenance choose (mechanic, prescribed burning, thinning, grazing, mix of);
- forest market condition (e.g. existence or not of a biomass market which can affect the cost of fuel treatments);
- fire recurrence (return period) and severity (estimation of potential losses);
- goods and services value (for instance, fire affecting forest land vs affecting WUI areas)

These variables can be integrated in the program design or be analysed through a variable-by-variable or scenario analysis inside the **sensitive analysis** (step 6). The sensitivity analysis should permit to be more flexible including context variables in both options.

Defining the study area: In option 1, potential fire surface according the fire patterns behaviours and the fire types should be, at least, the recommended study area of reference. Note that this area of influence has to consider all synoptic conditions that can generate a wildfire. In option 2, logically, region or massif selected should be the study area. By the way, any fire simulation needs an ignition point, and this should be located inside the area of influence of the fuel treatment.

Defining the time frame: Time frame should be as long as to recognise the fuel treatment effects as the first. Being long enough could compensate the lack of probabilistic definition of the fire event (see chapters 3.2.2.1 and 2) assuming in a qualitative probability of a fire event inside the period, although the particular ignition point cannot be established.

Step 2.- Identify the relevant project impacts

Objective:

Decide whose costs benefits should be recognized and the geographic scope of the analysis in order to limit the groups impacted by the policy.

Considerations for the wildfire risk management:

Regarding the distribution of the project impacts, at the first moment it’s very important to determine who will be the beneficiary; **social or private CBA** application (see chapter 3.1), because depending on if is a public administration or a private user, the computational cost and benefits would vary substantially. In fuel treatment and wildfire risk projects usually social CBA is recommended to integrate the environmental benefits and cost which usually are not directly perceived by the landowner in monetary terms; or the extinction cost normally assumed by the public bodies.

The **study area** definition done in step 1 will influence the set of cost and benefits to be calculated. Fuel treatment cost and benefits should be considered along all the study area. In all cases, a fire simulation will be limited in distribution (ignitions selected) and time (simulation running) and, according to this, a percentage of the potential surface will be affected, but cost of the total potential surface should be considered, independently if this is burnt or not finally. Impacts of forest fires beyond the boundaries of the study are (for instance, health problems in surrounding cities) could be considered as well.

A special attention should be put on the implicit benefits of burnt areas at landscape context for further fire events. Burnt areas will be understood as a loss at local level when has potentially positive effects at regional level reducing the potential of wildfires temporally due to the creation a mosaic of a low fuel loads.

Regarding the **time frame**, both the temporal useful life of the treatment as well as the necessary time to move from the initial scenario to the optimal conditions (final scenario) has to be considered. At least, costs and benefits should be related and evaluated within this time horizon. During the transformation period a fire event could strike forest and modify the proper transition from both scenarios.

As wide as we identify **indirect economic impacts** of a wildfire event (jobs creation, effects in other agrarian subsectors due to the land use changes or reallocation of funds from the sale of burnt wood, effects in wood industry after extra supply of burnt wood, etc.) and environmental impacts (including the extra benefits of getting fire resistant stands with more than one fire event) more able we are to integrate the social benefits of the project.

Regarding the **fire severity and ecosystem functionality** (see chapter 3.2.2.3), it is recommended to evaluate how many different low and high intensity wildfires could happens during the initial and final scenarios, and which impacts (negative and/or positive, see box 1) will rebound to our forest structure and the next fuel treatment planned (within the transformation cycle or the maintenance one). When comparing forest management scenarios including resistant stands to high intensity fires, it is recommended to simulate more than one fire event to highlight all the benefits of the fuel management (resistant stands will survive to several fire events in front on unmanaged dense forest stands for instance).

In the case of wildfire, **uncertainty** is affecting the identification of the project impacts, among others, as follow;

- The lack of sufficient, comparable and reliable data, especially in terms of suppression cost and post damage data, especially when the efficiency of the fire services has increased in recent years.
- The spatial and temporal distribution of wildfire event (developed in chapter 3.2).

- The knowledge of all potential impacts and those corresponding to different fire intensities and recurrence, especially in an increasing trend of wildfire risk and desertification processes.
- The change context of risk due to the global change (land use and climate change), which makes difficult to assume the previous (also in terms of fire behavior and, therefore, simulation) as a rule for the future.

According the ***additionally*** cost and benefits, special care should be done in the accountability of the suppression cost, distinguishing only that extra cost generated by the fire event. Suppression cost can be assimilated as *sunk costs*, which are those costs that would exist both with and without the project. Therefore, a proper identification of when the suppression cost start is necessary.

Step 3.- Quantification and monetize cost and benefits

Objective:
Assess how costs and benefits will change each year making sure to place all costs and benefits in the same unit.
Considerations for the wildfire risk management:
One of the main difficulties will be how to monetize the environmental services without market price. This is especially relevant in wildfire risk management strategies as forest policy is usually justified for the benefits that forest land are offering to society. Some indirect estimation can be calculated with the called environmental economics, but at the end, they are only estimations. Only those prices recognized by the market or, that could be recognized by the justice in a lawsuit will have, at the end, enough robustness to stand a decision at policy-making level.

An alternative to give a value to the environmental services is to move from externalities to functionality, focusing the attention to the forest cover or forest land functions in terms of protection, recreation, landscaping, water production, etc. Common examples affecting burnt areas could be; indirect cost of soil restoration after forest cover protection loss (especially in watershed valleys); loss of visits of tourists in restaurants and hotels …; loss of incomes coming from hunting; decrease of water supply or water quality, etc…

Some specific considerations to have into account dealing with wildfire risk management are as follow:

- When calculating the **inflation**, consider the relative prices of forest and other agrarian products, which not always increase over time.
- Take into consideration the taxes and how they are affecting the **shadow prices**, as usually taxes are often present in fuel treatment activities (grazing, forestry, etc.). Calculations in the sensitivity analysis (step 6) can be done with or without shadow prices.
- Separate clearly extra cost from the **sunk cost**, which are those that would exist both with and without the project. Most of emergency costs are inside the sunk costs.

- Efficiency in fire suppression is clearly affecting the **marginal vs. average costs and benefits** (suppression cost per hectare usually will be much higher in small fires than large ones). To create a suppression cost per surface intervals (for example, 0-1ha, 1-5ha ...) is recommended.

Step 4.- Discount costs and benefits

Objective:

Methodological step to convert future costs and benefits into present value. It generally ranges between 2-7%.

Considerations for the wildfire risk management:

Logically, as more long is the time reference of the analysis, more uncertainties regarding the social discount rate appears. Fuel treatments at landscape level especially in the restitution strategies takes time as the forest management results easily need some decades to be visible (for instance, converting high vulnerable uneven-age dense stand to less vulnerable open even-aged stands). As was mentioned in step 3, common inflation not always applies in forest products. The majority of studies regarding disaster risk reduction are using discount rates of 10-12% (Shreve and Kelman 2014).

Step 5.- Calculate the CBA performance indicators

Objective:

Compute indicators subtracting costs from benefits.

Considerations for the wildfire risk management:

Obviously, CBA indicators will be sensitive to the intrinsic value of those goods and services to be protected. Therefore, CBA applied to wildfire risk management will show high differences when dealing with wildland urban interface areas and forest land areas. For these reason, a correct appraisal of the forest land values is necessary to not underestimate the importance of the investments in non-urban areas.

When relevant impacts cannot be expressed in market price an alternative is limiting the approach to a cost-effectiveness assessment or Multi Criteria Assessment (see chapter 2.1). Considering the effects of the wildfires in the environmental services and social welfare, this will be, in some cases, the best choose. In all cases, although CBA is undertaken for those goods and services with market price, is recommended to list the qualitative social and environmental cost and benefits.

Step 6.- Perform sensitivity analysis

Objective:

To check the accuracy of your estimates and assumptions.

Considerations for the wildfire risk management:

Beyond the discount rate, the sensitive analysis also permits to modify the context assessment variables regarding, for instance, the market of forest products, established in step 1. The existence or not of a market for the biomass, for instance, or the tendency on the biomass price will influence the final cost benefit ratio. In case of long term policies for the fuel treatment the inclusion of context variables in the sensitivity analysis is recommended. Some uncertainties related the climate change scenarios can also be analyzed at this stage.

Step 7.- Make a recommendation

Objective:

Assess all results and account for other qualitative considerations.

Considerations for the wildfire risk management:

Typically, CBA and economic efficiency considerations should not be the sole criterion for evaluating policies, but rather be part of a larger decision –making framework respecting social, cultural, environmental and other considerations (Mecheler 2005). One recommendation is to integrate the CBA into a Multi-Criteria Analysis to address the qualitative variables, such as social and environmental benefits and losses joint together the CBA indicators calculation (step 5).

Main weakness for undertake a CBA over fuel treatment management at landscape level is the assumption of the fire event, as their occurrence is difficult to prevent in terms of recurrence and surface from a stochastic perspective (see chapter 3.2.2.1 and .2). In any case, the results of the analysis are offering complementary information for the policy makers "in case of". At least, the qualitative estimation of a landscape to be burnt should be argued, although the particular site or zone, particular date or period and particular likelihood or period range cannot be totally defined. In terms of general probability, the two main drivers affecting and increasing the level of risk; climate change and land use changes, should be discussed as future tendencies can support policy making decision process.

5. Conclusions

General conclusions can be outlined from all previous consideration of the CBA methodology applied in fuel treatment planning:

- CBA would be desirable to be integrate into wildfire risk mitigation projects, just as environmental impact is nowadays routinely conducted when new investments projects are undertaken.

- Natural disaster risk should be incorporate into CBA in a probabilistic manner (i.e. data on probability distribution of disaster need to be obtained), although it should never be forgotten that the cost-benefit analysis natural hazard risk reduction measures concerns the future. And it is well known that predicting the future is difficult, even with the most sophisticated scientific analysis. Therefore uncertainty is inherent in this process; hence we must proceed with caution.

- The most important handicap to carry out a fuel treatment CBA, in comparison with other natural hazards as floods, is the lack of probabilistic projection with regards at the spatial and temporal definition and distribution of the potential wildfire event (and, consequently, its affectation).

- The lack of information describing forest benefit outputs and values and their sensitivity to wildfires severity and fuel treatment is an important obstacle to cost-benefit analysis of fuel treatments. Cost and benefits assessment should comprise how they change depending on the fire intensity and recurrence, as well as, the long term benefits of resilient or resistant landscapes able to change the fire behavior and impacts.

- Despite all the difficulties and limitations conducting a fuel treatment CBA is strongly recommended at least to show the efficiency of the investments and/or estimate the economic consequences of inaction in front of the risk management. Proper capacity of fire event simulations integrating fire behavior patterns and fire type's knowledge is needed to adjust the assessment as much as possible to real projections.

- The expected value of net benefit resulting from fuel treatment will most likely be positive when combinations of the following conditions exist:
  - Timber and non timber forest benefit are high and would be significantly and adversely affected by wildfire for long periods
  - Potential costs resulting from wildfire, including suppression, restoration and property damage, are high and would be significantly reduced by fuel treatment.
  - The effects of fuel treatment in reducing potential benefits losses and wildfire costs and reducing wildfire threats are relatively lasting.
  - Fuel treatment costs are relatively low, but treatment significantly reduces wildfire threats.

- CBA represent a useful tool especially when the functionality of the environmental services can be dimensioned, in terms of gain or loss under the hazard, chiefly when this functionality (e.g. soil protection, snow avalanche protection…) has to be replaced by human actuations (e.g. artificial barriers) to ensure the safety of human infrastructures at risk.

- To deal with uncertainties regarding the wildfire risk management due to the land use and climate change as well as the influence of socioeconomic context in the long time frames of fuel treatment management policies, special efforts should be done describing the context and including scenarios in the CBA.

- Quantitative valuating should be complete with the qualitative valuating of non-market price environmental and social services through a cost-effectiveness or multi criteria assessment, to support decision makers when integrating cost assessment process into their decision making process.

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