Stakeholder Engagement Drivers: Insights from an Information System Innovation Project Supporting Wildfire Evacuation in Greece

Diogo Vallim
Copenhagen Business School
dv.msc@cbs.dk

Manolis Grillakis
Technical University of Crete
egrillakis@tuc.gr

Stylianos Manoudakis
Technical University of Crete
smanoudakis@tuc.gr

Amalia Giannakopoulou
Copenhagen Business School
agi.msc@cbs.dk

Anna Schmid
Copenhagen Business School
ajcs.msc@cbs.dk

Anastasia Phillis
Technical University of Crete
afili@tuc.gr

Apostolos Voulgarakis
Technical University of Crete
avoulgarakis@tuc.gr

George Arampatzis
Technical University of Crete
garampatzis@tuc.gr

Efthymios Altsitsiadis
Copenhagen Business School
ea.msc@cbs.dk

Isabel Fróes
Copenhagen Business School
ifr.msc@cbs.dk

ABSTRACT

The Samaria Gorge, a tourist destination in Crete, faces wildfire risk due to its dense forest, topography, number of visitors, and climate. As part of a H2020 project, the Gorge serves as a testing pilot for a new wildfire management platform that integrates technologies to improve fire detection, risk assessment, and resource allocation during a wildfire evacuation. A central component of the project is a multi-stakeholder network, which supports both governance and acceptance of solutions. To understand the drivers of network formation, we used a Social Network Analysis and Exponential Random Graphs Model approaches to identify the drivers of stakeholder collaboration. Our findings indicate that sectoral and wildfire management focus phase are factors driving connections, while the working in intersecting jurisdictions is not. The results highlight the challenges of multi-stakeholder collaboration, suggesting that policy frameworks and information systems need to develop specific mechanisms to encourage stakeholders to bridge collaborative gaps.

Keywords

Social Network Analysis, Exponential Random Graphs Model, Wildfire evacuation, Samaria Gorge.

INTRODUCTION

The Samaria Gorge is located in the southwest of the prefecture of Crete, the largest island of Greece. The Gorge, along with a wider region surrounding it, has been designated as a National Park and is part of the NATURA 2000 protected areas. It is a popular tourist landmark, attracting a significant number of visitors, ranging from 800 to 2,000 per day during the summer season. There are two natural entrances to the Gorge. The first is located at the

Omalos Plateau at Xyloskalo, which is at an elevation of 1,227 meters. The second entrance, situated at the lower end of the Gorge in the village of Agia Roumeli, is approximately 13 kilometers from Xyloskalo along the path, by the coast. The park is considered a high-risk area for wildfires. Evacuation during an emergency can be challenging due to the difficulty of detecting fires with conventional methods, the large number of visitors in summer, and the region's typical fire-prone conditions. The presence of flammable forest species, primarily pine and cypress, further increases the risk.

In this context, a group of actors, led by a local university in Crete, collaborated to develop a platform aimed at mitigating wildfire-related risks. Funded through the Horizon 2020 program, the platform sought to transform wildfire management by creating a unified technological ecosystem that integrates real-time sensing systems and incident management tools. The ultimate goal of the platform in Crete was to support evacuation planning and resource allocation in the challenging terrain of the Samaria Gorge Park.

The development and testing of the platform took place between 2022 and 2024. A key aspect of the implementation process was identifying and engaging a stakeholder network to support the project through two mutually reinforcing strategies. On one hand, the stakeholder network facilitated the testing of technologies and fostered social acceptance of the platforms' innovations. On the other, it served as a hands-on forum for discussion about wildfire risk, allowing different actors to debate solutions to promote effective governance in the project's implementation area. This collaborative effort provided feedback on the continuous improvements in the platform.

The stakeholder network included 38 entities, ranging from key organizations such as the Park Management Agency and the regional Directorate of Forests which oversaw the park, to local businesses that depend on park visitors, first responders, and local municipalities. Technology provider partners also played a role in supporting the project's development and deployment.

In addition to the project's governance objectives, the Chania wildfire management stakeholder network also served as a setting for empirical research. During the project's implementation in 2023 and 2024, two universities collaborated to develop a stakeholder analysis process. Following the method proposed by Reed et al. (2009), the analysis began with stakeholder identification, proceeded to mapping relationships using Social Network Analysis (SNA), and concluded with studies on the factors driving collaboration through Exponential Random Graph Models (ERGM). The analysis builds upon existing analysis of wildfire management networks (Fischer & Jasny, 2017; Hamilton et al., 2019) and innovates by applying network mapping methods to the implementation of an information system. Ultimately, the analysis supported implementation by identifying key information brokers and local information flows.

Preliminary results, presented in this working paper, suggest that sectoral and wildfire management focus phase homophily drives collaboration, whereas working in intersecting jurisdictions does not. These findings contribute to the literature on information systems and network governance for natural resource management, and underscore the challenges of promoting stakeholder collaboration as a wildfire risk management strategy. Additionally, they indicate that policy frameworks prescribing collaboration (UN, 2015; AGIF, 2023) and information systems addressing these complex challenges must develop targeted mechanisms to encourage stakeholders to bridge existing collaboration gaps.

STAKEHOLDER NETWORKS IN WILDFIRE MANAGEMENT

Stakeholder engagement has emerged as a central theme in wildfire management literature. To provide context for our analysis, this section examines the concept of stakeholders, the relevance of stakeholder engagement, and the strategies for conducting stakeholder analysis in the wildfire governance literature.

In this work, stakeholders are defined according to Reed et al. (2009), i.e. according to the understanding that "whoever owns a problem should be a co-owner of the process to solve it" (p.1934). This conceptualization is similar to Champ et al. (2012) who define stakeholders as "a collection of people sharing a common interest, activity, culture, or relationship to the outcome of an environmental-management decision" (p. 582). In the context of wildfire management this conceptualization encompasses: (1) Organizations of wildfire management and emergency response, such as fire brigades, civil defense and emergency rescue organizations; (2) Public and private organizations which need to be involved in wildfire risk management, such as service providers, tour guide associations, hotels, and wildland management services; and (3) residents, property owners and forest owners whose activities affect wildfire risk management or are subjected to wildfire risk.

This approach is consistent with recent academic research that highlights the importance of involving local communities in planning for increasingly complex wildfire crises (Lecina-Diaz et al., 2023) and framing wildfire management as a collective action challenge that depends on effective stakeholder coordination (Charnley et al., 2020; Juhola et al., 2024). It is also consistent with recent policy frameworks that recognize stakeholder engagement and the collaboration between responders and residents as a cornerstone of risk management and disaster response (AGIF, 2023; Casartelli and Mysiak, 2023, UN 2015). Such processes facilitate knowledge exchange and enable the co-creation of innovative strategies for environmental management (Sitas et al., 2016). Engaging stakeholders in collaborative efforts of risk management, evacuation and response planning involves navigating complex environments shaped by differing value systems, social conventions, and mental models. However, adopting such perspectives introduces further complexities, particularly in managing diverse relationships and reconciling varying stakeholder perceptions and responsibilities of wildfire risks.

One specific enduring challenge in wildfire management lies in addressing what scholars describe as the "wildfire paradox." Fire suppression strategies, including public awareness campaigns to prevent wildfires, have unintentionally increased risks by reducing the number of accidentally ignited fires, thereby allowing larger quantities of fuel to accumulate (Calkin et al., 2015) and thus increasing the risk of large wildfires. In the face of climate change, researchers and policymakers in wildfire-prone regions argue for "a new relationship with fire" (Thompson et al., 2018, p. 382). This shift entails recognizing wildfires as a social-ecological phenomenon (Steelman, 2016; Russo et al., 2024) and disasters as a multi-actor network phenomenon (Steelman et al., 2021).

Regarding the relevance of stakeholder analysis, academic research across various disciplines, including environmental management (Sitas et al., 2016), disaster management (Nowell et al., 2018), and governance (Kelly et al., 2019; Kirschner et al., 2023), has examined stakeholder networks to explore how network configurations influence governance systems' capacity to address wildfire-related challenges. For over fifteen years, this body of work has expanded by integrating insights from diverse governance frameworks, such as adaptive governance, collaborative governance, polycentric governance, intercultural governance, indigenous governance, and bottom-linked governance.

A central contribution to this field was made by Fischer and Jasny (2017), who were the first to apply a network governance approach specifically to wildfire-related issues. Their study analyzed the structure of a network of organizations, offering foundational insights into how network configurations impact governance outcomes. Bodin and Nohrstedt (2016) advanced understanding in this area, emphasizing the need to facilitate a more detailed and theory-driven approach on the mechanisms influencing the structure, nature, and effectiveness of collaborative networks.

Reed et al. (2009) highlight the utility of social network analysis (SNA) in providing insights into stakeholder networks. Specifically, SNA helps to "gain insight into the boundary of the stakeholder network; the structure of the network; identifies influential stakeholders and peripheral stakeholders" (p. 1937). The approach dialogues with the reference set by Wasserman and Faust (1994) and Carrington et al. (2005) which emphasize the value of networks as the central units of analysis, arguing that the relationships between stakeholders take precedence, while stakeholder attributes emerge from the relational processes in which they are embedded.

Despite the growing focus on these dynamics, Kirschner et al. (2023) highlighted significant challenges, including imprecise definitions and the absence of a consistent approach to studying wildfire governance. To address these gaps, the authors proposed a four-part analytic framework encompassing participation, collaboration and co-production, path-dependencies and place-based dynamics, and adaptation and anticipation.

Scholars studying the complexity of governance networks increasingly apply SNA to understand and quantify stakeholder interconnections (Calliari et al., 2019; Ceddia et al., 2017; Kapucu, 2014). SNA, described as "the quantitative method for mapping and analyzing patterns of social connections between individuals and organizations" (Scott, 2015, p. 449). An additional contribution is made by d Es'haghi and Karamidehkordi (2023), who combine SNA with interview data to evaluate a network's capacity to adapt to environmental change.

Finally, the integration of SNA with group statistical methods for stakeholder analysis is well-established in environmental studies. Our analysis builds on previous research, such as Lecina-Diaz et al. (2023), who examined stakeholder perceptions of wildfire-landscape interactions in abandoned rural areas of southern Europe, and Hauck et al. (2016), who explored information flows and social pressure in biodiversity governance. Additionally, we reference the work of Londres et al. (2023) on local initiatives' pathways to social-ecological outcomes.

METHODOLOGY AND CASE STUDY

The project stakeholder network was structured around the pilot activities and risk management issues of the Samaria Gorge Park. Since the park is located in the Chania region, in western Crete, Greece, several stakeholders acting at regional and national level were also mapped, creating what consists of a regional network. The network is composed of 38 stakeholders and 139 connections (see **Supplementary Material Table 1**).

The analysis consisted of a 4-step approach, starting with the identification of stakeholders and ending with the analysis of the factors that contribute to the establishment of connection through statistical analysis.

The first step identified the stakeholders participating in the Crete pilot network. The pilot leaders invited an initial group of stakeholders to workshops—based on their relevance to the pilot's focus area—to analyze their local wildfire management context, and to identify the challenges, needs, and potential contribution of the project. The group compiled a list of stakeholders for the pilot's context through an iterative and collaborative process. The identification process was unbounded, where stakeholders were not limited to those formally engaged with the pilot and were encouraged to take a holistic perspective of wildfire management challenges.

This initial step also included a categorization according to the jurisdictional reach. The stakeholders were separated into three groups, based on how wide their jurisdiction of operation is. The three levels of jurisdiction chosen are (a) Local, meaning that they influence or are interested only in the Samaria Gorge region (see **Figure 1**), (b) Regional, meaning that the area of their jurisdiction is wider than the Samaria Gorge, but bound to the Prefecture of Chania. Finally, the wider area of influence was (c) National, referring to stakeholders whose area of influence is larger than the Prefecture of Chania, Greece-wide, or international. While the network involves stakeholders that have a role in the prevention and preparedness, and the detection and response, phases of a wildfire, special attention was put on engaging stakeholders that play key roles in the case of an evacuation of Gorge visitors in the case of a wildfire, e.g. first aid responders.

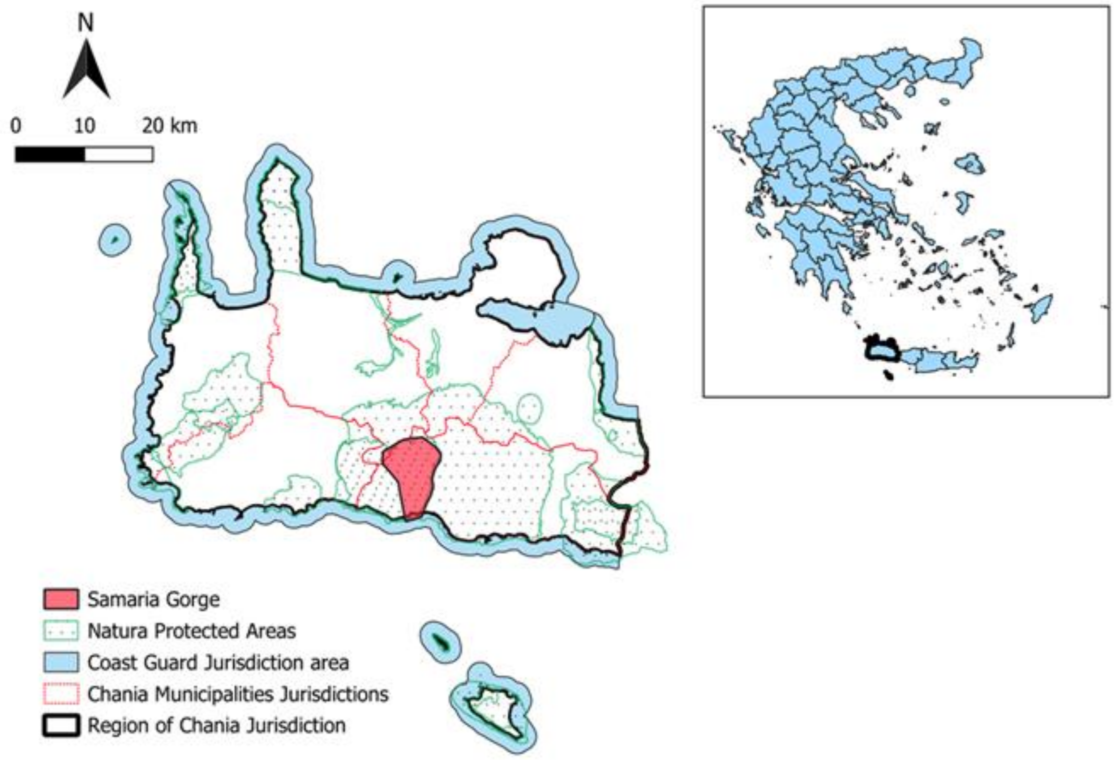

Figure 1. Chania Region and Samaria Gorge. In the upper-right panel, the location of the Chania region in Greece is shown.

The second step, stakeholder categorization, identified the sector, level, and phase of the organizations involved in wildfire management in Chania region. Categorization occurred directly after the initial workshops through a top-down approach in which the research team collaborated with the pilot leader to situate the stakeholders within three top-level categories and twelve sub-categories. In cases where stakeholders worked across multiple phases of wildfire management they were categorized based on their primary focus:

- Sector (government / civil society / private company): categorization based on the governance mode and strategic objectives of each stakeholder (AGIF, 2023).
- Level (local / regional / national / international): categorization based on the main level of operation for the stakeholder (Casartelli and Mysiak, 2023).
- Phase (review / prevention / preparedness / response / recovery): categorization of phases based on Moore's (2019) framework of wildfire management phases. Review refers to research of the fire issue and identification of options for positive change; Prevention focuses on preventing fires or minimizing their impact; Readiness refers to the preparation to fight fires; Response refers to the actions to manage unwanted damaging fires; Recovery focuses on repairing infrastructure and restoration of fire-damaged landscapes.

The stakeholder categorization was complemented by jurisdiction mapping. This mapping process identified the operational jurisdiction of each stakeholder in the Chania region. Stakeholders without a native connection to the region (such as technology providers) were attributed to the specific pilot testing location, the Samaria Gorge National Park.

The third step in the study consisted of a formal SNA (Social Network Analysis) mapping of the relationship between stakeholders. Data collection combined a survey and a workshop. The survey aimed to identify active stakeholders in the region by asking the participants what other stakeholders they connected with in their wildfire management functions. A connection was defined as a two-way interaction between autonomous actors who collaborate in the performance of their functions. Answers were weighted as 1 for regular connections and 2 for very important connections based on the ratings given by each individual respondent. Researchers turned this data into a preliminary social network graph which was then presented and discussed at a workshop in Chania on 24th of October 2023. The results of the SNA mapping provided the network map and the descriptive statistics on the Chania region wildfire management network (**Figure 2**).

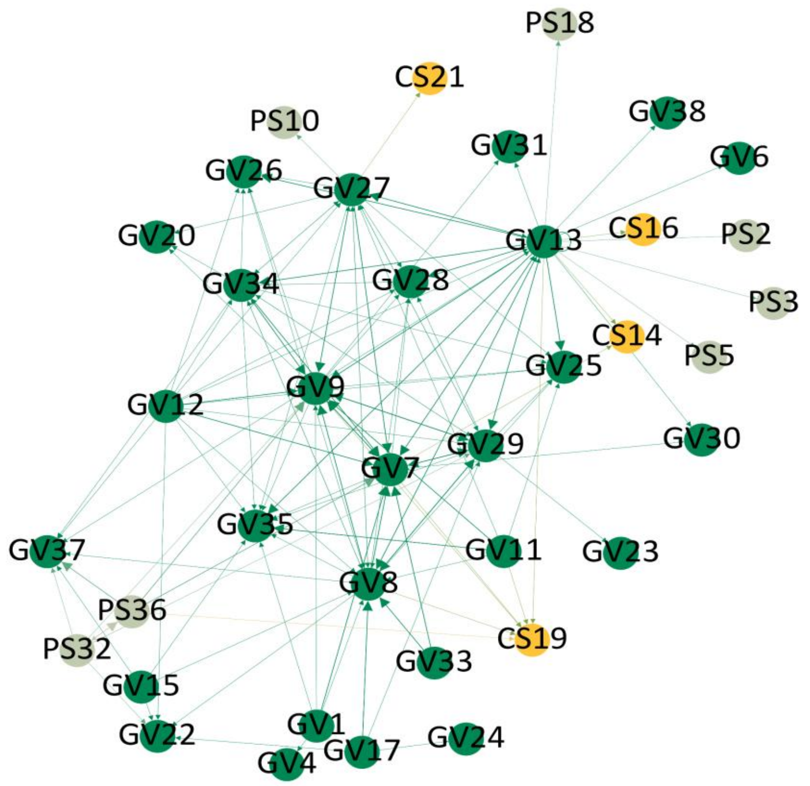

Figure 2. Chania Wildfire management network. Light green indicates private company stakeholders, dark green indicates government stakeholders and yellow indicates civil society stakeholders.

The fourth and final step of our analysis involved statistical modeling to identify factors contributing to stakeholder interactions in the Chania region. Following methodological approaches established by Fischer and Jasny (2017) and Hamilton et al. (2019), we employed an exponential random graph model (ERGM).

ERGM approaches evaluate the probability of connections between stakeholders in a network based on individual-level attributes (such as the categories identified in the second step of our analysis) and dyadic attributes (e.g., whether actors work in the same jurisdiction or any other edge attribute). The model assesses the likelihood of network connections by examining how specific characteristics influence relationships beyond random allocation.

The ERGM results quantify the extent to which an attribute is represented in the observed network relative to a random distribution of connections. Similar to logistic regression, ERGM coefficients estimate the likelihood of a tie between actors. Specifically, an ERGM coefficient represents the change in the log-odds of a connection occurring based on network characteristics. Central to our analysis is the investigation of homophily defined as the socio-psychological tendency of people to associate with those who share their beliefs, values, social strata, or physical locations (McPherson et al., 2001).

Our analysis focused on two primary dimensions:

- Category homophily: Examining the effect of shared characteristics among individual stakeholders (sectors, operational levels, and management phases).
- Dyadic attributes: Analyzing the impact of connection weights and shared jurisdictions.

Consistent with established social network analysis (SNA) practices, we interpreted connections between actors as indicators of collaborative dynamics, information sharing, and expertise exchange.

RESULTS

Stakeholder categorization and jurisdictional mapping (step 2) and SNA (step 3) resulted in the initial profiling, characterizing the Chania region pilot network in terms of number of stakeholders diversity of sectors, levels, and phases of operation (Table 1), and connections, average degree, network diameter, average path length, and density(Table 2) . The approach is similar to other cross pilot analyses conducted by Vallim et al. (2024) but presents more in-depth information on the Chania region Wildfire Management network, allowing the identification of the jurisdictional intersection.

The stakeholder network analysis provided a comprehensive overview of the wildfire management landscape in the Chania region. The stakeholder network comprised 38 unique stakeholders connected through 139 distinct dyadic relationships. The stakeholders were distributed across three sectors: Government (n=27) predominated in the network, representing approximately 71% of participants. Private companies (n=7, 18%) and civil society organizations (n=4, 10%) formed the remaining sector representation. Stakeholders spanned four operational levels. The national level was most prominent (n=17, 45%), followed by local-level actors (n=14, 37%). International stakeholders (n=5, 13%) and regional-level participants (n=2, 5%) completed the network.

Attribute		Value
N Stakeholders		38
N Connections		139
Sector	Government	27
	Civil Society	4
	Private company	7
Level	Local	14
	Regional	2
	National	17
	International	5
Phase	Review	10
	Prevention	11
	Preparedness	4
	Response	12
	Recovery	0

Table 1. Chania Wildfire Management Network Descriptive Analysis

The network's involvement across wildfire management phases was concentrated in three phases. Response phase stakeholders were most numerous (n=12), closely followed by prevention (n=11) and review (n=10) phases. Preparedness phase stakeholders were less represented (n=4). No stakeholders were exclusively focused on the recovery phase. The SNA results revealed the structural properties of the Chania wildfire management network. The average weighted in-degree of 4.63 suggests that stakeholders, on average, receive about 4-5 significant connections within the network (**Table 2**). The clustering coefficient of 0.35 indicates a moderate tendency for network closure. This implies that about 35% of potential triangular closed relationships are realized. Such a coefficient suggests that while the network has some clustered groups, it is not entirely tightly knit. The network density of 0.09 reveals a low-density network structure, indicating that only 9% of possible connections between stakeholders are actually present. The average path length of 1.87 suggests that information or resources can potentially flow quite efficiently through a relatively compact and accessible network structure. The Chania network stakeholders are, on average, less than two steps away from each other.

Attribute	Result
Average Weighted in Degree	4.63
Clustering Coefficient	0.35
Density	0.09
Average Path length	1.87

Table 2. Chania Region Wildfire Management Network Attributes

Finally, the results of the ERGM analysis reveal the relevance of the categorical variables (Sector, Level and Phase) to the formation of collaborative interactions. A significant finding is the strong tendency for network connections to form within similar sectors, as indicated by the highly significant sector homophily coefficient of 1.447 ($p< 0.001$) (**Table 3**). The significant coefficient suggests that stakeholders in the wildfire management network strongly prefer to connect with colleagues from their own sector, demonstrating a tendency of institutional clustering. Stakeholders in the government sector tend to establish connections with other stakeholders in the government. Similar patterns are observed in civil society and in private companies.

The jurisdictional level of operation also plays a significant role in network formation, with a coefficient of 0.586 ($p< 0.01$) (**Table 3**). The significance of the coefficient indicates that actors are more likely to form connections with others at the same jurisdictional level, though this effect is less pronounced than sector-based clustering. In contrast, the organizational phase appears to have no statistically significant influence on network connections.

The jurisdictional intersection and relevance of connections show no significant impact on network structure. This suggests that other factors beyond these dyadic attributes drive network formation in the Chania wildfire management context. The model's goodness of fit metrics, including a reduction in deviance from 1949.1 to 678.4, indicate a reasonably good fit, with lower AIC and BIC values also suggesting an effective representation of the network's underlying connectivity patterns.

Variable	Estimate
Edges	-23.85 (695.90)
Weighted Edges	20.00 (695.90)
Sector	1.45 (0.26)***
Level	0.59 (0.21)**
Phase	0.21 (0.23)
Jurisdiction	0.06 (0.30)

(Standard errors in parentheses)
$p \leq 0.05$(*), $p \leq 0.01$ (**), and $p \leq 0.001$ (***)

Table 3. Results of the ERGM of the likelihood of a stakeholder connecting with another stakeholder.

DISCUSSION

The quality of networks is determined not only by the total number of participating actors, but also by their density. Network density is measured by comparing the actual number of connections established to the total potential connections possible. Higher density is associated with several beneficial network attributes, including enhanced adaptability, faster response times, and reduced risk (Bodin and Crona, 2009; Calliari et al., 2019). To achieve these desired outcomes, the key strategy is to foster more connections between network actors.

Academic literature on wildfire management has extensively studied network connections and the factors driving actor collaboration. Homophily has been identified as a key factor in establishing connections and building network density. In network studies, homophily is observed when actors sharing specific attributes interact more frequently than would be expected by random chance (Jasny and Lubell, 2015). In the wildfire management networks homophily was seen to drive connections in the case of similar management goals, aligned geographic emphases, and attitudes (Fischer and Jasny, 2017), risk interdependency (Hamilton, Fischer and Ager, 2019) and being targeted educational campaigns (Charnley, Kelly and Fischer, 2020).

In line with these recent studies, the results of our analysis in the Chania region make two contributions to the understanding of the drivers of connections in wildfire management networks. First, we provide evidence that sector and focus phase sharing are factors that lead to increased probability of connections in wildfire management networks. The findings, which at first seem to confirm previous studies about the importance of homophily as a driver of collaboration (McPherson et al., 2001, Khanam et al., 2023) , also indicate an important aspect for the most recent policy recommendations regarding wildfire management. Policy frameworks recommending that wildfire management stakeholders collaborate across sectors (UN,2015; AGIF, 2023) - such as fire brigades and residents - or across phases - such as prevention, response and restoration - the homophily challenges posed by these two attributes.

Actors in one particular sector, i.e. government, will have a greater tendency to collaborate with actors in government, with the same dynamics applying to private companies and civil society organizations. A similar challenge is posed to actors focusing on the same wildfire management phase. Again, a stakeholder focusing on a particular phase, i.e. prevention, will be driven to collaborate with other organizations working on prevention. The evidence of sectoral and focus phase homophily indicates a potential challenge in bridging these categories and should be accounted for in policies aiming to promote integration.

The second aspect to be highlighted is the non-significance of the shared jurisdiction in driving collaboration. Here is an important caveat. The methodology used to identify jurisdiction intersections implied that two actors would be considered as intersecting not only in cases where their jurisdictions were the same, but also when they intersected at any point, or if they were nested into each other. According to this approach, our preliminary results indicate that sharing any area of your jurisdiction is not a precondition for actors to collaborate, including cases where local actor jurisdictions are nested into regional level ones, as in the case of local and regional governments.

The finding has important implications in regard to wildfire management recommendations for actors to collaborate. Our results demonstrate that sharing similar jurisdictions is not, per se, a factor leading actors to collaborate. Considering the results on homophily and the extant literature on the topic, one can say that sharing the same area of operation will not drive collaboration in the absence of other drivers, such as the sharing of categories, focus phase, or risk interdependency.

CONCLUSION

For information systems to effectively contribute to crisis response and management, they must be based on, and support, collaboration between actors operating emergency response and risk management systems and stakeholders and residents affected by their performance. In such a context it is crucial for system designers and operators to understand how stakeholder networks across responders and residents form and what drives collaboration in wildfire-prone areas.

We explored the attributes of a stakeholder network within an H2020 project that developed a unified technological ecosystem in western Crete, Greece. This system integrates advanced fire detection, risk assessment, and decision-support systems to improve evacuation procedures in a national park in the Chania region. Through this analysis, we identified factors that influence the establishment of connections between stakeholders and consequently, network density.

These findings have important implications for both theory and practice in wildfire management. From a theoretical perspective, we expand homophily analysis by identifying new categories of connection drivers in networks. Specifically, we show that shared sectors (i.e. government, civil society, etc.) and operational phases (prevention, response, restoration) are important factors in establishing network connections, while the intersection of jurisdictions is not.

From a practical standpoint, our findings highlight the challenges of promoting collaboration and building networks in wildfire management. Notably, we demonstrate that operating in jurisdictions that intersect does not drive collaboration. The results of our analysis suggest that wildfire management frameworks and their associated information systems need to develop specific mechanisms and incentives to encourage stakeholders to bridge these collaborative gaps across their different categorical profiles.

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SUPPLEMENTARY MATERIAL

Network	Phase	Jurisdiction	Network	Phase	Jurisdiction
HGV1	Response	N	HGV20	Response	N
HPS2	Readiness	L	HCS21	Response	N
HPS3	Readiness	L	HGV22	Review	N
HGV4	Response	N	HGV23	Readiness	N
HPS5	Review	L	HGV24	Response	R
HGV6	Review	L	HGV25	Response	R
HGV7	Response	N	HGV26	Response	R
HGV8	Prevention	N	HGV27	Response	R
HGV9	Response	N	HGV28	Response	R
HPS10	Readiness	N	HGV29	Prevention	R
HGV11	Prevention	N	HGV30	Review	L
HGV12	Prevention	N	HGV31	Review	L
HGV13	Response	N	HPS32	Prevention	L
HCS14	Review	L	HGV33	Prevention	N
HGV15	Prevention	N	HGV34	Prevention	R
HCS16	Review	L	HGV35	Readiness	N
HGV17	Prevention	L	HPS36	Prevention	L
HPS18	Review	L	HGV37	Review	N
HCS19	Prevention	N	HGV38	Review	L

Network member codes for sector: GV denotes Government, PS Private Sector Companies and CS Civil Society
For Jurisdiction: L denotes Local, R denotes regional, and N denotes national.
Focus phase of operation follows Moore (2019): (1) Review, (2) Prevention, (3) Readiness, (4) Response, and (5) Recovey

Annex Table 1. Chania network stakeholder profiles.