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Bridging the gap in the knowledge on the role of spatial planning in the reduction of wildfire risk: insights from Portugal

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Abstract

The 2017 wildfires marked a dramatic milestone in Portuguese society, which corresponded to extreme intensity and the inherent loss of life, property, and thousands of burned forest hectares. This high impact led to a paradigm shift regarding prevention and firefighting, highlighting the need for an integrated fire management approach and assuming as imperative the integration of wildfire risk reduction on spatial planning at the municipal level. This turning point was expressed in the prolific legislative production, namely in the guidelines for preventing and fighting wildfires, given by the Resolution of the Council of Ministers (RCM) n.º 157-A/2017; on the principles set out in the Directive for Preventing and Fighting Wildfires, defined by the RCM n.º 20/2018; in the approval of the National Plan for the Integrated Management of Wildfires (PNGIFR), emanated from the RCM n.º 45-A/2020, which established the need to implement an Integrated Management System for Wildfires (SGIFR), whose vision and objectives were defined in the RCM n.º 12/2019, and its operating rules were enacted in the Decree-Law n.º 82/2021.

As such, the SGIFR establishes, at a national level, strategic guidelines with a view to risk reduction, changing the behaviour of owners, users, and other beneficiaries of the rural territory. In addition, SGIFR proposes integrating wildfire risk reduction in spatial planning through the insertion of a fire hazard map, namely in the master plan's constraints map (i.e., the map where are identified the administrative easements and public utility restrictions that may constitute limitations or impediments to any specific form of land use). The constraint map is one of the documents of the Municipal Master Plan, i.e., the fundamental legal instrument in the management of the municipal territory that defines the strategic framework for territorial development and the spatial organization model of the municipal territory.

This paper identifies the weaknesses of the approach proposed by the SGIFR to promote wildfire risk reduction through spatial planning. Firstly, we used an online questionnaire answered by 175 municipalities of Portugal, in order to examine the local technicians' experience in applying the legislation of spatial planning and wildfire management policies. In a second step, we collected data from a Delphi survey with 27 experts and from a focus group with 9 experts with the aim to confirm or disconfirm the importance of each need for integration between land use planning and rural fire management, indicated by the questionnaire of 175 municipalities. One of the main weaknesses is related with the integration of the fire hazard map in the constraints map of the Municipal Master Plan, considering the high inter-annual variability of fire hazard and the long-term definition of the municipal development model. This procedure will create building permit constraints which can limit the development and continue to favour the depopulation of the rural areas.

This paper contributes to bridging a critical gap in knowledge on the role of spatial planning in the reduction of wildfire hazard and exposure, given that the characteristics of fire hazard are distinctive from other natural hazards (e.g., floods, costal erosion, earthquakes).

1. Introduction

Wildfire losses are increasing in many parts of the world related with the expansion of wildland urban interfaces and the occurrence of extreme wildfires, whose intensity and frequency are expected to increase due to climate

change (Keeley & Syphard, 2016). As these events overwhelm the control capacity (Tedim et al, 2018; Tedim et al., 2020), a stronger focus on prevention and mitigation, within a adaptative planning framework, is required. Spatial planning and development regulations are recognized as an instrument for reducing wildfire hazard and exposure across wildland-urban-interface (Mowery et al., 2019, Mockrin et al., 2020; Gatti & McGee,2021; Gonzalez-Mathiesen et al., 2021). While among other natural hazards (e.g., floods, coastal erosion, earthquakes) there is a long experience using spatial planning to reduce risk, in wildfire domain remain some critical gaps in knowledge and operationalization strategies (Mockrin et al., 2020), as wildfires are complex socio-ecological processes that mostly has anthropic origin.

In Portugal, the National Plan for the Integrated Management of Wildfires (PNGIFR), emanated from the Resolution of the Council of Ministers (RCM) n.º 45-A/2020, which established the need to implement an Integrated Management System for Wildfires (SGIFR), and its operating rules enacted in the Decree-Law n.º 82/2021, intent to integrate wildfire management into spatial planning instruments. The main instrument for this integration is the hazard map that is going to be one more layer of the Constraints Map of the Municipal Master Plans. The national hazard map was published in March of 2022 by the Portuguese Institute for the Conservation of Nature and Forests and was produced using a methodology that considers deterministic factors (Verde & Zêzere, 2010; Oliveira, Gonçalves, & Zêzere, 2021). The Municipal Master Plans (PDM's) inform spatial planning development and the buildings permits. The Master Plans regulate, at spatial level, the land use in order to promote the sustainable development in a given municipal territory, while its Constraints Map express restrictive areas that limit the desirable development at a site, safeguarding the biophysical and cultural character of the territory, as well as avoiding the occupation of areas with the highest hazard index. In this context, SGIFR determines that the interdiction of building permits in high and very high wildfire hazard areas (APPS) and major restrictions in very low, low and medium hazard areas, which have, by a SGIFR legal obligation, to be integrated in the Constraints Map of Master Plans.

This paper contributes to research on the difficulties, needs, and impact of the integration of wildfire hazard map into spatial planning namely into the Municipal Master Plans, first stablished by the Forest Fire Defence System (SDFCI - Decree-Law n.º 124/2006, of 28 June) and now determined by the Integrated Management System for Wildfires in the Continental Territory (SGIFR - Decree-Law n.º 82/2021. First, it identifies the difficulties that local governments face in the implementation of the new legislation, namely in the integration of wildfire hazard map into spatial planning. Second, it measures the consensus among experts. Third, pertinent recommendations are presented.

The overall research question is: What are the benefits and disadvantages of the hazard map integration in the Constraints Map of the Master Plans? The paper is organized as follows: Section 2 summarizes the mixed – methods used to collect and analyse data; Section 3 is dedicated to the analysis of legal environment of spatial planning and wildfire management integration; Section 4 presents the results about the identification of major difficulties and suggestions of local technicians, collected by an online survey and a Delphi survey, concerning the risk reduction in spatial planning at municipal level; Section 5 formulates the discussion about the challenges and opportunities regarding the integration of fire hazard map in the constraints map of the municipal Master Plans; and Conclusions are stated in Section 6.

2. Data and methods

2.1. Review of government documents

To prepare the two steps method used in this research, we started by reviewing government documents.

2.2. Data collection

As a first step, an online survey was sent between April and June of 2022, to 275 municipalities (the municipalities of Lisbon, Porto and São João da Madeira, were excluded because are urban areas). The questionnaire was formed by two questions: i) "*What are the main difficulties you face with the implementation of the SGIFR (DL n.º 822021, of October 13, in its latest version)?"*; ii) "*Do you agree with the decision to integrate the wildfire hazard map in the Constraint Map of the spatial plans? Please justify your reply.*". The response rate was 64%. It exceeds the necessary minimum sample size (161 replies for a confidence level of 95% and a margin of error of 5%), using Kish (1995) and Laureano (2013) equation**,** for extrapolating conclusions from the results.

The 175 municipality responses were organized by five territorial regions within the SGIFR governance structure: North (with 53 replies; 62% of the region's municipalities), Centre (with 50 replies; 73% of the region's municipalities), Lisbon and Tejo River Valley (with 24 replies; 44% of the region's municipalities), Alentejo (with 25 replies: 53% of the region's municipalities) and Algarve (with 10 replies; 63% of region's municipalities) (Figure 1). Thirteen (13) municipalities chose to remain anonymous.

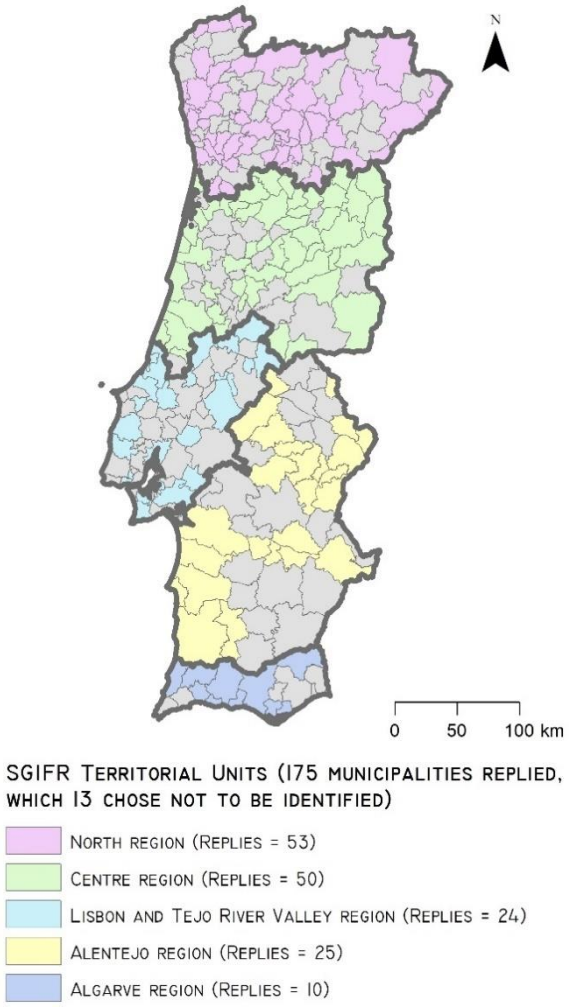

Figure 1 – Municipalities that responded the online survey per region.

The data collected was analysed in NVivo software, version 1.6.1 (1137). Coding in NVivo enabled to categorization of the survey open responses and consequently made it possible to count the frequency of each response.

In a second step, a workshop was held at Guarda Municipal Council on June 3, 2022, where a Delphi questionnaire was operated with 27 experts in spatial planning and wildfire management in order to differentiate the importance of the main categories emanated from the previous step. Thus, an one round real-time Delphi survey was supported by a 5-point *Likert* scale (*1 - Completely disagree; 2 - Disagree; 3 - Fairly agree; 4 - Agree; 5 - Completely agree*).

Procedures for measuring consensus vary widely, so there are several methods available to determine the convergence of opinion among Delphi participants (Rayens & Hahn, 2000; Gracht, 2012; Beiderbeck et al., 2021). These authors support the use of the interquartile range (IQR), where the low values are an indicator of consensus *([0 - 1] Most agreement]1 - 2[Average agreement [2 - 3] Low agreement*) (Gracht, 2012). According to Rayens & Hahn, (2000), a null interquartile range indicates complete consensus. Despite this, it was still decided to use the arithmetic mean (Mean). In this sense, an arithmetic mean value above 3.5 (integrating the answers *4 - Agree*; *5 - Completely agree*) expresses a tendency of concordant answer, while an average value lower than 2.5 (*1 - Completely disagree*; *2 - Disagree*) reflects a discordant trend. On the other hand, another indicator was used, namely the percentage of concordant answers (*Level of Agreement Responses*), which helps

the analysis of the response trend. The IQR of Delphi responses was calculated in Statistical Package for the Social Sciences 26 (IBM, 2022).

Finally, a focus group, in the workshop held in Guarda municipality with nine experts in spatial planning and wildfire management, was conducted to elicit, spontaneously, knowledge that had not been collected by the online questionnaire and the Delphi survey due to its more formatted nature.

3. Spatial planning and wildfire management integration: legal environment

The National Program for Spatial Planning Policy (PNPOT), the main Portuguese instrument for spatial planning on a national scale, in its revised version of 2019, approved by the Law n.º 99/2019, of September 5, stated that the "*articulation of the master plans with the instruments of forest management, forest defence and wildfire fighting, is paramount in order to build a more integrated planning approach that better responds to the challenges of the territories and to safeguard people and goods*".

RCM n.º 12/2019, of January 21, approved the mission of the Integrated Management System for Wildfires (SGIFR), namely the protection of people and property from wildfires, based on the clear definition of responsibilities concerning the management of the rural territory and the protection of people and buildings against wildfires, integrating all actors in a joint action within prevention and suppression processes. The same initiative enshrined the urgent establishment of the National Plan for the Integrated Management of Wildfires (PNGIFR) as a replacement for the previous National Plan for the Defence of Forests against Wildfires (PNDFCI), which saw its goals exceeded as a result of the accumulation of fuel and systemic frailties aggravated by heat waves or extreme weather events with increasing personal and property damage.

This context of vegetation accumulation and of perception bias of risk by populations that did not change risk behaviours required to the adoption of multiple and integrative solutions. Thus, the RCM n.º 45-A/2020, June 16th, gave the motto for the PNGIFR: guiding the integrated management of wildfires in a territory that seeks to be lived by a population with context-sensitive behaviours under efficient risk management options. The PNGIFR introduced an innovative risk governance model, identified strategic objectives and measures to be implemented, clarifying the roles and responsibilities of the various entities that cooperate to achieve the defined goals.

Subsequently, the Integrated Management System for Wildfires in the Continental Territory (SGIFR) promulgated by Decree-Law (DL) n.º 82/2021, defined the norms and institutional articulation processes in the integrated management of wildfires with two axes of intervention: protection against wildfires, oriented towards the safeguarding of people and buildings, and rural fire management, oriented towards the defence and valorisation of rural territories, considering its protection role by reducing conditions for the occurrence and progression of wildfires.

The SGIFR revoked the previous Forest Fire Defence System (SDFCI). which had been instituted by Decree-Law n.º 124/2006, of 28th June. As such, the previous requirement to draw up Municipal Plans for the Defence of Forests against Wildfires (PMDFCI) of the SDFCI was replaced by the requirement of Municipal Programs for the Execution of Integrated Management of Wildfires of the SGIFR.

Unlike the Master Plans (PDM's), the PMDFCI's and its hazard maps, as they were not, legally, spatial plans, were not directly binding on individuals as they did not meet the requirements of public advertising and public discussion, essential for the production of effects by any normative act, as enshrined in the respective paragraph 2 of article 119 and paragraph 5 of article 64 of the Portuguese Republic Constitution (Oliveira, 2018), situation only solved by the Law n.º 76/2017, 17th August.

In light of this goal of spatial planning and wildfire risk reduction alignment, the SGIFR, as the previous SDFCI, stipulates the integration of fire hazard index classes (very low, low, medium, high, very high) in the constraints map of the PDM's, and defines constraints on building permits within and outside the areas of high and very high fire hazard index classes, which are designated Priority Areas for Prevention and Safety (APPS).

4. Results

4.1. Main difficulties faced by the municipalities with the implementation of the SGIFR

4.1.1. The results from the online survey

The forestry technicians that responded to the online survey identified several difficulties regarding the integration of hazard map into the constraint map of Master Plans (table 1).

The main difficulties (table 1) are:

i) "new hazard map does not correspond to the existing reality in the territory" due to the spatial resolution; the fact that is not based on the Master Plan's urban spaces; the redundancy of the previous hazard maps, among others aspects. The greatest worries regions are from Centre region (22% of replies) and from North region (19% of replies) (supplementary table S1) that have around 50% of their territory in high and very high hazard index (table S2), but also from Alentejo (16% replies), where 56% of the surface presents low or no wildfire risk

ii) "land use map (COS) 2018 does not reflect the existing reality at the local level", which is a main worry from Algarve region (10% of replies);

iii) "obstacles to cultural and sporting activities)" as the articles 67 and 68 of SGIFR establish the prohibition of many activities in high and very high hazard areas and in days with high weather risk. This is a worry of the Centre region (4% of replies) (1% of national replies);

iv) "difficulties in surveying and mapping burned areas", being a worry of Alentejo municipalities ($% of replies) (1% of national replies);

v) "confusion between the concept of Hazard (structural) and Fire weather index (daily)", stated by 4% of Centre region replies (1% of national replies);

vi) "difficulty in understanding the criteria for defining hazardous areas", evidenced by 2% of Centre replies (1% of national replies);

vii) "the execution of the fuel management strips has contributed to colossal forest destruction", conduced by North region (2% of replies) (1% of national replies);

viii) "the current dimensions of the fuel management strips [around the houses] are not justified, as there is no gain in defence beyond 30 meters in size", concluded by North region (2% of North replies) (1% of national replies).

Table 1 – Main difficulties faced by the municipalities with the implementation of the SGIFR: responses to online survey (N=175).

	Responses (N=175)	**%**
RISK MANAGEMENT TOOLS		
New hazard map does not correspond to the existing reality in the territory (spatial resolution; not based on the Master Plan's urban spaces; redundancy of the previous hazard maps, among others)	30	17 %
Land use and land cover map (COS 2018) does not reflect the existing reality at the local level	2	1%
Obstacles to cultural and sporting activities (articles 67 and 68 of the SGIFR)	2	1%
There are difficulties in surveying and mapping burned areas	2	1%
Confusion between the concept of Hazard (structural) and Fire Weather Index (daily)	1	1%
Difficulty in understanding the criteria for defining hazardous areas	1	1%
The execution of the fuel management strips has contributed to colossal forest destruction	1	1%
The current dimensions of the fuel management strips are not justified, as there is no gain in defence beyond 30 meters in size	1	1%

4.1.2. Consensus of the Delphi panel

Subsequently, the robustness of the consensus in the Delphi survey responses (N = 27 experts) regarding the difficulties and needs regarding the integration of the hazard map in the constraint map of Master Plans was analysed. Those who generate a strong consensus were "hazard map does not correspond to the existing reality in the territory (spatial resolution; not based on the Master Plan's urban spaces; redundancy of the previous hazard maps, among others)" (mean=4.41; IQR=1; level of agreement responses=85%), "Land use map (COS) 2018 does not reflect the existing reality at the local level" (mean=4.11; IQR=1; level of agreement responses=85%); "confusion between the concept of Hazard (structural) and Fire Weather Risk (daily)" (mean=3.93; IQR=1; level of agreement responses=78%); and "difficulty in understanding the criteria for defining hazardous areas" (mean=4.37; IQR=1; level of agreement responses=89%) (table 2).

Table 2 – Main difficulties faced by the municipalities with the implementation of the SGIFR: consensus analysis of Delphi panel responses (N=27).

	Mean of Delphi Group (N = 27)	**Interquartile Range (IQR) [0 - 1] Most agreement]1 - 2[Average agreement [2 - 3] Low agreement**	**Level of Agreement Responses = Agreements / S opinions expressed**
RISK MANAGEMENT TOOLS			
Hazard map does not correspond to the existing reality in the territory (spatial resolution; not based on the Master Plan's urban spaces; redundancy of the previous hazard maps, among others)	4.40	1	85%
Land use map (COS) 2018 does not reflect the existing reality at the local level	4.11	1	85%
Confusion between the concept of Hazard (structural) and Fire Risk (daily)	3.92	1	78%
Difficulty in understanding the criteria for defining hazardous areas	3.85	1	70%
Obstacles to cultural and sporting activities (articles 67 and 68 of the SGIFR)	3.75	2	54%
The execution of the fuel management strips has contributed to colossal forest destruction	3.41	3	48%
The current dimensions of the fuel management strips are not justified, as there is no gain in defence beyond 30 meters in size	3.41	2	48%
There are difficulties in surveying and mapping burned areas	3,00	2	33%

4.2. Agreement with the decision to integrate the wildfire hazard map in the Constraints Map of the Master Plans

4.2.1. Results from the online survey

Regarding the integration of the wildfire hazard in the constraints map of Master Plans, most municipalities agree with their integration (74%) (table 3). Within the regions, the results are:

i) Lisbon and Tejo River Valley respondent municipalities agree with the integration (96% of replies, where high and very high hazard represent 24% of the territory);
ii) Alentejo respondent municipalities agree with the integration (92% of replies, where high and very high hazard represent 5% of the territory);
iii) North region respondent municipalities agree with the integration (79% of replies, where high and very high hazard represent 49% of the territory);
iv) Centre region respondent municipalities agree with the integration (74% of replies, where high and very high hazard represent 51% of the territory);

v) Algarve region respondent municipalities agree with the integration (60% of replies, where high and very high hazard represent 34% of the territory).

Table 3 - Agreement with the decision to integrate the wildfire hazard map in the Constraints Map of Master Plans: responses to online survey (N=175).

	Responses (N=175)	**%**
YES	130	74%
DECISION MARKING		
The integration of the hazard map facilitates decision making regarding the licensing of construction and expansion of buildings in rural areas depending on the hazard	37	21%
The integration of the hazard map in Constraint Map of Master Plan is necessary in order to bind individuals	5	3%
The hazard map must be integrated into the Master Plan constraint map only if it is prepared by the municipality	1	1%
HAZARD MAP METHODOLOGY		
The methodology of the hazard map standardizes the criteria, at a national level, for the elaboration of this cartography, leaving no room for discrepancies	5	3%
The methodology for executing the hazard map should be reviewed and should be dynamic	4	2%
The artificialized territories in the Land Use Map (COS 2018) do not correspond to the urban spaces of the Master Plan, which makes procedural analysis difficult in the context of the constraints to the construction of the SGIFR	2	1%
EXPECTED IMPACTS		
But the structural hazard map leads to major restrictions	3	2%
The hazard map must not lead to the prohibition of occupation of rural areas, increasing their vulnerability, abandonment, and inherent increase in hazardousness	1	1%
Hazard index encourages the management of rural areas insofar as the less dangerous nature of the plots will increase their financial value	1	1%
NO	45	26%
EXPECTED IMPACTS		
The structural hazard map leads to major restrictions	9	5%
MISMATCHES IN THE PLANNING FRAMEWORK		
Hazard index, due to its dynamic nature, becomes impracticable to be transposed to Master Plan's Constraints Map	5	3%
There is an incompatibility between the rigidity of the Spatial Plans and the dynamics of transformation of the Territory	1	1%
The hazard map must maintain its independent character from the Spatial Plans, supporting forestry planning and rural fire management	1	1%
LEGAL ENVIRONMENT		
The hazard map binds individuals without having been published for public consultation	3	2%
HAZARD MAP METHODOLOGY		
The hazard map should be carried out by the municipalities	1	1%
The hazard map was created by identifying spaces with high fire recurrence and from a standpoint of definition of defence areas, so it cannot be used as a building constraint	1	1%

However, both those who agree and those who disagree present suggestions for improvement in this subject.

The concordant responses were categorized in Decision Making, Hazard Map Methodology, and Expected Impacts.

Regarding decision making, the concordant respondents stated that "the integration of the hazard map facilitates decision making regarding the licensing of construction and expansion of buildings in rural areas depending on the hazard" (21% of national replies; 33% of Lisbon and Tejo River Valley; 24% of Alentejo region replies; 21% of North region replies; 20% of Algarve region replies; 14% of Centre region replies)

In addition, "the integration of the hazard map in Constraints Map of Master Plans is necessary in order to bind individuals" (3% of national replies; 4% of North region replies; 4% of Centre region replies; 4% of Alentejo region replies).

However, there are municipalities that consider that "hazard map must be integrated into the Master Plan constraint map only if it is prepared by the municipality" (1% of national replies; 2% of North region replies) explaining.

Concerning hazard map methodology one of the positive aspects is that "the methodology of the hazard map standardizes the criteria, at a national level, for the elaboration of this cartography, leaving no room for discrepancies" (3% of national replies; 8% of Lisbon and Tejo River Valley replies; 2% of North region replies).

Nevertheless, the are municipalities that establish some conditions like "the methodology for executing the hazard map should be reviewed and should be dynamic" (2% of national replies; 6% of North region replies), and that "the artificialized territories in the Land Use Map (COS 2018) do not correspond to the urban spaces of the Master Plan, which makes procedural analysis difficult in the context of the constraints to the construction of the SGIFR" (1% of national replies; 10% of Algarve region replies; 2% of Centre region replies).

About the expected impacts, the concordant respondents acknowledge that "the structural hazard map leads to major restrictions" (2% of national replies; 4% of Centre region replies), "the hazard map must not lead to the prohibition of occupation of rural areas, increasing their vulnerability, abandonment, and inherent increase in hazardousness" (1% of national replies; 10% of Algarve region replies), and "hazard index encourages the management of rural areas insofar as the less dangerous nature of the plots will increase their financial value" (1% of national replies; 4% of Lisbon and Tejo River Valley replies).

Discordant respondents, on the other hand, presented answers that were grouped into four themes: Expected Impacts, Mismatches in the Planning Framework, Legal Framework and Hazard Map Methodology.

For these respondents, the main expected impacts are related to major restrictions determined through the hazard map (5% of national replies; 10% of Algarve region replies; 6% of North region replies; 6% of Centre region replies).

Within mismatches in the planning framework, they say that "hazard index, due to its dynamic nature, becomes impracticable to be transposed to Master Plan's Constraint Map" (3% of national replies), "there is an incompatibility between the rigidity of the Spatial Plans and the dynamics of transformation of the Territory" (1% of national replies; 2% of Centre region replies) and that "the hazard map must maintain its independent character from the Spatial Plans, supporting forestry planning and rural fire management" (1% of national replies; 10% of Algarve region replies).

Among legal environment, they state that the hazard map binds individuals without having been published for public consultation" (2% of national replies; 10% of Algarve region replies; 4% of Centre region replies).

In regard to hazard map methodology, "the hazard map should be carried out by the municipalities" (1% of national replies; 2% of North region replies) and "the hazard map was created by identifying spaces with high fire recurrence and from a standpoint of definition of defence areas, so it cannot be used as a building constraint" (1% of national replies; 2% of North region replies).

4.2.2. Consensus of the Delphi panel

Regarding the justification of the concordant and discordant answers, and the suggestions for improvement, there is a consensus in: "the methodology for executing the hazard map should be reviewed and should be dynamic" (mean=3.56; IQR=1; level of agreement responses=89%); "the artificialized territories in the Land Use Map (COS 2018) do not correspond to the urban spaces of the Master Plan, which makes procedural analysis difficult in the context of the constraints to the construction of the SGIFR" (mean=3.56; IQR=1; level of agreement responses=63%); "the methodology of the hazard map standardizes the criteria, at a national level, for the elaboration of this cartography, leaving no room for discrepancies" (mean=3.15; IQR=1; level of agreement responses=37%); "the structural hazard map leads to major restrictions" (mean=3.96; IQR=0; level of agreement responses=81%); "the hazard map binds individuals without having been published for public consultation" (mean=4.15; IQR=1; level of agreement responses=77%); and "hazard index, due to its dynamic nature, becomes impracticable to be transposed to Master Plan's Constraint Map" (mean=3,52; IQR=1; level of agreement responses=52%).

Table 4 – Agreement with the decision to integrate the wildfire hazard map in the Constraints Map of Master Plans: responses to online survey (N=175): consensus analysis of Delphi survey responses (N=27).

	Mean of Delphi Group (N = 27)	**Interquartile Range (IQR) [0 - 1] Most agreement]1 - 2[Average agreement [2 - 3] Low agreement**	**Level of Agreement Responses = Agreements / S opinions expressed**
YES			
HAZARD MAP METHODOLOGY			
The methodology for executing the hazard map should be reviewed and should be dynamic	4.37	1	89%
The artificialized territories in the Land Use Map (COS 2018) do not correspond to the urban spaces of the Master Plan, which makes procedural analysis difficult in the context of the constraints to the construction of the SGIFR	3.56	1	63%
The methodology of the hazard map standardizes the criteria, at a national level, for the elaboration of this cartography, leaving no room for discrepancies	3.15	1	37%
EXPECTED IMPACTS			
But the structural hazard map leads to major restrictions	3.96	0	81%
The hazard map must not lead to the prohibition of occupation of rural areas, increasing their vulnerability, abandonment and inherent increase in hazardousness	3.85	2	63%
Hazard index encourages the management of rural areas insofar as the less dangerous nature of the plots will increase their financial value	3.15	2	44%
DECISION MARKING			
The integration of the hazard map in Constraint Map of Master Plan is necessary in order to bind individuals	3.89	2	63%
The hazard map must be integrated into the Master Plan constraint map only if it is prepared by the municipality	3.7	2	1%
The integration of the hazard map facilitates decision making regarding the licensing of construction and expansion of buildings in rural areas depending on the hazard	3.59	2	63%
NO			
LEGAL ENVIRONMENT			
The hazard map binds individuals without having been published for public consultation	4.15	1	77%
MISMATCHES IN THE PLANNING FRAMEWORK			
There is an incompatibility between the rigidity of the Spatial Plans and the dynamics of transformation of the Territory	3.81	2	62%
Hazard index, due to its dynamic nature, becomes impracticable to be transposed to Master Plan's Constraint Map	3.52	1	52%
The hazard map must maintain its independent character from the Spatial Plans, supporting forestry planning and rural fire management	3.15	2	42%
EXPECTED IMPACTS			
The structural hazard map leads to major restrictions	3.96	0	81%
HAZARD MAP METHODOLOGY			
The hazard map should be carried out by the municipalities	4,00	2	69%
The hazard map was created by identifying spaces with high fire recurrence and from a standpoint of definition of defense areas, so it cannot be used as a building constraint	3.69	2	54%

It is not surprising that the highest participation rate and greatest concern with hazard related restrictions was from municipalities in the North region and the Center region, as these are the regions that have around of 50% of their territory in high and very high hazard index (table S2).

As discussed in the focus group, the constraints on building in areas with high and very high hazards are stranglers for the territorial development and could increase the depopulation of the interior, which will generate even less human capacity for fuel management and, thus, could increase the hazard. As for the integration of the hazard map in the Master Plan constraint map, it was discussed that the hazard map is a cartography that can undergo annual changes and it makes no sense to integrate it into a constraint map of the Master Plan that is only reviewed every 10 years.

5. The integration of the fire hazard map in the constraints map of the municipal master plan: challenges and opportunities

The Portuguese authorities estimate fire hazard, based on a deterministic approach (Verde & Zêzere, 2010; Oliveira, S., Gonçalves, A., & Zêzere, J. L., 2021). This approach uses fire probability, slope and land cover factors, aggregating it in quintiles, which correspond to five hazard classes, in order to create the fire hazard map as specified by SDFCI (Decree-Law n.º 124/2006). Therefore, the fire hazard map has usually been the product of multiplying probability and susceptibility to wildfires, while potential damage has been the product of multiplying the economic value and vulnerability (AFN, 2012). As such, the fire risk assessment is based on multiplying the Fire Hazard with the Potential Damage. In the case of the Fire Hazard inputs, it should be noted that the probability results from dividing the number of recorded wildfire occurrences and the number of years in its series, expressed as a percentage. As such, the time series of wildfire occurrences must be as long as possible (Parente et al., 2016).

Using the number of occurrences as a methodological input for the hazard map calculation works for the majority of fires and it is a prolific exercise, but do not apply to extreme fires conditions (Tedim et al., 2020), whose intensity and recurrence are expected to increase with a changing climate (Keeley & Syphard, 2016).

Susceptibility, on the other hand, derives from the multiplication of susceptibility classes depending on two factors, namely slope and land use/cover. In this context, the susceptibility is increasing as the slope increases. Regarding land use, forest land use classes are associated with greater susceptibility, while agricultural classes have a low to medium susceptibility. At this point, several methodological challenges arise. Regarding the slope calculation, it is imperative to use a Digital Terrain Model with the maximum possible spatial resolution, so that the areas with the greatest susceptibility are identified with high accuracy.

The accuracy between reality and what is mapped is also a challenge in terms of land use mapping. In this subject, the Corine Land Cover (CLC) cartography with a minimum mappable unit of 25 hectares (ha) and a time series with five reference years (1990, 2000, 2006, 2012 and 2018), or the Land Use and Occupation Map (COS) with a minimum mappable size of 1 ha and time series with five reference years (1995, 2007, 2010, 2015 and 2018), are commonly used. Even concerning cartography with a smaller and, therefore, more exact mappable size unit, it is important to consider the disadvantages of the COS use at local scale, depending on its level of accuracy and generalization rules adopted at the time of its preparation.

The COS vectorial map derives from the orthophotomaps interpretation, related to the previous years (up to 2 years before), with a spatial resolution of 20 linear meters and the mentioned 1 ha in terms of minimum mappable area. By this combination of factors, the COS map, when used, is already out of date. Another issue is that its spatial resolution is not compatible with the identification of isolated housing, scattered housing, or road network. In the case of the master plans, the maps should be done at a scale of at least 1/1000, so that human infrastructures are effectively represented (buildings and local road network). In this context, an opportunity in the calculation of the fire hazard is the use of land use maps with higher resolution and smaller mappable units that allow greater accuracy to the real land use, carried out with a constant periodicity that allows the expression of the dynamic influence of land use and land cover changes on fire hazard index of a given territory.

However, the integration of the fire hazard map in the constraint map of the master plans can be an opportunity or a threat, depending on the spatial resolution and degree of generalization of the COS that serves as an input of fire hazard index.

This integration can, therefore, generate a spatialization of the areas with the greatest fire hazard that is crystallized in the municipal master plans, thus, failing to assume the impact on the hazard index reduction of the fuel management initiatives and the dynamics of land use and land cover change. Another threat can arise from the trend that master plans are only revised in 10, 20 or more years.

In this way, it emerges the challenge to improve the calculation of fire hazard due to the constant search for inputs permanently updated and with greater accuracy, considering that integrating fire hazard into the constraint map of the municipal master plans could fail the risk reduction strategy due to the lack of recognition of its dynamic character.

Regarding the factors currently considered for the calculation of the hazard index, it is important to mention that extreme wildfires do not comply with them, given their intensity and degree of uncertainty (Tedim et al. 2018; 2020). As such, integrating risk reduction in spatial planning is paramount, but the strategy to be carried out must be dynamic and adaptive, without falling into the temptation of completely eliminating uncertainty and risk, which is impossible.

6. Conclusions

The integration of the fire hazard map in the constraints map of the Municipal Master Plans, proposed by the SGIFR, represents a challenge, considering the high inter-annual variability of fire hazard, the long-term definition of the municipal development model and the methodology (including the data accuracy) used to assess hazard. The procedure imposed by the current wildfire policy will create building permit constraints that can limit the development of rural areas and the growth of rural agglomeration. These restrictions could continue to favour the depopulation of the rural areas and the creation of more hazardous landscapes by abandonment.

The current existing static regulation system poses growing mismatches, economic, environmental, and social losses. The integration of spatial planning and wildfire risk reduction policies should more comprehensive. Multisector approaches able to mobilize synergies in an adaptive regulation system are paramount and, in this sense, the present paper identified the most pressing opportunities to improve the hazard map and spatial plans alignment.

7. Author Contributions

Conceptualization, F.T. and A.S.A.; methodology, F.T. and A.S.A.; formal analysis, F.T. and A.S.A.; investigation, F.T. and A.S.A.; resources, F.T. and A.S.A.; data curation, A.S.A., F.C., and D.P.; writing—original draft preparation, F.T., A.S.A. and J.A.; writing—review and editing, F.T. and A.S.A.; supervision, F.T; project coordination, F.T. All authors have read and agreed to the published version of the manuscript.

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9. Conflicts of Interest

The authors declare no conflict of interest.

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