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Policies towards the resilience of road-based transport networks to wildfire events. The Iberian case

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Wildfires are becoming more intense and frequent. This problem has tested the knowledge, response capacity, and resilience achieved by society throughout history, making it clear that they are insufficient to face this new wildfire regime. The effectiveness of the related policies mainly focused on fire suppression rather than prevention is increasingly insufficient and questionable. Consequently, there is a clear lack of tools to assess the impact of wildfire preventive actions. Therefore, it is imperative to review wildfire management practices, policies, and the tools used to support decision-making in this regard. This study performs an analysis of wildfire policies applied in the Iberian Peninsula case (Portugal and Spain), including cross-border policies and the role of road transport networks. A novel simplified methodology is included to evaluate different normal and extreme forest fire management policies in road transport infrastructures. The methodology includes different parameters related to wildfires, such as sources of exposure, identification of natural and artificial barriers, and traffic conditions that capture the economic characteristics of the studied area. The information provided by the tool is useful for strategic investment planning, resource prioritization, and evacuation time management. In addition, due to its simplicity of application, it is a useful tool for cross-border areas.

Keywords: Policies; resilience; road traffic networks; extreme wildfire events; Iberian case

1. Introduction

Road networks are one of the most critical infrastructures for regions' development, enabling the safe mobility of people and goods during the usual business. Under wildfire events, they are usually the main means of evacuation and

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provide accessibility for fire suppression. Once the wildfire is over, the first efforts usually focus on recovering the functionality of the road traffic networks to minimize the economic and social impact on the affected communities. Despite the important role of road networks, scientific literature dealing with road traffic networks and wildfires pays attention only to the evacuation role, disregarding the protection and recovery of the road networks. This aligns with the common approach of wildfire management policies that focuses on fire suppression rather than prevention and protection.

Recently, a new generation of extreme wildfire events (EWEs) characterized by erratic and difficult-to-predict behaviour and with the potential to rapidly spread, has challenged the existing wildfire management policies. Wildfire events such as the one in Pedrógão Grande in Portugal in June 2017, leaving 65 people dead and 153 injured and the fire in the Spanish region of Vall d'Ebo in August 2022 causing the displacement of thousands of people (AFP and Euronews, 2022), have shown the need to re-think these policies.

A few tools allow for determining the impact of different investments in prevention and protection with explicit consideration of their benefits for the safety and security of communities. In this line, it is necessary to study the road traffic networks under wildfire scenarios beyond just evacuation. To close this gap, Arango et al. (2023) propose a simplified GIS-based tool that allows ranking the different roads of a traffic network according to the priority of intervention to reduce their exposure level to wildfires along with the road's criticality.

In this paper, the Iberian Peninsula case is under study. Portugal and Spain have a long tradition of wildfires because of their geo-climatic conditions, such as drought, wind, high temperatures, and inadequate forest management policies. Approximately 6300 wildfires have been reported since 2008, causing the burning of 2.8 million hectares (EFFIS, 2022). Their national and transboundary policies and practices around prevention, protection, and suppression are discussed to provide a geo-political context. The consideration of road traffic networks in the policy and decision-making processes is also analyzed. The GIS-based fire analysis tool, GIS-FA, by Arango et al. (2023) is evaluated in its capacity to improve wildfire management in the case of the Pedrógão Grande wildfire. This is an interesting case because it shows the relevance of considering the road traffic networks more integratively (not only as an evacuation means) in wildfire management. The analysis of the tragic episode reveals that using the GIS-FA during the wildfire could have helped to save lives. Moreover, the tool could have been used in advance to identify the area's exposure and support adequate protection strategies, hence increasing the resilience of the road network and community to wildfires.

The rest of the document is organized as follows. Section 2 discusses the Iberian policies and practices related to wildfire management. Then, the GIS-FA is presented in Section 3. The case of the Pedrógão Grande wildfire is analyzed in Section 4 and conclusions are drawn in Section 5.

2. Iberian policies on wildfire management

In both Portugal and Spain, the wildfire policies present a similar framework. The fire mitigation strategy is based on national legislation that governs the forest area and its management. The forestry policy in Spain is based on Law 43/2003 (Ley de Montes), meanwhile, the Portuguese policy is based on Law 76/2017 (*Sistema de Defesa da Floresta Contra Incêndios*). At the same time, each of the regional Spanish communities, or District Centres in Portugal, has legislative autonomy to establish laws and guidelines for their territory (always complying with the guidelines set by the government). The Civil Protection agency of each country manages work groups, equipment, and other devices throughout the national territories and their districts to support prevention and suppression tasks. Moreover, the Civil Protection agency coordinates emergency responses and is responsible for approving the emergency plans of each regional community. This agency is also in charge of informing the managers of the road networks and traffic police when a wildfire can affect this infrastructure.

The Spanish forestry law establishes common guidelines on training in prevention and suppression. Related to fire prevention, the fragmentation of forest areas is a solution to regulate the exercise of all the activities that can increase fire risk. Another safety standard is to provide a minimum 15-meter-wide safety strip, free of waste, spontaneous scrub, and dry vegetation, for homes, buildings, and industrial installations in forest areas. Similarly, the ditches and easement areas of roads, highways, and railways that cross forest areas shall be kept clean for a minimum width of 2 meters. It is recommended that preventive work has to be carried out throughout the year. Related to wildfire suppression, firefighting services prioritize using public infrastructures such as roads, telephone lines, airports, reservoirs, seaports, and all those necessary to communicate and supply these services. The Spanish laws and recommendations are comprehensive guidelines. Coordination and firefighting mechanisms during suppression work quite well. However, because of the advance of large forest fires, the last tendency is demanding an increase in investment in forest fire prevention programs, that is, the promotion of long-term preventive actions. The target is to move from a management model mainly based on specific actions and maintenance of infrastructures such as tracks, firebreaks, or water points, to value extensive forestry and agricultural uses in rural areas to create an agroforestry territory resilient to forest fires (WWF, 2021).

In recent decades, Portugal has been the subject of several analyses by fire specialists. The recommendations have been relatively consistent, identifying four main areas in need of improvement: (1) the prevention of negligent human ignitions, (2) the creation of a structural fire defense system consisting of fuel management strips and the fuel load reduction in critical areas, (3) the improvement of firefighting capabilities through the implementation of perimeter control tactics and comprehensive fire management strategies, and (4) the restructuring of the firefighting organization. Based on the lessons learned from the 2017 and 2018 fires, the Portuguese National Forest Fire Defence Plan was modified. The new plan, developed by the Agency for Integrated Rural Fire Management (AGIF) and approved by the Portuguese Congress, contains a fuel management program from 2020 to 2030 to reduce exposure to wildfires. Unlike its predecessor (i.e., the plan that governed from 2006 to 2018) this one is based on two central axes: I) the management of rural fires; and II) the protection against rural fires. This is because the previous plan, although it encouraged prevention, its main focus was on suppression means. Prevention measures are also mainly fuel treatment mosaics or linear fuel-cutting networks designed with local stakeholders.

Natural hazards do not care about administrative borders, so it is frequent to find fires initiated in one country that cross the border and cause serious damage in a neighboring country. Especially in the border area between Portugal and Spain, which is one of the longest land borders in Europe with about 1200 km. Both countries have similar landscapes and orography, and most of the border territory is predominantly rural, especially in Portugal. Meanwhile, the urban network is poorly developed with small settlement concentrations. Thus, the collaboration of the two countries is essential for the defense of their communities against the increased risk of large forest fires.

Because of the similarities between the management of wildfire policies, the first steps to cross-border cooperation Portugal-Spain is not difficult. In fact, since 1980, there has been a technical cooperation and mutual assistance agreement between the Portuguese and Spanish firefighting and rescue services with an additional protocol on forest fires in border areas. It was formalized through the so-called Évora protocol, signed by the two countries on March 9th, 1992 (Interreg, 2021). It aims to allow rapid intervention and mutual assistance in the event of forest fires in Galicia (northern Spain) and northern Portugal, whenever the urgency of the situation requires. Within border areas, special attention will be given to fires that are less than 15 km from the border and whose propagation conditions (i.e., wind, relief, fuel patterns, etc.) suggest that there is a very high probability that the fire crosses the border in a short period.

Although collaboration between the entities of both countries has been a reality for decades, the intensity of joint action still needs to be strengthened, especially in terms of prevention and protection actions. As there is such a wide variety of entities and projects, more work must be done on integrating, coordinating, and sharing data and experiences to make the actions more effective.

Related to transport network management and wildfire management, the managers of infrastructures develop strategies and prevention works following national operational guidelines, in both countries. For example, they are responsible for cleaning a minimum width of up to 10 m along the roads and performing fuel management work on infrastructure. During the suppression works, together with the traffic police or national guard, they support evacuation and provide information on alternative routes in case of road closures. Also, they are essential in the post-event works, assessing infrastructure damage and managing the works to recover the damaged infrastructure. According to their competencies, security forces, the national direction of traffic, or meteorology national agencies are key organizations for the prevention, protection, and suppression of wildfires.

In summary, the existing policies rely on a well-functioning road infrastructure during wildfire events for enabling evacuation and suppression activities. However, neither country provides specific protection for road infrastructure beyond recommending the maintenance of clean road edges. The inability of the roads to support evacuation and suppression efforts can result in dramatic consequences, as shown by the case of the Pedrogão Grande wildfire discussed in Section 4. Protection measures either limiting the exposure level of road networks to wildfires or guaranteeing that the more exposed roads are not critical for the connectivity of the network would benefit wildfire management. The following section presents a methodology to support decision-making processes in this regard.

3. Methodology for assessing intervention priority levels.

Arango et al. (2023) propose the GIS-FA, a methodology that calculates the priority level for wildfire protection of a road network using two criteria. First, the exposure level to wildfires for the different roads of the network is given by the metric Fire Arrival Time (FIRAT). As a result, an exposure map is obtained of the average time for a random fire, either normal or EWE, to reach a given asset of the road network. The FIRAT calculation considers the Rate of Spread (ROS) associated with a burning source (or fire barrier) and a wildfire intensity, and the Equivalent Fire Distance, EFD. The EFD allows the aggregation of different sources and barriers around a road of the network. Seven wildfire categories are included in the analysis based on their corresponding ROS values, as summarized in Table 1. The second criterion relates to the consequences and is reflected by a criticality map of the road network. The criticality of a road within the traffic network is estimated by the increase in total travel time in the network caused by the disruption of the road, i.e., their closure. Whereas the first criterion introduces aspects related to the environmental conditions of the road, thus reflecting the impact of the economic, social, and political activities, the second considers the location of the road within the network, the configuration of the network, the traffic demand and the road's performance in terms of travel time. In this way, the social dimension of wildfires is considered. When combining exposure and criticality, a map is obtained in which the roads of the traffic network are ranked according to the priority for intervention in the context of fire management. For a more detailed description of the parameters, procedures, and results of the methodology, the reader is referred to Arango et al. (2023).

Table 1: Wildfire category according to Tedim et al. (2018)

	Normal Wildfires				Extreme Wildfires		
Wildfire category	1	2	3	4	5	6	7
ROS (m/min)	5 - 15	15 - 30	15 - 30	50 - 100	50 - 100	250 - 300	> 300

Its application is demonstrated using the traffic network in the Leiria region of Portugal, where the municipality of Pedrógão Grande is located. The network includes national, complementary, and secondary roads (Figure 1). The most important ones are N236, N236-1, and N2. Road IC8 corresponds to a complementary network that supports the national road network.

The exposure level of the road network expressed in terms of FIRAT (in minutes) for wildfire category 1, i.e., a normal fire, and for wildfire category 5, considered an EWE, are given in Figures 1a and 1b, respectively. Figure 2 shows the priority level for wildfire protection obtained when combining the exposure and criticality maps.

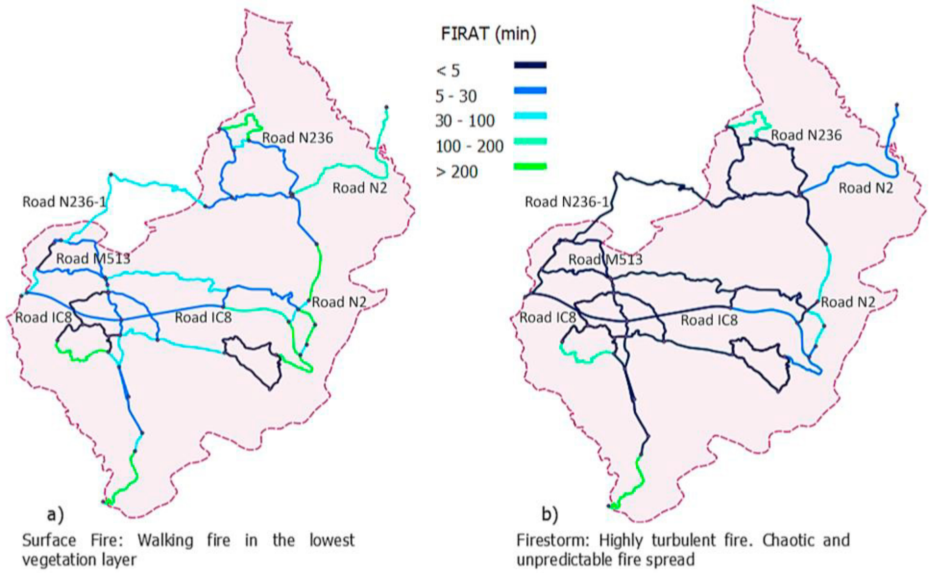

Figure 1: Exposure map is given by the FIRAT (min), Pedrógão Grande Road Network, Portugal. (a) Normal Fire, Category 1; (b) Extreme wildfire Category 5

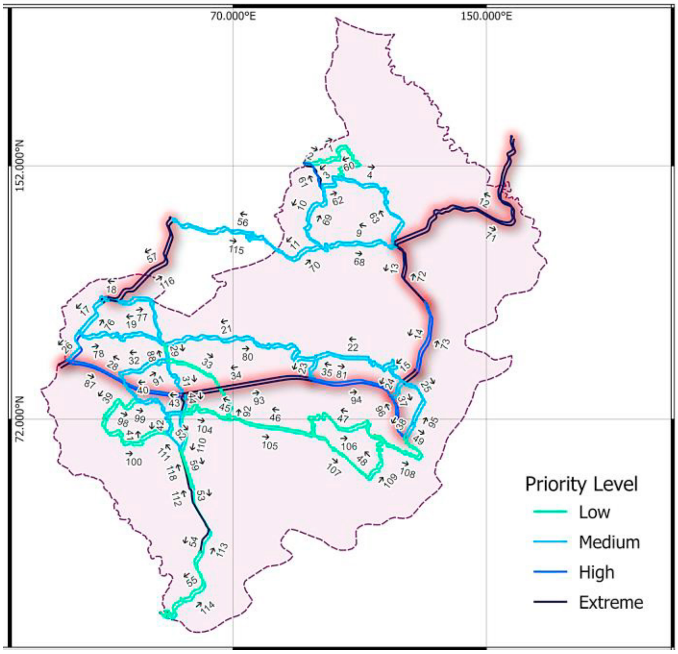

Figure 2: Priority level for wildfire protection, Pedrógão Grande Road Network, Portugal

4. The Portuguese case. Lessons learned.

The municipality of Pedrógão Grande, located in the district of Leiria, was severely devastated by a wildfire in 2017. The Pedrogão Grande wildfire is an example of an EWE showing how weather patterns have changed. The fire occurred in late Spring; a season not associated with this type of event as the weather conditions are less favourable for a fire. Therefore, the wildfire was not foreseen by any emergency service in Portugal or Europe. The event resulted in 65 fatalities, including a fireman (CTI, 2017), almost half of which occurred on a short stretch of about 300 m on the national N236-1 when the residents tried to escape in their cars. The value of the loss of goods and services amounted to more than 523 million euros.

In 2017, there existed legislatively regulated preparedness measures for the creation and application of municipal forest fire defense plans. These measures consisted of fuel management, mainly the implementation of strips or barriers (10 m on each side of the road network). However, in the case of Pedrógão-Grande, the municipal plan was not approved, therefore, despite the planning of the fuel management strips, they were not implemented.

There are three stages of wildfire evolution relevant to the discussion of this section. Stage I - the passage of the fire through the village of Escalos Fundeiros, one of the first points reached when the fire started. Stage II - the passage of the fire through Vila Facaia village and Stage III - the arrival of fire to the N231-6 road when the fire is estimated to become EWE. The fire reached each of the points in that order (i.e., first I, then II, then III). The technical data are considered according to the official reports delivered by the CTI (2017). All the points are located inside the study area, see Figure 3. The estimated propagation speed when the fire reached Escalos Fundeiros (Stage I) was 0.47 km/h (7.83 m/min) and at the time of the fire's passage through the locality of Vila Facaia (Stage II), the fire registered a maximum propagation speed of 5.3 km/h (88.33 m/min) in the SE-NW direction. The elapsed time for the fire to spread from Vila Facaia to Road N236-1 (Stage III) was 10 minutes. After the fire reached the road, the corresponding propagation speed became 15.2 km/h (253.33 m/min). The quick and unexpected change of the wildfire propagation rate from 5.3 km/h to 15.2 km/h surprised those on the roads, particularly those traveling on N236-1 in the direction of Figueró dos Vinhos - Castanheira de Pera.

4.1 Identification of exposure and priority levels in the Pedrógão-Grande case

The methodology presented in Section 3 is applied to the Pedrógão-Grande case. For analysis purposes, the critical road segment of N236-1 where the deaths occurred, is analyzed (see Figure 3). The equivalent fire distance, EFD, calculated for the road segment is 804 m. Note that EFD is a theoretical value estimated based on the surrounding conditions of the road. The EFD, when multiplied by the ROS of a wildfire, provides the time needed for that fire to reach the road. The speed of the fire observed at Stage II, just before reaching the critical road segment is 88.33 m/min. Accordingly, the theoretical time for the fire to reach the road is 9.10 min. On the other hand, this wildfire is categorized as a wildfire category 4 (see Table 1). The corresponding FIRAT for a wildfire of category 4 is between 8 and 16 mins. It was reported that the fire reached the road segment within 10 mins from Vila Facaia.

Also, as shown in Figure 2, the N236-1 road is assigned an extreme-to-high priority level mainly because of its high traffic intensity. The analyzed segment has a medium priority level because of the existence of a detour nearby through the roads IC8 and M513. However, as shown in Figure 3, the IC8 and M513 roads have a larger exposure level, making the detour potentially useless.

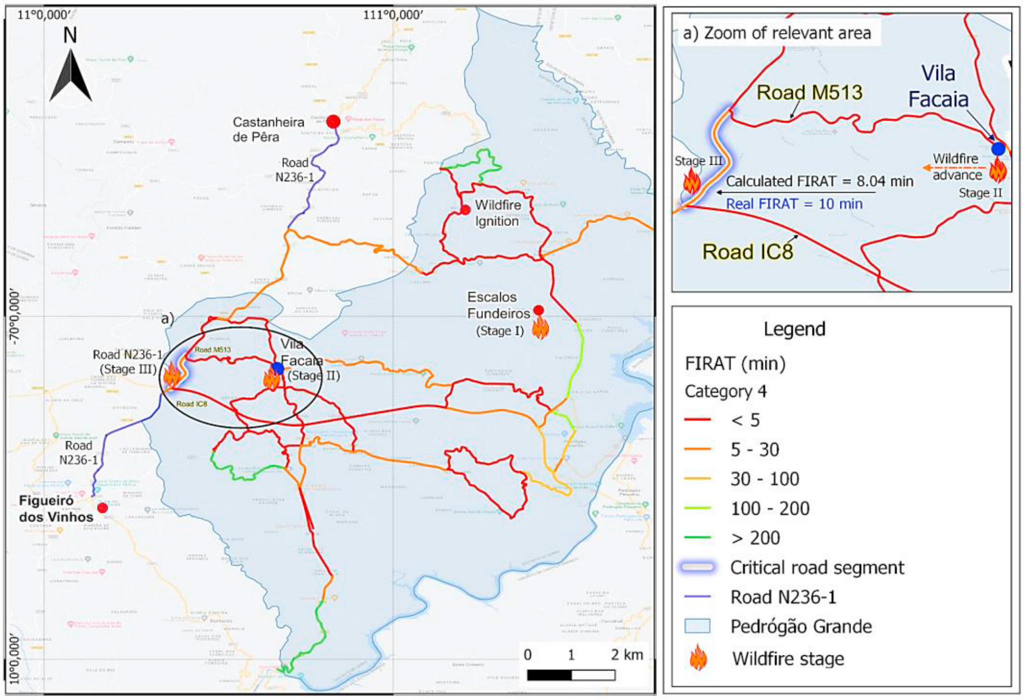

Figure 3: Representation of the wildfire event in Pedrógão Grande, overlapped on the exposure map given by the FIRAT for a wildfire category 4

4.2 Alternative outcomes of the event when using exposure and priority levels.

During the wildfire, traffic management was oriented toward evacuation. Road closures were applied gradually according to the wildfire advance. All the roads closed during the wildfire are shown in Figure 4, denoted by the crossed lines (i.e., +++). A few minutes before Stage II (Vila Facaia), the road IC8 was closed up to the intersection with N236-1; it was one of the last to be closed. However, due to communication problems, the N236-1 road was still in operation. The users were trapped in the middle of flames and smoke between the intersections with IC8 and M513 roads, better seen in Figure 3. This situation is captured by the exposure map (FIRAT) for fire category 4. Roads IC8 and M513, and the adjacent road segments of the N236-1 (northbound and southbound) are highly exposed to fires of this category, depicted in red, whereas the studied segment of N236-1 still had more time to be reached by fire, depicted in orange. That may be the reason the residents were trapped at that specific point. The availability of this tool could have added relevant information, resulting in better evacuation management.

In the early stages of the fire, efforts were concentrated on fire suppression and not on evacuation. When the possibility of evacuation of the affected localities was contemplated it was too late as the rapid development of the fire did not allow for anticipating the necessary actions to save the lives lost. None of the villages affected in the most critical period, i.e., those located east of N 236-1, were evacuated. Figure 4 shows how at that fire category (i.e., FIRAT map for category 4) any possibility of evacuation by road was almost impossible, as most roads were compromised.

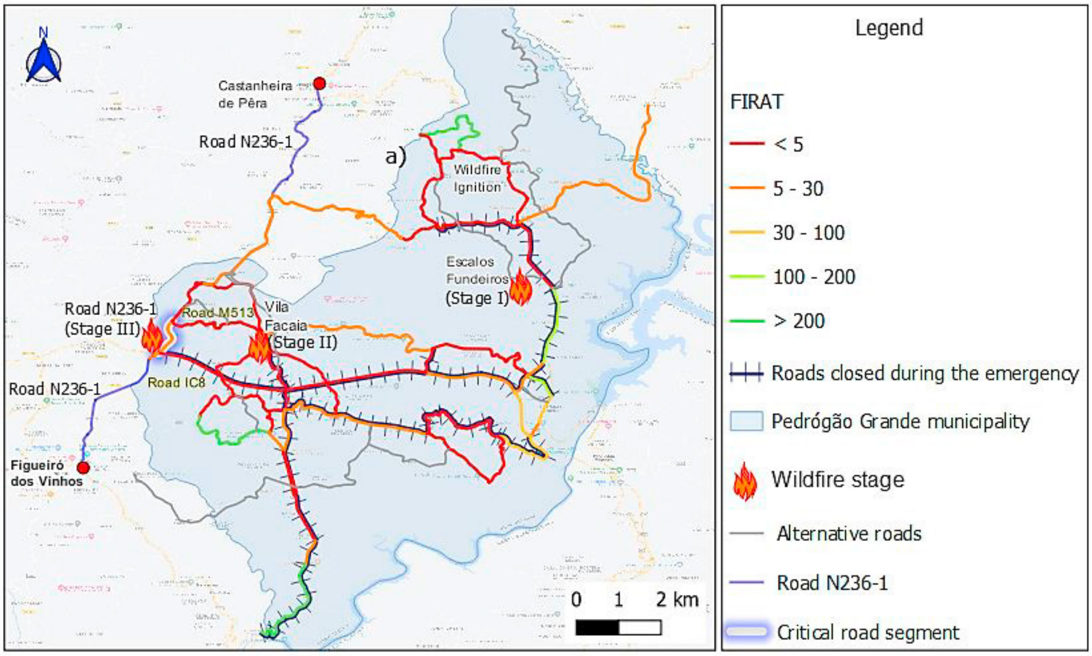

Figure 4: Traffic management for Pedrógão Grande Road Network. Actions taken overlapped on the exposure map (FIRAT) for wildfire category 4.

GIS-FA can serve as support to handle these types of emergencies. Using the FIRAT maps, the available time for evacuation can be estimated and actions can be taken on time. For instance, during Stage I, the propagation speed reached 0.47 km/h (7.83 m/min), a wildfire of category 1. The exposure map in Figure 1.a shows that the roads surrounding Escalos Fundeiros present a FIRAT between 5 and 30 min. This means that at this stage if the fire is not effectively suppressed between 5 and 30 min, these roads must be closed, because they can be reached by the fire in that time. If there are population centers nearby, the evacuation plan can be seriously compromised. Based on the precautionary principle, the analysis can also be done with higher fire intensities (i.e., categories 2 and 3).

4.3 Ability of GIS-FA to support policies.

The complexity level of decision-making in wildfire management has increased due to changes in the patterns and behaviour of the new fire regime (EWEs), the limited suppression capacity, and the limitations of resources. Probabilistic risk identification and scenario-planning models are the most widely used tools to support technical decision-making on wildfire management and future investments. However, these models, which are based on historical records and forecasts, are not able to predict EWEs. A good example of this is the Pedrógão Grande wildfire, whose fire behaviour was not predicted by any emergency service. The outlier behaviour cannot be successfully captured by probabilistic models. On the other hand, scenario-based models are useful to understand the system's behaviour under specific conditions determined by the analyst, excluding any other conditions. They are very useful to retrospectively analyzing the evolution of a given wildfire, however, their usefulness to address all the plausible scenarios associated with a future wildfire is arguable.

GIS-FA avoids the probabilities of fire occurrence and the associated uncertainty because it is based on the identification of the elements propagating or blocking wildfires around the roads, no matter where they originated. And still, it allows considering different fire intensities. It is neither data intensive nor computationally demanding; the data required mostly come from open sources. On the other hand, it includes different parameters related to the phenomenon, e.g., sources of exposure and natural and artificial barriers; assets and traffic conditions that capture the economic characteristics of the studied area. This allows evaluation of the impact of different measures or types of policies included in the management of infrastructures at the level of assets or systems and ecological or environmental management. Therefore, the information provided by GIS-FA is useful for strategic investment planning, resource prioritization, and evacuation time management.

When applied to the discussed case, decision-makers could have identified that the area had a very high exposure level to wildfires, with many of the roads with FIRAT below 30 mins even for a fire of category 1 (Figure 1a). That means that for a random wildfire event, they can have important connection issues if they are not able to suppress the fire within that time. Then, they could have made decisions in advance to improve the resilience of the area to wildfires. Figure 2 shows some roads associated with high priority for intervention. For instance, decreasing the exposure level of the northern branch of the N236-1 might have allowed the evacuation towards the north of the road. The impact of different strategies can be also evaluated through GIS-FA.

The proposed tool still has some limitations. For instance, it does not consider some factors affecting the spread of wildfires, such as geography and topography. Also, the analysis of several affected links at the same time is not included in the criticality calculation yet. This inconvenience was shown by reducing the criticality of the discussed road section due to the possibility of a detour, however, not considering that the detour was more exposed and potentially useless.

5. Conclusions

The emergence of the new wildfire regime marks the need to reconsider the knowledge, practices, and tools currently used. This applies equally to the fire-management approach, based mainly on the suppression and mitigation of impacts caused by fires. The wildfire of Pedrógão Grande has revealed some of the limitations of this management system, namely, the prioritization of suppression over adaptation, lack of understanding of the new wildfire problem, the organizational culture of the governmental system, and limitations of communication between institutions and communities. Therefore, tools aiming at improving these limitations should be the focus of the scientific community, especially those that allow quantifying the impact of different protection measures.

Within the patchwork of legislation across administrations and countries, there seems to be a blind spot regarding the relevance of adequate consideration of the resilience of road networks to wildfires. The road traffic networks should be designed and managed with consideration of their environment, so then, be prepared to respond as expected in the face of wildfire events and be able to recover from them, regardless of the intensity of the event.

GIS-FA can help in this process as demonstrated in this paper. The tool enables professionals and stakeholders to facilitate decision-making in the context of wildfire management. The analysis of the tragic episode that occurred in Pedrógão Grande reveals that using the GIS-FA during the wildfire could have helped to save lives. In addition, the ease of application of this method allows its use in cross-border cases and in other systems, e.g., power distribution systems.

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