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Rural development funding and wildfire prevention: Evidences of spatial mismatches with fire activity

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A R T I C L E I N F O

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A B S T R A C T

The European Union Rural Development Program (RDP) is a major driver of landscape change over time in Europe. In a context of climate and land use changes and consequent fire risk exacerbation, understanding the possible contribution of RDP measures to wildfire risk mitigation could help planning subsidies allocation criteria in a more efficient way for fire prevention. However, little is known on the links between the spatial allocation of RDP subsidies, relevant for wildfires prevention, and the spatial distribution of fire activity. Our study aims to fill this knowledge gap through an exploratory analysis carried out in Italy and based on fire activity indicators of the period 2007–2017, RDP expenditure at municipal level in the period 2017–2013, and a series of ancillary indicators. We selected RDP measures specifically addressing wildfires (direct prevention) and those whose implementation has an impact on fire regime (indirect prevention). Our results suggest a low association between RDP expenditure for fire-related measures and subsequent reduction of wildfire activity. Principal Component Analysis suggests a role of managed rural areas in mitigating fire activity, as well as a spatial mismatch between wildfire prevention expenditure and high fire activity contexts. We claim the need for a deeper integration of territorial planning information within the RDP funding allocation criteria. Also, integrating RDP indirect prevention measures within fire management plans would be a cost-effective approach to leverage the impact of public policies on wildfire risk management, by allocating the limited financial resources to high-risk areas.

1. Introduction

Rural landscapes in Southern Europe have been increasingly exposed to wildfires during the last decades because of a complex interplay of a warming and drying climate (Koutsias et al., 2013; Lozano et al., 2017; Mavrakis and Salvati, 2015), landscape-scale accumulation of fuel (Barbati et al., 2015; Calviño-Cancela et al., 2017), and increase of urban settlements and Wildland-Urban Interface (European Environment Agency EEA , 2016; Mancini et al., 2018b). In addition to all these drivers, fire regimes can be also influenced by socio-economic factors, especially if they are coupled with fire-prone landscapes, such as, for instance, economically disadvantaged contexts with persistent unemployment, rural poverty, social inequalities, population aging and rural abandonment are associated with more frequent fire events (Mancini et al., 2018a; Oliveira and Zêzere, 2020). In turn, this altered fire regime has largely affected ecosystem services provided by natural systems such as soil protection, biomass production, carbon sequestration and habitat provision (Corona et al., 2015). Shifts towards more severe and expensive fire seasons, in terms of related costs of fire suppression, call therefore for a paradigm change in wildfire management policy, in order to rebalance public expenditures between suppression and those wildfire prevention activities able to mitigate the negative impacts of fire

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(Moreira et al., 2020).

Although the European Union (EU) lacks a common policy on forest fire management, various EU General Directorates are involved in developing and monitoring measures on information, prevention, suppression and restoration of burned areas. Within this framework, the Rural Development Program (RDP) represents the most substantial public financial instrument to support the competitiveness, environmental performance and viability of rural areas. By consequence, a better knowledge of the possible nexus between structural causes affecting wildfire risk in rural landscapes and RDP measures (i.e., specific activities that may be funded by the RDP to achieve the goals of the European rural policy) is needed.

Notwithstanding the complex and indirect causal pathways, sustainable and evidence-based (Corona, 2018) land management can mitigate the effects of several disturbances associated to land degradation (e.g. Keesstra et al., 2018, 2021), including wildfires, by maintaining farming, pastoral and forestry activities in rural landscapes. A well-managed land use mosaic is in fact able to reduce fuel load and continuity, thus generating cascading effects on the reduction of the spread, growth, intensity and severity of fires, and consequently on fire-fighting effectiveness (Moreira et al., 2011; Lasanta et al., 2018; Alcasena-Urdíroz et al., 2019; Aquilué et al., 2020). Along with fuel management measures which help reduce fuel loads or change the spatial arrangement of fuels in forest areas (i.e. "direct prevention"), other actions capable to support a well-managed landscape mosaic, through the maintenance of forestry, farming and grazing activities, are also recognized as wildfire prevention (i.e. "indirect prevention") (Ascoli et al., 2021; Mavsar and Plana, 2007; Plana et al., 2021) and especially in fire exposed marginal areas, where the rate of land abandonment is higher, RDP subsidies could therefore play a crucial role in promoting farm permanency (Ciaian et al., 2015; Guth et al., 2020). Even though the majority of RDP measures are not designed to prevent wildfires directly, many measures might help counter land abandonment and boost land management activities able to reduce fuel accumulation and continuity (e.g. agriculture, grazing, sustainable forestry), thus indirectly contributing to wildfire prevention.

To better understand whether RDPs generate a leverage effect on wildfire risk reduction, the spatial dimension of budget allocation is also of interest. In general, a well-developed association and cooperation between land owners facilitates the attraction of RDP subsidies (Camaioni et al., 2016; Kazakova-Mateva, 2020; Kiryluk-Dryjska et al., 2020). By consequence, in relative terms (i.e. per unit of land area), urban and central EU Regions can be more supported than hyper-rural and peripheral ones (Camaioni et al., 2013), as evidenced by several works focused on the spatial allocation of RDP expenditure (Piorr and Viaggi, 2015; Zasada et al., 2015; Zasada and Piorr, 2015), highlighting the conditions of neighbourhood as a pivotal factor of measure success. A few scholars argued the importance of concentrating the spatial allocation of RDP budget for certain measures where there is a need for them to meet regional and sub-regional objectives (Fastelli et al., 2017; Uthes et al., 2017; Zasada et al., 2018), while others analysed the impact of RDP subsidies on farm's inefficiencies (Pechrová, 2015), showing that there are significant differences between subsidized and not subsidized farms, if a viability gap remains between small and large farms (Veveris et al., 2019).

It must be noted though, that despite such extensive research efforts, the possible contribution of RDP measures to wildfire risk mitigation remains understudied and that little is known about the links between the spatial allocation of RDP subsidies, relevant for the prevention of wildfires, and the spatial distribution of fire activity.

Among the fire-affected Mediterranean countries, Italy is an interesting case study to showcase the complexity of this issue, because of its physically and socially articulated geography (Ferrara et al., 2017) and rapidly changing land use structure (Camarretta et al., 2018; Salvati et al., 2017). Evidence shows that the abandonment of farming and extensive grazing activities in marginal and mountain areas, depopulation and social transformation in forest-related economy (Cimini et al., 2013; Ferrara et al., 2017; Masini et al., 2018; Reynaud et al., 2020) are replacing the traditional mosaic of pastures, croplands and forests with flammable shrublands and young dense forest stands, increasing wildfire hazard in rural lands.

This study provides therefore a critical analysis of RDP expenditure in Italy, with a specific look to wildfire prevention. More specifically, we seek to answer the following questions:

1. What is the overall allocation and the spatial distribution of expenditures on direct and indirect wildfire prevention-related RDP measures?
2. To what extent their level of implementation, measured by total expenditure at municipal scale, is linked to the territorial needs of wildfire management, quantified by fire activity?
3. Is spatial variation in the total expenditure of municipalities associated to specific conditions of the territory (land use, socioeconomic context, topography, accessibility) or to fire activity indicators?

2. Materials and methods

2.1. Study area

Our study focuses on Italy, a country where marked geographical gradients determine a complex spatial pattern in both socioeconomic and environmental variables, forest types and fire regimes (Elia et al., 2020; Incerti et al., 2007; Salvati et al., 2017; Scarascia et al., 2006). Northern Italy is a territory with a predominant industrial and advanced service economy, and a landscape configuration divided into a highly anthropized lowland (the Po plain) with negligible occurrence of forests, and mountainous districts (the Alps) specialized in snow tourism, agricultural productions and more traditional industries. Central Italy is characterized by the Apennines mountain ranges, where some of Italy's most important national parks are concentrated, as well as a rich animal and plant biodiversity. Southern Italy is mostly a dry territory, with population concentrated in few compact urban areas and economically disadvantaged rural contexts at risk of depopulation (Salvati et al., 2017). From the post-war period onwards, land use changes have promoted fuel load accumulation, resulting from vegetation succession in abandoned farms or pastures. Falcucci et al. (2007) measured a 74% increase in forest cover during the period 1960–2000, and a 20% decrease in agricultural areas. High forest cover in rural districts is proved to be spatially associated with local communities facing depopulation, unemployment, low educational levels and subsistence agriculture (Ferrara et al., 2017).

In Italy in the period 1980–2017, a total surface of 4061,988 ha burned, with an annual mean burned area of 106,894 ha (Rete Rurale Nazionale, 2019). An analysis of the 2007–2017 national fire statistics shows in particular that the largest amount of ignitions are located in Southern Italy, and that almost 50% of the area burned is concentrated in Sicily and Sardinia, the two main islands of the country. Grasslands, Mediterranean pine forests and shrublands are the most affected land cover classes in terms of burned area (Mancini et al., 2017).

It must be noted that the mean annual area affected by wildfires in Italy is comparable with that of other European Mediterranean countries. As reported by San-Miguel-Ayanz et al. (2021) the mean annual burnt area in Italy amounts to 0.34% of the total national surface for the period 1980–2020, while in Greece, Portugal and Spain to 0.32%, 0.13% and 0.31%, respectively.

2.2. Data collection

Variables describing the structure of 2007–2013 RDP expenditures by municipality were retrieved from a dataset provided by the Italian Council for Agricultural Research and Economics (CREA), a dataset which includes the total expenditure (amount in Euros) by individual

RDP measure at municipal level recorded at the end of the 2007–2013 budget allocation period. It is worth noting that the payment of the resources committed at the end of the programming period was made in some cases after 2013. Therefore we have also included those payments that occurred in the two-year period beyond the conclusion of the RDP program.

According to the RDP data structure, the municipal scale was used for the subsequent spatial analysis and municipalities' boundaries were retrieved from the 2011 vector dataset released by the Italian National Institute of Statistics (ISTAT).

For our analysis, RDP measures that directly involved investments in restoring forestry potential damaged by natural disasters and fire, as well as specific fire prevention actions (e.g. firebreaks, fuelbreaks, water points), were considered as "direct prevention" actions (Ascoli et al., 2021; Plana et al., 2021). In this regard, it should be noted that in the RDP 2007–13 there is no measure with a one-to-one relation with direct wildfire prevention. The RDP measure more closely related with direct wildfire prevention (or post-fire restoration) is the 2.2.6 (Restoring forestry potential and introducing prevention actions). However, funds spent under this measure well reflect the relative importance allocated to prevention of forest hazards out of all activated RDP measures, since wildfire is the most important hazard in Italian forests (Ascoli et al., 2021; Cesaro and Romano, 2008). This RDP measure was therefore assumed as the best available proxy for the cumulated volume of expenditures in fire prevention.

Moreover, we simultaneously identified seventeen "indirect prevention" measures (see Table 1), i.e. measures financing those investments that help counteract specific drivers of land abandonment and lack of management, which in turn are recognized to increase fire hazard at landscape scale (Ascoli et al., 2021; Moreira et al., 2011).

Wildfires statistics in Italy were collected by the State Forestry Corp for regions with an ordinary legislation status and by Regional Forest Services for the autonomous ones. These data include the number of fires as well as fire perimeters and total burned area. We collected and quality checked the 2007–2017 official dataset, in order to compile a fire activity geodataset for the whole country.

In order to compare the spatial distribution of fire prevention-related RDP subsidies with territorial needs of wildfire management, we calculated two types of indicators of fire activity in each municipal area during the period 2007–2017: fire occurrence (cumulative number of fires, number of fires per ha) and fire incidence (cumulative burned area, burned area per unit of municipal area, mean fire size).

Being the fire behaviour strongly affected by climatic and geographic features (Ganteaume et al., 2013), as well as by the socioeconomic context (Ferrara et al., 2019), in addition to fire activity indicators, a set of variables was selected according to Mancini et al. (2018b) to characterize the environmental and socioeconomic conditions of each municipality in Italy (Table 2).

The land use variables were derived from Corine Land Cover (CLC 2012). Five indicators, in particular, were chosen, as they represent the amount of land area covered by artificial surfaces, agricultural areas, forests and semi-natural areas. Additional indicators were retrieved from CLC 2012 maps to better assess territorial variables related to fire activity, while the socioeconomic variables were derived from official statistics provided by ISTAT, and they are referred to an intermediate year within the time interval of the fire dataset (2007–2017). In addition, climate features directly related to fire danger (Mavrakis and Salvati, 2015) were retrieved from WorldClim database, according to Mancini et al. (2018a).

2.3. Statistical analyses

Considering only the municipalities where at least one wildfire event occurred during the 2007–2017 period (n = 5156), we identified, on the one hand, those municipalities that spent more in RDP direct or indirect fire prevention measures (RDP hotspots) and, on the other, those municipalities that showed the larger proportion of municipal area affected by wildfires (wildfire hotspots). Municipalities showing values above the 80th percentile of the distribution of the proportion of municipal area affected by wildfires were classified as wildfire hotspots (n = 1032). The same threshold was used to identify the RDP hotspots amongst municipalities with expenditure on direct or indirect fire prevention RDP measures (see Table 1), based on their respective unitary expenditure values (€ Km^{-2}) (RDP hotspots: n = 147 for direct measures; n = 1018 for indirect measures). A contingency table was then produced to determine the pairing between municipalities with higher concentration of RDP fire-related funds and wildfire hotspots.

A multidimensional exploratory analysis was carried out in order to verify possible associations between the variables describing the expenditure on direct prevention (i.e. the share of total expenditure for measure 2.2.6 in total RDP expenditure and the cumulated volume of expenditure for measure 2.2.6 per unit of forest area) and territorial, climatic, and socio-economic features, and fire indicators (Table 2). This analysis allowed to profile each Italian municipality on the basis of the intrinsic relationships between total expenditures for the selected RDP measures, territorial indicators and, fire activity indicators. Accordingly, a PCA was run in R environment using the 43 indicators reported in Table 2 at municipal level for the whole Italy (n = 8094). The calculation

Table 1
Drivers of landscape change that are increasing landscape flammability and 2007–2013 RDP measures that have the potential to mitigate fire hazard. From Moreira et al. (2011), modified.

	Drivers	Landscape patterns	Fire hazard	Counteracting RDP measures
Direct prevention	Deficit of funding, plans and actions for wildfire prevention	Forests +Shrublands +Grasslands and pastures -Agricultural areas -	+	**M2.2.6** - Restoring forestry potential and introducing prevention actions
Indirect prevention	Decrease of farming activities	Forests +Shrubland +Agricultural areas -	+	**M1.2.1** - Modernisation of agricultural holdings; **M1.3.2** - Participation of farmers in food quality schemes; **M1.3.3** - Information and promotion activities; **M2.1.4** - Agro-environmental payments
	Decrease of pastoral activities	Forests +Shrubland +Grasslands and pastures -	+	**M2.1.1** - Natural handicap payments to farmers in mountain areas; **M2.1.2** - Payments to farmers in areas with handicaps, other than mountain areas; **M2.1.5** - Animal welfare payments
	Population ageing and decline/ Emigration	Forests +Shrubland +Agricultural areas -	+	**M1.1.1** - Vocational training and information actions; **M1.1.2** - Setting up of young farmers; **M1.2.4** - Cooperation for development of new products, processes and technologies in the agriculture and food sector and in the forestry sector; **M3.2.1** - Basic services for the economy and rural population; **M3.2.2** - Village renewal and development
	Decreased exploitation of timberand wood resources	Forests +Shrubland +	+	**M1.2.2** - Improvement of the economic value of forests; **M1.2.3** - Adding value to agricultural and forestry products; **M1.2.5** - Infrastructure related to the development and adaptation of agriculture and forestry; **M2.2.5** - Forest-environment payments; **M2.2.7** - Non-productive investments

Table 2
List of variables included in the PCA.

Acronym	Selected variables	Unit of measurement	Source
RDP expenditure variables			
Sp	RDP expenditure per forest and agricultural unit area	(€ Km^{-2})	RDP expenditure dataset (CREA)
X1.11	Measure 1.1.1 expenditure out of total RDP expenditure	(%)	
X1.12	Measure 1.1.2 expenditure out of total RDP expenditure	(%)	
X1.21	Measure 1.2.1 expenditure out of total RDP expenditure	(%)	
X1.22	Measure 1.2.2 expenditure out of total RDP expenditure	(%)	
X1.23	Measure 1.2.3 expenditure out of total RDP expenditure	(%)	
X1.24	Measure 1.2.4 expenditure out of total RDP expenditure	(%)	
X1.25	Measure 1.2.5 expenditure out of total RDP expenditure	(%)	
X1.32	Measure 1.3.2 expenditure out of total RDP expenditure	(%)	
X1.33	Measure 1.3.3 expenditure out of total RDP expenditure	(%)	
X2.11	Measure 2.1.1 expenditure out of total RDP expenditure	(%)	
X2.12	Measure 2.1.2 expenditure out of total RDP expenditure	(%)	
X2.14	Measure 2.1.4 expenditure out of total RDP expenditure	(%)	
X2.15	Measure 2.1.5 expenditure out of total RDP expenditure	(%)	
X2.25	Measure 2.2.5 expenditure out of total RDP expenditure	(%)	
X2.26	Measure 2.2.6 expenditure out of total RDP expenditure	(%)	
X2.27	Measure 2.2.7 expenditure out of total RDP expenditure	(%)	
X3.21	Measure 3.2.1 expenditure out of total RDP expenditure	(%)	
X3.22	Measure 3.2.2 expenditure out of total RDP expenditure	(%)	
X22out2	Axis 2.2 expenditure out of total Axis 2 expenditure	(%)	
X226outFor	Measure 2.2.6 expenditure per unit of forest area (CLC class 3)	(€ Km^{-2})	
Fire activity variables			
Sfire	07–17 cumulative burned area	(ha)	Italian National Forest Service fire dataset, modified
Nfire	07–17 cumulative number of ignitions		
SfireoutCom	Ratio of 07–17 burned area to municipal area	(%)	
NfireoutCom	07–17 no. of ignitions per unit of municipal area	(n/ha)	
Mfire	Mean size of 07–17 wildfires	(ha)	
Territorial variables			
clc1.	Share of urban (CLC class 1)	(%)	2012 Corine Land Cover (EU)
clc2.	Share of agriculture (CLC class 2)	(%)	
clc31.	Share of forests (CLC class 3.1)	(%)	
clc32.	Share of shrubland and grassland (CLC class 3.2)	(%)	
clc33.	Open spaces with little or no vegetation (CLC class 3.3)	(%)	
Conif	Conifer-dominated forests per unit of forest area	(%)	
UrboutFor	Urban-forest length per unit of municipal area	(m km^{-2})	
Disp	Dispersed urban area per unit of urban area	(%)	
Str	Roads density per unit of municipal area	(m km^{-2})	
Alt	Mean altitude	(m)	Statistical atlas of Italian municipalities (ISTAT)
Contextual variables			
Ab	Population density	(persons km^{-2})	Population-Households Census (ISTAT)
AzAgr	Mean farm size	(ha)	2010 Agricultural census (ISTAT)
Climate variables			
MaxT	Max temperature of the warmest month	(°C)	WorldClim 1970–2000
MeanTDr	Mean temperature of the driest quarter	(°C)	
MeanTWarm	Mean temperature of the warmest quarter	(°C)	
PrecDr	Precipitation of the driest quarter	(mm)	
PrecWarm	Precipitation of the warmest quarter	(mm)	

was done by a singular value decomposition of the centred (i.e. variables were shifted to be zero centred) and scaled (i.e. variables were scaled to have unit variance before the analysis) data matrix (Salvati and Zitti, 2007). Based on the interpretability criterion (Kim and Mueller, 1978; O'Rourke and Hatcher, 2013; Stevens, 2012), the number of relevant axes was chosen by retaining components with eigenvalue > 1.5 and loading > |0.35|. Finally, we applied Kaiser-Meyer-Olkin measure of sampling adequacy, which tests whether the partial correlations among variables are small, and Bartlett's test of sphericity, which tests whether the correlation matrix is an identity matrix ($p < 0.001$), to assess model appropriateness.

3. Results

3.1. Descriptive statistics of selected RDP measures

At national level, the selected RDP measures (Table 1) accounted for 80% of the total RDP expenditure, as shown in Fig. 1. Most of the expenditure was directed to measures 1.2.1 and 2.1.4. While the total expenditures of measures with an indirect effect in mitigating fire risk (selected measures other than measure 2.2.6) accounted for 77.1% of

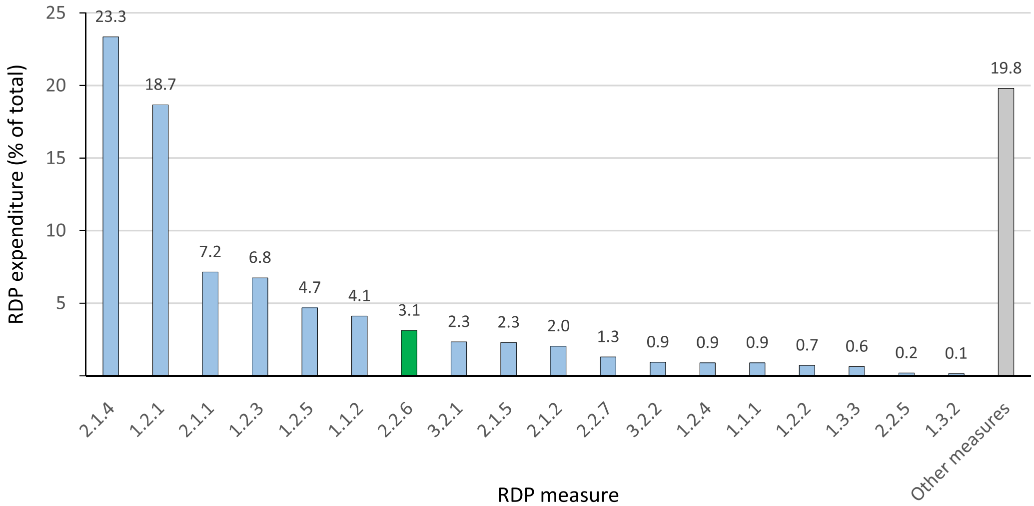


Fig. 1. Share of RDP expenditures by selected measures on the total RDP expenditure in Italy (reference period: 2007–2013). The expenditures for indirect prevention are reported in light blue. The green bar indicates the expenditure for direct fire prevention (measure 2.2.6). The total for the other RDP measures is shown in light grey.

the total RDP expenditure, the budget allocated for direct prevention (measure 2.2.6), accounted only for a small proportion of both the total RDP expenditure (3%) and the fire prevention-related selected measures expenditure (4%). Overall, fire prevention-related measures were equally distributed within Axis 1 (Improving the competitiveness of the agricultural and forestry sector), and 2 (Improving the environment and the countryside) in terms of budget allocated (38% and 39% of total RDP expenditure, respectively), while only a small proportion (3.3%) was spent on Axis 3 (Improving the quality of life in rural areas). In addition, a refined analysis revealed significantly higher expenditures on Axis 2.1 (agro-environmental measures specifically addressing agricultural landscapes) measures (35.3%), when compared to Axis 2.2 (agro-environmental measures specifically addressing forest landscapes) ones (6.8%).

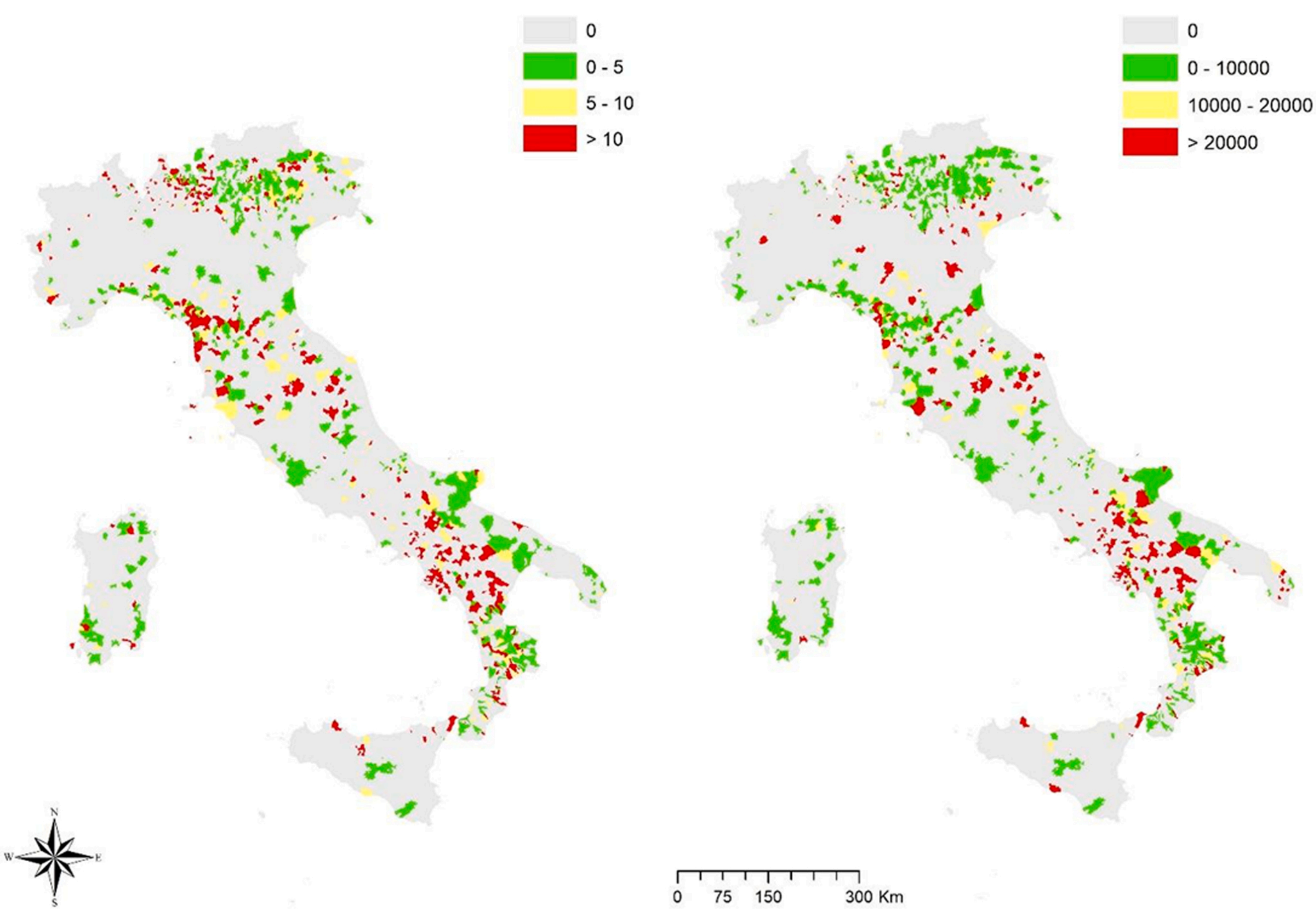


Fig. 2. Spatial distribution of 2007–2013 RDP expenditure for measure 2.2.6. Left: % expenditures in measure 2.2.6 out of total RDP expenditures. Right: expenditures in measure 2.2.6 per unit of forest area (€ Km^{-2}).

Interestingly enough, the distribution of measure 2.2.6 expenditures across municipalities in Italy was largely heterogeneous and spatially polarized (Fig. 2). Most municipalities (90%) had, in fact, no expenditures related to such measure. A small number of municipalities (4%) spent less than 5% of the total RDP budget on measure 2.2.6, and even a smaller number of municipalities (2%) spent between 5% and 10%. In about 300 municipalities (4%), more than 10% of the total RDP expenditure was allocated to measure 2.2.6. Municipalities located in mountainous and hilly areas along the Apennines were more active in the implementation of the measure if compared to those in plains and coastal zones. A similar spatial distribution was also found with respect to the total expenditure for measure 2.2.6 per unit of forest area. Values above 20,000 € km^{-2} were observed mainly in Southern Italy (Campania, Basilicata, and Calabria regions), and more sparsely in Tuscany. Territorial clusters of municipalities with an average total expenditure of more than 10,000 € km^{-2} were observed in the coastal areas of Tuscany and the Southern Apennines (Campania, Basilicata, Puglia, and Calabria). The overall spending structure of measure 2.2.6 was extremely fragmented at both national and regional levels.

3.2. Hotspot analysis

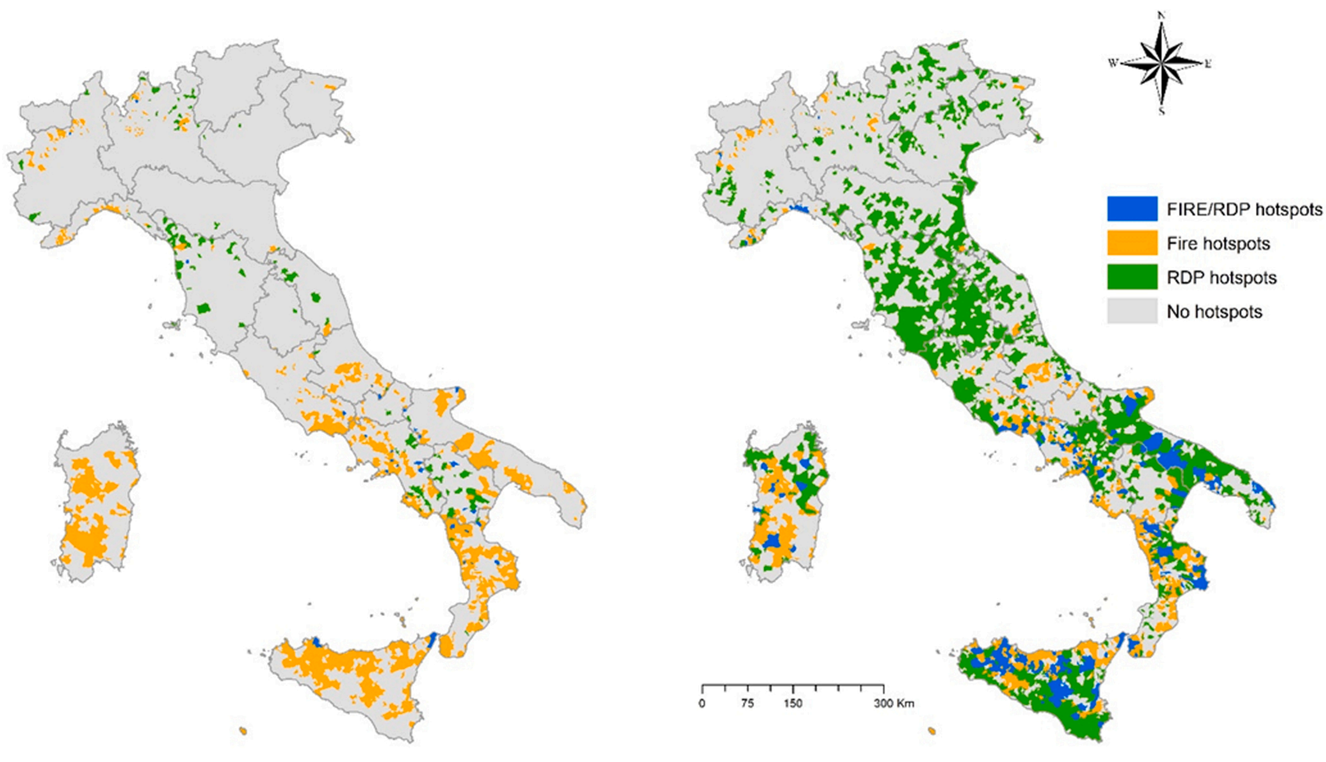
The hotspot analysis showed a low spatial association between the concentration of the expenditure in RDP fire-related funds and wildfire activity. Only 3% of the 1032 municipalities classified as wildfire hotspots also resulted as hotspots for 2.2.6 expenditure (Fig. 3), and are mainly located in Southern Regions. Despite the largest number of fire hotspots are found in Southern Regions, the greatest part of municipalities classified as RDP attractors for direct prevention were found in Central and Northern Regions, these latters being not major fire-prone.

Looking at the expenditure on measures indirectly contributing to fire prevention, hotspots for RDP can be found in the whole country, with a greater proportion in Southern and Central Italy. The percentage of wildfire hotspots paired with RDP hotspots for indirect prevention amounts to only 16%, mostly corresponding to Southern Italy municipalities.

3.3. Principal Component Analysis

Both the Kaiser-Meyer-Olkin measure of sampling adequacy (0.85) and Bartlett's test of sphericity ($p < 0.001$) clearly indicate that the model is appropriate to analyse these data. Accordingly, five principal components (PCs) were extracted from the PCA based on 43 indicators at the municipal level (Table 2), explaining 42% of the total variance (Table 3), and results show a considerable fragmentation as well as a lack of spatial clusterization for RDP expenditures addressing fire-related issues. Overall, we did not find a significant correlation between RDP expenditure for fire-related measures and their localization in a territorial context with high fire activity (Table 3).

PC1 reflects a positive elevation gradient, confirmed by climatic variables, in the direction of increasing forest surface and decreasing cultivated areas. RDP measure 2.1.1 "Natural handicap payments to farmers in mountain areas" was significantly associated with this gradient, being the expenditure for the action positively correlated with



		RDP hotspot	
		yes	no
Fire hotspot	yes	33	999
	no	114	4010

DIRECT PREVENTION

		RDP hotspot	
		yes	no
Fire hotspot	yes	166	866
	no	852	3272

INDIRECT PREVENTION

Fig. 3. Spatial distribution of the municipalities over the 80th percentile for (i) fire activity (orange), (ii) RDP expenditure (green), and for both (blue) and related statistics of the total number of municipalities for each combination. On the left are shown the results for expenditure on direct measures (i.e. measure 2.2.6) and on the right the results for expenditure on indirect measures.

Table 3
Principal Components Analysis attributes showing selected components and loadings (in bold significant values >|0.35|). See Table 2 for a description of the variables.

	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.577	4.344	3.076	2.289	1.978
Variance (%)	15.296	10.103	7.152	5.324	4.601
Cumulative variance (%)	15.296	25.399	32.552	37.875	42.476
	Loadings				
Sp	-0.063	0.029	-0.141	-0.171	0.000
X1.11	-0.076	-0.029	**-0.505**	-0.133	0.014
X1.12	-0.264	-0.319	**-0.523**	0.212	-0.077
X1.21	-0.256	-0.233	**-0.664**	0.206	-0.039
X1.22	0.070	-0.139	-0.320	0.014	0.150
X1.23	-0.195	-0.137	**-0.637**	0.111	-0.037
X1.24	-0.162	-0.139	**-0.716**	-0.073	-0.012
X1.25	-0.066	-0.151	-0.248	-0.015	0.089
X1.32	-0.110	-0.003	-0.293	0.200	-0.116
X1.33	-0.111	-0.038	**-0.537**	-0.062	-0.005
X2.11	**0.566**	-0.117	0.002	-0.044	-0.108
X2.12	-0.221	**-0.375**	0.204	-0.005	-0.237
X2.14	-0.131	0.290	0.037	0.100	**-0.376**
X2.15	-0.170	-0.331	0.161	-0.041	-0.255
X2.25	0.095	-0.053	0.001	-0.043	0.173
X2.26	0.076	-0.123	-0.056	-0.108	**0.588**
X2.27	0.026	-0.140	0.012	-0.031	**0.501**
X3.21	-0.060	-0.095	**-0.435**	0.038	-0.029
X3.22	0.017	-0.110	-0.115	0.011	0.080
X22out2	-0.079	-0.014	-0.038	-0.044	**0.755**
X226outFor	-0.048	-0.025	-0.143	-0.064	0.254
Sfire	-0.189	**-0.637**	-0.032	-0.246	-0.174
Nfire	-0.243	**-0.665**	-0.057	-0.269	-0.080
SfireoutCom	-0.159	**-0.621**	0.192	**-0.395**	-0.114
NfireoutCom	-0.175	**-0.494**	0.186	**-0.435**	0.014
Mfire	0.021	**-0.357**	0.080	-0.133	-0.132
clc1.	-0.267	**0.476**	-0.176	**-0.678**	-0.130
clc2.	**-0.748**	0.221	0.040	**0.406**	-0.088
clc31.	**0.650**	-0.205	0.021	-0.132	0.290
clc32.	**0.443**	**-0.524**	0.091	-0.063	-0.154
clc33.	**0.595**	-0.104	-0.131	0.051	-0.212
Conif	**0.447**	-0.256	-0.146	0.010	-0.230
UrboutFor	0.146	0.202	-0.032	**-0.495**	0.069
Disp	-0.154	0.206	-0.072	-0.158	-0.032
Str	**-0.474**	**0.447**	-0.042	**-0.417**	-0.093
Alt	**0.897**	-0.288	-0.087	0.001	-0.054
Ab	-0.259	0.343	-0.209	**-0.616**	-0.122
AzAgr	-0.068	0.242	0.042	0.219	-0.153
MaxT	**-0.938**	0.138	0.120	0.011	0.055
MeanTDr	**-0.573**	**-0.502**	0.154	0.094	0.120
MeanTWarm	**-0.955**	0.050	0.138	0.012	0.072
PrecDr	**0.474**	**0.588**	-0.150	0.005	-0.029
PrecWarm	**0.669**	**0.512**	-0.176	-0.177	-0.078

altitude.

When looking at PC2 a distinctive cluster emerges characterized by municipalities associated with a considerable proportion of urban areas, population concentration, and a dense road network. Besides, a negative association (i.e., < -0.35) was found with RDP measure 2.1.2 “Payments to farmers in areas with handicaps other than mountain areas”. This cluster encompasses municipalities with a low fire activity.

PC3 highlights instead a marked clusterization of municipalities with reduced reliance on RDP Axis 1. Indeed, all the fire-related selected measures of Axis 1, together with measure 3.2.1 “Basic services for the economy and rural population”, were negatively associated with PC3. The dominant territorial profile of these municipalities indicates the presence of intensive farming systems in lowlands or gentle hilly areas, with moderate use of agricultural subsidies and a more heterogeneous socio-economic structure mixing agriculture and industrial activities with traditional (and sometimes advanced) services.

PC4 represents areas with a pronounced agricultural vocation, as shown by the negative association with population density and share of urbanized surface, as well as by the positive association with the proportion of rural areas in total municipal area. This component highlights a negative association with two wildfire variables, i.e. the number of ignitions and the area burned per unit of municipal area.

Finally, PC5 represents areas where RDP Axis 2.2 expenditures are concentrated, in particular for measures 2.2.5 and 2.2.6. In these areas, RDP Axis 2.2 measures have a higher weight than other measures of Axis 2 in terms of expenditure volume. However, Axis 2.2 does not have an association with fire activity indicators, pointing out a lack of spatial correlation between fire prone areas and the total expenditures in RDP measures that have a direct (or even indirect) effect on fire prevention and mitigation.

4. Discussion

It is by now self-evident that wildfires over Europe are becoming more dangerous under current trends of climate and land use change. If on the one hand, earlier studies have focused on the need for a new approach to wildfire risk management, concentrating the limited resources on prevention and preparedness actions to support suppression efficacy and safety (Corona et al., 2015; Moreira et al., 2020), an integrated strategy for wildfire management planning is undeniably the better cost-efficient solution to mitigate wildfire risk at a large spatial scale (Plana et al., 2015). In this regard, the EU RDP could play a major role. Indeed, the RDP is the main source of public subsidies for farming activities, in marginal areas in particular, and it is capable of maintaining a mixed land use mosaic, which can effectively mitigate fire impacts and increase fire-fighting effectiveness (Moreira et al., 2011). However, under growing budget constraints, a better targeting of funds has become even more crucial, and therefore we explicitly addressed the spatial links between RDP expenditures and fire activity. We focused on the Italian case since it is a representative fire-exposed Mediterranean country with a complex geography, and a detailed dataset of RDP expenditure at municipal level was made available for this country.

The main findings of our exploratory analyses suggest a lack of evident association between the allocation of RDP fire prevention-related measures and wildfire activity at municipal level. PCA component 4, showing an association between the selected RDP measures and fire activity indicators (i.e., burned area and number of ignitions per unit of municipal area), suggests on the one side a relevant role of managed rural areas in mitigating fire activity, and on the other, a spatial mismatch between direct prevention expenditures and high fire activity contexts. The lack of association between expenditure on measure 2.2.6 and fire activity may appear surprising because this measure, as established in the European regulations, can apply to medium to high fire risk areas only as defined by fire management plans (art. 42.2 of the Council Regulation (EC) No 1698/2005). In Italy, as in other Mediterranean countries, fire risk at the municipal level is classified by the Regional fire management plans (art. 3, Italian Law 353/2000). In Tuscany Region, for instance, 41% and 56% of the municipalities are grouped into medium or high fire risk classes. Therefore, the mismatch between the expenditure on direct fire prevention and fire activity cannot simply be explained by the structure and the eligibility criteria of RDP calls, is rather ascribable to other causes, such as for instance the higher efficiency of a limited number of municipalities to access the funds. Furthermore, in Italy the culture and technical capacity in fire prevention are still underdeveloped and limited to particular areas (Ascoli and Bovio, 2013), as highlighted in our hotspot analysis.

Our results suggested that RDP subsidies on both direct and indirect measures were dispersed across the territory, resulting in inefficient allocation of financial resources in the perspective of cross-sectorial wildfire risk management, and highlight the need for a stronger integration of territorial planning within the RDP funding. Moreover, the lack of coordination regarding the spatial allocation of RDP subsidies for the selected measures, that indirectly favour landscape resilience and resistance to fires, was probably due to the fact that in the RDP calls there was no eligibility or rewarding criteria to incentivize these measures in high fire risk areas. It is our contention that favouring the implementation of measures that have an indirect effect on fire hazard mitigation in high fire risk areas would make the allocation of subsidies more efficient, and that what we have come to define "indirect prevention" (Ascoli et al., 2021; Plana et al., 2021) plays a crucial role in mitigating fire risk at large spatial scales, as demonstrated by various studies (Aquilué et al., 2020; Barbati et al., 2015; Corona et al., 2015).

A cost-effective approach towards a more integrated policy for wildfire risk management would consist in linking those RDP measures promoting indirect prevention to fire risk assessment. In fact, under past and current RDPs, only direct fire prevention measures (i.e., measure 2.2.6 in 2007–2013 RDP, and sub-measure 8.3 in 2014–2020 RDP) include eligibility criteria related to fire risk, as defined by the Regional fire management plans. The implementation of more rewarding criteria to grant aid for indirect fire prevention measures in fire risk areas would clearly increase the impact of these measures also on fire risk mitigation. To this end a feasible solution has been experimented in the Tuscany Region, where multi-measure calls have been launched during the 2014–2020 RDP period. The aim of such calls was to encourage farmers and other local stakeholders (e.g. land and fire management agencies, economic actors) to jointly present a complex long-term project with a clear objective, including wildfire risk mitigation, which would allow to resort to different funding lines within the RDP (see Regione Toscana, 2020, Annex A).

Another issue concerns the scale of fire risk assessment often defined at municipal scale in Italy. When fire risk is assessed exclusively at municipal level, it may not optimize the use of RDP measures in strategic areas for wildfire prevention. Since no fire risk information is available at sub-municipal scale, funds might be used where they are not needed (e.g. low fire risk areas within a high fire risk municipality), negatively affecting the leverage on fire risk reduction of the investment. Another notable initiative in Tuscany, under the 2014–2020 RDP, was to provide a reward to RDP projects addressing specific hazard reduction needs, defined at an adequate spatial scale (sub-municipal) by 14 territorial fire management plans based on detailed fire risk analyses and strategic fuel management criteria. Integrating eligibility criteria on fire risk ranking at sub-municipal level within RDP funding allocation criteria would therefore help concentrate prevention actions (and funding) where strictly necessary. Accordingly, integrated (and possibly landscape-scale) approaches seem crucial in order to deal with increasing fire risk across European countries (Plana et al., 2015).

A possible development of our study is related to a more precise localization of the RDP expenditures, considering that the database used in our study links the expenditure to the legal residence of the beneficiary, rather than to the land parcels benefiting from payments made under the RDPs. Despite this bias may appear negligible, since most farmers usually work nearby their residence (within the same or the neighbouring municipalities), accessibility to spatial data on cadastral parcels benefiting from RDP payments (the so -called Land Parcel Identification System, managed by the Member States Integrated Administration and Control System) would really help monitor, in the ex-post evaluation RDPs, also the effect of fire-related measures on reducing fire activity.

Another improvement of the analysis could come from a detailed analysis of activities realised under the financed projects. Depending on the regional priorities of the RDP, the 2.2.6 funding can in fact be allocated to prevention of forest hazards other than wildfires (e.g. storms, avalanches). Though such bias may appear of minor relevance in most of the Italian regions, since wildfire is the most important and frequent natural hazard in Mediterranean context, further research at regional level would better identify actual amount of RDP funds spent exclusively for fire prevention, and not for other purposes. This approach will also be useful to analyse the effects of 2014–2020 RDP, where the sub-measure 8.3 is devoted to fund "prevention of damage from forest fires, natural disasters". It must be remembered that the dataset of this period was not included in the analysis since final cumulated data of total expenditures by measure and municipality are not available at present.

5. Conclusions

Europe is increasingly exposed to wildfires, fire management is rapidly evolving as new needs emerge and new tools become available. A more integrated approach to wildfire risk management is needed therefore, so as to prevent the negative impacts of wildfires and the EU RDP has the potential to reduce land abandonment, which is causing rural areas to become more vulnerable to wildfires.

For the first time, in this research study we bring evidence about the weak nexus between wildfire territorial diffusion and fire-related RDP measures expenditures, which have been proved not to be concentrated in municipalities with higher fire activity in Italy. As shown, the allocation of measure 2.2.6 subsidies (i.e. funds destined to direct fire prevention in the RDP 2007–2013) is not significantly correlated with territorial features exacerbating wildfire vulnerability, and the spatial structure of total expenditures by individual or aggregated measures appears to be particularly fragmented.

Accordingly, we argue that the information from fire management planning (e.g. fire risk plans based on strategic fuel management principles) should be integrated within the policy decision of RDP subsidies allocation by introducing a reward criterion to be applied not only to direct measures of fire prevention, but to the whole set of RDP measures presenting indirect effects on landscape flammability. The less disperse the fire-related RDP funds allocation, the higher the chance to reach the size of land management investments required to mitigate wildfire risk at a landscape scale. In conclusion, considering that wildfire risk management is a cross-cutting issue, which goes beyond administrative boundaries and sectorial competences, we contend and strongly believe that the analytical approach applied in this study can be extended to other European Mediterranean countries.

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