Smart-solutions for wildfire risk prevention: bottom-up initiatives meet top-down policies under EU Green Deal

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Abstract

Wildfire risk prevention through fuel management generally lack of economic sustainability. In marginal areas of southern Europe, this limits fire prevention programs to reach the critical mass of interventions required to modify landscape flammability, the fire regime and its impacts.

This study investigates key fuel management initiatives for wildfire risk prevention in southern EU countries. We compared local approaches through bottom-up selection of 38 initiatives, which we analysed systematically through a set of criteria: sustainability, cost-benefit ratio, synergies and inter-sectoral cooperation, integration between strategic prevention planning and multiple land governance goals (e.g. civil protection, biodiversity conservation), innovation and knowledge transfer, and adaptive approach.

We summarized lessons learned from the most innovative initiatives, by identifying solutions and models for building sustainable fuel management at the landscape scale, under integrated wildfire management principles. We came to define "smart-solutions" for wildfire prevention. These make a synergistic use of private, public and European resources to activate value chains that valorise the products, and take advantage of by-products and services generated by fuel management activities and their positive externalities on ecosystem services. These mechanisms catalyse the interest of multiple stakeholders (economic actors, private consortium, land and fire management agencies) improving the cost-efficiency of landscape fuel management.

We contend that the EU Green Deal offers the political backing and enabling framework (mainstreaming of EU strategies and funding opportunities) to boost the replication of the smart-solution model for wildfire risk prevention, but multi-actor and cross-sectoral cooperation between stakeholders will be a critical asset for the local implementation.

Keywords: "wildfire risk prevention", "fire resistant and resilient landscapes", "fire smart", "fuel management", "EU Green Deal", "bioeconomy"

1. Introduction

In Europe, there is general agreement for a wildfire risk management change towards cause-oriented policies (Tedim et al., 2016; Moreira et al., 2020), with a holistic perspective integrating prevention, preparedness, response and recovery (Rego et al., 2010; Bacciu et al., 2022). A major goal is to foster fire-smart territories (Tedim et al., 2016): high fire risk territories in which socio-economic activities and related land uses concur directly (e.g. strategic fuel management to improve suppression capacity) or indirectly (e.g. fuel reduction through extensive livestock) in limiting wildfire impacts, while obtaining benefits for ecosystem services and local economic development (Fernandes, 2013a; Varela et al. 2020).

The European Commission is currently pursuing multiple strategies with enormous implications on wildfire risk prevention and the capacity of building fire-smart territories (FST). The Bioeconomy strategy (European Commission, 2018) aims to make production chains sustainable, greening industrial products and promoting renewable resources, enhancing the active role of forests (Baskent et al., 2021; Jonsson et al., 2021). Wildfire risk prevention might greatly benefit from this strategy, thanks to incentives to sustainable wood and non-wood products mobilization and active land management in high fire risk areas (Verkerk et al., 2018). The EU Bioeconomy strategy is framed within the EU Green Deal objectives, which set out the roadmap for making the EU economy sustainable and climate-neutral by 2050 (European Commission, 2019). The EU Green Deal acts as a container for other EU strategies, i.e. Biodiversity Strategy (European Commission, 2020a), LIFE programme[1], Green Infrastructure (European Commission, 2013), Farm to Fork Strategy (European Commission, 2020b), EU Strategy on Adaptation to Climate Change (European Commission, 2021a), and the Forest Strategy (European Commission, 2021b), which can be implemented in synergy to set in motion mutually beneficial cooperation around wildfire risk prevention. Europe also provides incentives for land management, useful in the territorial planning of wildfire risk mitigation. Rural Development Programs (RDPs)[2] include, for example, many measures directly connected to wildfire risk management, such as sub-measures 8.3 (prevention of damage from wildfires) and 8.4 (restoration of damage from wildfires), or indirectly connected such as 4.3 (modernization of agriculture and forestry), and 8.5 (investments for forest resilience) of the RDP plan 2014-2020. These European strategies, together with investments for research and innovation, such as Horizon 2020[3], are the tools for achieving the EU Green Deal objectives and emerge as important repositories of resources for building FST.

Although European policies embody great potential for the transition process towards FST (Wunder et al. 2021), there are many difficulties to implement them at local level (Tedim et al., 2016). Indeed, local policies often encounter multiple constraints and limitations in adopting a cross-sectoral and multilevel vision, which

[1] https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.getProjects&themeID=49&projectList
[2] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development_en
[3] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-gd-1-1-2020

complicates a transdisciplinary approach to wildfire risk management that would be able to maximize synergies and to make optimum use of EU resources. For example, one major limitation is the complexity of landscape governance in rural areas due to ownership (i.e., different land tenure rights in private and public lands, ownership fragmentation) (Twidwell et al., 2019), or because of conflicts in land development goals, often torn between static conservationism and active land management (Kovac et al., 2018). Major constraints include the fragmentation of competences and responsibilities across multiple fire and land management agencies, and private owners (Fernandes et al., 2020), and lack of economies of scale necessary for reaching economic sustainability in fire hazard reduction at the landscape-scale, hindering investments, particularly in marginal lands (Azevedo et al., 2011; Pereira and Navarro, 2015; Sil et al., 2019).

Despite constraints, noteworthy local initiatives have been recently emerging in fire-prone landscapes of southern Europe, with the ability to create synergies among bottom-up needs and top-down policies, so as to intelligently plan and implement sustainable fuel management programs and nature-based solutions in coherence with rural development, spatial planning, and risk mitigation goals (Tedim et al., 2016; Varela et al., 2020; Colonico et al., 2022). These grassroots initiatives uncover opportunities to make the best use of funding and multi-actor private/public cooperation to set in motion processes leading to FST. Hence, we identified the need to mainstream these local innovative approaches through bottom-up selection. In this study, first we research and select a set of relevant fuel management programs for wildfire risk prevention in southern EU countries. We next analyse, extract and summarize lessons learned from best and most innovative initiatives, identifying solutions and models for building sustainable fuel management processes at the landscape scale, based on principles under the Green Deal paradigm and a synergistic use of private, European resources and integrated wildfire risk management principles.

2. Wildfire prevention initiatives selection

2.1 Identification of wildfire prevention initiatives

Initiatives search started by identifying agencies involved in wildfire prevention programs in Greece, Italy, Portugal, and Spain, i.e., among EU countries most exposed to wildfire impacts (Moreira et al., 2020), and where many diversified wildfire prevention programs are in place (Varela et al., 2020). The responsibilities of wildfire prevention lie with different organisations in each country, based on national legislation and regional governance structures (San-Miguel-Ayanz et al., 2021). Accordingly, we made a survey of the public agencies involved in fuel management programs in each country based on best available knowledge. In total, we contacted 67 agencies (Table A.1). Through a refined consultation process of agencies' personnel, we identified relevant wildfire prevention initiatives at the local level and key responsible persons for each initiative.

In order to harmonize the data collection, we designed a common survey template to interview responsible persons in charge of each initiative. The survey covered a wide spectrum of information: initiative promoters, activities implemented according to the Disaster Risk Management (DRM) cycle (Prevention, Preparedness, Response, Recovery) (UNISDR, 2009), and funds supporting fuel management (private investments, local/regional funds or EU funding scheme, e.g., Life Programme, RDPs). Within the DRM, in the prevention stage, the survey distinguishes actions directly addressing wildfire risk (i.e., planned and implemented with the main goal of reducing wildfire spread capacity) and those activities indirectly affecting wildfire risk through fuel reduction at the landscape level (e.g. agro-forestry, grazing). The survey included a section with a set of open-ended questions about the type of fuel management activities, their limitations and needs of improvement for efficient wildfire risk reduction, indicators to assess and monitor prevention effectiveness, and additional details. These topics were the basis to select relevant initiatives and carry out a swot analysis on a subsample of initiatives. The format of the survey, and all compiled forms, are available on the website of the Prevail project[4], which has been funded by the EU Civil Protection Mechanism Program for demonstrating the close link between fuel management, preparedness and response to wildfire.

2.2 Analysis criteria to select fire prevention initiatives

To analyse selected initiatives and extract best strategies and lessons learnt, we identified five criteria, and sub-criteria (Table 1), which are key elements for building FSTs (Tedim et al., 2016): (i) sustainability, (ii) cost-efficiency in risk reduction, (iii) synergies and cooperation, (iv) knowledge exchange and transfer, and (v) adaptive management. These criteria were considered essential as they include multiple needs addressed in the above-mentioned European strategies (e.g., Bioeconomy, Biodiversity, Forest), while meeting wildfire prevention requirements.

Survey interviews were analysed to assess to what extent selected initiatives fulfilled the above-mentioned criteria and sub-criteria (Table 1) and highlight best and innovative solutions for creating FSTs. For each initiative, the representation of each criterion was evaluated using a score from "Not at all represented" (0) to "Totally represented" (4). This assessment served to show up to what extent an initiative might fulfil most of the criteria or be strong in some of them. By evidencing the most represented criteria and the implemented actions in each initiative, we assessed its "readiness level", regarding its potential for broad implementation in the frame of sustainable wildfire risk management.

Finally, a SWOT analysis was carried out to identify initiatives strengths, weaknesses, opportunities and threats on a subsample of initiatives. A set of key characteristics were analysed: economic feasibility, stakeholders involvement, legal frame, social and environmental awareness.

[4] https://www.prevailforestfires.eu/wp-content/uploads/2021/04/4.2.pdf

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147 ***Table 1.*** *Criteria and sub-criteria adopted to assess wildfire prevention initiatives.*

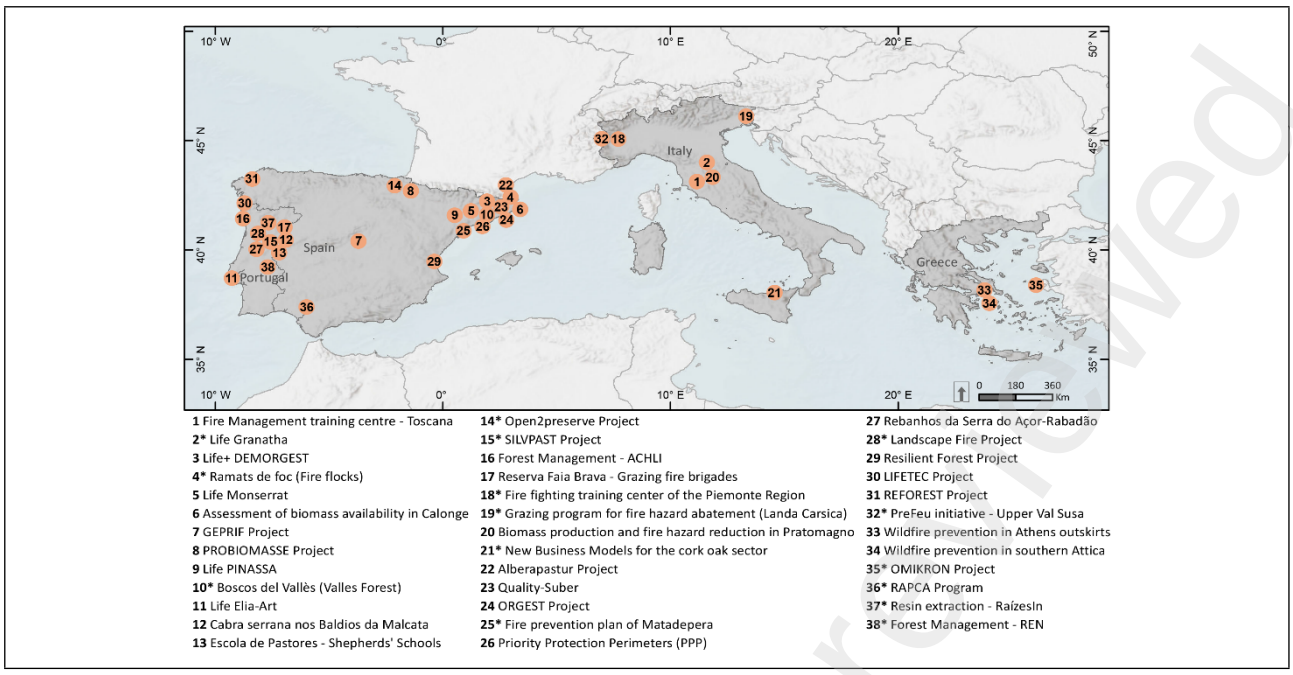
Criteria	Sub-criteria	Description
Sustainability	**Circularity**	Resource-efficient valorisation of agro-forestry products (biomass, wood, livestock, etc.) resulting from fuel management in integrated and multi-output production chains, sustaining fire hazard reduction while benefiting the local economy, involving multiple sectors under a fire management vision, and producing positive self-feeding cycles.
	Short supply chain	Local supply chains of primary and secondary products resulting from fuel management programs, including a marketing strategy that valorises the regulation of ecosystem services delivered by the wildfire risk reduction.
	Biodiversity conservation and fire ecology restoration	Coherence with environmental conservation under EU Biodiversity strategy (e.g., Natura 2000 sites), enhancing the maintenance of ecosystem services. The selection of fuel management techniques and their spatio-temporal planning are based on the ecological understanding of ecosystem dynamics in current and desirable fire regimes.
	Social sustainability	Fuel management programs with a strong social component, involving local communities in landscape management and valuing community choices in pursuit of shared goals. Management activities derive from local needs and their outcomes produce benefits to the community. Local community information and training in risk management and participatory processes involves multiple social components.
Cost-Efficiency in Risk Reduction		Initiatives showing cost-benefit/efficiency criteria both in terms of market price and/or environmental and social services. Funding not directly related to fire management converges on it, optimizing cost-effectiveness. Similarly, land management activities not directly related to fuel management can be planned to support fire prevention and reduce subsequent costs of preparedness, response and recovery actions.
Synergies and Cooperation	**Source of funding**	Integration of multiple funding sources (both local and European) in fuel management programs allowing for a wide range of wildfire risk management actions. Multiple funding denoting high continuity in local land management, allowing for constancy in the management of fire-prone landscapes. Additional funds from those who get benefits from wildfire risk reduction (including private actors) are mobilised.
	Integrating multiple land management goals	Multidisciplinary approach and presence of shared land management goals involving different actors in the wildfire risk management program, maximizing efforts and diversifying solutions in risk management. The convergence of multiple goals allows for a cross-sectoral and multidisciplinary approach that generates coordination among different actors and integrates different strategies into wide-ranging projects.
	Participation and good governance	High level of cooperation at the local level considering the community as a central node. Exposed population and economic sectors are included in the risk planning process, and a shared vision about each one's role on risk reduction is achieved, meanwhile risk awareness and culture are promoted. Communication is maintained with local communities to track long-term fire prevention effects.

Knowledge exchange and transfer		Best knowledge is mobilised and capitalized in cooperation with research and development institutions, and knowledge transfer to the actors involved in risk reduction strategies is promoted, empowering them. Implementation of advanced fuel management techniques, traditional practices and nature-based solutions (e.g., variable retention harvest, prescribed burning, prescribed grazing, etc.) is promoted.
Adaptive management	**Impact assessment**	Use of indicators and monitoring programs to evaluate fire prevention effectiveness in the short/mid term considering both the environmental (fire regime change, ecosystem maintenance) and the socio-economic component (local production, security), assessing these impacts at the landscape scale.
	Lesson learnt approach	Implementation of a lessons learned approach incorporating best results and failures of action implementation, making them robust and sensitive to local conditions and regional contexts that benefit from other similar experiences.

3. Description of wildfire prevention initiatives

The survey identified 38 initiatives (Fig. 1) fulfilling at least one or more key evaluation criteria (Table 1). Initiatives covered a wide range of southern European landscapes and fire regimes, from the Alpine region with a continental climate, where wildfires typically occur during autumn-winter (from October to March) (Valese et al., 2014), to the Mediterranean region, characterised by prolonged dry periods and fires concentrated in summer (Moreira et al., 2020). Some initiatives in Atlantic and Continental biogeographical regions were examined also. The survey included both coastal and inland areas, in order to give a view as comprehensive as possible of the contexts where fire risk reduction is applied. In Spain, 17 initiatives were identified (45% of total initiatives), 11 in Portugal (29%), 7 in Italy (18%), and 3 in Greece (8%) (Table A.2).

More than half of initiatives (60%) were carried out by public agencies, and 40% by private ones (Fig. 2). Public actors were predominant in Italian and Spanish initiatives, whereas private agencies in Portuguese and Greek ones. In terms of funding programs, initiatives have been financed by regional, national, and European funds, mainly from the Life and Rural Development Program (RDP), and other forms of funding related to private investments (Fig. 3a). Concerning the Disaster Risk Management phases, Direct Prevention (85%), Indirect Prevention (80% overall, see Table A.3) and Preparedness (50%) were the dominant phases with implemented activities across initiatives. The most represented indirect prevention activities were those dedicated to maintaining the landscape mosaic, including agriculture, grazing and forestry production. On the other hand, Response activities were the least represented (only present in 4 initiatives), followed by Recovery activities (7 initiatives) (Fig. 3b).



169 ***Figure 1.*** *Selected fuel management initiatives in southern European countries fulfilling one or more key*

170 *criteria (Table 1). Stars associated to initiative id indicate those programs described in detail in Table 2.*

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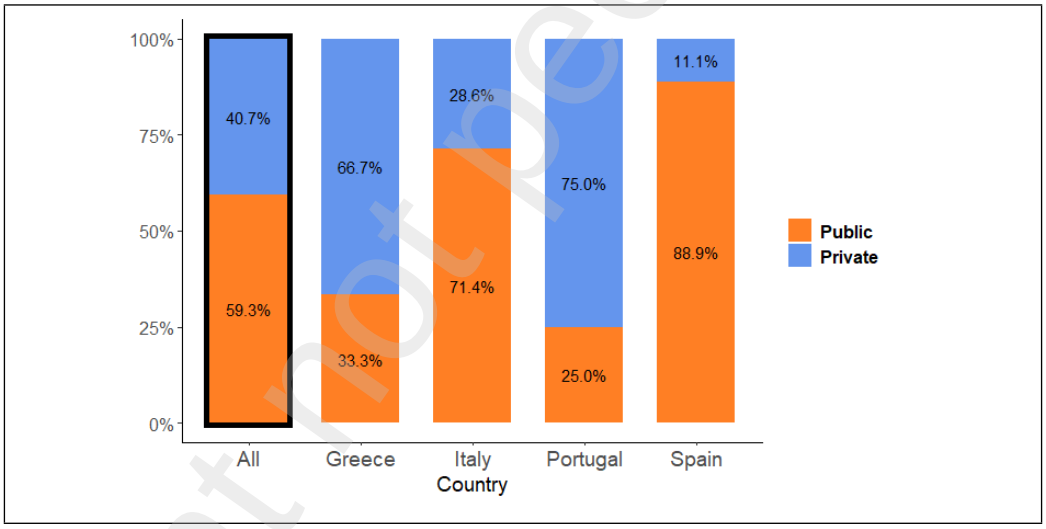

172 ***Figure 2.*** *Promoters (public/private agencies) of the 38 fuel management initiatives.*

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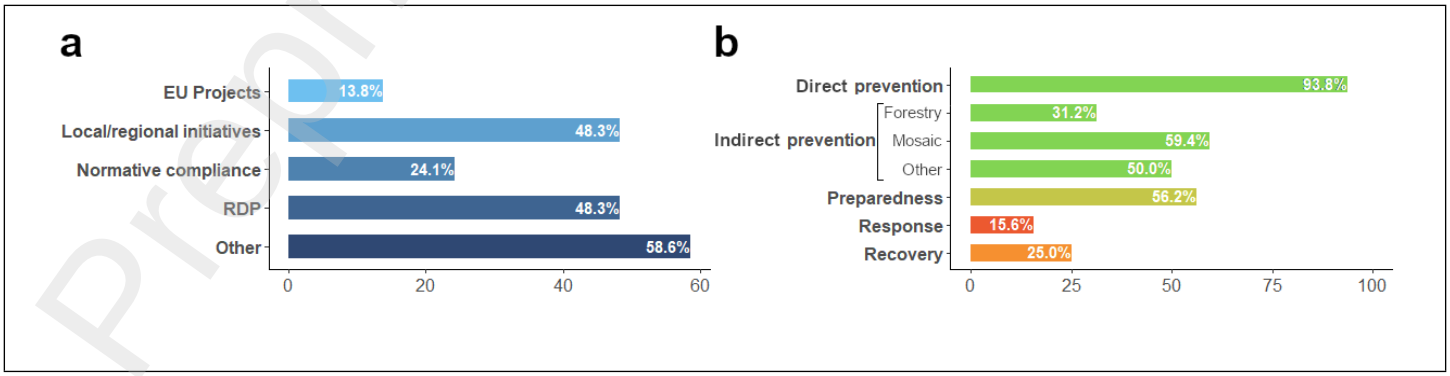

174 ***Figure 3*** *– Source of funding (a) and DRM cycle phase covered (b) for all 38 fuel management initiatives.*

The selected initiatives were analysed according to the average of the scores (from 0 to 4) assigned to each of the 6 evaluation criteria Table 1). As summarized in Fig. 4, most of the criteria received a score between 2.2 and 2.4 points, on average. The cost-efficiency ratio showed lower values (1.4 points on average) while the average score assigned to Adaptive Management was the lowest (0.4). The surveys and individual sheets of each initiative are available on the PREVAIL project website[5]. The overall ranking and the specific scores assigned to each criteria are available in Table A.3.

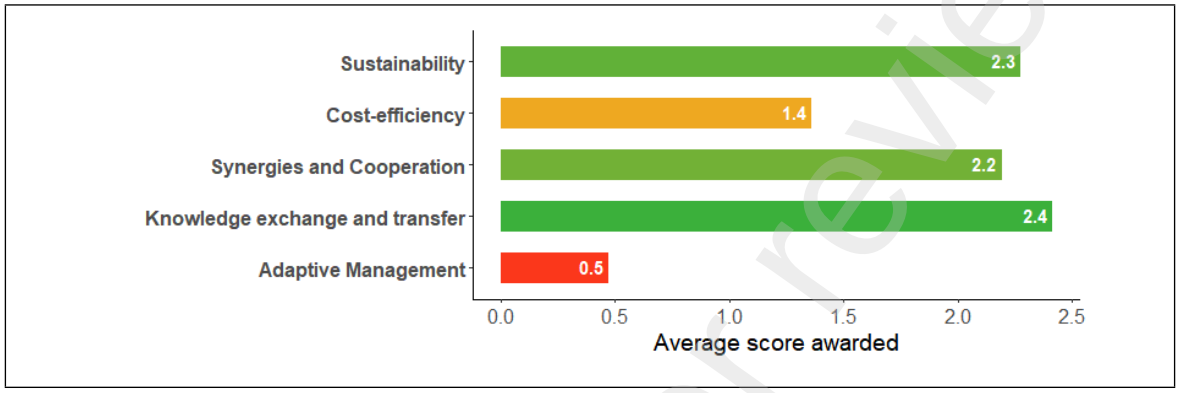

Figure 4. *Average score assigned to the 6 criteria shown in Table 1, used to rank the 38 fuel management initiatives.*

Table 2 shows information of the most ranked initiatives, including their name, the Environmental Zones (Metzger et al., 2005, 2012), the Köppen-Geiger climate classification according to Beck et al. (2018), description of the fuel management activities that contribute to wildfire hazard reduction, social and environmental services provided and actors involved. Management of vegetation fuels includes several fuel management techniques such as prescribed grazing with bovine, goat and sheep (Lovreglio et al. 2014), silvicultural treatments (e.g., variable retention harvest, selective thinning, prescribed burning), and mechanical clearings (Corona et al., 2015). Fuel management is carried out in strategic areas defined by specific municipal to regional fire prevention plans. Strategic areas may be: (i) fuel break networks planned to support firefighting according to the expected behaviour of recurrent large-fires (Costa et al., 2011); (ii) forest blocks where the need to increase the resistance and resilience of ecosystem services to fire disturbance is prioritized (e.g., protection from soil erosion, direct protection of infrastructures exposed to rock falls, recreational use) (Ascoli et al., 2018); and (iii) wildland-urban interface areas to protect sensitive residential, service or production areas (Elia et al. 2014).

Table 3 reports the results of the SWOT analysis, which allows to visualise strengths, weaknesses, opportunities and threats for the application of the selected wildfire risk prevention initiatives.

[5]PREVAIL project Deliverable 4.2, https://www.prevailforestfires.eu/project/dissemination/

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201 ***Table 2.*** *Description of a selected subset of the most ranked fire prevention initiatives.*

Initiative ID *(as in Figure 1)*	**Initiative name**	**Environmental zone**	**Climatic classification**	**Contribution to fire hazard reduction**	**Activated chain and social/environmental services**	**Cooperation actors**
2	LIFE Granatha	Mediterranean mountains *[Italy]*	Temperate, no dry season, hot summer (Cfa)	Biomass and shrub cover reduction in scrubland through mechanical cutting, prescribed burning and grazing in fuel breaks and blocks.	Production and marketing of organic brooms made of *Ericaceae* (the "granatha"). Bird species and habitats (4030) conservation. Training of fire-fighting operators (AIB).	Fire-fighting operators of Toscana region (AIB), local farmers and producers.
4	Ramats de foc (Fire flocks)	Mediterranean mountains *[Spain]*	Temperate, no dry season, warm summer (Cfb)	Reduction of herbaceous and shrub biomass by grazing (horses, goats, sheep) in strategic areas for wildfire prevention.	Dairy products and beef, goat and sheep meat under the 'Ramats de Foc' label (Figure 5), which unites local farmers, butchers and restaurateurs.	Municipalities, private landowners, local farmers, Fire Service.
5	LIFE Montserrat	Mediterranean North *[Spain]*	Temperate, dry summer, hot summer (Csa)	Fuel management in strategic areas through grazing and prescribed burning. Ecosystem-based measures to increase resilience and stability of forests against fires.	Supply chain of dairy, beef, goat and sheep meat products under the 'Can Mimó' label. Biodiversity and habitat conservation and improvement. Creation of a mosaic landscape to decrease fuel connectivity.	Regional Government, Forest Owners association, a Private foundation, Natura 2000 sites, Natural Park Board, Fire Service, Municipality.
7	GEPRIF Project	Mediterranean North *[Spain]*	Temperate, dry summer, hot summer (Csa)	Generation of scientific and technical information regarding fuel management, actions and opportunities of extinction activities, as well as post-fire recovery processes, within the framework of sustainable forest management.	Increase the effectiveness of forest treatments to reduce the severity of fire in ecological terms.	Research institutions and public administrations.
10	Boscos del Vallès (Valles Forest)	Mediterranean North *[Spain]*	Temperate, no dry season, hot summer (Cfa)	Fuel control through biomass reduction, sustainable forest management, wildfire prevention infrastructures	Biomass buying-selling market for small and big biomass consumers (private, hospital, university, etc.), generation of proximity energy.	Municipalities, County council, Forest Defence Association (ADF), forest owners, forest research centres.
14	Open2Preserve Project	Lusitanian Mediterranean North *[Portugal and Spain]*	Temperate, dry summer, warm summer (Csb)	Minimize the wildfire risk in open mountain areas of high environmental value by performing fuel management through grazing (sheep and horses) and mechanical treatments.	Provide a replicable landscape management model to rural actors and disseminate it through training courses and participatory meetings.	Local agriculture and forest producers, universities.
15	SILVPAST Project	Lusitanian *[Portugal]*	Temperate, dry summer, hot summer (Csa)	Fuel management through grazing (cows and horses), remote sensing monitoring (drone and gps collars), biodiversity monitoring and conservation, support decision-making.	Increase *Quercus pyrenaica* forage for animals, helping landowners save money on animal feed.	Forest owners and managers, landowners, policy makers (from local to the national level).

18	Firefighting training centre of the Piemonte Region	Mediterranean mountains / Alpine South *[Italy]*	Temperate, no dry season, warm summer (Cfb)	Training programs in firefighting and prescribed burning techniques, fuel management along fuel breaks in strategic areas through prescribed burning and grazing management, grass and shrub cover reduction assessment.	Fuelbreak cleaning for cows' transit and touristic activities (trekking and skiing).	Regional authorities, a private enterprise, Fire brigades volunteers and operators, local farmers and community.
19	Grazing program for fire hazard abatement (Landa Carsica)	Mediterranean mountains / Alpine South *[Italy]*	Temperate, no dry season, hot summer (Cfa)	Fuel management in strategic areas through prescribed burning and grazing (sheep). Restore pastures' productivity.	Land assignment to local farmers, value chain of products from grazing (meat), sheep breeding for didactic ends.	Private landowners, "Landa Carsica" business network of local farmers.
21	New Business Models for the cork oak sector	Mediterranean South *[Italy]*	Temperate, dry summer, hot summer (Csa)	Biomass and shrub cover reduction with mechanical cutting in *Quercus suber* woods.	Production of semi-processed products for bio-building, cork-based panels and granulates. Use of the resulting biomass for factory heat. Cork forest restoration (habitat 9330).	Private agencies, universities, local cork producers.
25	Fire prevention plan of Matadepera	Mediterranean North *[Spain]*	Temperate, dry summer, hot summer (Csa)	Fuel management through grazing (goats and sheep), sustainable forest management, biodiversity conservation.	Employment and agricultural management to feed livestock, proximity market line for cattle products (meet).	Natural Park board, Association of Forest Defence (volunteers), Municipality, farmers, shepherds and local producers.
27	Rebanhos da Serra do Açor-Rabadão	Lusitanian *[Portugal]*	Temperate, dry summer, warm summer (Csb)	Maintenance of the primary firebreaks network and fuel management around the local town through goat grazing.	Dairy goat products. Eucalyptus and conifers forest plantations preservation. Community interaction in a pedagogical perspective through visits.	Local farmers, forestry producers, Municipality, local community.
32	PreFeu	Alpine South *[Italy]*	Cold, no dry season, warm summer (Dfb)	Variable retention harvest to increase forest stand resistance in priority areas for ecosystem services maintenance.	Local supply chain of wood products for small to medium biomass consumers, construction timber, and wood design products (e.g., Mompantable – Figure 5).	Consortium for management of public forests in Upper Susa valley, municipalities, private forest owners, local forestry enterprises, architectural designers.
35	OMIKRON Project	Mediterranean South *[Greece]*	Temperate, dry summer, hot summer (Csa)	Forest fuel management (biomass removal, pruning, forest roads), development of fuelbreaks and initial attack firefighting interventions.	Population sensitization and education, learning-by-example procedure, fire prevention patrols.	OMIKRON Association and volunteers' team, Municipality of Chios, Fire Service, Forest Service, Chios region.
36	RAPCA Program	Mediterranean South *[Spain]*	Temperate, dry summer, hot summer (Csa)	Fuel control and biomass removal in fuel breaks through grazing (sheep, goat).	Maintenance of fuel breaks, payment for environmental services (fire prevention) to local shepherds.	RAPCA staff, local shepherds, extensive farms, forest managers, local municipalities, environmental NGO representatives, researchers.

37	RaízesIN	Lusitanian *[Portugal]*	Temperate, dry summer, warm summer (Csb)	Resin extraction in pine forest stands (common land areas), fuel management and fire detection.	Territorial enhancement through fuel management (indirect prevention) and constant surveillance (active prevention) in the peak of the fire season.	Municipalities, Commoners, Universities.
38	REN	Lusitanian *[Portugal]*	Temperate, dry summer, hot summer (Csa) or warm summer (Csb)	Vegetation management and forest defence against fires in electricity and gas easements	Maintenance of fuel breaks, increase biodiversity, network of green infrastructures through reforestation with native species.	Landowners, commoners

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204 ***Table 3.*** *SWOT matrix for nature-based smart solutions implementation to achieve FSTs.*

Strengths	**Weaknesses**
▪ Convergence towards multiple land management goals maximising cost-benefits ▪ Increasing recognition of fuel management as a civil protection tool, protecting strategic buildings and Wildland Urban Interface areas ▪ Policy demand for integration of the DMR cycle phases (Prevention, Preparedness, Response) increasing fire management effectiveness (e.g. Sendai framework) ▪ Potential alignment among wildfire risk reduction through direct and indirect prevention and the maintenance and promotion of existing mosaic landscape and sustainable forest management ▪ Several fuel reduction options through multiple well-known techniques (prescribed burning, prescribed grazing, silvicultural treatments) ▪ Diversity of initiatives with high level of adaptation to the complexity, cross-sectoral, spatial and temporal extension of wildfire risk management ▪ Existing non-wood and wood production in public and private forests and forest products value chains in many territories (bioeconomy and green energy) ▪ Compatible combination of wildfire risk management actions with nature conservation ▪ Recognition in official EC documents the need of having resilient landscapes to face wildfire risk reduction	▪ Segmentation of competences in wildfire management hampers coordination and the building of a common strategy ▪ Limited budget and lack of human resources to implement the actions needed ▪ Excess of bureaucracy (legal processes related to some instruments, plans or actions to be developed) ▪ Non-economic viability of some local activities (e.g., low market value of products) ▪ Lack of investment capacity in rural areas and poor value change of forest products ▪ Lack of operational tools and guides adapted to local conditions ▪ Lack of legal mechanisms to involve beneficiaries of ecosystem services - wildfire prevention (private sector, such as tourism) to its provision (e.g., poor PES development regarding risk mitigation) ▪ Operational and administrative difficulties (legal, data access, permissions, etc.) in managing fuels according to strategic planning within private forest ownerships ▪ Lack of resources and skills to undertake participatory processes within wildfire risk top down planning

Opportunities	Threats
▪ Cooperation between international partners and local actors, and within communities under a common goal approach (protection of lives, protected areas, landscapes and economies) ▪ Increase of capabilities, training and knowledge of Fire Service professionals ▪ Contribution of several EU projects provide innovation and transferability among regions under common challenges ▪ Increased risk awareness (communication actions to society, environmental education, etc.). ▪ Contribution to decrease land abandonment ▪ Promotion of local economies and development of marginal territories, through either ecotourism, recreational activities or new business models ▪ Foster the use of forest, agricultural and grazing products (promotion of bioeconomy and circularity within EU policies) ▪ Development and certification of local short supply chain ▪ Increasing awareness and policy support to the need of development and maintenance of wildfire prevention infrastructure (increasing hazardous conditions due to climate change) ▪ Experimental areas for reforestation after fire ▪ Preparation and implementation of annual Forest Fire Protection Plans ▪ Societal valorisation of the green and urban infrastructure ▪ Increasing social understanding of the root causes of wildfires in the Mediterranean ▪ Social valorisation of short-value chains and proximity products ▪ Social worry and attention towards wildfire risk ▪ Requirement for climate change adaptation actions according to sectoral policies (EC adaptation strategy)	▪ Aging and lack of generational turnover in rural areas ▪ Limited capacity of engagement involvement of private forest owners to contribute with their land to extend fuel management actions and reach an economy of scale ▪ The need to move forward on prevention policies should not reduce the efforts also needed to maintain a strong suppression service ▪ Lack of implementation and traceability of wildfire prevention plans and forest management plans ▪ Excess of limitations to conduct fuel management according to urban planning regulations ▪ Legal impediments to implement prescribed burns ▪ High competences for the limited resources within RDP where prevention (not linked to the market) is not the priority ▪ Lack of policy support to long-term actions (needed to make a change at landscape level) ▪ Potential conflicts (real or perceived) between biodiversity conservation and fuel management ▪ Competences for risk mitigation resources in front of other natural hazards (e.g., floods) which are also being increased under a climate change context ▪ Domination of response lobby within the integrated wildfire risk management agenda ▪ Collapse of public service to face climate change challenges ▪ Inertia within the public bodies facilitates competences segmentation and add difficulties to the operational coordination, which at the end is transferred to the local actors limiting the motivation of individuals

▪ Development of Urban Agendas and implementation of risk reduction to foster resilience to climate change	

4. Towards a fire-smart solution model

Wildfire risk prevention initiatives in southern Europe are very diverse, including two main categories according to the type of economic support: (i) recognition of services (other than wildfire prevention) that derive from positive externalities generated by the fuel management at the landscape and periurban scales; and (ii) production of goods from the transformation of the biomass extracted with prevention interventions, also enhancing the transformation of by-products.

The first category includes solutions where the convergence of multiple interests on prevention activities leads to the recognition of positive externalities. Several initiatives aimed at reducing wildfire risk by fuel management while acting positively on different ecosystem services such as regulation services (e.g., carbon sequestration, erosion prevention, pollination, etc.), support services (local habitats and biodiversity conservation) and cultural services (eco-tourism, landscape mosaic). As an example, several initiatives have seen the convergence of strategic fire prevention planning with the conservation of priority habitats of EU interest. Notably, interventions to reduce vegetation flammability use techniques with specific ecological effects such as grazing (e.g., height and type of cut, trampling) or prescribed burning (e.g., stimulation of flowering and seed germination, input of charcoal into the soil, mosaic of burnt and unburnt islands) that diversify vegetation structure and have positive effects on some habitats (e.g., 4030, 6110, 62A0, 6220*, 6410, 9330, 9540 of the EU Habitat Directive) (Fernandes et al., 2013a). When targets of fire prevention and nature conservation coincide (Pais et al., 2020), this justifies the use of resources for the maintenance of the Natura 2000 network for fire prevention as well. In the LIFE Montserrat (Miñambres, 2018) and LIFE Granatha (Ascoli et al., 2017), fuel management is complemented by high environmental awareness, fostering habitat and biodiversity conservation and connectivity between landscape patches, including links to Natura 2000 sites (Table 2). In some initiatives, fire hazard reduction itself was recognized as an environmental service by activating mechanisms such as the “payment for ecosystem services''. In Spain, the RAPCA initiative (Table 2) remunerates shepherds for their grazing activity for their direct effect on fire hazard reduction in planned areas, valorising fire prevention as an ecosystem service (Varela et al., 2018).

The second category of initiatives includes smart solutions implementing a short supply chain under a circular bio-economy perspective, valuing fire-marketing products like wood as a raw material and agricultural and pasture products. Some initiatives based on prescribed grazing as a fuel reduction technique activated dairy supply chains or cow-calf lines with interesting examples of products commercialization. As an example, the Fire flocks initiative in Catalonia registered the “Ramats de Foc” label distributed in points of sale and restaurants throughout the north-east of the region (Domènech and Soy, 2020), in which value is added to the sale of grazing products through a label that certifies the herds' positive effect on fire risk management

(Fig. 5a). Similarly, the Catalan Priority Protection Plans for Forest Areas initiative promotes wine production in vineyards planted within firebreaks (Fig. 5b), enhancing all the positive externalities resulting from fire prevention in a circular and sustainable economy. The 'Vi fumat' label serves to give visibility to the contribution of vineyards as firebreaks together with the marketing and valorisation of the specific flavours due to the effect of smoke on that vintage. In Italy, the Life Granatha project produces biological brooms with heather harvested along fuelbreaks and blocks planned for fire hazard reduction (Ascoli et al., 2017). An initiative to reduce post-fire hazardous fuel accumulation in high fire severity areas affected by the "Mompantero fire", the largest fire in Italy during the extreme fire season of 2017, transforms the dead wood extracted in different products such as the "Mompantable" (Fig. 5c) sensitizing the population to the problem of extreme fires through the product. These are some smart solutions emerging from selected initiatives in which fire prevention finds financial justification through the creation of added value for dairy and other products under a green marketing logic.

Figure 5. *Fire-marketing products: dairy products from the "Ramats de foc" project, Catalunya, Spain (a); 'Vi Fumat' wine which served as a fuel break in a 2012 la Junquera wildfire, Catalunya, Spain (b); "Mompantable" produced with pine forests affected by high fire severity in Val Susa, Italy (c).*

Another key element of fire-smart solutions is the cooperative and synergistic approach to foster the convergence of wildfire prevention goals with multiple land management goals, environmental well-being and local development, while optimizing cost-efficiency. Examples are the initiatives carried out by the Fire

Management Training Centre of the Tuscany region, in Italy, where prescribed burning activities are integrated in the training program of fire-fighting operators (Ascoli and Bovio, 2013). There, preventive interventions to protect both the Centre and the surrounding forest area are carried out as part of the regional training programs in fire management techniques (e.g., prescribed burning, counterfire, use of equipment, vehicle driving). Such a solution aligns the needs of the preparedness and the fire prevention sectors, creating synergies that increase the cost-efficiency of wildfire risk management. The RAPCA Program is another example of cooperative approach, in which fire prevention is ensured by the involvement of more than 200 local shepherds (Varela et al. 2018). Similarly, in the SILVPAST project[6], the landscape planning for fire prevention is combined and favoured by the productive agricultural, pastoral and forestry territorial realities and the political actors involved in local and national land management (Proença, 2019). This also occurs with REN activities, by involving landowners into the creation of a national network of green infrastructures using native species. At the local level, the resin extraction carried by RaízesIN promotes, not only fuel management of the pine stands, but also early fire detection and job creation within the local communities. In several initiatives, we documented synergies between local cooperation and international support. The Open2preserve Project (Tresserras et al., 2018) and the Landscape fire Project[7] (and other selected Interreg Sudoe and LIFE projects) perfectly embody this vision, being promoted and financed by European funds, regional administrations, research institutes, local associations, and private foundations, laying the framework for long-term management programs of fire-prone landscapes.

Documented fire-smart solutions made an optimum use of the best existing knowledge in fire prevention, resulting in innovative projects with a clear social and territorial scope. The Boscos del Vallès project (Renom, 2018) or the PreFeu initiative (Table 2) stand out as a major innovation, working in fire prevention through the valorisation of biomass and exploitation of its products to energetically power several local public facilities (e.g., the hospital and sports facilities of the Autonomous University of Barcelona). In addition, these initiatives contribute to local forest landscape management and engage students in environmental education through risk awareness and communication actions in schools.

Finally, some smart solutions adopted an adaptive management approach, monitoring prevention efforts and learning from experiences. Among the criteria (Table 2), adaptive management is the least represented (Fig. 4), probably because of the recent implementation of most initiatives. However, a long-term example is the GEPRIF Project (Silva et al., 2017), in which the efficiency of corrective measures for post-fire forest hydrological restoration, new biodegradable materials for post-fire erosion risk reduction and the cost-effectiveness of prevention, extinction and rehabilitation activities are evaluated. Likewise, the OMIKRON

[6] https://www.terraprima.pt/en/projecto/23
[7] https://life.cimvdl.pt/

volunteers group works according to the lessons-learnt approach, plan monitoring interventions and try to constantly increase the number of members to build up a wide range of experiences from which to learn.

5. Emerging properties of smart-solutions

The selected initiatives are a pool of examples, grounded in real-world settings, from which to extract key elements for sustainable wildfire prevention programs in southern Europe and provide insight and concrete solutions to devise a general model. Fig. 6 summarises the main emerging components characterizing smart-solutions for wildfire risk prevention.

The need for mobilizing multiple resources to achieve the critical mass of fuel treatments at the landscape scale was a key driver in documented initiatives. Limited financial resources are a prominent barrier to wildfire prevention in southern Europe, especially when direct prevention is decoupled from the market, and indirect prevention is not integrated into wildfire risk management planning. In the planning process, management needs often emerge that are not covered under available budgets. Consequently, prioritization of actions is a common approach (Fernandes, 2013b; Elia et al. 2014), but massive treatments are never implemented and/or maintained, eventually generating frustration among wildfire risk planners. Here, we documented smart-solutions creating local short value chains that support wildfire risk management by different types of products under labels highlighting or certifying wildfire prevention (Fig. 6). Focusing on local, national or international certification of wildfire risk management is a possible way forward to increase the economic viability of local rural activities in marginal territories, acting on the production chain and on the sustainability of their products. In this regard, the creation of fire prevention-related marketing is fundamental since it produces positive externalities at a socio-economic level and creates added value. Smart-solutions for wildfire prevention have the capacity to involve society (consumers) in the solution, buying "wildfire prevention" through the shopping basket. Moreover, by this mechanism, the wildfire issue and possible mitigation actions become clearer to the consumer/citizen, as well as the need to support forest owners, shepherds and farmers for well-being and the provision of ecosystem services that the society needs. In other terms, the wildfire prevention-marketing labelling has a pedagogical function facilitating the public support to long-term and cross-sectoral policies for wildfire risk management.

In marginal areas where sustainable supply chains fail because of a lack of commercial opportunities, new mechanisms and additional private or public resources are needed to carry out fuel management at the landscape scale. Smart-solutions for wildfire prevention involve the recognition that in marginal land, the response-centred strategy may have limits under current land use and climatic change in protecting ecosystem services from wildfire negative impacts (Moreira et al., 2020), and that decreasing landscape wildfire spread capacity is a necessary complementary strategy. When this occurs, private and public actors may be more willing to support the cost of securing the territory from wildfires. As an innovative source of income, smart-solutions propose wildfire prevention as an ecosystem service needed to protect other

ecosystem services. Documented solutions integrated fire management with other land governance goals (Fig. 6) by linking strategic fuel management to the achievement of a "resilient landscape" in terms of rural development, biodiversity conservation, water provision, mitigation of other natural risks, landscape aesthetic, and providing civil protection to critical infrastructures and economic activities (e.g., tourist sector increasingly vulnerable under worsening wildfire risk). The recognition of the role of fire prevention in achieving landscape resilience leads multiple stakeholders in supporting economically fire prevention programs, e.g. water companies, agencies that manage infrastructures vulnerable to multiple natural hazards such as rock falls, landslides and avalanches (e.g., highways, touristic resorts), municipalities benefiting from uphill forest ecosystem services, or Nature 2000 sites and Natural Parks. The mechanisms we documented in selected initiatives are multiple, such as schemes of Payment for Ecosystem Services, specific taxes, environmental compensatory measures or carbon credits marketing.

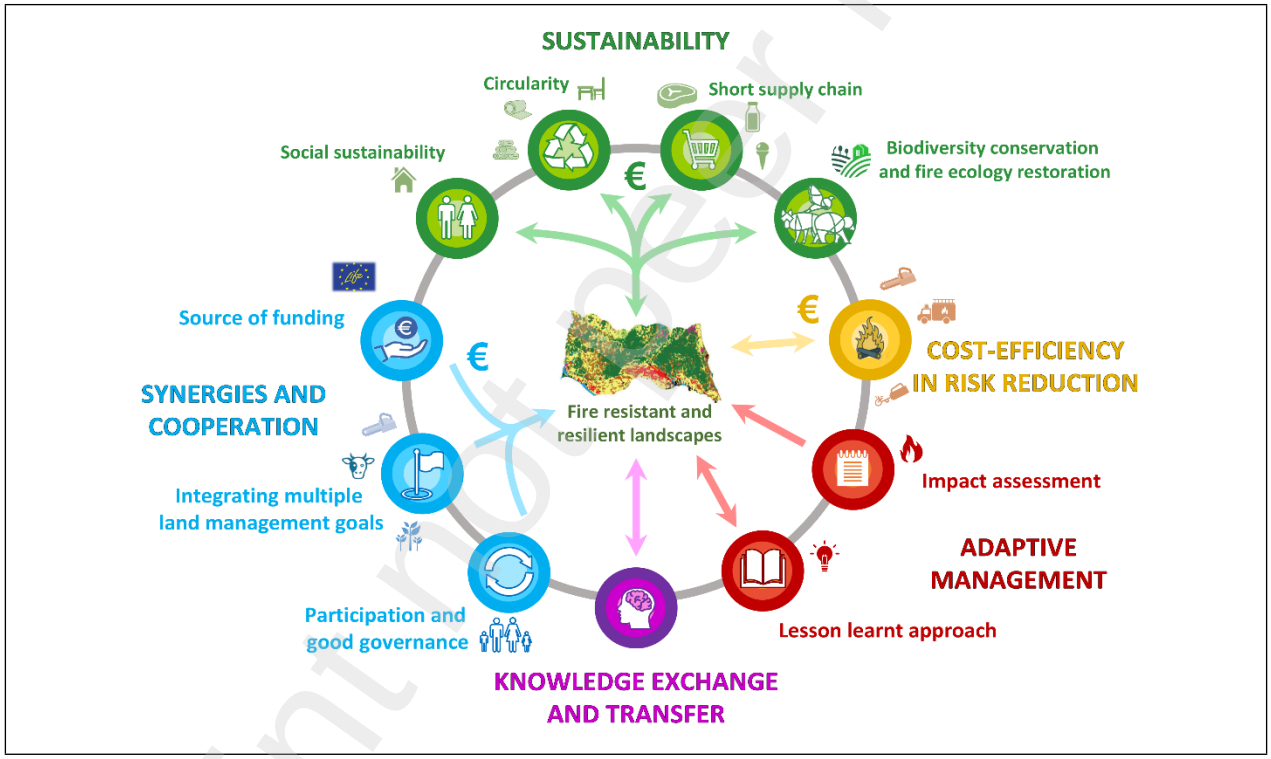

Figure 6. *Key emerging components that characterizes a smart-solution for wildfire risk prevention.*

6. Prospects for smart solutions replication under the EU Green Deal

The European Green Deal appears as the right framework at the right time to design, implement and maintain the smart-solution model here discussed (Fig. 6), and trigger or support wildfire prevention programs. The variety of funding sources documented in selected initiatives (Fig. 3) shows various routes to create synergies between private investments and regional incentives, national and European funds. These initiatives confirm the importance to invest in cross-sectoral policies applied at the local level and, at the same time, to make European funding strategies more accessible to local realities. Integrating multiple sources of funding at

different levels, starting from the local and national level (regional incentives, RDPs, etc.) to the international level (EU measures and strategies), allows for a higher level of stability and continuity in wildfire management actions triggering and supporting private investments. Although Green Deal policies are providing the enabling framework, i.e., the "nurturing environment" (mainstreaming of strategies and funding opportunities), it is up to local and Regional level Authorities to take up these impulses and translate them into governance participatory models, in the perspective of integrated wildfire risk management. Lessons learned from the concrete initiatives here documented suggest that the success of a smart-solution is often supported by local clusters of institutions and people (public administrations, trade associations and unions, communities, public at large) “rowing in the same direction”. An interesting common characteristic from the studied initiatives is the multi-agency involvement, which underlies the importance of close collaboration and cooperation across the different sectors involved in DRM (Fig. 3). The type of agencies involved and their cooperation schemes might be very diverse since fire management in southern European countries is highly heterogeneous among regions reflecting legacies to the local administrative structure and policies (San-Miguel Ayanz et al, 2021). The need to adopt transversal and transdisciplinary approaches is not only a theoretical paradigm: it is an increasing and concrete necessity for sustainable wildfire risk management in southern Europe (Rego et al., 2018).

Reliance on EU funds has sometimes been perceived difficult, as reported in the SWOT analysis (Table 3). This barrier, in connection with the segmentation of competences in wildfire management, can be detrimental to structuring shared governance. In this perspective, the concept of multi-actor clusters can be of example not only to public authorities responsible for wildfire management, but also to other agencies that benefit from the creation of FSTs (e.g. public agencies responsible for urban development, civil-protection, and tourism). These public authorities have a role to play to leverage the impact of public policies on wildfire risk management, starting from a shared vision on the use of public funding for wildfire prevention. In order to bring substantial improvements to the current lack of investment capacity in fire-prone territories, it is essential to make an efficient and coherent use of the multiple sources of funding (avoiding redundancies, gaps and conflicting goals). It is likewise necessary to ensure that funding from international, European, even national levels are complementary to the regional ones, and that investments are allocated to strategically pre-planned actions according to the local/regional fire risk mitigation needs.

Some key-components of the smart-solution model can also be taken up by management authorities when designing the structure of call for proposals for accessing EU funding. A number of funds under shared management between the European Commission and the Member States (e.g. EU Agricultural Fund for Rural Development, EU Regional Development Fund, EU Territorial Cooperation) can be deployed by management authorities to prepare their own programmes and calls targeting fire prevention in fire-prone rural or wildland-urban interface territories. These calls can require projects to apply a cross-sectoral and multi-actor approach, which are the necessary engines to set in motion local economies around wildfire prevention. In

this regard, the EU Green Deal offers the required political backing and financial budget to stimulate the development of multi-actor projects targeting the build-up of FSTs. Concrete routes for the replication and up-scaling of the smart-solution model under the EU Green Deal are, as examples, coupling the Farm to Fork initiative to chains that prevent wildfire in high fire risk zones (as identified by strategic fire prevention plans), supporting strategic fuel management as a nature-based solution among climate change adaptation strategies, or ensuring under the Urban Agenda a periurban green infrastructure offering wildfire protection instead of hazard (Plana and Serra, 2021). Another simple example of fostering coherent policies for wildfire risk mitigation under the EU Green Deal concerns the planting of the 3 billion new trees foreseen by the EU Forestry Strategy. Past mistakes made by Europeans in the early 20th century must be avoided, when forest restoration programs largely used flammable Mediterranean pine species and eucalypts over large areas, creating the rise in fire hazard at the landscape scale that we face today (Moreira et al., 2020). Criteria for afforestation/reforestation should incorporate the concept of fire resistant and resilient territories. Similarly, rewilding targets under the EU Biodiversity Strategy (i.e. 10% of EU land surface under strict nature conservation) should account for trade-offs related to wildfire risk mitigation.

Finally, re-designing the way rural development funds are allocated can leverage the impact of this policy on wildfire risk mitigation. Indeed, under past and current RDPs, only specific wildfire prevention measures (i.e., measure 2.2.6 in 2007-2013 RDP, and sub-measure 8.3 in 2014-2020 RDP) included eligibility criteria related to wildfire risk, as defined by wildfire risk management plans. A better way forward is to open multi-measures calls for integrated territorial projects in high wildfire risk areas. Such projects can integrate active prevention measures (e.g. fuel management, fuelbreaks) with other rural development measures providing indirect prevention (e.g. active forest management and forest products mobilization, mosaic landscape maintenance, grasslands and complementary grazing in the forest understory), while pushing the development of marginal territories, through ecotourism, recreational activities or new business models (Colonico et al., in 2022). This would encourage multiple actors to join forces and apply for calls where they develop a complex long-term project with a clear objective, including wildfire risk mitigation.

7. Conclusions

Extreme wildfires are a complex phenomenon that emerges from the interaction between multiple physical, biological and socio-economic factors of a territory (Ascoli et al., 2021; Fernandes, 2013a; Tedim et al., 2018; Wunder et al., 2021). The increasing frequency of extreme wildfire events might halt the provision and recovery of ecosystem services and jeopardize rural land development and other strategic sectors (Moreira et al., 2020). To mitigate the impacts on ecosystem services, it is necessary to implement integrated solutions that act on key factors, in a concrete and sustainable way from an economic, social and environmental point of view (Tedim et al., 2016, Varela et al., 2020).

What we have come to define “smart solutions for wildfire risk prevention” are initiatives sharing a common backbone of key principles. It must be noted that there is no one-size-fits-all for smart-solutions to achieve FSTs and land managers must consider various kinds of interventions when implementing direct prevention through fuel management (Corona et al., 2015). However, our analysis shows how current “smart” wildfire prevention initiatives applied in southern Europe follow a similar scheme involving:

(i) political and economic recognition of wildfire prevention as an ecosystem service delivering positive externalities for a circular and sustainable economy;

(ii) integration between different sectoral policies (e.g. forestry, agriculture, nature conservation, energy, tourism) within a unified strategy for managing wildfire risk, which private investments, product certification agencies, and EU funding programmes (LIFE Programme, Rural Development Programme) can contribute to;

(iii) a planning process that optimizes limited economic resources to achieve wildfire risk reduction at the landscape scale, by combining direct prevention, spatially distributed in strategic points to support suppression, with mid-long term fuel management programs, connected to forest bio-based economies;

(iv) capacity to expand areas treated by fuel management activities, by clustering both public and private land through ownership associations methods, allowing convergence on common goals and shared intervention strategies between economic, social and land management actors;

(v) use of diversified types of treatments to reduce hazardous fuels (variable retention, commercial and selective thinning, prescribed burning, rotational grazing) designed on the ecological understanding of the role of fire in the ecosystem and integrating those cultural fuel management practices as nature-based solutions;

(vi) valorisation of products generated by fuel management by means of agro-food marketing and certification (e.g. "Ramats de Foc" and "Vinyes de Contrafoc" in Catalonia), to reward farmers also for the environmental service delivered in mitigating wildfire risk;

(vii) strong social engagement of local communities in wildfire risk management, through participatory processes involving population, authorities and economic sectors to share the responsibility for the ongoing fire prevention efforts.

It must be emphasized that the novel wildfire risk scenario, featured by extreme fire events increasingly extending on the wildland-urban interface (Moreira et al., 2020), represents an urgent challenge, but also a stimulus to turn wildfire risk management in an opportunity for the sustainable and inclusive growth of marginal territories. The smart-solutions for wildfire risk management offer concrete tools for civil and environmental protection. However, the recognition of the role of fuel management as a civil protection strategy requires the public recognizing that a society exposed to flammable hazardous landscapes is not

only more dangerous, but less cost-efficient than building FSTs planned to protect people, ecosystem services, values and economies from the impact of extreme wildfire events.

As the recognition of fire-smart solutions is the result of common European efforts, similarly, their uptake and replication on a European scale necessitates networking between the various initiatives and institutions involved in wildfire risk management, to create a mutually beneficial exchange platform of best practices[8].

In conclusion, if the EU Green Deal provides the strategic vision to mainstream and align local land management initiatives within the path of sustainable and inclusive growth, the smart solutions for wildfire risk prevention represent a concrete example of EU Green Deal implementation on the ground of Disaster Risk Management. It must be emphasized that a successful and shared governance process for wildfire prevention must not only take into account local specificities, but also strengthen the cultural perception of the role of traditional activities contributing to fuel management, so as to make visible their "cost-efficiency" in terms of reducing the cost of direct prevention and wildfires potential impact (Plana, 2010). In this perspective, we contend that if the future call for proposals of public funding programmes will be designed to include, at least some, of the criteria of the smart-solution model here presented, private and public actors will be more attracted to join forces and co-design solutions adapted to real needs of marginal territories.

[8] Smart-solutions analysed by the PREVAIL Project are hosted in the "Lessons on fire" (https://lessonsonfire.eu/en/solutions-map) and GoProFor (https://www.lifegoprofor-gp.eu/) platforms.

464 **References**

465 Ascoli, D., Bovio, G., 2013. Prescribed burning in Italy: issues, advances and challenges. iForest-
466 Biogeosciences and Forestry, 6(2), 79. https://doi.org/10.3832/ifor0803-006

467 Ascoli, D., Berretti, R., Campedelli, T., Londi, G., Miozzo, M., Tellini, G., 2017. Il Progetto LIFE Granatha:
468 Coltivazione delle eriche e fuoco prescritto per la conservazione dell'habitat degli uccelli delle
469 brughiere. Sherwood 230: 28-32

470 Ascoli, D., Russo, L., Giannino, F., Siettos, C., Moreira, F., 2018. Firebreak and Fuelbreak. Encyclopedia of
471 Wildfires and Wildland-Urban Interface (WUI) Fires. Springer International Publishing, Cham, 1-9.
472 https://doi.org/10.1007/978-3-319-51727-8_70-1

473 Ascoli, D., Moris, J.V., Marchetti, M., Sallustio, L., 2021. Land use change towards forests and wooded land
474 correlates with large and frequent wildfires in Italy. Annals of Silvicultural Research 46(2).

475 Azevedo, J.C., Moreira, C., Castro, J.P., Loureiro, C., 2011. Agriculture Abandonment, Land-use Change and
476 Fire Hazard in Mountain Landscapes in Northeastern Portugal, in: Landscape Ecology in Forest
477 Management and Conservation. https://doi:10.1007/978-3-642-12754-0

478 Bacciu, V., Sirca, C., Spano, D., 2022. Towards a systemic approach to fire risk management. Environmental
479 Science & Policy, 129, 37-44. https://doi.org/10.1016/j.envsci.2021.12.015

480 Baskent, E.Z., Borges, J.G., Vacik, H., Reynolds, K.M., Rodriguez, L.C.E., 2021. Management of multiple
481 ecosystem services under climate change, bioeconomy and participation. Forests 12, 1–7.
482 https://doi:10.3390/f12010104

483 Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future
484 Köppen-Geiger climate classification maps at 1-km resolution. Scientific data, 5(1), 1-12.
485 https://doi.org/10.1038/sdata.2018.214

486 Colonico, M., Tomao, A., Ascoli, D., Corona P., Giannino, F., Moris, J., Romano, R., Salvati, L., Barbati, A. (2022).
487 Rural development funding and wildfire prevention: evidences of spatial mismatches with fire activity.
488 Land Use Policy, 117, https://doi.org/10.1016/j.landusepol.2022.106079

489 Corona, P., Ascoli, D., Barbati, A., Bovio, G., Colangelo, G., Elia, M., Garfì, V., Iovino, F., Lafortezza, R., Leone,
490 V., Lovreglio, R., Marchetti, M., Marchi, E., Menguzzato, G., Nocentini, S., Picchio, R., Portoghesi, L.,
491 Puletti, N., Sanesi, G., Chianucci, F., 2015. Integrated forest management to prevent wildfires under
492 Mediterranean environments. Annals of Silvicultural Research 39: 1-22.
493 http://dx.doi.org/10.12899/ASR-946

494 Costa, P., Castellnou, M., Larrañaga, A., Miralles, M., Kraus, D., 2011. Prevention of Large Wildfires using the
495 fire types concept. UT GRAF-Generalitat de Catalunya, Barcelona, 87 pp.

Domènech, R., Soy, E., 2020. Girona – Fire Flocks, grazing systems to reduce wildfire severity. C 25 Girona, Spain Aims 499–507.

Elia, M., Lafortezza, R., Colangelo, G., Sanesi, G., 2014. A streamlined approach for the spatial allocation of fuel removals in wildland–urban interfaces. Landscape Ecology, 29(10), 1771-1784. https://doi.org/10.1007/s10980-014-0070-7

European Commission, 2013. Green Infrastructure (GI) - Enhancing Europe's Natural Capital 11.

European Commission, 2018. Una bioeconomia sostenibile per l'Europa: rafforzare il collegamento tra economia, società e ambiente. European Commission 17.

European Commission, 2019. The European Green Deal 53, 24. https://doi.org/10.1017/CBO9781107415324.004

European Commission, 2020a. EU Biodiversity Strategy for 2030 - Bringing nature back into our lives 1689–1699.

European Commission, 2020b. Farm to Fork Strategy - For a fair, healthy and environmentally-friendly food system.

European Commission, 2021a. EU Strategy on Adaptation to Climate Change. COM/2021/82 Final

European Commission, 2021b. New EU Forest Strategy for 2030. COM/2021/572 Final.

Fernandes, P.M., 2013a. Fire-smart management of forest landscapes in the Mediterranean basin under global change. Landscape and Urban Planning 110, 175–182. https://doi.org/10.1016/j.landurbplan.2012.10.014

Fernandes, P.M., Davies, G.M., Ascoli, D., Fernández, C., Moreira, F., Rigolot, E., Stoof, C.R., Vega, J.A., Molina, D., 2013b. Prescribed burning in southern Europe: Developing fire management in a dynamic landscape. Frontiers in Ecology and the Environment 11. https://doi.org/10.1890/120298

Fernandes, P.M., Delogu, G.M., Leone, V., Ascoli, D., 2020. Wildfire policies contribution to foster extreme wildfires. In Extreme Wildfire Events and Disasters, pp. 187-200. Elsevier. https://doi.org/10.1016/B978-0-12-815721-3.00010-2

Ingaramo, R., Salizzoni, E., Voghera, A., 2019. Ecosystem Service Valuation for Forest Landscape Resilience: Managing Fire Risk, in: Urban Resilience for Risk and Adaptation Governance: Theory and Practice. pp. 129–146. https://doi.org/10.1007/978-3-319-76944-8_9

Jonsson, R., Rinaldi, F., Pilli, R., Fiorese, G., Hurmekoski, E., Cazzaniga, N., Robert, N., Camia, A., 2021. Boosting the EU forest-based bioeconomy: Market, climate, and employment impacts. Technological Forecasting and Social Change 163, 1–15. https://doi.org/10.1016/j.techfore.2020.120478

Kovac, M., Hladnik, D., Kutnar, L., 2018. Biodiversity in (the Natura 2000) forest habitats is not static: its

conservation calls for an active management approach. Journal for Nature Conservation 43, 250–260. https://doi.org/10.1016/j.jnc.2017.07.004

Lovreglio, R., Meddour-Sahar, O., Leone, V., 2014. Goat grazing as a wildfire prevention tool: A basic review. IForest 7, 260–268. https://doi.org/10.3832/ifor1112-007

Metzger, M. J., Bunce, R. G., Jongman, R. H., Sayre, R., Trabucco, A., Zomer, R., 2013. A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring. Global Ecology and Biogeography, 22(5), 630-638. https://doi.org/10.1111/geb.12022

Metzger, M. J., Shkaruba, A. D., Jongman, R. H. G., Bunce, R. G. H., 2012. Descriptions of the European environmental zones and strata (No. 2281). Alterra.

Miñambres, L., 2018. Life Montserrat: ramaderia, prevenció d'incendis i gestió d¡hàbitats. Agro-Cultura 71, 11–13.

Moreira, F., Ascoli, D., Safford, H., Adams, M.A., Moreno, J.M., Pereira, J.M.C., Catry, F.X., Armesto, J., Bond, W., González, M.E., Curt, T., Koutsias, N., McCaw, L., Price, O., Pausas, J.G., Rigolot, E., Stephens, S., Tavsanoglu, C., Vallejo, V.R., Van Wilgen, B.W., Xanthopoulos, G., Fernandes, P.M., 2020. Wildfire management in Mediterranean-type regions: Paradigm change needed. Environmental Research Letters 15, 1–6. https://doi.org/10.1088/1748-9326/ab541e

Pais, S., Aquilué, N., Campos, J., Sil, Â., Marcos, B., Martínez-Freiría, F., Domínguez, J., Brotons, L., Honrado, J.P., Regos, A., 2020. Mountain farmland protection and fire-smart management jointly reduce fire hazard and enhance biodiversity and carbon sequestration. Ecosystem Services, 44, 101143. https://doi.org/10.1016/j.ecoser.2020.101143

Pereira, H.M., Navarro, L.M., 2015. Rewilding European Landscapes. https://doi.org/10.1007/978-3-319-12039-3_7

Plana, E., 2010. Gestione forestale e prevenzione degli incendi. Analisi economica a scala di paesaggio. Sherwood - Foreste ed Alberi Oggi 166:11-16

Plana, E., Serra, M., 2021. Integrated wildfire risk assessment and planning method including stakeholder engagement for resilient communities at local level. In Plana, E., Serra, M., Sabella, C., Mayer, C., Hengst-Ehrhart, Y., Hartebrodt, C., Franciosi, C., Giambelli, M., Pagès, D., Gasulla, N., Martí, G., Garcia, C., Bertran, M., Canaleta, G., Vendrell, J., Andrecs, P., Hagen, K., Plörer, M., Sequeira, A.C., Skulska, I., Acácio, V., Ferreira, M., Colaço, M.C. ,2021. Climate change impacts on natural hazards risk management and Civil Protection of wildfires, floods, storms, avalanches, rockfalls and landslides. RECIPE project (Grant Agreement nº 874402), pp. 46-50

Proença, V., Teixeira, C. M., 2019. Beyond meat: ecological functions of livestock. Science, 366(6468), 962-962. https://doi.org/10.1126/science.aaz7084

561 Rego, F., Rigolot, E., Fernandes, P., Montiel, C., Silva, J.S., 2010. Towards integrated fire management.
562 European Forest Institute (EFI) 16. https://hal.inrae.fr/hal-02823739

563 Rego, F.C., Moreno, J.M., Vallejo, V.R., Xanthopoulos, G., 2018. Forest Fires. Sparking firesmart policies in the
564 EU. N. Faivre (editor). European Commission, Directorate-General for Research and Innovation Climate
565 Action and Resource Efficiency. 53. https://doi.org/10.2777/181450

566 Renom, I.G., 2018. Boscos del Vallès - Prevenció d'incendis a partir de la dinamització del mercat de la
567 biomassa forestal. Consell Comarcal Del Vallès Occidental 2, 20.

568 San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Libertà, G., Artes, vivancos tomas, Jacome, F. oom
569 duarte, Branco, A., De rigo, D., Ferrari, D., Pfeiffer, H., Grecchi, R., Nuijten, D., Leray, T., 2021. Forest
570 Fires in Europe, Middle East and North Africa 2020. Publications Office of the European Union,
571 Luxembourg. https://doi.org/doi: 10.2760/216446

572 Sil, Â., Fernandes, P.M., Rodrigues, A.P., Alonso, J.M., Honrado, J.P., Perera, A., Azevedo, J.C., 2019. Farmland
573 abandonment decreases the fire regulation capacity and the fire protection ecosystem service in
574 mountain landscapes. Ecosystem Services 36, 1–13. https://doi.org/10.1016/j.ecoser.2019.100908

575 Silva, J.S., Rego, F.C., Fernandes, P., Rigolot, E., Silva, J.S., Rego, F.C., Fernandes, P., Rigolot, E., Integrated, T.,
576 Fernandes, P., 2020. Towards Integrated Fire Management. Outcomes of the European Project Fire
577 Paradox.

578 Tedim, F., Leone, V., Amraoui, M., Bouillon, C., Coughlan, M.R., Delogu, G.M., Fernandes, P.M., Ferreira, C.,
579 McCaffrey, S., McGee, T.K., Parente, J., Paton, D., Pereira, M.G., Ribeiro, L.M., Viegas, D.X.,
580 Xanthopoulos, G., 2018. Defining extreme wildfire events: Difficulties, challenges, and impacts. Fire 1,
581 1–28. https://doi.org/10.3390/fire1010009

582 Tedim, F., Leone, V., Xanthopoulos, G., 2016. A wildfire risk management concept based on a social-ecological
583 approach in the European Union: Fire Smart Territory. International Journal of Disaster Risk Reduction
584 18, 138–153. https://doi.org/10.1016/j.ijdrr.2016.06.005

585 Tresserras, R.M.C., Azpilicueta, L.M., Garciandia, L.S.E., Martínez, M.V.S., Istilart, J.L.S., Echavarren, L.E.,
586 Durruty, J.L., Unzue, O.U., Aróstegui, A.Y., Ortigosa, A.P. de M., 2018. Open2Preserve: preservación de
587 espacios abiertos de montaña. Navarra Agraria 231, 30–32.

588 Twidwell, D., Wonkka, C.L., Wang, H.H., Grant, W.E., Allen, C.R., Fuhlendorf, S.D., Garmestani, A.S., Angeler,
589 D.G., Taylor, C.A., Kreuter, U.P., Rogers, W.E., 2019. Coerced resilience in fire management. Journal of
590 Environmental Management 240, 368–373. https://doi.org/10.1016/j.jenvman.2019.02.073.

591 UNISDR, 2009. UNISDR Terminology on Disaster Risk Reduction, United Nations Office on Disaster Risk
592 reduction, Geneve.

593 Valese, E., Conedera, M., Held, A. C., Ascoli, D., 2014. Fire, humans and landscape in the European Alpine

region during the Holocene. Anthropocene, 6, 63-74. https://doi.org/10.1016/j.ancene.2014.06.006

Varela, E., Górriz-Mifsud, E., Ruiz-Mirazo, J., López-i-Gelats, F., 2018. Payment for targeted grazing: integrating local shepherds into wildfire prevention. Forests, 9(8), 464. https://doi.org/10.3390/f9080464

Varela, E., Pulido, F., Moreno, G., & Zavala, M. Á. 2020. Targeted policy proposals for managing spontaneous forest expansion in the Mediterranean. Journal of Applied Ecology, 57(12), 2373-2380.

Verkerk, P.J., Martinez de Arano, I., Palahí, M., 2018. The bio-economy as an opportunity to tackle wildfires in Mediterranean forest ecosystems. Forest Policy and Economics 86, 1–3. https://doi.org/10.1016/j.forpol.2017.10.016

Wunder, S., Calkin, D. E., Charlton, V., Feder, S., de Arano, I. M., Moore, P., Rodríguez y Silva, F., Tacconi, L., Vega-García, C, 2021. Resilient landscapes to prevent catastrophic forest fires: Socioeconomic insights towards a new paradigm. Forest Policy and Economics 128. https://doi.org/10.1016/j.forpol.2021.102458

Acknowledgment

Funding information:

The study was supported by the project “PREVAIL PREVention Action Increases Large fire response preparedness” (826400 — PREVAIL — UCPM-2018-PP-AG), funded by the European Union Humanitarian Aid and Civil Protection (DG-ECHO) and by Fire prevention for the wood supply chains (Pre-Feu) – Rural Development Program 2014-2020 - Measure 16.2.1 - Action 1 of the Piemonte Region.

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