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Article

Forest Fire Causes and Motivations in the Southern and South-Eastern Europe through Experts' Perception and Applications to Current Policies

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Abstract: Forest fires causes and motivations are poorly understood in southern and south-eastern Europe. This research aims to identify how experts perceive the different causes of forest fires as defined in the classification proposed by the European Commission in 2013. A panel of experts (N = 271) was gathered from the EU Southern Member States (France, Greece, Italy, Portugal, and Spain) and from Central (Switzerland) and south-eastern Europe (Croatia, Serbia, Bosnia and Herzegovina, Republic of North Macedonia, and Turkey). Experts were asked to answer a questionnaire to score the importance of the 29 fire causes using a five point (1–5) Likert Scale. Agricultural burnings received the highest score, followed by Deliberate fire for profit, and Vegetation management. Most of the events stem from Negligence, whereas malicious fire setting is arguably overestimated although there are differences among the countries. This research demonstrates the importance of different techniques to enhance the knowledge of the causes of the complex anthropogenic phenomenon of forest fire occurrence.

Keywords: Delphi method; EFFIS; forest fire causes; forest fire motivations; Likert Scale; anthropogenic causes

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1. Introduction

In Mediterranean Europe, forest fires burn an average of approximately 450,000 hectares every year (i.e., ca. 0.4% of the forested area; [1–3], with occasional peaks >700,000 hectares (e.g., 984,188 hectares in 1985, 895,738 hectares in 2017, 766,020 hectares in 1989, 742,498 hectares in 2003, and 734,195 hectares in 1994). Together with western USA and south-eastern Australia, the Mediterranean Basin and the so-called "*Fire Club*" in particular (i.e., Portugal, Spain, France, Italy, and Greece; [4]) represent thus a forest fire hotspot worldwide. In recent decades, ongoing land cover changes resulting from a socio-economic conversion towards a service-oriented and urban society combined with climate change, have resulted in an enhanced risk of fast-spreading and intense extreme forest fires [5–7]. This was, for instance, the case in Portugal, where the worst fire season occurred in 2017 with a total burnt area of 540,638 hectares, 47.9% of which refer to just eight extreme forest fire events [8].

Despite the importance of the problem and the implementation of the European Forest Fire Information System (EFFIS) promoted by the European Commission [9], Mediterranean fire statistics still lack accuracy and precision in reporting ignition causes and related motivations. In particular, a shared and homogeneous approach is still missing among countries [10], and there is no common procedure on how to merge data of individual forest fire reports into the official annual fire statistics. For instance, in Portugal, agricultural burning is always a negligent cause of fire; in Spain, fire setting in agricultural activities can be classified as either negligent or intentional forest fires, leaving the classification to the expertise of the forestry professional that works in the area [11,12].

In addition, most European and north African countries of the southern rim of the Mediterranean basin (Morocco, Algeria, Tunisia, Israel, Lebanon) belong to EFFIS network and are components of the so-called MENA countries (Middle East North Africa). Libya and Egypt are not considered, although they are MENA countries, because there are no forests in their territory and provide no data on ignition source or report very high percentages of unknown causes (e.g., Algeria > 50%; [13,14]). Furthermore, post-fire investigation by specific techniques such as the Method of Physical Evidences (MPE; [15]) is a time-consuming activity, which in many European countries cannot be systematically applied for cost reasons. There is also a lack of motivation of some people to fill in the database. As a result, causes and motivations of forest fires in Europe and in the Mediterranean basin in particular remain still poorly understood, and cross-country comparative analyses and interpretations are very challenging. Such a gap and lack of accuracy in the information represents a missed chance for improving the forest fire risk management policy at the European level [16,17] and in the Mediterranean basin in particular, where most fires are of anthropogenic origin and start voluntarily, or take place in the framework of authorized/tolerated practices [7,8]. Detailed information on fire causes and motivations are crucial to develop actions aimed at modifying social and individual attitudes and behaviors causing forest fires outbreaks [18]. The final goal should be to build a common forest fire culture and governance framework across Europe for going beyond the current forest fire management policies, which are mainly focused on suppression strategies. Paying more attention to an integrated approach will imply including innovative prevention approaches, such as detailed recording and monitoring of the ignition sources and a related risk communication to targeted social groups.

The aims of this research are to: (i) identify existing discrepancies between fire causes and motivations according to the official fire statistics of southern and south-eastern European countries and the perception of local experts who usually compile such statistics but who are also operationally involved in the field of forest fire prevention and control; (ii) verify existing common expert perceptions of specific fire causes and motivations among selected EU countries; (iii) verify the suitability of the harmonized classification of fire causes proposed by the European Commission [10] as a unified reference for forest fire causes at the European level; and (iv) promote a discussion aiming to favor the use of the proposed harmonized classification in order to increase the chances of broad support and acceptance among all concerned European countries.

2. Materials and Methods

2.1. Study Area

The study area consists of 11 European countries, from five EU southern Member States of the Mediterranean basin (i.e., France, Greece, Italy, Portugal, and Spain) to six countries from Central (Switzerland) and south-eastern Europe (Croatia, Serbia, Bosnia and Herzegovina, Republic of North Macedonia, and Turkey) (Figure 1). Data from Spain are limited to Galicia, which is the region with the highest number of events [19]. Similarly, for France, we considered the south-eastern and most fire-prone part of the country (Region Sud Provence-Alpes-Côte d'Azur; Region Occitanie and the southern part of the region Auvergne-Rhône-Alpes) and Corsica, as opposed to the south-western regions, mostly less affected by fires. Switzerland represents an interesting case because of high fire frequency on the southern slopes of the Alps, the Insubric Region, an area climatically rather similar to the Mediterranean situation and prone to human-induced fires in the spring season, especially in March and April [20] and showing an increasing trend in *Lightning* fires in summer [21]. Countries of East Europe have been considered because forest fire projections [22] show that this region could become a new fire-prone area in future years [23].

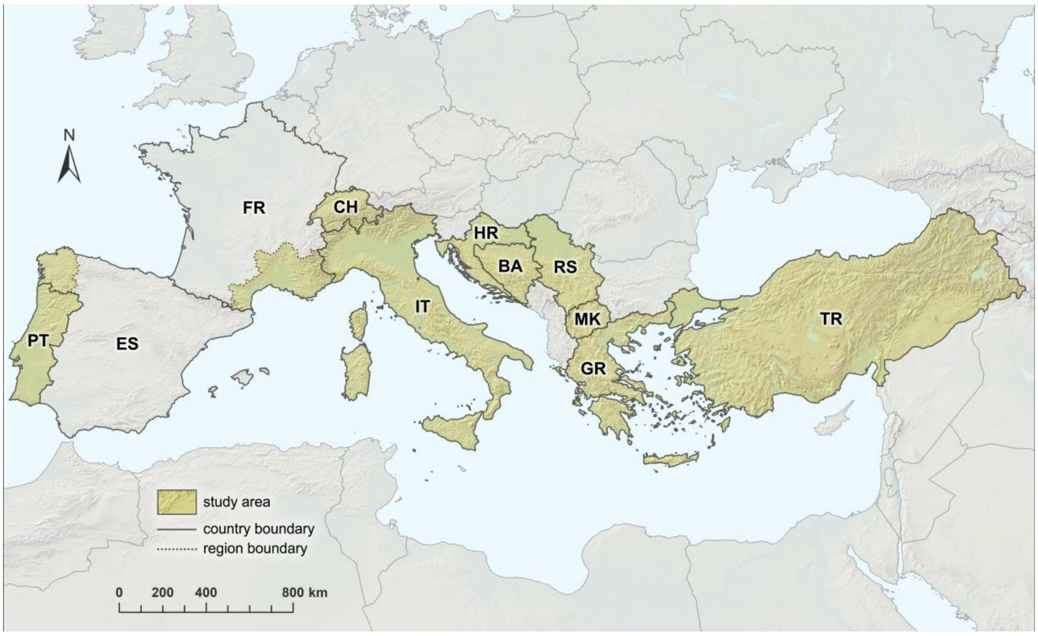

Figure 1. Study area with the countries involved (PT = Portugal, ES = Spain, FR = France, IT = Italy, CH = Switzerland, HR = Croatia, BA = Bosnia and Herzegovina, RS = Serbia, MK = Republic of North Macedonia, GR = Greece, TR = Turkey). Shaded areas represent the reference regions of the respondents.

2.2. The EU Harmonized Classification of Forest Fire Causes

In this paper, we will refer to the harmonized classification scheme of forest fire causes proposed by the European Union in 2013 [10], which is not a mandatory act but was rather published with the aim of encouraging countries participating in the EFFIS network to improve and homogenize the information on the forest fire ignition sources.

The harmonized classification covers most relevant causes and motivations of forest fires occurring in the European area and consists of a three-level hierarchical structure referring to the following first-level six categories: *Unknown* (category 100); *Natural* (category 200); *Accident* (category 300); *Negligence* (category 400); *Deliberate* (category 500); and

Rekindle (category 600). The second level consists of eight categories that are further split into 29 classes of causes identified by the three-digit code of the third level [10].

2.3. Fire Experts Survey

Information about expert perception of main causes and motivations of forest fires in their region of interest had been acquired by asking professionals in the firefighting and fire management sector (e.g., Forest Services, Fire Services, and Civil Protection) to respond to an ad hoc questionnaire with close-ended questions sent by email (Table S1, Supplementary Materials).

This procedure relies on the informed intuitive opinions and collective judgment of experts [24–27] in order to obtain more reliable responses than individual statements [27–29]. Compiling a collective judgment from a series of questionnaires is the basis of the Delphi method, an iterative process used to collect and distill the informed judgments of experts in the case of insufficient data and/or incomplete knowledge on cause and effect in regard to phenomena under study [30]. This method has been previously used in the field of forest fires to explore the current state of fire communication [31] and in the analysis of forest fire causes in Europe e.g., [30–39] and in EU/MENA countries [40,41].

In this specific case, a simplified version of the canonical Delphi method was adopted, discarding a second survey round with feedbacks, which was not considered necessary for the specific aims of the study. In a first step, the experts were asked to rate on a five points Likert Scale (ranging from 1, non-important to 5, extremely important [42], each of the 29 EU harmonized causes in terms of the perceived importance in their geographical area of competence. In a second step, they were asked to rank in decreasing order the four most important items rated in class 5 and/or 4 (in case of a lack of items in class 5). The questionnaire was translated into the local official language in order to make the survey easily accessible to the respondents and to assure the best possible data quality.

The selection of experts operationally working on forest fires was based on the personal knowledge of the authors, who contacted potential participants in each target country. We ended up with a total of 271 participating experts belonging to different institutions and representing 11 countries (Table 1). The number of experts from each country varied from five for France to 53 for Greece.

Table 1. Number of experts and their affiliation, per country.

Country	Number of Experts	Professional Status or Affiliation
Portugal	25	Fire Service, Forest Service, National Guard
Spain (Galicia Region)	29	Fire Service, "Guardia Civil" (Gendarmerie: Forest fire causes investigators and Environment Protection Service)
France (south-eastern France)	5	n.a.
Italy	39	State Forest Service (CFS-Corpo Forestale dello Stato [1])
Switzerland	13	Forest Service, Fire Service, Research Institute
Croatia	13	Forest Service, Civil Protection
Bosnia and Herzegovina	15	Forest Service, Civil Protection
Serbia	30	Fire Service, State Forest Service
Republic of North Macedonia	25	Forest Service, Civil Protection, Fire Service, Volunteers
Greece	53	Forest Service, Fire Service
Turkey	24	Forest Service

[1] In 2017, CFS was suppressed by the Law 124/2015. Personnel, means, and competences were transferred to the Carabinieri (Gendarmerie-like military corps with police duties) and only partially to the Corpo Nazionale dei Vigili del Fuoco (Fire Department).

2.4. EFFIS Forest Fire Data

Data on forest fires were kindly provided by the European Forest Fire Information System (EFFIS), which allows access to three different statistics:

A. Reported yearly totals of number of fires and burnt area supplied by the contributing countries and published every year in the *Forest Fires in Europe, North Africa and Middle East* Reports (e.g., [9]). These data are considered official as they are directly provided by the national authorities. They may differ among countries in how they are reported, for instance, when the definition of forest fire differs. For this dataset, no data are available for Bosnia and Herzegovina and Serbia.

B. Regional yearly fire statistics computed from the individual fire events supplied by the contributing countries were aggregated according to ignition categories (raw data of single fires are currently not publicly available). These data display differences not only among but also within single countries on the recording protocol (e.g., only in public state forests or only in the most fire-prone regions). As a result, totals may show discrepancies with respect to the yearly data reported in the option A. For this dataset, no data are available for Bosnia and Herzegovina, Serbia, and the Republic of North Macedonia.

C. Yearly statistics resulting from systematic large fire mapping (usually greater than 30 hectares) by EFFIS, based on satellite imagery.

For the comparison with the expert perception of fire causes, we used the available fire records of the B dataset for the period 2000–2015 (Table S2). We first checked the suitability and the representativeness of the B dataset with respect to the others by displaying the corresponding mean annual statistics. As reported in Figure 2, the three datasets displayed a good general accordance. Dataset B displayed overall only slightly lower values for burnt areas and number of fires compared to the A dataset. The most noticeable differences were Spain (burnt area) and France (fire frequency). Dataset C was based on larger fires, which were two orders of magnitude lower in number, but it overall had most of the burnt area and confirmed the ranking of the countries.

Figure 2. Yearly fire statistics available from 2000 to 2015 for the three different EFFIS forest fire datasets. Symbols represent means; segments stretch from lower to higher annual values. Lowest yearly values were not plotted for dataset C in order to enhance the figure readability. The X and Y axes are plotted on a logarithmic scale.

2.5. Data Processing and Analysis

Response items collected by the questionnaires in our research were first analyzed using descriptive statistics such as the mean ($\overline{x}$) and standard deviation (SD) as recommended for interval scale items [43]. Visual representations were made by using crossbar plots computed with the smean.cl.boot function from the Hmisc R-package, which is a very fast implementation of a basic nonparametric bootstrap for obtaining confidence limits for the population mean without assuming normality.

Ignition causes were then grouped into the first-level categories using the following stepwise procedure. For each first-level category of causes, we first calculated a rating for each respondent by taking the highest value among the single causes of the concerned category. When the highest value concerned two or more singles causes rated 4 (“very important”) or three or more that were rated 3 (“important”), the overall importance of the category was increased by a unit point, that is, to 5, i.e., “extremely important”, and 4, i.e., “very important”, respectively. Finally, values were averaged among experts and were compared to the available EFFIS statistics on fire causes (B dataset) from 2000 to 2015 by considering cause frequency according to both fire occurrence and burnt area. Comparisons were visually performed by plotting the percentages according to fire statistics against the averaged experts' opinions. We first analyzed the importance of the *Unknown* causes and then the partitioning of the remaining known causes (without *Unknown* and *Other classes*).

We then performed a hierarchical cluster analysis for grouping single countries according to the similarity of the expert perception (i.e., average rating of each cause category for each considered country [44]). For calculating dissimilarities between observations, the Euclidean distance was used. Ward's minimum variance method (ward.D2) for agglomeration was applied according to [45]. Following the method by [46], the cluster analysis was performed on the basis of the frequency of the ignition source with the first rank per country. The optimal number of clusters was determined by the average silhouette width.

The statistical analyses were carried out in the R (3.5.) statistical environment [47], using the packages {ggplot2} [48] and {treemap} for graphics [49], {sf} for spatial objects [50], and the {factoextra} package for the hierarchical clustering [51].

3. Results and Discussion

3.1. Unknown Causes

For the sake of reality, in our opinion, *Unknown* cannot represent a cause or motive of a fire, just the absence of knowledge of it [6]. This cognition is, however, crucial because assessing prevention activities with an unknown target is the same as a shot in the dark.

The proportion of *Unknown* causes (category 100) and their perception among experts varied considerably among countries (Figure 3). The fire cause remained unknown in more than 75% of the cases in Portugal, Greece, and Croatia, and in less than one third in Galicia, Italy, and Croatia. With reference to the burnt area, the percentages of fires of *Unknown* cause were moderately to considerably lower, suggesting a major effort to unveil the cause of larger fires. Mean ratings among experts showed values higher than 3 in 64% of the countries (i.e., 7 cases out of 11), confirming that the lack of knowledge on the fire causes is perceived as an issue in most of the countries (Figure 3; Table S2 and Figure S2 of the Supplementary Materials). In general, the assumed importance showed a proportionality with the reported EFFIS fire statistics, except an underestimation for Croatia and Greece and, to a lesser extent, for Italy (Figure 3).

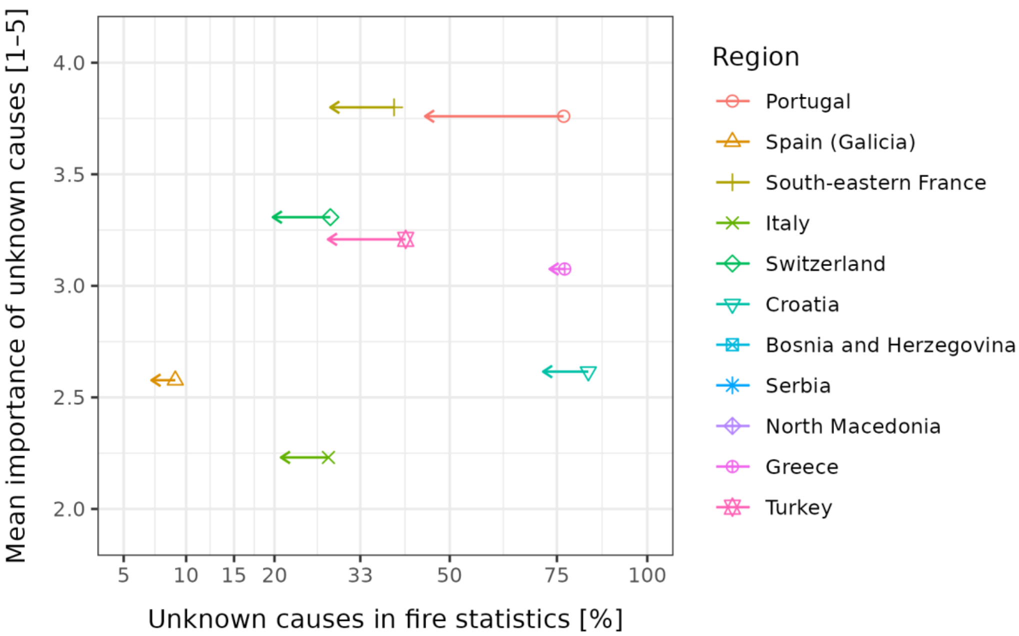

Figure 3. Mean expert rating and fire statistics (Dataset B) of *Unknown* causes. Segments span the difference in the percentages represented by fire frequency (symbols of the regions) and burnt area (arrowheads). The X axis is plotted on a square root-transformed scale. Data were not available for Bosnia and Herzegovina, the Republic of North Macedonia, and Serbia.

3.2. Known Causes

Figure 4 reports the statistics and the expert rating on known and specified causes only. Due to differences in the protocols of the data collection, *Deliberate* causes (category 500) had very high percentages for both fire frequency and burnt area in Galicia (Spain) and Italy. On the contrary, these countries had the lowest percentages of causes due to *Negligence* although it was highly rated among experts, confirming a different procedure in recording negligent or deliberate causes compared to the other regions. For the remaining countries, there was a generally good agreement between expert rating and the statistical frequency of the single causes, with an exception for *Natural* fires (category 200) in south-eastern European countries, covering Greece and Turkey.

As a general rule, fire causes with a frequency surpassing 15% in the statistics were rated "important" to "very important" (code ranging from 4 to 5) by experts. *Lightning* in Greece and Turkey represented the only underestimated exception in this context, whereas *Accident* tended to be overestimated by experts in most countries, as well as *Rekindle* in some cases and *Deliberate* in Turkey.

Known ignitions from *Natural* causes (category 200) were less than 10% in the western part of the Mediterranean basin (from Portugal to Italy), while they constituted an appreciable percentage in Switzerland and in the Eastern part, with a peak in Greece with more than 38% of the fires with known cause. In the latter country, the value was the result of poor-quality data from Greece, starting from the huge percent of *Unknown* causes and the easy assumption of natural cause for the remaining ignitions. At the time of more reliable data from the Forest Service (up to 1998) lightning-caused ignitions never exceeded 5% [52]. In south-eastern European countries, experts tended to underestimate the importance of this fire ignition cause [4,53,54]. This is probably due to the general small size of the *Natural* fires, which resulted in a significantly lower proportion in terms of burnt area (less than 2%). The opposite occurred in Croatia and partially in Portugal, where the burnt area due to *Natural* causes had slightly higher percentages with respect to the number of fires.

As a result, the average expert rating was higher than 3 for Croatia ("important") and higher than 4 ("very important") for Switzerland only.

Fires due to *Accident* (category 300) exceeded 10% in Turkey only, where 13% of the fires made up 43% of the area burnt by fires of known origin. In other countries, this ignition caused quite similar percentages in terms of number of fires and burnt areas. In spite of the overall limited proportion of fires due to *Accident*, fire experts rated this cause mostly as "very important" (above 4), which may not reflect reality.

Negligence (category 400) was the most frequent known cause in Portugal (43%), Switzerland (61%), and Turkey (61%) and the second most frequent in the other countries. Percentages of burnt area were usually lower than those of fire number, indicating a fire size generally lower than the average. Experts rated this cause as the most important one in most countries, with the exception of Galicia and south-eastern France (rank 2), where the smaller burnt area resulted from fires due to professional work, such as forestry or agriculture.

Debatable discrepancies with fire statistics were found in Galicia and Italy, where fires due to *Negligence* reached only 5.1% and 14.7%, respectively, although for experts, they represented the second most frequent cause. Such differences may be due to the different recording protocol of *Agricultural burnings*, which some countries register as *Negligence* and others as *Deliberate* ignition (category 500), which were in fact by far the most frequent known cause in Galicia (88.9%) and Italy (82.5%) and also in Croatia (44.5%) and south-eastern France (40.0%). Interestingly, fires deliberately ignited are generally significantly larger with respect to the other ignition causes (arrows pointing right in Figure 4), especially in south-eastern France (up to 64.7% of the burnt area) and Greece (53.3% of the burnt area, compared to 16% of the fires), suggesting that fires were mostly set when conditions for fire were favourable. Average ratings from the survey strongly confirmed the overall importance of this cause, with most of the values higher than 4. Only Turkey had a very low fire statistic, with 6.2% of the deliberately ignited fires among the ones of known origin.

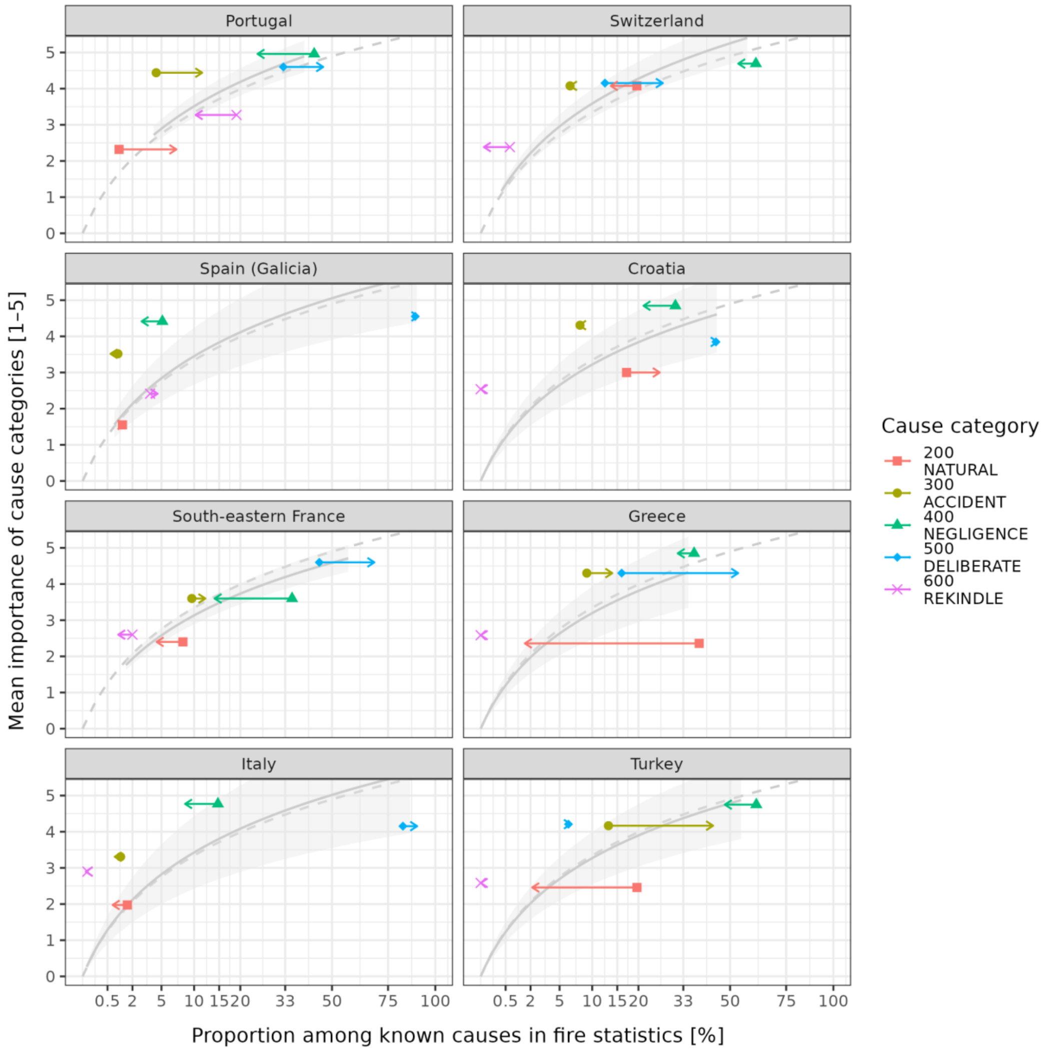

Figure 4. Mean expert rating and fire statistics (Dataset B) of known causes. Segments span the difference in the percentages represented by fire frequency (symbols of the regions) and burnt area (arrowheads). Solid grey lines represent a logarithmic fitting of the data (average values were used for fire statistics) with the 68% confidence interval. The dashed line represents the reference fit across all countries (see Figure S1 in the Supplementary Materials). The X axis is plotted on a square root-transformed scale.

Rekindle (category 600) generally remained an insignificant cause in the fire reports of the analyzed countries, with the only exception of Portugal, where it reached a percentage of 19%. Nonetheless, the average expert's ratings were between 2 and 3, with the only and coherent exception of Portugal, which was higher than 3. We can assume that here experts rather rated the likelihood of a fire to restart according to their field experience. As a matter of fact, most of such restarts are usually not registered as a new forest fire, but rather as the continuation of the previous one. This is the case for instance in Croatia, Greece, and Turkey, where no fire report mentions this ignition category.

3.3. Subcategories of the Known Causes as Perceived by Experts

Hereafter are presented and discussed the most relevant known causes belonging to the third level of the EU harmonized classification. For the full statistics and graphical representations see Table S3 and Figures S3–S5 in the Supplementary Materials.

3.3.1. Natural Causes

In absence of *Volcanism* (class 202), which is linked to the active phases of the Etna and Stromboli volcanoes in Italy, *Natural* causes (category 200) are basically limited to *Lightning* (class 201), whereas *Gas emissions* (class 203) have no significance (Figure 5, Table S3).

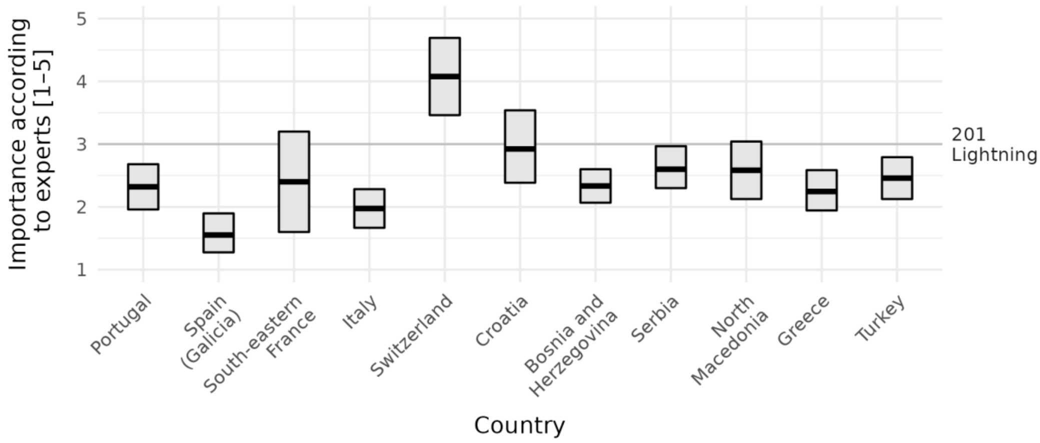

Figure 5. Crossbar plot of the importance of ignitions due to *Lightning*, according to the smean.cl.boot function from the Hmisc R-package, grouped by country.

Although *Lightning* was reported as a very important ignition source in some European areas (e.g., Castilla y León in Spain; Finland; the Alpine area of Switzerland) [7,55–58], the average rating of the experts did not exceed 3 for all countries but Switzerland, where the mean was 4.1 ± 1.2.

3.3.2. Accident Causes

Figure 6 reports the expert ratings for the different ignition classes of the *Accident* causes (Category 300): *Electrical power* (class 301), *Railroads* (class 302), *Vehicles* (class 303), *Works* (class 304), *Weapons* (class 305), *Self-ignition* (class 306), and *Other accidents* (class 307).

Ignition due to *Work* (i.e., ignition by sparks emitted by engines and machinery in industry, forestry and agriculture, explosions, welding, grinding, smoldering on job sites or flammable vapors produced during industrial activities) resulted in the highest rated class (3.7 ± 0.9 for Portugal, 3.2 ± 1.3 for south-eastern France and 3.4 ± 1.0 for Greece), followed by *Railroads* (sparks due to overheated wheel brake shoes in mountain environments, e.g., 3.2 ± 1.1 for Croatia) and *Electrical power* (i.e., 3.8 ± 1.2 for Turkey, 3.2 ± 1.0 for Portugal, 3.2 ± 0.8 for Croatia, 3.1 ± 1.0 for Greece, and 3.0 ± 1.2 for Serbia).

Forest fires caused by a variety of power line failures are rather uncommon in Europe, with the only exception of Switzerland [59,60], whereas they are frequent and important in other geographic areas such as California [60] and Australia [61]. Nevertheless, an extreme forest fire event caused by the contact between the vegetation and a 15 kV power line took place in Portugal in 2017 (the Pedrógão Grande fire, which burnt 28,624.7 ha, killed 66 people, and injured more than 250 people [62]). Although this event occurred after our survey, the average rating of this igniting cause was still quite high (i.e., 3.2 ± 1.1).

The other classes of *Accident* ignitions (*Vehicles, Weapons and explosives, Self-ignition, and Other accidents*) were rated of minor impact (mean < 3). We highlight the minimum rating of *Self-ignition*, which is in contrast to the frequent mention of auto combustion supposedly caused by high temperatures in media reports [63]. *Self-ignition* is, however, rather frequent in piles of coal, hay piles and compost piles (linen rags, pistachio nuts, sawdust, manure, nitrate film) that may easily self-ignite because of the accumulation of heat produced by exothermic bacterial fermentation or oxidation.

The ignition source profile emerging from the table specifically showed that forest fires caused by *Accident* ignition (anthropogenic events beyond the responsibility of actors) were concentrated in Greece, Croatia, Portugal, Serbia, and Turkey, with the maximum value for

Power lines in Turkey, *Works* in Portugal, and *Railroads* in Croatia. The only *Accidental* cause considered important for south-eastern France was *Works*.

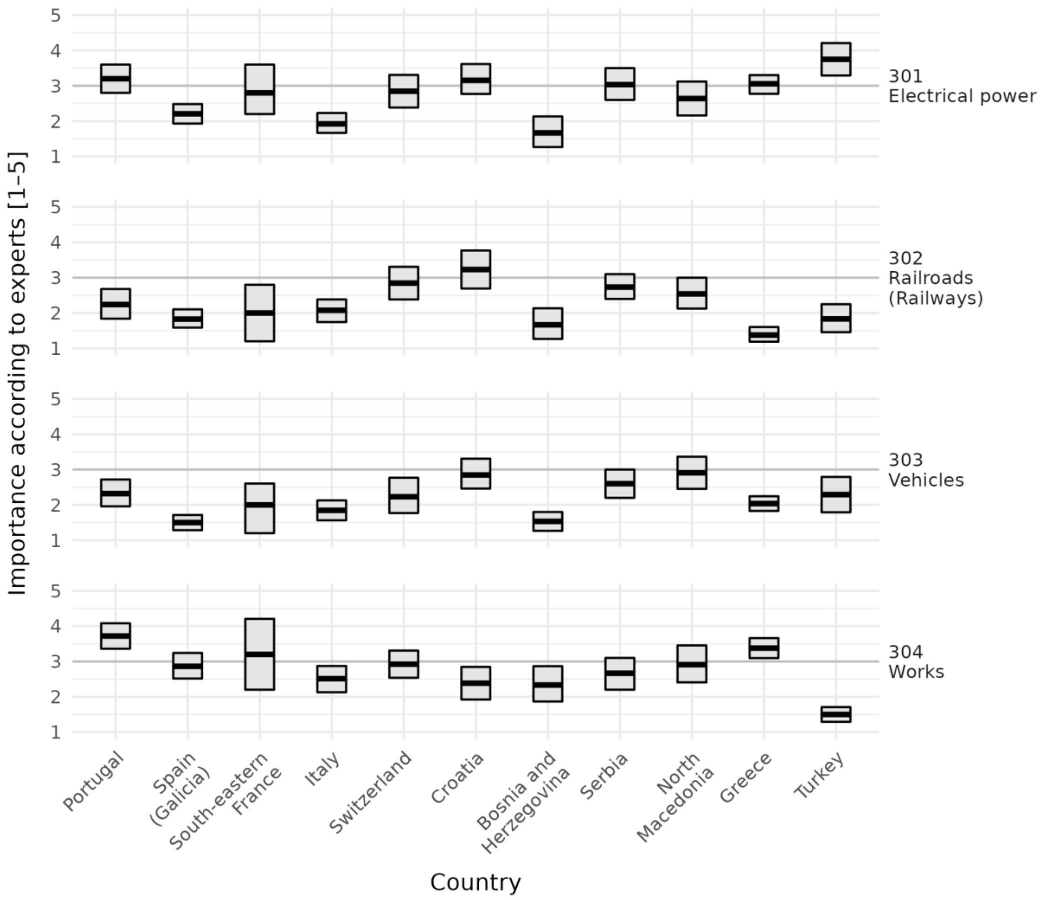

Figure 6. Crossbar plot of the importance of ignitions due to *Accident causes*, according to the smean.cl.boot function from the Hmisc R-package, grouped by country.

3.3.3. Negligent Use of Fire

Figure 7 reports the expert ratings for the different ignition classes due to *Negligent use of fire* (group 410). *Vegetation management* was rated very high in Portugal (4.3 ± 1.1) and Switzerland (4.2 ± 1.3), whereas it reached a mean >3 in six other countries (France, Republic of North Macedonia, Greece, Italy, Serbia, and Spain). *Agricultural burning* not only exhibited the highest values as a case of *Negligent use of fire* (>4 in eight out of 11 countries), but also displayed low variability, thus highlighting a strong agreement among experts within the same country. The minimum value of the mean in this class pertains to France and Switzerland, both <3, where *Agricultural burning* was not important. For *Waste management*, experts reported rather high values (mean > 3) in all countries, except France, Italy, Spain, and Switzerland.

Recreation activities were rated as relevant in Switzerland (3.9 ± 1.1) and south-eastern Europe (3.2 ± 1.6 in Bosnia and Herzegovina, 3.4 ± 1.3 in the Republic of North Macedonia, and 3.4 ± 1.6 in Turkey), where outdoor barbecuing or the use of grills is a frequent and traditional activity for the preparation of the national grilled dish of minced meat [64].

The results showed the frequent use of fire as a management tool (agricultural management, burning of residuals, elimination of solid household waste) as the most important source of involuntary ignition. The ignition source profile emerging from the survey may be connected to the former *traditional fire use* (TFU) for land and resource management purposes. TFU is still a common way of "*problem-solving*" by aged rural societies [38,65], which has been translated to household waste disposal when/where the use of fire partially solves the lack of landfills for urban solid waste. *Recreation* and *Other negligent use of fire*, on the contrary, were rated of lesser importance in most of the surveyed countries. This contrasts with common places that still depict recreation and the presence of tourists as problems of forest fire outbreak and spread [66–68].

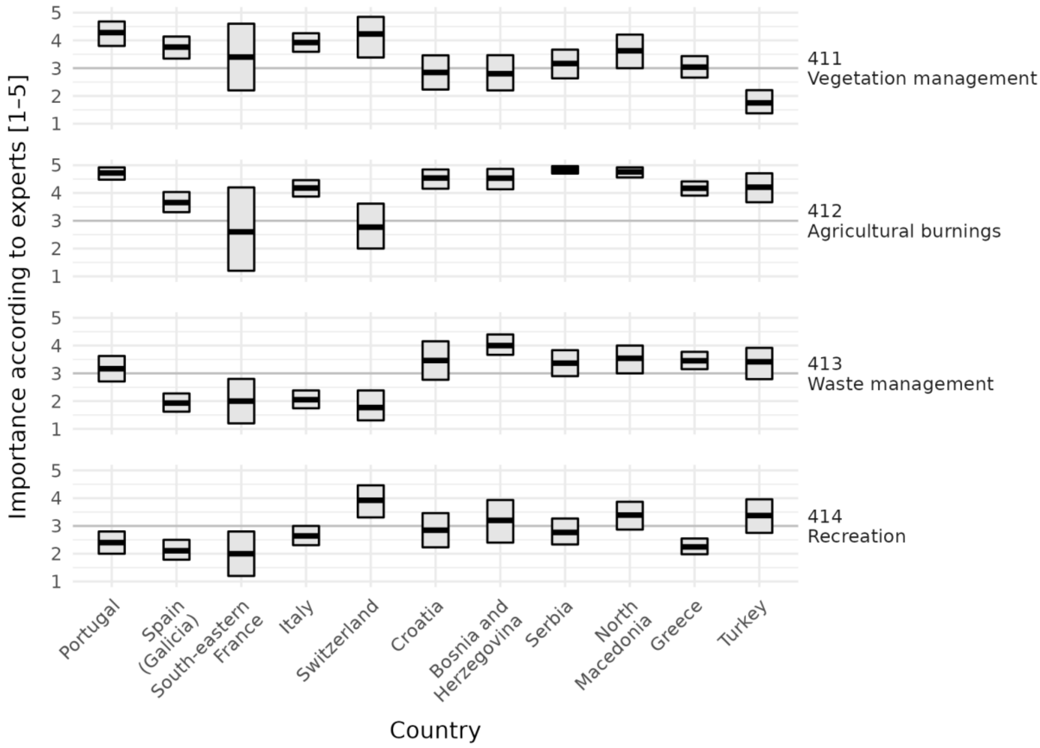

Figure 7. Crossbar plot of the importance of ignition due to *Negligent use of fire*, according to the smean.cl.boot function from the Hmisc R-package, grouped by country.

3.3.4. Use of Glowing Objects

Figure 8 highlights the expert ratings for the four classes belonging to the unintentionally induced fire category due to the *Use of glowing objects* (group 420).

The highest expert rating was reached by the improper extinguishing of *Cigarettes*: seven countries exceeded the mean value of 3, with the highest values for Turkey (3.9 ± 1.2), Serbia (3.9 ± 1.2), and Croatia (3.8 ± 1.3). Forest fire caused by cigarettes and tobacco pipes is commonly considered among the main sources of fire ignition, although the potential number of such forest fires has drastically dropped in recent years due to the decrease or even banning of tobacco use and to the innovative "*fire-safe*" smoking technology in cigarettes [63]. Despite the high rating by experts, the probability for a cigarette to be a source of ignition is rather low and is highly dependent on the position of the cigarette on the fuel and on the general environmental conditions in terms of moisture and temperature [63,69,70].

The Swiss experts' high rating concerning *Fireworks, firecrackers, and distress flares* (3.3) with a relatively small SD (±0.9) is easily explained by the long-lasting tradition of fireworks and celebration fires on Swiss national day (i.e., 1 August). In this context, regional Swiss authorities issued in recent decades a fireworks ban decree in order to prevent unwanted fire ignitions in the case of high fire risk on the national day [71,72].

Hot ashes and *Other use of glowing objects* refer to forest fires due to working activities such as apiculture, fumigation or disinfection, as well as glowing firebrands emitted from chimneys [10] and were generally rated with a reduced incidence. Exceptions are Croatia (3.0 ± 1.7) for *Other use of glowing objects* and Croatia (3.2 ± 1.5), Republic of North Macedonia (3.0 ± 1.3), and Serbia (3.1 ± 1.0) for *Hot ashes*. It is, however, worth noticing the rather high SD values for these classes, which reflects the scarce convergence on the importance of these classes by the national experts.

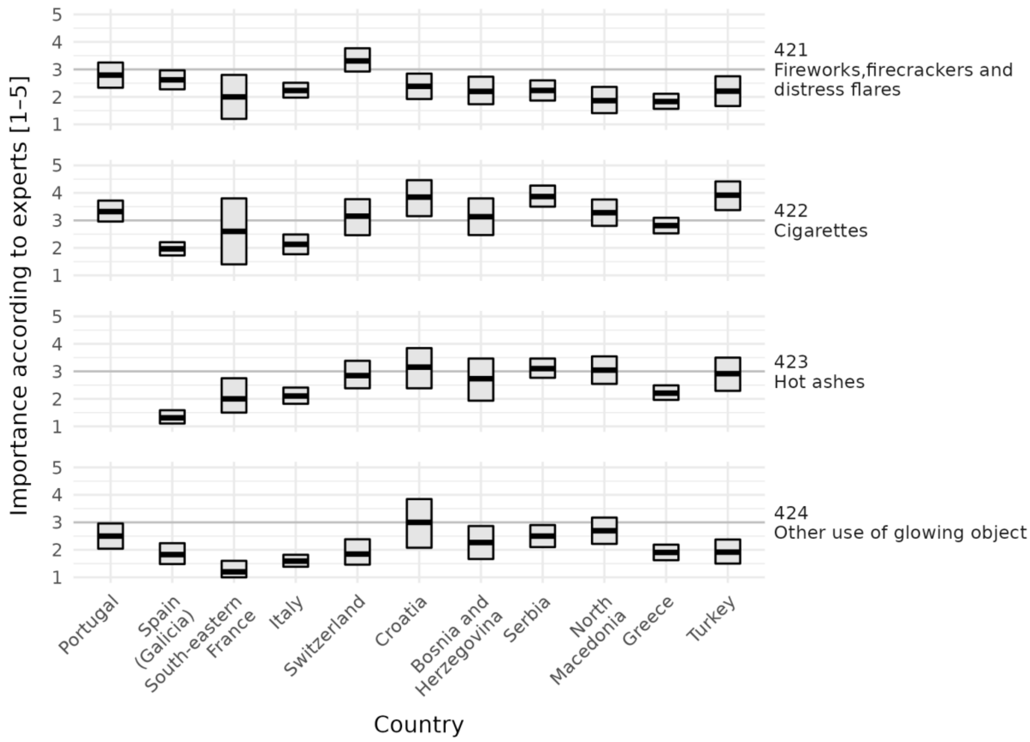

Figure 8. Crossbar plot of the importance of ignition due to *Negligent use of glowing objects*, according to the smean.cl.boot function from the Hmisc R-package, grouped by country.

3.3.5. Deliberate Causes

Figure 9 reports the *Responsible deliberate* causes (group 510) and *Irresponsible deliberate* (class 520) fires. The classification of *Responsible* fires, i.e., arson motivated (Camia et al. 2013), is split into six classes: *Interest (profit)* (class 511); *Conflict (revenge)* (class 512); *Vandalism* (class 513); *Excitement (incendiary)* (class 514); *Crime concealment* (class 515); *Extremist reason* (class 516) and is evidently inspired by the classification of voluntary fires proposed by [73–75].

For *Interest (profit)*, mean values ≥4 were registered in the Republic of North Macedonia (4.2 ± 1.2) and France (4.0 ± 0.7), and mean > 3 in Greece, Italy, Serbia, and Spain.

Conflict (revenge) exhibited the highest values in France (3.6 ± 1.5)—where the frequency of forest fires due to different motives was very low compared to that of fires with undetermined motives as they are very difficult to investigate—and Spain (3.6 ± 1.2), whereas *Vandalism* exhibited generally low values of the mean, with the exception of Portugal (4.1 ± 1.0), Bosnia and Herzegovina (3.7 ± 1.3), Spain (3.3 ± 1.1), and the Republic of North Macedonia (3.2 ± 1.3). In some areas of Portugal (e.g., NUTS level 2—North Region), vandalism represented 13% of officially assessed deliberate motives [65]. This is an illuminating example of the extremely high and unrealistic percentage of fire setting, which appears as an umbrella term used to capture a wide set of motives including willful mischievous destruction but also boredom relief [76,77]. This may also act as an expedient to give a label to forest fire events of unknown origin [65], thus improving official statistics.

Scarce importance was attributed to *Excitement (incendiary)*, with values of mean > 3 only in France (3.2 ± 1.8), Portugal (3.1 ± 1.3), and Switzerland (3.0 ± 1.2).

Crime concealment was not an important cause with the exception of the Republic of North Macedonia (3.8 ± 1.4). Only low values (means < 3) were in the *Extremist reason* (Figure S5 of the Supplementary Materials), an uncommon motivation that seems strongly related to an existing history of political conflicts.

The *Irresponsible* causes (group 520) were split into *Mental illness* (class 521) and *Children* (class 522).

Experts rated Mental illness (e.g., pyromania) as of considerable importance in the Republic of North Macedonia (3.6 ± 1.2), Portugal (3.5 ± 1.4), and Spain (3.3 ± 1.3). Pyromania is a rather uncommon pathological disorder characterized by intentional and repeated fire setting by a person who is deeply fascinated by fire and related paraphernalia [78]. The term is highly misused and blurred as a conceptually wrong synonym of arson or *Deliberate* fire [33,79,80].

The words arsonist and pyromaniac differ in the mindset of the fire setter, being typically criminal in the case of arson, following a wave of impulse of control disorder, from a buildup of tension that can only be released by deliberate fire setting in the case of pyromania. Pyromaniacs thus engage in intentional and pathological fire setting, while arsonists willfully and maliciously set fire or aid in setting fire [19]. Following the American Psychiatric Associations, formal diagnostic criteria for the diagnosis of pyromania are strict [81,82], which may thus justify the frequent misuse of the term. As a result, the role of pyromaniacs is often overestimated [19].

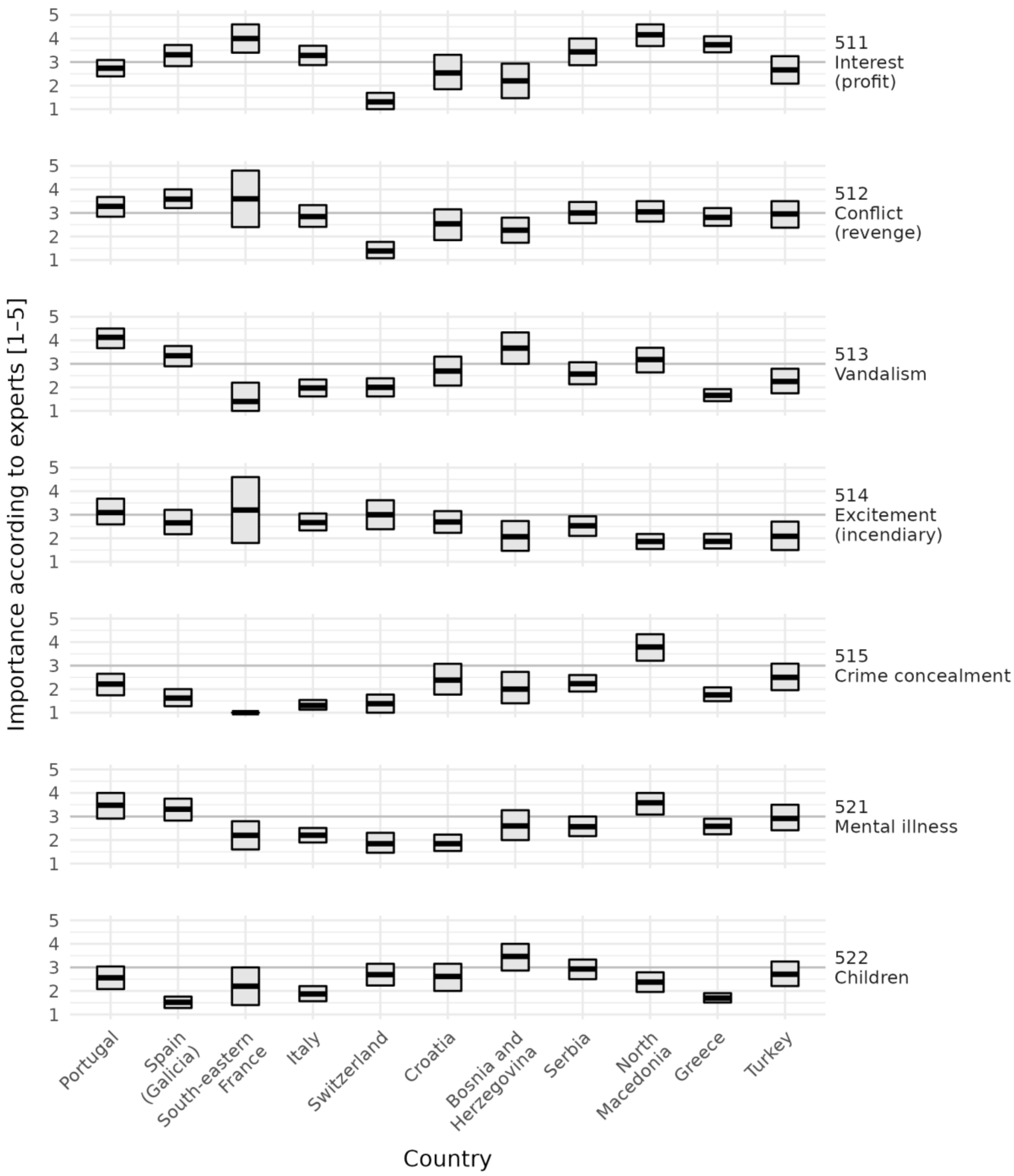

Figure 9. Crossbar plot of the importance of ignitions due to *Deliberate* causes, according to the smean.cl.boot function from the Hmisc R-package, grouped by country. Given the very low incidence of class 516, the relative graph is omitted.

The motivation related to irresponsible acts of *Children* had mean values >3 only in Bosnia and Herzegovina (3.5 ± 1.2). Children's' actions appear scarcely important and can also be interpreted as a way of satisfying curiosity or boredom relief repeatedly observed in other countries (e.g., for Algeria [77]).

The ignition source profile emerging from our survey shows how experts rate the whole cluster of deliberate forest fires as less important than negligent fires. This varies among countries, but is not true for France due to the much larger areas burnt by the deliberate fires. This indirectly confirms the excessive emphasis by mass media in associating charred landscapes to both responsible and *Irresponsible deliberate* fires, partially also because of the greater likelihood for such fires to become large [83,84]. In this respect, our results provide support for the growing evidence that arson-caused forest fires are overestimated across the world [19].

3.3.6. Rekindle

Rekindle (class 600) originates "from the pressure on the suppression system which works at constantly very high levels of capacity utilization, and is constantly requested to immediately combat all the new fires" [85], frequently without adequate time to guarantee a correct mop-up. In our survey, this category exhibited dispersed values of the mean and related SD, meaning that experts were not aligned on the perception of facts and provided dispersed ratings (Figure 10). Out of the 11 countries, only the Republic of North Macedonia (4.0 ± 0.9), Portugal (3.3 ± 1.0), and Serbia (3.2 ± 1.3) had a mean >3.

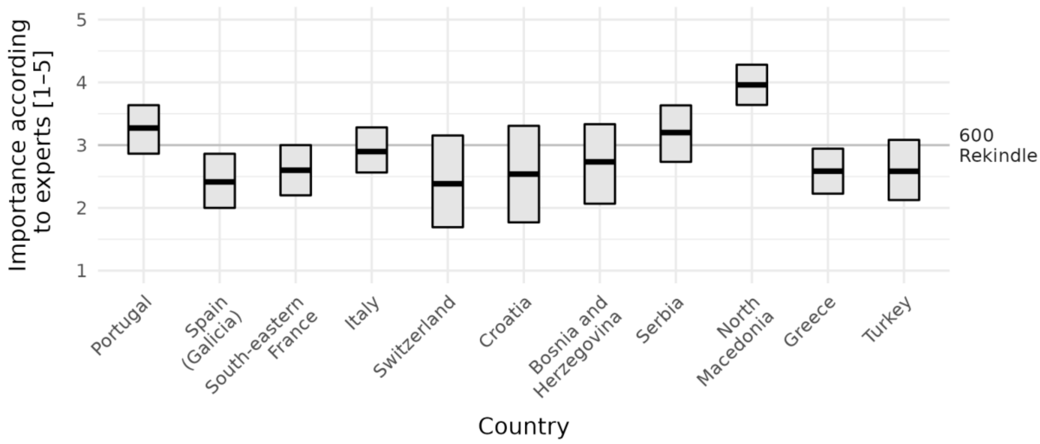

Figure 10. Crossbar plot of the importance of ignitions due to *Rekindle*, according to the smean.cl.boot function from the Hmisc R-package, grouped by country.

3.4. *Rank of Motivations*

The frequency of the first four main motivations (C1, C2, C3, C4), identified by the experts are reported in Table S4 of the Supplementary Materials, according to country and rank. In total, 26 out of the 29 officially registered ignition motivations were used by the experts in this section of the survey, and 20 were selected at least by one expert as the most important motivation. This highlights how the perception of ignition sources is not well focused but so dispersed that experts do not always converge toward a small number of them.

The ten most important motivations across all countries are shown in Figure 11. A considerable number of experts were aware of the high number of fires whose cause remains unknown, representing the second most assigned top ranking motivation, and the fourth most frequent one considering all ranks 1 to 4.

Among the known causes, the most important motivations were related to forest fire unintentionally set by people for *Agricultural burnings* (class 412) and for *Vegetation management* (class 411), exhibiting a frequency of 39.8% and of 11.3% of first ranked causes, respectively. Other causes in this category were less important, with *Waste management*

(413) and *Cigarettes* (class 422) scoring 3.2% and 1.6% among the causes of rank 1. However, *Cigarettes* were surprisingly the fourth most ranked cause when considering all rankings from 1 to 4. It should be noted that there was high variability among countries.

Once again, *Deliberate* fires appeared with a lower importance compared to fires due to *Negligence*, confirming that emphasis attributed to them is excessive. Among them, forest fires set for *Interest (profit)* (class 511), either directly for monetary gain or from a goal other than money, seemed to be the most important one (9.0% of the top rated causes), followed by *Excitement (incendiary)* (class 514), and *Conflict (revenge)* (class 512) at 5.2% and 4.6%, respectively.

Lightning (class 201) and *Electrical Power* (class 301) were the most cited causes belonging to the categories of *Natural causes* and of *Accidents*, respectively, accounting for 1.8% of the first-ranked causes.

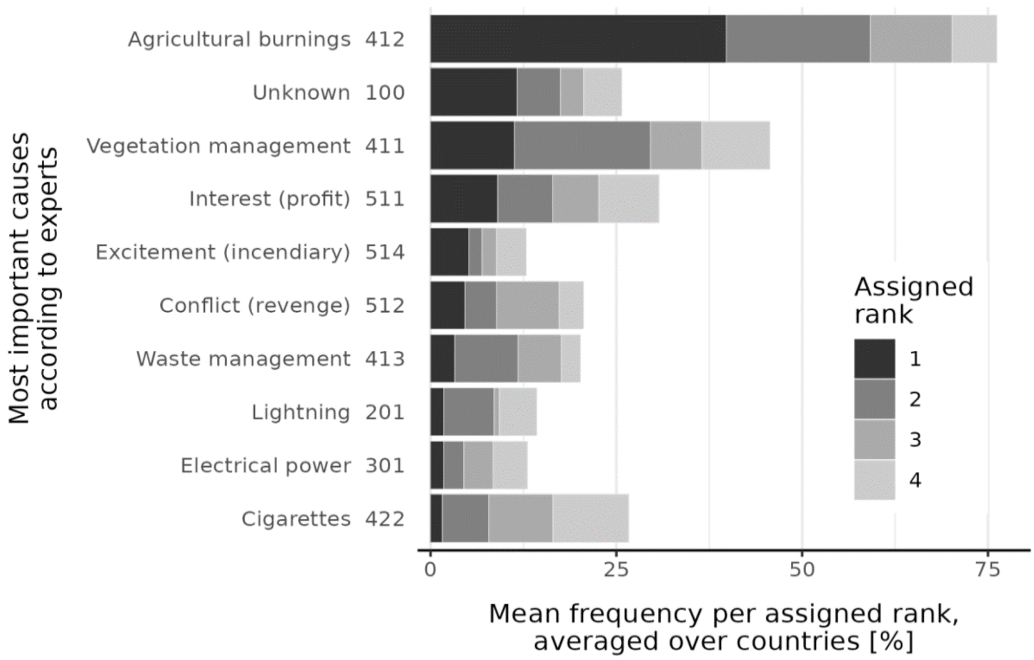

Figure 11. Bar plot of the frequencies of the most important causes identified by the experts, according to assigned importance rank (1 to 4) and averaged among the countries. Only the 10 most relevant causes are shown, ordered in decreasing importance according to the first rank frequencies (black colour).

3.5. Cluster Analysis

The cluster analysis based on the detailed fire ignition classes clearly discriminated the Mediterranean *Fire Club* countries (i.e., Portugal, Italy, Spain, France, and Greece) from the other ones. Within the *Fire Club*, Portugal displayed a rather standalone status, probably because of some positive (i.e., *Railroads*, *Weapons* within accidental causes; *Hot ashes* within negligent behavior; *Vandalism* within responsible deliberate causes) and some negative (i.e., *Vegetation management* within the traditional use of fire and deliberate fire setting for *Interest (profit)*) outliers with respect to the other four countries (Figure 12).

The second cluster encompassed a well-defined group of the south-eastern European countries (which includes Bosnia and Herzegovina, Croatia, the Republic of North Macedonia, Serbia, Turkey) and Switzerland. Similarly to Portugal in the first cluster, Switzerland displayed several outliers with respect to the south-eastern European countries of this group (i.e., higher rating for *Lightning*-induced fires, *Vegetation management*, and *Fireworks*; lower rating for deliberate fires set for interest or revenge), justifying its standalone status. The clusters well depicted existing differences in culture, history, and social behaviors of the concerned countries with respect to the TFU [86].

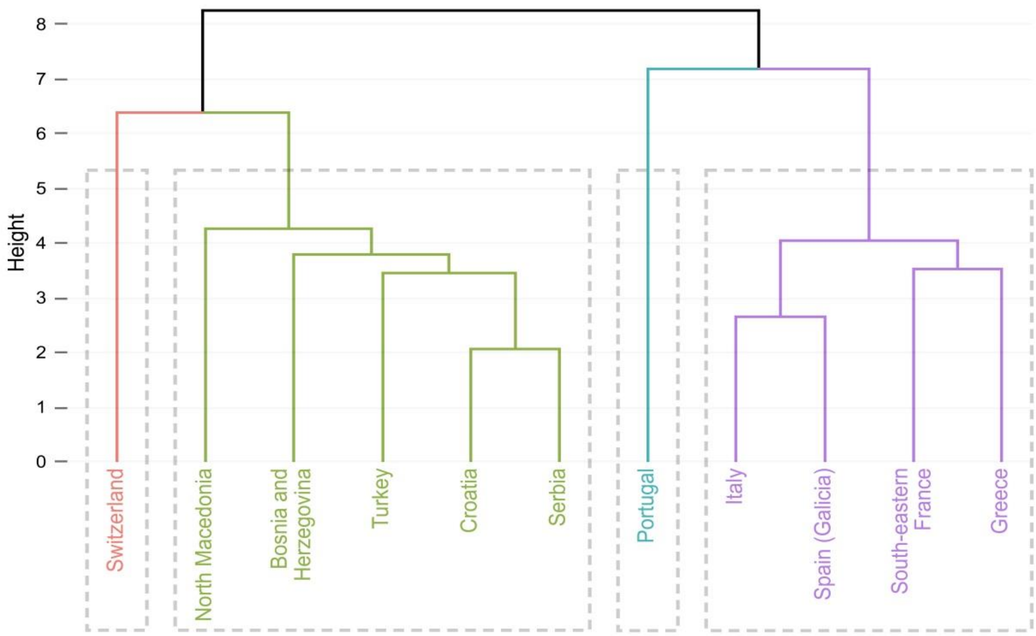

Figure 12. Hierarchical cluster analysis based on the average ratings of the fire causes by experts.

4. Concluding Remarks

Our research clearly highlights existing discrepancies between experts' perception and fire statistics on forest fire causes and motivations in the study area. In particular, some ignition sources such as arson appeared with high percentages in national statistics. This may be the result of a lack of the necessary deductive reasoning and systematic investigative approach in the post-event analysis [15,32]. Given the high number of occurrences, it is in fact rather difficult to carry out detailed procedures for identifying all ignition points [87] and to deduce the precise fire cause based on the visible evidence left by fire on vegetation, stones or structures/constructions. Further, since the use of fire has been criminalized in the legislative corpus of most Mediterranean countries, it is also rather difficult to catch the culprits in the act. They can adopt a *burn and escape* or a *burn and run* strategy to escape control and avoid penal and monetary sanctions. Therefore, whereas negligent fires due to agricultural or industrial activities are quite easy to recognize, the same cannot be said for malicious ones. As a result, many of the known causes reported in national statistics are rather plausible hypotheses, often formalized or just guessed and not confirmed causes determined by identifying the physical evidence on the ground [10]. This may eventually represent an expediency to curtail the high percentage of unknown motivations in official statistics [16,65].

Existing common expert perception of specific fire causes and motivations is confirmed by the results of the survey, which showed that most of events resulted from negligent behaviors, whereas malicious fire setting was arguably overestimated. Among experts, the subjective perception of the relative importance of the fire causes and motivations and the related clustering of the participating countries was quite coherent. Some minor discrepancies among (mean values) and within countries (high SD) were observed, which are based on the statistical evidence and related reasoned arguments. This confirms the suitability of the harmonized classification proposed by the European Commission of fire causes as a unified reference for the forest fire causes at the European level [10]. It is necessary to foster the use of such classification in order to increase the chances of broad support and acceptance by all concerned European and non-European countries of the EFFIS network and to obtain harmonized statistics to improve forest fire management policies.

More attention and resources should be devoted to the identification and detailed documentation of the complex causes of forest fire as a social phenomenon [4]; this should become a priority to avoid guiding prevention in a wrong direction, thus misleading the efforts aiming at modifying the attitudes, habits, customs, and behaviors of the concerned populations. It may also help to identify to which segments of the population risk communication should be addressed or whether message differentiation among target segments is advisable.

To conclude, less emphasis should be given to interventional actions and fire suppression, which are certainly mediatically impressive and more politically expedient. The advocated percent distribution of a budget of 60:40 between prevention and suppression [88] makes it crucial to identify why and where fires occur. We, also suggest an easier and safer legal use of fire, providing alternative opportunities and activities, and engaging local communities in these changes that could markedly decrease the high number of negligent fires.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13040562/s1, Figure S1: Mean expert rating and fire statistics of known causes across all countries; Figure S2: Crossbar plots of the importance of the cause according to the smean.cl.boot function from the Hmisc R-package, grouped by country. For the aggregation procedure of single fire causes refer to the Methods section in the manuscript; Figure S3: Crossbar plots of the importance of the single fire causes in categories 100 to 300, according to the smean.cl.boot function from the Hmisc R-package, grouped by country; Figure S4: Crossbar plots of the importance of the single fire causes in category 400, according to the smean.cl.boot function from the Hmisc R-package, grouped by country; Figure S5: Crossbar plots of the importance of the single fire causes in categories 500 to 600, according to the smean.cl.boot function from the Hmisc R-package, grouped by country; Table S1: Questionnaire filled by the experts and relative instructions; Table S2: Data available from EFFIS fire statistics; Table S3: Descriptive statistics (mean $\pm$ standard deviation) of the answers of the respondents, grouped by wildfire cause and country; Table S4: Frequency of the fire causes in according to rank and country and related percentage.

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