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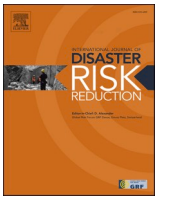

Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal

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ABSTRACT

Fuel management for wildfire risk prevention generally lacks economic sustainability. In marginal areas of southern Europe, this limits fuel treatment programs from reaching the critical mass of required treated area 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 a bottom-up selection of 38 initiatives, which we analyzed systematically through a set of fire-smart criteria: sustainability, cost-benefit ratio, synergies and inter-sectoral cooperation, integration between strategic prevention planning and multiple land governance goals (e.g., rural development, biodiversity conservation, energy supply), innovation and knowledge transfer, and adaptive management.

We summarized lessons learned from the most innovative initiatives, by identifying solutions and functional approaches for building sustainable fuel management at the landscape scale, under fire-smart management principles. These make synergistic use of private, public and European resources to activate value chains that valorize the products, by-products and services generated by fuel management activities and their positive externalities on ecosystem services. The multiple mechanisms include fire-marketing, Payment for Ecosystem Services schemes, specific taxes, or environmental compensatory measures. These mechanisms catalyze the interest of multiple stakeholders (economic actors, private owners, 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 framework (mainstreaming of EU strategies and funding opportunities) to enable the replication of documented fire-smart models and functional approaches to wildfire risk prevention.

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1. Introduction

In Europe, there is general agreement for a wildfire risk management change towards cause-oriented policies [1,2], with a particular focus on those drivers behind the increased flammability at the landscape scale, such as land-use abandonment [3,4]. As a consequence, a major goal of European policies is to foster fire-smart territories [1,5] in which land use activities (e.g., agro-forestry, nature conservation) concur with planned fuel treatments (e.g., fuel breaks) in regulating the spatial distribution of fire and its impacts [6,7], improving fire suppression effectiveness [8] while obtaining benefits for ecosystem services and local economic development [9, 10].

The European Commission is currently pursuing multiple policies with enormous implications for wildfire risk prevention and the capacity to build fire-smart territories (FSTs). The Bioeconomy strategy [11] aims to make production chains sustainable by greening industrial productions and enhancing the role of forests [12,13]. Wildfire risk prevention might greatly benefit from this strategy, thanks to incentives for sustainable wood and non-wood products mobilization and active land management in high fire risk areas [14, 15]. 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 [16]. The EU Green Deal acts as a container for other EU strategies, i.e., Biodiversity Strategy [17], LIFE program,[1] Green Infrastructure [18], Farm to Fork Strategy [19], EU Strategy on Adaptation to Climate Change [20], and the Forest Strategy [21], which can be implemented in synergy with wildfire risk prevention. Europe also provides incentives for land management, which are useful in the territorial planning of wildfire risk mitigation. Rural Development Programs (RDPs)[2] include several measures directly connected to wildfire risk management, such as sub-measures 8.3 (prevention of damage from wildfires) and 8.4 (restoration after 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 FSTs [7].

Although European policies embody great potential for the transition towards FSTs [22], which was already shown by simulation analyses of landscape dynamics under alternative policy scenarios [6,23,24], there are many difficulties to implement them at local level [5]. Indeed, local policies often encounter constraints and limitations in adopting a cross-sectoral and multilevel vision, which complicates a transdisciplinary approach to wildfire risk management that maximizes synergies and optimizes EU resources. Major limitations include the fragmentation of abilities and responsibilities across multiple land and fire management agencies [25], which limits finding trade-offs and synergies in land development goals, e.g., rewilding policies vs. fire hazard abatement [9,26,27], and within wildfire risk management sectors, e.g. prevention vs. response [2]. Moreover, the complexity of landscape governance in rural areas due to ownership (i.e., different land tenure rights in private and public lands, ownership fragmentation), limits the engagement of private owners in large-scale fuel management programs [28]. All these constraints hinder the necessary landscape-level management, and fuel reduction programs often do not reach the economy of scale that is needed to be economically sustainable over time [6,29,30].

Despite these constraints, noteworthy local initiatives have been emerging in fire-prone landscapes of southern Europe, with the ability to create synergies among bottom-up needs and top-down policies and implement sustainable fuel management programs based on fire-smart principles [1,10,31–34]. These initiatives uncover opportunities to make the best use of funding and multi-actor private/public cooperation necessary to build FSTs. Hence, we identified the need to mainstream these innovative local approaches through bottom-up selection. In this study, we research and select relevant fuel management programs for wildfire risk prevention in southern EU countries according to a set of criteria, which are key elements for building FSTs [1]. We further analyze, extract and summarize lessons learned from the best and most innovative initiatives. Finally, we identify solutions and functional approaches to build sustainable fuel management programs at the landscape scale, which enhance co-benefits between fire risk mitigation and multiple land management goals, based on a synergistic use of private, public, and European resources.

2. Methods

2.1. Key criteria to select fire-smart initiatives for wildfire risk prevention

To select and analyze initiatives for wildfire risk prevention based on fire-smart principles, we identified five criteria, and nine sub-criteria, which have been highlighted by several authors as key elements to build FSTs (Fernandes et al., 2013a [1,28]; Bacciu et al., 2020; [24]. These criteria include (i) sustainability, (ii) cost-efficiency in risk reduction, (iii) synergies and cooperation, (iv) knowledge exchange and transfer, and (v) adaptive management (Table 1). These criteria were considered essential as they include multiple needs addressed in the above-mentioned European strategies (e.g., Bioeconomy, Biodiversity, Forest), while simultaneously meeting wildfire prevention requirements.

2.2. Identification of wildfire prevention initiatives

The initiatives search started by identifying national and regional agencies responsible for wildfire risk prevention in Greece, Italy, Portugal, and Spain, i.e., among EU countries most exposed to wildfire impacts [2], and where many diversified fuel management programs are in place (e.g., [10,33,34]. The responsibilities of wildfire prevention lie with different organizations in each country

[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.

based on national legislation and regional governance structures [35]. Accordingly, we conducted a survey of the public agencies involved in fire prevention in each country based on the best available knowledge. In total, we contacted 67 agencies (Table A1). Through a refined consultation process of agencies' personnel, we identified relevant fuel management programs implemented at the local level and key responsible persons. Fuel management programs are hereafter named as initiatives.

In order to identify fire-smart attributes of each fuel management initiative (according to the criteria listed in Table 1) and 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) [36], funds supporting fuel management (private investments, local/regional funds or EU funding scheme, e.g., Life + Program, RDPs), and mechanisms to sustain fuel management costs (e.g., value chain characteristics, wood valorization, payment for ecosystem services, marketing activities, associated ownership). The survey investigated the level of integration between fuel treatments strategically planned with the intent to mitigate fire risk [8], such as fuel breaks to support fire-fighting (here after "direct prevention"), and those land use activities (e.g., agro-forestry, grazing) that display a fire regulation capacity [6] with the side-effect of mitigating wildfire risk at the landscape level (here after "indirect prevention"). The survey included a section with a set of open-ended questions about the type of fuel management techniques (e.g., pyrosilviculture, prescribed burning), performance indicators to assess and monitor prevention effectiveness, major limitations and needs of improvement for efficient wildfire risk reduction, and additional details. 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.

2.3. Survey analyses

Survey interviews were analyzed to assess to what extent selected initiatives fulfilled the above-mentioned fire-smart criteria and sub-criteria (Table 1) and highlight the best and most 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 showed to what extent an initiative might fulfill 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 sustainable wildfire risk management.

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

3. Results

The survey identified 38 initiatives planning and implementing fuel management at the landscape scale (Fig. 1) and fulfilling at least one or more key fire-smart 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) [37], to the Mediterranean region, characterized by prolonged dry periods and fires concentrated in summer [2]. Some initiatives in Atlantic and Continental biogeographical regions were also examined. The survey included coastal and inland areas, to be as comprehensive as possible of the contexts where wildfire risk reduction is applied. We identified 17 initiatives in Spain (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 initiatives. In terms of funding programs, initiatives have been financed by regional, national, and European funds, mainly from the Life and RDPs, 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 of 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).

The selected initiatives were analyzed according to the average score (from 0 to 4) assigned to each of the six evaluation criteria Table 1). As summarized in Fig. 4, most criteria received an average score between 2.2 and 2.4 points. The cost-efficiency ratio showed lower values (1.4 points on average) while the Adaptive Management was the lowest (0.4 on average). 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.

Table 2 shows information on the highly ranked initiatives, including their name, the Environmental Zones ([38], [39], the Köppen-Geiger climate classification according to Ref. [40]; description of the fuel management activities that contribute to wildfire risk reduction, social and environmental services provided, actors involved and performance metrics. Management of vegetative fuels includes several fuel management techniques such as prescribed grazing with bovine, goat and sheep [41], pyrosilvicultural treatments (e.g., variable retention harvest, selective thinning, prescribed burning), and mechanical clearings [42]. Fuel management strategies

[4] https://www.prevailforestfires.eu/wp-content/uploads/2021/04/4.2.pdf.
[5] PREVAIL project Deliverable 4.2, https://www.prevailforestfires.eu/project/dissemination/.

Table 1
Fire-smart criteria and sub-criteria adopted to select and analyze wildfire prevention initiatives.

Criteria	Sub-criteria	Description
Sustainability	**Circularity**	Resource-efficient valorization 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 strategy, and producing positive self-feeding cycles.
	Short supply chain	Local supply chains and valorization of primary and secondary products resulting from fuel management programs by means of agro-food marketing, certification and payments for ecosystem services delivered by the wildfire risk reduction.
	Biodiversity conservation and fire ecology restoration	Coherence with environmental conservation under the 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 is based on the ecological understanding of ecosystem dynamics in current and desirable fire regimes.
	Social sustainability	Fuel management programs with a strong social engagement of local communities in wildfire risk management and valuing community choices in determining key goals. Management activities derive from local needs and their outcomes produce benefits for the community. Local community information and training in risk management and participatory processes involving population, authorities and economic sectors to share the responsibility for the ongoing fire prevention efforts.
Cost-Efficiency in Risk Reduction		Planning processes that optimize limited economic resources to achieve wildfire risk reduction at the landscape scale, by combining diversified fuel management strategies (e.g., pyro-silviculture, prescribed burning, prescribed grazing) spatially distributed in strategic points to support response. Initiatives showing cost-benefit/efficiency criteria both in terms of market price and/or environmental and social services. Use of funding not directly related to fire management converges on it, optimizing cost-effectiveness. Similarly, agro-forestry activities exerting a fire regulatory capacity are spatially planned to support fire risk mitigation goals contributing to reduce costs of preparedness, response and recovery. Expansion of fuel managed areas, by clustering public and private land through ownership association, allowing convergence on common goals and shared intervention strategies between economic, social and land management actors.
Synergies and Cooperation	**Source of funding**	Integration between different sectoral policies (e.g., forestry, agriculture, nature conservation, energy, tourism) within a unified strategy for managing wildfire risk. Using multiple funding sources (both local, European and from the private sector) to sustain fuel management programs allowing continuous and long-lasting management of fire-prone landscapes.
	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 inclusion 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 available knowledge is mobilized 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 learned 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.

are determined by fire prevention plans outlined at different scales, ranging from municipalities to regions [8]. Strategic areas may be: (i) fuel break networks planned to support firefighting according to the expected behavior of recurrent large-fires [43]; (ii) forest blocks where the need to increase the resistance and resilience of ecosystem services to fire disturbance is prioritized (e.g., direct protection of infrastructures exposed to rock falls, recreational use) [8,44]; and (iii) wildland-urban interface areas to protect sensitive residential, service or production areas [45].

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

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

ID (Fig. 1)	Initiative name	Environmental zone	Climatic classification	Contribution to fire hazard reduction	Activated chain and social/ environmental services	Cooperation actors	Performance metrics
1	Firefighting training centre of the Toscana Region	Mediterranean mountains *[Italy]*	Temperate, dry summer, hot summer (Csa)	Fuel management along fuel breaks in strategic areas through prescribed burning, mastication and variable retention harvest.	Training program in firefighting, prescribed burning techniques, off-road driving and tree felling. Fuelbreak cleaning for touristic activities (trekking).	Forest land management authorities, a private enterprise, Professional and volunteers fire brigades.	• Start: 2012 • Area: 172 ha • Economic metric: - 30% of fuel management costs are paid with regional resources allocated for training firefighters (response sector) and fuel treatments are carried out during training activities
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.	• Start: 2017 • Area: 150 ha • Economic metric: - Organic brooms price is 1.4 €/broom of which 17% is the added value for landscape maintenance when compared to market prices - 10% of fuel management costs are paid with regional resources allocated for training firefighters (response sector)
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 (Fig. 5), which unites local farmers, butchers and restaurateurs.	Municipalities, private landowners, local farmers, Fire Service.	• Start: 2016 • Area: 600 ha • Economic metric: - Increase in number of butcheries and restaurants selling "fire flocks label" products: 6 butcheries and 1 restaurant in 2018 to 32 butcheries and 18 restaurants in 2022 - Shepherds receive PES from the administration: 140€/ha/year in strategic zones, and 70€/ha/year in complementary areas
5	LIFE Montserrat	Mediterranean North *[Spain]*	Temperate, dry summer, hot summer (Csa)	Fuel management in strategic areas through grazing and prescribed burning. Ecosystem-based	Supply chain of dairy, beef, goat and sheep meat products under the 'Can Mimó' label. Biodiversity and	Regional Government, Forest Owners association, a Private foundation, Natura 2000 sites, Natural	• Start: 2014 • Area: 32000 ha of territory benefited, including 3000 ha treated for wildfire risk reduction

(*continued on next page*)

Table 2 (*continued*)

ID (Fig. 1)	Initiative name	Environmental zone	Climatic classification	Contribution to fire hazard reduction	Activated chain and social/ environmental services	Cooperation actors	Performance metrics
				measures to increase resilience and stability of forests against fires.	habitat conservation and improvement. Creation of a mosaic landscape to decrease fuel connectivity.	Park Board, Fire Service, Municipality.	• Economic metric: - Increase in associated forest owners for aggregated land management: 34 owners in 2014 to 75 owners and managed in 2019 (>3000 ha added) - Increase in associated shepherd participating to the program: from 3 in 2016 to 14 in 2019 (additional 860 animals acting over 1420 ha) - Restored habitat: Habitat 9540 (1290 ha) and Priority Habitat 6220 (181ha)
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.	• Start: 2012 • Area: 29700 ha of territory benefited • Economic metric: - Total potential wood volume: 2386528 m3 - Logistic Centre: 4000 t of wood 720 t of wood chips; 9500 t annual wood mobilization; 6650 t wood chips production - Hospital boiler: 2500 t of wood chips/year - University boiler: 352 t of wood chips/year - Biomass price: 73,1€/t
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.	• Start: 2014 • Area: 1720 ha • Economic metric: - Shepherds do not pay the rent of the public areas on which they graze for their fire prevention service, saving on average 60 euro/ha/year
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	Production of semi-processed products for bio-building, cork-	Private agencies, universities, local cork producers.	• Start: 2016 • Area: 800 ha • Economic metric:

(*continued on next page*)

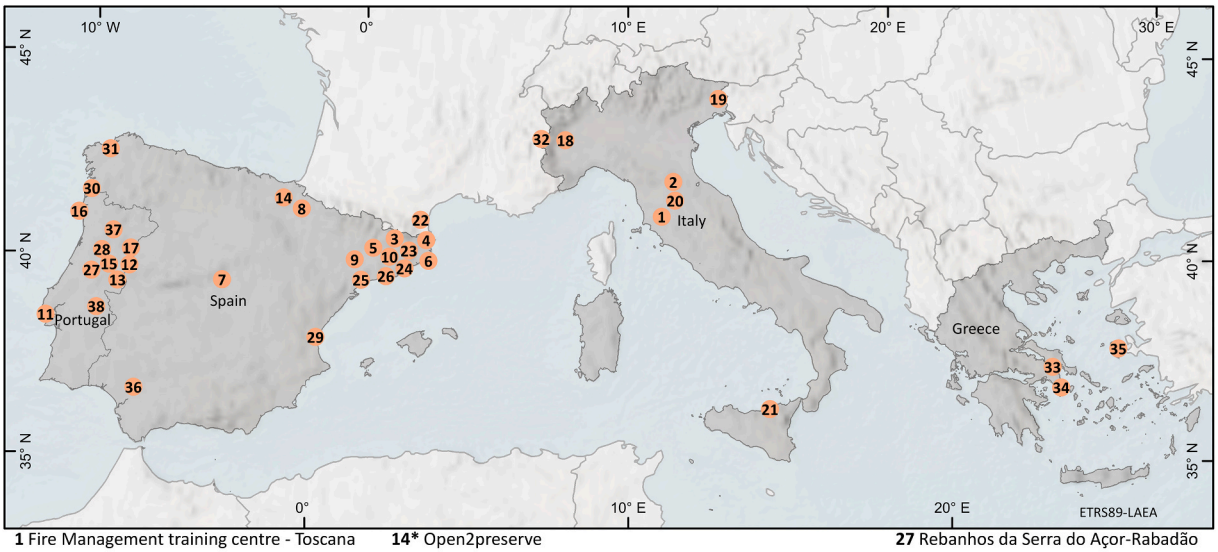
Table 2 (*continued*)

ID (Fig. 1)	Initiative name	Environmental zone	Climatic classification	Contribution to fire hazard reduction	Activated chain and social/ environmental services	Cooperation actors	Performance metrics
				cutting in *Quercus suber* woods.	based panels and granulates. Use of the resulting biomass for factory heat. Cork forest restoration (habitat 9330).		- Cork oak price is 65 €/quintal of which 10% is the added value for landscape maintenance when compared to market prices
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.	• Start 2018 • Area: 124 ha • Economic metric: - Shepherds do not pay the rent of the public areas they graze for their fire prevention service, saving on average 150 euros/ha/year - Subsidy to grazing activities using flocks of goats for fire prevention (25€/ha/year)
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 – Fig. 5).	Consortium for management of public forests in Upper Susa valley, municipalities, private forest owners, local forestry enterprises, architectural designers.	• Start 2018 • Area: 500 ha • Economic metric: - Variable retention harvest in fuel-breaks extracts on average 100 m3/ha - The Mompantable price is 600 €/table and the fire-marketing increased sales 10x which led to the production of 150 tables/year since 2018 - 10% of water use costs paid by citizens of downstream cities are allocated to forest management including pyrosilviculture
35	OMIKRON Project	Mediterranean South *[Greece]*	Temperate, dry summer, hot summer (Csa)	Forest fuel management (biomass removal, pruning, forest roads) in fuelbreaks and initial attack firefighting interventions is carried out by volunteers.	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.	• Start: 2003 • Area: 66 ha • Economic metric: - Forest Service and the Municipality of Chios do not pay wages to the volunteers for the fuel treatments. Based on an estimate of 52 man-days/ha and a daily cost of 90€/day for workers, a total

(*continued on next page*)

Table 2 (*continued*)

ID (Fig. 1)	Initiative name	Environmental zone	Climatic classification	Contribution to fire hazard reduction	Activated chain and social/ environmental services	Cooperation actors	Performance metrics
							contribution of 308,880 € is estimated
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.	• Start: 2003 • Area: 6000 ha • Economic metric: - Shepherds receive PES from the administration: initial bonus of 300 € for participating in the scheme and a variable share from 42€/ha to 90€/ha considering the grazing difficulty
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.	• Start: 2012 • Area: 300 ha (4 common land areas: Tresminas, Revel, Vales, and Covas) • Economic metric: - Subsidy to resin collectors for fire surveillance service (€55/year per worker)
38	REN	Lusitanian *[Portugal]*	Temperate, dry summer, hot summer (Csa) or warm summer (Csb)	Vegetation management and forest defense against fires in electricity and gas easements.	Maintenance of fuel breaks, increase biodiversity, network of green infrastructures through reforestation with native species.	Landowners, commoners.	• Start: 2010 • Area: 35000 ha (21000 ha forest areas, 32700 ha rural areas). • Economic metric: - sReduction of 20% of costs for fuel management along power lines due to vegetation conversion to native species, because of both lower maintenance costs (e.g. less flammable vegetation, regular spacing) and additional interventions carried out by land owners which take profit from native species.



1 Fire Management training centre - Toscana
2* Life Granatha
3 Life+ DEMORGEST
4* Ramats de foc (Fire flocks)
5 Life Monserrat
6 Assessment of biomass availability in Calonge
7 GEPRIF Project
8 PROBIOMASSE Project
9 Life PINASSA
10* Boscos del Vallès (Valles Forest)
11 Life Elia-Art
12 Cabra serrana nos Baldios da Malcata
13 Escola de Pastores - Shepherds' Schools
14* Open2preserve
15* SILVPAST Project
16 Forest Management - ACHLI
17 Reserva Faia Brava - Grazing fire brigades
18* Fire fighting training center of the Piemonte Region
19* Grazing program for fire hazard abatement (Landa Carsica)
20 Biomass production and fire hazard reduction in Pratomagno
21* New Business Models for the cork oak sector
22 Alberapastur Project
23 Quality-Suber
24 ORGEST Project
25* Fire prevention plan of Matadepera
26 Priority Protection Perimeters (PPP)
27 Rebanhos da Serra do Açor-Rabadão
28* Landscape Fire Project
29 Resilient Forest Project
30 LIFETEC Project
31 REFOREST Project
32* PreFeu initiative - Upper Val Susa
33 Wildfire prevention in Athens outskirts
34 Wildfire prevention in southern Attica
35* OMIKRON Project
36* RAPCA Program
37* Resin extraction - RaízesIn
38* Forest Management - REN

Fig. 1. Selected fuel management initiatives in southern European countries fulfilling one or more key fire-smart criteria (Table 1). Stars associated with initiative ID indicate those programs described in detail in Table 2.

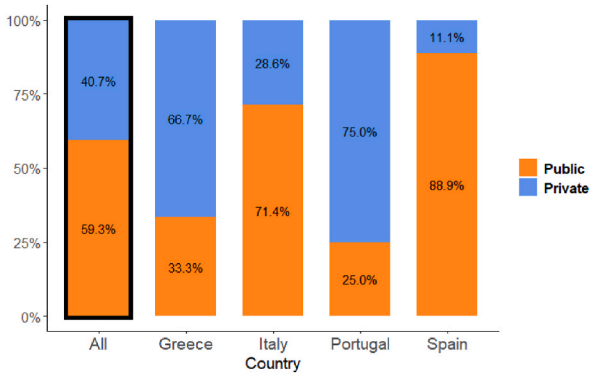


Fig. 2. Promoters (public/private agencies) of the 38 fuel management initiatives.

4. Discussion

4.1. Towards a fire-smart solution model

The selected initiatives are a pool of applications of fire-smart criteria (Table 1) in southern Europe. Although this pool is non-exhaustive, it is useful to extract key elements for sustainable fuel management and provide functional approaches and concrete solutions to devise a general model. Fig. 6 summarizes the main emerging components characterizing a fire-smart solution 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. Indeed, limited financial resources are a prominent barrier to wildfire prevention in southern Europe, especially when fuel management is decoupled from the market, and agro-forestry land uses with a fire regulatory capacity (i.e. [6], are not integrated into wildfire risk management planning. In the documented initiatives, the achievement of sustainable fuel

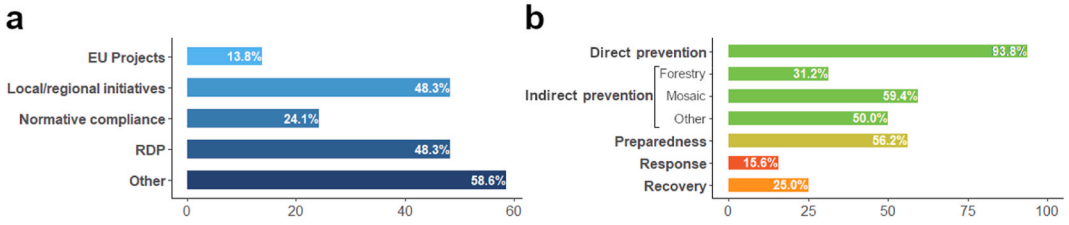


Fig. 3. Source of funding (a) and DRM cycle phase covered (b) for all 38 fuel management initiatives.

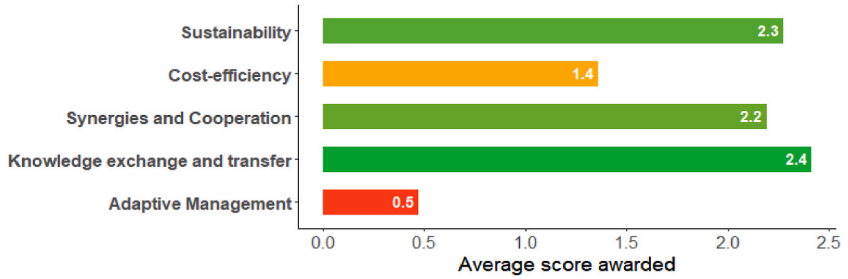


Fig. 4. Average score assigned to the six criteria shown in Table 1, used to rank the 38 fuel management initiatives.

Fig. 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).

management followed three types of mechanisms (Fig. 6): (i) economics of market and non-market valuation; (ii) economics of multi-objective management increasing cost-efficiency, and (iii) benefits of leveraging existing knowledge, and utilizing adaptive management approaches.

The first type of mechanism includes the production of goods with a market value by valuing the biomass extracted with fuel treatments, and related by-products, and the recognition of positive externalities generated by fuel management at the landscape scale

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

Strengths	Weaknesses
■ Convergence towards multiple land management goals maximizing 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 a 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 to have resilient landscapes to face wildfire risk reduction	■ Segmentation of competencies 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 ownership ■ 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 provides 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) ■ Certification of local short supply chain ■ Increasing awareness and policy support for the necessity 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 valorization of the green and urban infrastructure ■ Increasing social understanding of the root causes of wildfires in the Mediterranean ■ Social valorization 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) ■ Development of Urban Agendas and implementation of risk reduction to foster resilience to climate change	■ 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 competition for the limited resources within RDP where prevention (not linked to the market) is not the priority ■ Lack of policy support for long-term actions (needed to make a change at the 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 ■ Financial and technical capacity of public authorities too weak to cope with the multi-sectoral challenges of climate change ■ Inertia within the public bodies facilitates competences segmentation and adds difficulties to the operational coordination, which in the end is transferred to the local actors limiting the motivation of individuals

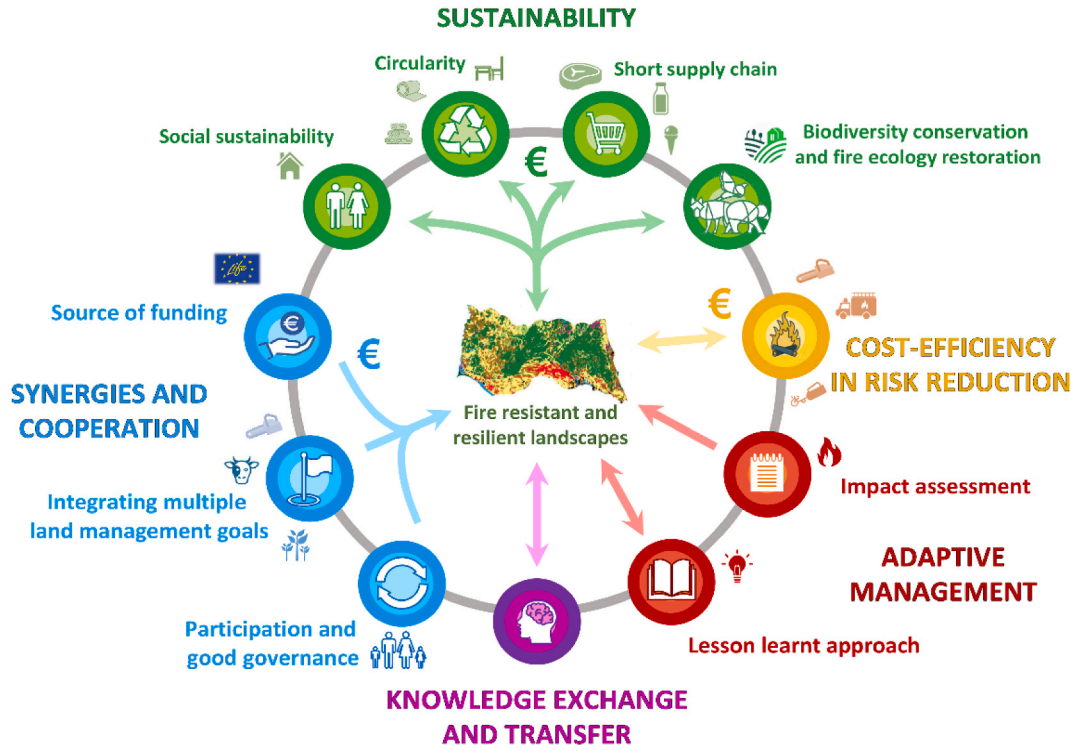


Fig. 6. Key emerging components that characterize a fire-smart solution for wildfire risk prevention.

(non-market valuation). Several initiatives created a short supply chain under a circular bio-economy perspective, valuing fire-marketing products like wood, agricultural and pasture products under labels highlighting or certifying wildfire prevention (Table 2). For example, the Life Granatha project in the Pratomagno area, central Italy, produces biological brooms with heather harvested along fuelbreaks and blocks managed for fire hazard reduction and habitat conservation [44]. Based on market analysis, the initiative sells brooms at 1.4€ (vs. a market price of 1.2€), i.e., the consumers are willing to pay 17% more than the market price for the fire prevention and habitat conservation services of the broom production chain. Some initiatives based on prescribed grazing as a fuel management technique activated dairy supply chains or cow-calf lines with interesting examples of products commercialization. The Fire Flocks initiative in Catalonia registered the "Ramats de Foc" label, which is distributed in points of sale and restaurants throughout the northeast of the region [33,46]. In this initiative, the herds' positive effect on fire risk management is communicated to the consumer through a label that certifies the fuel management activity (Fig. 5a). Notably, from 2018 to 2022, business establishments selling the Fire Flocks products have increased seven times (Table 2), creating an economy of scale behind the fire prevention activity. 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 gives visibility to the contribution of vineyards as fuelbreaks together with the marketing and valorization of the specific flavors due to the effect of smoke on that vintage. In the European Alps, the "Mompantero fire", the largest stand-replacing fire in Italy during the extreme fire season of 2017 [47], has set in motion an initiative to reduce post-fire hazardous dead-wood accumulation. The wood mobilized from salvage logging in the wildfire affected site is transformed in different products such as the "Mompan-table" (Fig. 5c), while product branding is used to draw customers attention to the problem of extreme wildfires. This communication campaign has increased product sales tenfold between 2018 and 2022, when compared to previous years, at a cost of 600 euros/table with a production of 120 tables/year, which sustains the fuel reduction program. Similarly, product sales resulting from fire prevention activities brought additional income to the local producers from the sale of biomass in the Bosco de vallès initiative, or from the sale of secondary products such as resin in the RaízesIN initiative (Table 2).

These are some fire-smart solutions in which fire prevention finds financial justification through the creation of added value for dairy and other products under a green marketing logic. Local, national or international certification of rural activities that prevent wildfires is a possible way to increase the economic viability of local production chains in marginal territories. In this regard, the creation of fire prevention-related marketing is fundamental since it produces positive externalities at a socio-economic level and creates benefits. These initiatives can involve society (consumers) in the solution, who will buy "wildfire prevention" through the shopping basket. 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 words, wildfire prevention marketing and labeling can facilitate public education and support of long-term, cross-sectional policies for wildfire risk management.

In marginal areas where sustainable supply chains fail because of a lack of commercial opportunities, new mechanisms are needed to manage fue at the landscape scale. Fire-smart solutions for wildfire prevention involve the recognition that in marginal lands, the response-centered strategy may have limits under current land use and climate change in protecting ecosystem services and the population from negative wildfire effects [2], and that decreasing landscape flammability is a necessary complementary strategy [6,8,48]. When this is clearly communicated and understood, private and public actors may be more willing to support the cost of securing the territory from wildfires. As an innovative source of income, some documented fire-smart solutions proposed wildfire prevention as an ecosystem service that allowed the activation of mechanisms such as the "payment for ecosystem services'' (PES). An example of PES is implemented in the FireFlocks project, in which shepherds are compensated by the public administration for each hectare grazed within the initiative, valorizing fuel reduction as an ecosystem service: 140€/ha/year in strategic areas and 70€/ha/year in complementary areas (Table 2). Similarly, the RAPCA initiative remunerates 200 shepherds for their grazing activity in areas planned for fire risk mitigation, valorizing fire prevention as an ecosystem service with payments of a fixed initial bonus of 300€ for participating in the PES scheme and a variable share ranging from 42€/ha to 90€/ha depending on grazing difficulty [49]. In north-west Italy, where the PreFeu project takes place (Table 2), 10% of the costs for potable water that citizens of downstream cities pay are used by the forestry consortium of the Municipalities located upstream to support sustainable forest management and wildfire prevention to protect water catchments [50].

Besides market and non-market valuation, other documented mechanisms include the convergence of multiple interests into prevention activities, which sets the basis for a unified risk management strategy integrating different sectoral policies (e.g., forestry, agriculture, nature conservation, energy, tourism) and their related funding schemes (Fig. 6). Documented solutions integrated fire management with other land governance goals, by linking strategic fuel management to the achievement of a "resilient landscape" in terms of biodiversity conservation, water and energy provision, landscape aesthetic, and providing civil protection to critical infrastructures and economic activities (e.g., tourist sector increasingly vulnerable under worsening wildfire risk). For 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 nature-based techniques with specific ecological effects such as grazing (e.g., height and type of cut, trampling, fertilization), closer-to-nature pyrosilviculture (e.g., canopy gaps dynamics, species substitution), or prescribed burning (e.g., stimulation of flowering and seed germination, the input of charcoal into the soil, mosaic of burnt and unburnt islands), which diversify vegetation structure and have positive effects on some habitats (e.g., 4030, 6110, 62A0, 6220*, 6410, 9330, 9540 of the EU Habitat Directive) [8,48,51]. When fire prevention and nature conservation targets coincide [9], this justifies the use of resources for biodiversity maintenance (e.g., Natura 2000 sites, National Parks) for fire prevention as well. In the LIFE Montserrat [52] and LIFE Granatha [53] projects, 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). This also occurs with REN activities in Portugal, by involving landowners in the creation of a national network of green infrastructures using native species.

In some initiatives, the cooperative and synergistic approach to foster the convergence of wildfire management goals, while optimizing cost-efficiency, has been implemented between sectors of the DRM cycle (Fig. 3). Examples are the initiative carried out by the Fire Management Training Centre of the Tuscany region, in Italy, where prescribed burning activities are integrated into the training program of fire-fighting operators [54]. 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, and vehicle driving). The resin extraction carried by RaízesIN promotes not only fuel management of the pine stands, but also early fire detection by the workers who preside over the territory for the extraction of the resin. Such solutions align the needs of the preparedness and the fire prevention sectors, creating synergies that increase the cost-efficiency of wildfire risk management.

Documented fire-smart solutions made 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 [55], or the PreFeu initiative (Table 2), stand out as a major innovation, working in fire prevention through the valorization of biomass and exploitation of its products to 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. 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 [56], which evaluates the efficiency of post-fire forest hydrological restoration, the application of new biodegradable materials to reduce the risk of post-fire erosion, and the cost-effectiveness of prevention, extinction and rehabilitation activities. Likewise, the OMIKRON volunteers group works according to the lessons-learned approach, and tries to constantly increase the number of members to build up a wide range of experiences from which to learn, including the first prescribed burning program in Greece, in cooperation with the World Wide Fund for Nature (WWF) and the Institute of Mediterranean Forest Ecosystems of the Hellenic Agricultural Organization [57].

4.2. Prospects for smart solutions replication under the EU green deal

The documented fire-smart solutions build synergies between local bottom-up needs and top-down objectives of the European Green Deal (e.g., adapting to climate change, preserving and restoring biodiversity, farm to fork, circular economy, and supply of clean energy), and therefore represent concrete functional approaches that are able to integrate policies with wildfire risk mitigation with

consistency. The Open2preserve [58], the PreFEu [50] and the Landscape fire[6] fuel management initiatives (and other selected LIFE projects) perfectly embody this vision, being promoted and financed by multiple European programs, regional administrations, local associations, and private foundations, and laying the framework for long-term land management that integrates coherently principles and goals of multiple policies. This is not a trivial issue since the overall functions of policy integration are to dissolve contradictions, reduce redundancies, and exploit synergies between policies [59]. For example, the broad-scale reforestation by planting 3 billion trees, which is promoted by the EU biodiversity strategy for 2030 and the EU Forestry Strategy, requires considering the potential trade-offs between climate-smart interventions and the rising wildfire risk under climate change. Similarly, policies under the Biodiversity Strategy and agriculture must recognize the key role of open habitats of conservation importance, such as low-intensity farming systems of high ecological value, and their potential role in increasing biodiversity, mitigating fire hazard at the landscape scale and reducing fire suppression costs [27]. Furthermore, interventions targeted at the supply of clean energy such as the installation of new wind turbines in flammable wooded landscapes under the Just Transition mechanism of the EU Green Deal, should not overlook the need to protect facilities and to prevent the risk of fire ignitions.

The fire-smart solutions showcase various routes to address these trade-offs by outlining methods to leverage mutually beneficial projects across climate change mitigation, biodiversity conservation, and fire-smart land management priorities. These initiatives confirm the importance of investing in cross-sectoral policies applied at the local level and, at the same time, to make European funding strategies more accessible to local entities. Integrating multiple sources of funding at all levels, starting with local and national initiatives (regional, RDPs, etc.), and extending up to international programs (EU measures and strategies), will increase stability and continuity of 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 recommendations and translate them into governance participatory models, in the perspective of integrated wildfire risk management. Lessons learned from the documented initiatives suggest that the success of a fire-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". Accordingly, a common characteristic emerging 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 [35]. 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 [5].

Reliance on EU funds has sometimes been perceived as difficult, as reported in the SWOT analysis (Table 3). This barrier, in connection with the segmentation of competencies in wildfire management, can be detrimental to structure shared governance. In this perspective, the concept of multi-actor clusters can be an 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 in leveraging the impact of public policies on wildfire risk management, starting from a shared vision of using 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 efficient and coherent use of multiple funding sources (avoiding redundancies, gaps and conflicting goals). It is likewise necessary to ensure that international, European, and national funding is complementary to the regional funding and that investments are allocated to strategically pre-planned actions according to the local/regional fire risk mitigation needs.

Some key-components of the fire-smart solution model can also be taken up by management authorities when designing the structure of the call for proposals for accessing EU funding. Several 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 programs 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 engage 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. Specific route for the replication and up-scaling of the fire-smart solution model within the framework of the EU Green Deal is coupling the Farm to Fork strategy to value chains that prevent wildfire in high fire risk zones (as identified by strategic fire prevention plans) or around infrastructures to be protected (e.g., new wind turbines). Likewise, strategic fuel management represents a nature-based solution for climate change adaptation. Similarly, the establishment of periurban green infrastructures, offering wildfire protection instead of hazard, can be pursued under the New Urban Agenda [60]. Another simple example of fostering coherent policies for wildfire risk mitigation under the EU Green Deal is the development of criteria for afforestation/reforestation initiatives. These should incorporate the concept of FSTs, select native and less fire-prone tree species, restore open woodland vegetation, give priority to agro-forestry over dense tree plantations, and use understory biomass as a source of bio-energy to reduce fuel accumulation (Moreira and Pe'er, 2018; [2,27]. Similarly, 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 [48].

Finally, re-designing the allocation of rural development funds 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.

[6] https://life.cimvdl.pt/.

A better way forward is to design calls that join multiple measures to implement integrated land development projects in high wildfire risk areas. This expands the vision from sustaining agriculture and forest management to strengthening the fire regulatory role of agro-forestry in reducing fire hazard at the landscape scale (Moreira and Pe'er, 2018). Such projects can integrate active prevention interventions with other RDP measures supporting indirect prevention, while pushing the economic growth 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 with long-term projects with clear objectives, including wildfire risk mitigation.

5. Conclusions

Extreme wildfires are a complex phenomenon that emerges from the interaction between a territory's multiple physical, biological and socio-economic factors [8,22,61,62]. To mitigate wildfire impacts on ecosystem services, it is necessary to implement integrated solutions that act on key driving factors, in a concrete and sustainable way from an economic, social and environmental point of view [2,10].

In this study, we document and analyze several initiatives that share a common backbone of key principles, aiming to build "fire-smart territories" [1]. It must be noted that there is no one-size-fits-all solution and land managers must consider various kinds of interventions when implementing direct prevention through fuel management [42]. However, our analysis shows how current fire-smart solutions currently implemented through several initiatives 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, a territory's private investments, product certification agencies, and EU funding programs (LIFE Program, Rural Development Program);
(iii) a planning process optimize fuel reduction treatments to best allocate limited economic resources, aiming to achieve landscape-scale wildfire risk reduction and leverage economically efficient treatment methods (e.g., silviculture, grazing, agriculture);
(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 pyrosilviculture, 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) valorization of products generated by fuel management with agro-food marketing and certification (e.g., "Ramats de Foc" and "Vinyes de Contrafoc" in Catalonia), to reward farmers for the environmental service delivered in mitigating wildfire risk;
(vii) strong social engagement of local communities in wildfire risk management, through participatory processes involving civilians, 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 expanding into the wildland-urban interface [2], represents not only an urgent challenge, but also a stimulus to turn wildfire risk management into an opportunity for sustainable and inclusive growth of marginal territories. The fire-smart solution model discussed here offers concrete civil and environmental protection tools. However, the recognition of fuel management as a civil protection strategy requires the public to recognize 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.

The uptake and replication of fire-smart solutions at the European scale requires a network of the various initiatives and institutions involved in wildfire risk management, in order to create a mutually beneficial exchange platform of best practices.[7]

In conclusion, if the EU Green Deal provides the strategic vision to mainstream and align local land management initiatives within sustainable and inclusive growth, the fire-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, to make visible their "cost-efficiency" in terms of reducing the cost of direct prevention and wildfires potential impact [63]. In this perspective, we contend that if the future public funding programs are designed to include, at least some, of the criteria of the fire-smart solution model here discussed, private and public actors will be more attracted to join forces and co-design solutions that are adapted to real needs of marginal territories.

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[7] Fire-smart solutions analyzed by the PREVAIL Project are hosted in the "Lessons on fire" (https://lessonsonfire.firelogue.eu/) and GoProFor (https://www.lifegoprofor-gp.eu/) platforms.

(Agritech) project.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

We have shared some of the data and results in supplementary materials, and the link to the original interviews has been added in footnotes in the text

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2023.103715.

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