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"It takes two to tango": a qualitative study of cross-sectoral collaboration at the community-wildfire-energy interface in Alaska

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Abstract

The increasing frequency of wildfire-related power outages and energy infrastructure-related wildfires requires cross-sector collaboration. We aimed to characterize the roles and responsibilities, decision-making processes, and informational needs and sharing practices among cross-sector organizations, including how these differ between single-hazard and interacting hazard contexts and how social vulnerability is incorporated into operational decision-making. Semi-structured interviews were conducted with 23 practitioners from electric utilities, fire and emergency management, infrastructure and transportation, and public health and health care organizations serving Alaska communities, at local, regional and statewide levels. Transcribed interviews were analyzed using inductive and deductive content and thematic analysis informed by systems thinking and complexity theory. Discussion centered on communication/coordination during response to wildfire or power outages as distinct hazards, with attention to their interactions primarily among sectors with direct operational experience. Three inter-related themes were identified: (1) hazard familiarity, sectoral roles and the limited integration of social vulnerability, (2) cross-sector interdependence in power outage and wildfire management, and (3) relational and structural conditions shaping coordination and collaboration. Despite growing interdependence among organizations, this did not consistently translate into cross-sector collaboration during planning and preparedness stages. New and compounding hazards may require new forms of collaboration among less familiar organizations and alignment around shared goals to safeguard public health. These findings highlight the need to move beyond reactive coordination during response toward more proactive collaboration in mitigation, prevention, and preparedness. Strengthening cross-sector engagement will require improved understanding of interdependence and the development of formal and informal relationships and is needed for achieving equitable energy resilience, particularly for socially vulnerable households.

1. Introduction

Continued burning of fossil fuels and deforestation are raising global temperatures, which are projected to reach at least 1.5 degrees of warming by 2050, increasing the likelihood of compounding heat and drought that contribute to extreme wildfire conditions [1, 2]. As fire weather intensifies, interactions between wildfires and power systems have become increasingly significant. Powerlines have been implicated in some of the most destructive wildfires, contributing to increased liability risk for electric utilities (EUs) [3–5]. Furthermore, wildfires can damage electrical infrastructure, increasing the cost of electricity and causing prolonged power outages (POs) for customers [3, 5]. In response, EUs have implemented measures such as proactive de-energizations (also known as Public Safety Power Shutoffs [PSPS]) and operational adjustments to reduce ignition risks; however, such actions can result in longer and/or more frequent POs [3, 5, 6]. Additionally, during wildfire response, EUs may need to emergently de-energize powerlines for operational safety. Together, these disruptions create complex hazard scenarios that pose risks to public health and safety through cascading impacts on critical services (e.g. communication, emergency response, healthcare infrastructure, water systems); essential needs (e.g. food refrigeration, electricity-dependent medical equipment, assistive technology); and indoor environmental conditions (e.g. air quality, temperature regulation) [7–9], with disproportionate burdens on low-income and disadvantaged communities [6, 10].

Because of arctic amplification, the high northern latitude regions are warming close to four times as fast as the global average [11]. Alaska is warming 2.6 times faster than the contiguous U.S [12]. Approximately 60%–70% of Alaska's land area is covered with boreal forests—an ecosystem that is adapted to cold winters and dry summers—much of which is dominated by black spruce (*Picea mariana*), a highly flammable, fire-adapted conifer [12, 13]. More frequent extreme temperatures, earlier snowmelt, drought, permafrost thaw, invasive insects and pathogens, and high summer lightning activity have contributed to more destructive wildfires in recent years [12–17]. The complexity of mitigating wildfire risk in fire-adapted ecosystems has been recognized since the early 21st century [18], as communities in these systems coexist with and continue to adapt to wildfires [19]. A primary risk-reduction strategy is fuel management, including thinning, shearblading, prescribed burning, and the construction of fuel breaks [20–22].

Wildfire poses a unique threat to EUs in Alaska because they serve residents through small systems that have little to no redundancy, nor ability to import power from others [23]. More than 60 000 people live off the road system in over 200 remote Alaskan villages served by mostly diesel microgrids, which are self-contained and lack the ability to import power if something goes wrong [23–25]. The most extensive regional power system is the Railbelt electric grid, a single 500-mile system from Delta Junction through Fairbanks and Anchorage to the Kenai Peninsula that provides electricity to four cooperative EUs serving three quarters of Alaskans (figure 1) [23, 25], most of whom are located in the wildland urban interface [23, 25, 26]. The Railbelt electric grid has minimal alternate routes and is completely isolated [23, 25], effectively functioning as a large microgrid.

The vulnerability of Alaska's electric grid to wildfire was made apparent when the Swan Lake Fire was ignited by lightning and burned nearly 15 miles of a transmission line from the state's largest hydroelectric plant to the Railbelt in 2019 [27, 28]. It took four months to repair, and meanwhile EUs were required to substitute clean energy with methane gas, costing ratepayers millions of dollars [27]. Additionally, Alaska experienced 202 power line-related fires from 2014 to May of 2023 that burned 10 116 acres, of which three wildfires were significant according to the Department of Forestry [29–32]. Although several states have required EUs to adopt wildfire mitigation plans, often in conjunction with legislation addressing or clarifying EU liability [6], the State of Alaska does not. Wildfire mitigation plans include elements such as vegetation management, PSPS (pro-active power line de-energization), enhanced safety settings that trip faster after a fault detection and limit reclosing (i.e. the automatic re-energization of power lines after a fault) under high fire-weather conditions, among other strategies [33]. The State of Alaska has attempted three times to pass legislation that would limit EU liability when trees outside its rights-of-way fall on power lines—an approach that, while aiming to avert catastrophic EU losses, is argued could shift risk and costs onto adjacent landowners and weaken incentives for cooperative hazard-tree mitigation [34]. There is an effort underway to develop standards for the utilities along the Railbelt [35] that could reduce liability, but standards development is a very long process.

The destruction of energy infrastructure by wildfire has the potential to harm the economic viability of villages and the health of rural Alaskans. For some Alaska communities, the cost of energy is already the highest in the nation, especially where diesel must be shipped in on barges or, even more expensively, airplanes [23]; the additional cost of repair due to wildfire would be significant. Due to lack of supplies and technical support in rural areas [36], POs due to wildfire can be lengthy, affecting both

social and health systems. Energy security is deeply tied to water security; in remote Alaska communities, energy is required for water and sewer services and high energy costs contribute to water insecurity, defined as the reduced access to sufficient water for basic household needs [37]. Water insecurity has been associated with increased hospitalizations for respiratory and skin infections due to the reduced ability to maintain hygiene [37, 38]. Additionally, dependence on freezers for food storage has been noted as a key pinch point for food security and sovereignty in the state, which is notably affected by the access to and cost of energy [39].

There are also numerous public health and safety impacts from acute energy insecurity in the form of POs, as they are associated with a wide range of adverse health outcomes, including higher rates of all-cause mortality and morbidity [7, 8, 40–43]. POs can compound the effects of wildfire smoke and extreme heat, which pose their own risks [44–53]. In addition, recent studies have shown that POs can mediate or moderate the health impacts of extreme weather, such as extreme heat [54] and major storms [42, 55, 56]. POs that originate with extreme weather are often of larger scale, involve simultaneous impacts on other infrastructure, and can disrupt and overwhelm health systems and communication systems, which can then impair emergency response capacity.

Vulnerability to long-duration POs can arise because of health risks, insufficient outage preparedness, and barriers to evacuation [57]. Residents in group settings (e.g. adult family homes, nursing homes, assisted living facilities), older adults, and disabled home healthcare patients who rely on electricity-dependent medical equipment can be particularly vulnerable to wildfires, wildfire smoke, and POs [58–62]. For nursing home residents, evacuations and POs during disasters have been associated with increased mortality [63–66], leading studies to emphasize sheltering-in-place, when feasible and safe, as preferable to evacuation [63]. Similarly, individuals who rely on electricity-dependent medical equipment have been found to shelter-in-place and delay healthcare during wildfire smoke episodes [41, 67].

While adequate back-up power can mitigate PO risks when sheltering-in-place, it is costly and frequently inaccessible to those with limited financial resources, including those experiencing chronic energy insecurity [6, 68]. As a result, registries—lists of people most vulnerable—are commonly used to notify people in the case of a PO [62]. However, registries have significant limitations; they do not prevent or shorten POs and face challenges related to privacy, liability and data maintenance, as lists must be kept accurate and up to date [62, 69]. Additionally, there can be confusion about the legality and requirements for sharing information between EUs and local governments [70]. These limitations reflect broader systemic challenges in addressing social vulnerability [69], defined as a 'multidimensional process that emphasizes the role of social, institutional, political and economic systems that shape future experiences of disasters' [7].

1.1. Theoretical background and research purpose

Concepts such as vulnerability, adaptation, and resilience appear frequently in climate change and health research, yet they are often used in different ways that can obscure ethical implications [71–79]. Vulnerability is frequently framed as an individual attribute—such as disability or age—rather than as a condition shaped by structural factors, including housing, labor conditions, healthcare access, and policy decisions [80]. This individualizing lens can shift responsibility onto those most affected, rather than addressing the broader systems that produce and reinforce vulnerability [81]. Similar critiques have been raised for resilience, which is often framed as the ability of individuals or communities to cope with and recover from disruptions [82]. While this resilience framing highlights adaptability, it can also reinforce expectations that individuals should manage risk independently, without addressing underlying inequalities or whether returning to prior conditions is desirable or equitable [82]. Adaptation is likewise contested, with dominant approaches emphasizing risk management, often maintaining existing systems rather than transforming the structural conditions that shape vulnerability and inequity [83]. Taken together, these critiques highlight that vulnerability, resilience, and adaptation are not simply technical concepts, but reflect underlying assumptions about responsibility, power, and the distribution of risk and resources.

Building on these critiques, there has been growing recognition of the importance of equity in community resilience, with evidence suggesting that more equitable investment and planning can improve outcomes for socially vulnerable populations while strengthening overall system resilience [84, 85]. Within this broader context, natural, built, and social systems are interdependent and play critical roles in shaping how communities experience and respond to disruptions [84, 85]. However, responsibilities for community resilience are distributed across private and public sectors, resulting in a decentralized governance system, presenting a collective action challenge [86].

In the context of wildfire-energy interactions (e.g. wildfire and POs), EUs are central actors, as they make decisions about investments and operations with important implications for public health and

safety. However, traditional approaches to infrastructure resilience are 'antithetical to equity,' as the needs of socially vulnerable populations are not systematically incorporated into planning [68, 84]. Further, power restoration practices rarely consider the vulnerability of individuals and communities [84]; instead, power restoration is prioritized for more densely populated areas and critical infrastructure. Protections provided by EUs to socially vulnerable populations may be limited to delaying disconnections due to non-payment [87].

Emergency managers, wildfire managers, and local and state governments are often not legally required to consider social vulnerability in their planning or allocation of resources [88–90]. Instead, emergency managers are required to conduct vulnerability assessments to receive federal funding, such as through the Federal Emergency Management Association [88–90]. However, vulnerability assessments are often inaccessible to emergency managers practicing in poorer communities because they are too costly, usually requiring paid consultants [88]. Additionally, decision-making supports for wildfire risk assessments are often based on wildfire hazard and susceptibility of the built environment and do not incorporate social vulnerability [89]. As a result, important aspects of vulnerability are not fully incorporated into decision-making, and equity may not consistently be treated as a shared objective across sectors.

EUs often coordinate with other private and public organizations to carry out emergency management functions related to their operations, although regulations and structures governing whether and how EUs interact with other organizations vary across contexts. When EU responsibilities remain undefined, EUs and their partners likely rely on informal mechanisms of interaction. Despite documented failures in coordination between EUs and public agencies during wildfire response [70, 91, 92], little is known about how cross-sector organizations work together before, during, and after wildfire-energy interactions or how they collaborate to reduce the impacts on socially vulnerable populations.

Cross-sector collaborations and private-public partnerships have been frequently cited as essential for promoting energy equity and equitable disaster response, such as for low-income populations [82] or older adults or those who require electricity to power their medical equipment [93]. Cross-sector collaborations are defined as 'the linking or sharing of information, resources, activities, and capabilities by organizations in two or more sectors to achieve jointly an outcome that could not be achieved by organizations in one sector separately' [94]. These relationships are often considered instrumental to addressing difficult and 'messy' public health problems that involve social and economic factors [95, 96].

Within public health and emergency and disaster research, cross-sector collaboration and partnership are commonly framed through a systems-thinking lens, which emphasizes interdependence, feedback, and self-organizing processes that are non-linear and unpredictable [96–98]. Systems thinking conceptualizes complex systems as collections of interacting elements whose relationships shape system behavior and outcomes [99]. Complexity theory, or complexity science, focuses specifically on complex adaptive systems (CAS), in which interactions among elements produce changes that are often non-linear [99]. As a result, such systems cannot be understood as the sum of their individual components or through reductive analysis of isolated elements [98, 99]. Instead, CAS are characterized by emergence, where system-level properties arise from interaction rather than 'any single part,' and are viewed as self-organizing systems shaped by interactions among actors [98]. Although, outcomes cannot be reliably predicted, examining the patterns of interaction can help explain system behavior and inform management strategies [98, 99].

With increasing need for interdisciplinary approaches to improve cross-sector collaboration and enhance community resilience to wildfires and energy infrastructure interactions, this study addressed three related questions using qualitative methods. How do practitioners:

(1) Understand their roles and responsibilities across risk-reduction, preparedness, and response activities related to POs, including those occurring in the context of wildfire and wildfire-energy infrastructure interactions?

(2) Describe information sharing practices and cross-sector coordination and collaboration across risk-reduction, preparedness, and response activities related to POs and wildfire-energy infrastructure interactions, and how do these descriptions differ between single-hazard and interacting hazard contexts?

(3) Access and share information about social vulnerability with other organizations, and how is this information described in relation to operational decisions and prioritization across PO mitigation, preparedness and response?

This approach enabled us to analyze how practitioners understand systemic interdependencies and organizational dynamics within cross-sector emergency management systems. Practitioner perspectives

are often underrepresented in research and a clearer understanding of how cross-sector collaboration is managed in practice is needed [100]. The study draws on systems thinking and complexity theory [98, 101] to examine how these dynamics reflect system properties such as interdependence and feedback-driven adaptation. This work addresses a critical knowledge gap as it represents a first-of-its-kind effort tailored to the Alaskan context, with broader implications for other regions.

2. Method

2.1. Study design and interview guide

Leveraging our research partnerships at the Alaska Center for Energy and Power and the Alaska Fire Science Consortium, we used a purposive and snowball sampling strategy to identify appropriate key informants located in regions with an increasing risk of wildfire and with experience planning for, or responding to, the co-occurrence of wildfire and POs in their community. We sought representation from areas affected by wildfires in Alaska, at local, borough, and state levels, and across different sectors including emergency management, tribal corporations or villages, land, forest, and wildland fire management, and public health in fire-prone regions. Study regions were served by a mix of municipal and volunteer fire departments, as well as regional hospitals and smaller local clinics that provide primary and emergency care, with patients transferred to regional hospitals for higher levels of care when needed. Emergency management capacity also varied across communities, with some areas having dedicated emergency managers, while others relied on volunteer or community-based coordinators. In many of these smaller and more remote communities, organizational capacity was limited, and individuals often held multiple roles across emergency response and community services.

After attending a 20 h workshop on applied qualitative research methods in May 2023, the team conducted virtual semi-structured interviews with 23 key informants involved in decision-making or response roles related to wildfire and POs in Alaska occurred between June and September 2023. Interview questions (supplementary material 1) focused on community and organizational roles, experiences with POs and wildfire events, the intersection of wildfire and energy infrastructure, tools and information used for planning and response, interagency collaboration and data sharing, and perceived gaps and opportunities to improve coordination and protect socially and medically vulnerable populations. Interviews were audio-recorded, transcribed, anonymized, and entered in NVIVO qualitative data analysis software Version 14 [102]. This study was reviewed and approved by the University of Alaska Anchorage (Protocol #1934958) Institutional Review Board.

2.2. Data analysis

We used deductive and inductive content and thematic analysis [103, 104] to examine informants' descriptions of the wildfire/energy infrastructure decision-context, across built, natural, and social environments. We conducted both *a priori* and open (emergent) coding, beginning with coding categories guided by our research questions and definitions of emergency management stages (table 1), without prescribing to a circular view of emergency management [105, 106]. Content analysis uses a descriptive approach to coding data that is less abstract than thematic analysis [103, 104]. We grouped codes at relative surface level of the data ('manifest' codes) under higher order headings, generating categories and subcategories. The coding was iterative, as codes were changed and subcodes were created as analysis progressed. As coding developed, codes were grouped under higher-order headings, and relationships across codes were examined to develop broader categories and themes. This process involved increasing levels of interpretation ('latent' analysis), moving beyond descriptive coding to identify patterns and underlying meanings in the data.

All interviewers conducted initial coding of one or more transcripts, further developing the codebook. The first and second author then co-coded 21 of the 23 transcripts, meeting weekly to compare coding decisions, refine code definitions, and resolve discrepancies through discussion and consensus. The remaining two transcripts were coded independently by the first author.

In the later stages of analysis, the first author conducted the final phase of thematic analysis, synthesizing codes into higher-order themes and rearranging and refining code groupings to develop the final analytic structure. The thematic analysis was informed by systems thinking and complexity theory [97, 107], guiding attention to how individuals were aggregated or arranged in subgroups, patterns of

Table 1. Definitions of emergency management stages.[a]

Prevention or mitigation	Preparedness or planning	Response	Recovery
Activities carried out before, during, or after an event to lessen the likelihood or severity of hazard impacts and minimizing potential damage.	Activities undertaken before an event or during critical danger periods that are intended to strengthen organizational capacity and ensure readiness for response.	Activities that are carried out when a hazard threatens to exceed routine operational capacity and that require extraordinary action.	Actions that facilitate the return to pre-event conditions or adaptation to a 'new normal.'

[a] Definitions of the emergency management stages [105].

Table 2. Informant characteristics ($N = 23$).

Characteristic	Category	*n (%)*
Sector[a]	Emergency management	3 (13%)
	Healthcare and public health	6 (26%)
	Land, Forest, and wildland fire Management	6 (26%)
	Local fire department	4 (17%)
	Infrastructure & transportation Management	2 (9%)
	Electric utilities	3 (13%)
Region	Interior	7 (30%)
	Southcentral	10 (43%)
	Statewide	6 (26%)
Organizational identity	Tribal/indigenous organizations	5 (21%)
	State government	4 (17%)
	Federal government	2 (9%)
	Local/borough government	6 (26%)
	Private/non-profit	6 (26%)

[a] The total exceeds 23 because one informant worked in both Public Health and Emergency Management.

interaction and how these related to system characteristics (including recurrent issues in behavior and outcomes), how individuals described adapting and learning, and how context influenced system functioning. Data analysis was performed between February 2024 and July 2025.

3. Results

We interviewed a total of 23 key informants after they provided verbal consent (table 2). Interviews averaged 35 min (range 13–67). Informants represented a range of sectors in areas of the interior and Southcentral Alaska at increasing risk of wildfire (figure 1), with six of them serving areas throughout the state. Most informants were located in areas with a history of wildfire and all areas were considered to be of high fire risk (figure 1). Only one EU informant worked for an EU connected to the Railbelt; the other two worked for statewide EUs—including one cooperative and one that is employee owned—serving a total of 99 remote communities and villages. However, several informants from other sectors were located in areas served by other Railbelt-connected EUs.

Abbreviations for the sectors represented include:
EM = Emergency management
EU = Electric utility
FM = Land, Forest, wildland fire management
HPH = Healthcare and public health
ITM = Infrastructure & transportation management
LFD = Local fire department

Three dominant themes and their associated subthemes were identified (table 3). Theme 1 provides context on sectoral roles and responsibilities, while Theme 2 describes cross-sector interdependence in key activities. Theme 3 examines how relationships, interactions, and structural arrangements shape

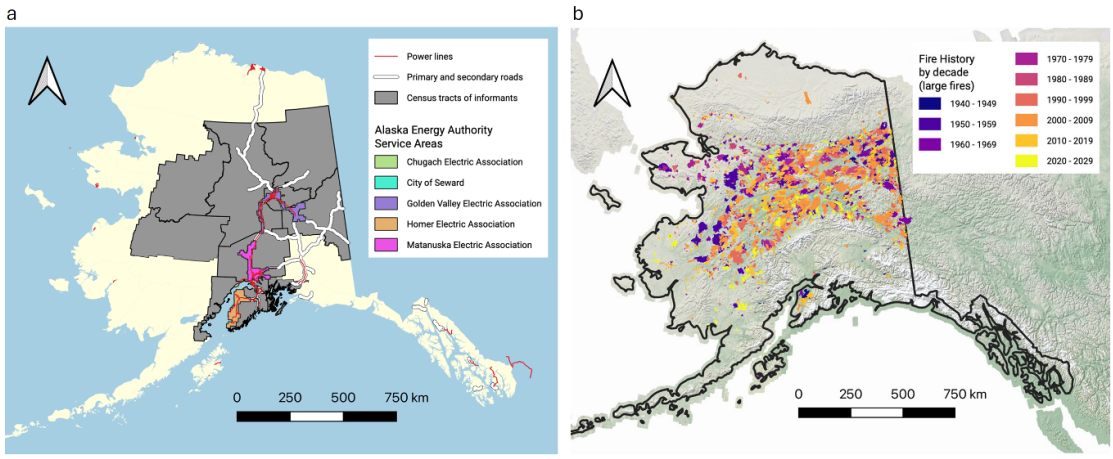

Figure 1. Study area, infrastructure, and wildfire context in Alaska. (a) Census tracts where informants were located (shaded in gray) [108, 109]. Six informants held statewide roles and are not associated with a single census tract. The Alaska Road System is depicted by white lines [110], major powerlines are shown as red lines [111], and service areas where informants were located are shown in different colors [112]. (b) Perimeters of historical wildfires from 1940 to 2025, colored by decade, are from the Alaska Large Fires Database [113] maintained and updated daily through the fire season bythe Alaska Interagency Coordination Center (AICC) [114]. The data was retrieved from the AICC web service [115]. State outline and the elevation basemap are from Natural Earth. Free vector and raster map data @ naturalearthdata.com. Maps produced using QGIS 3.22.5-Białowieża [116].

Table 3. Organization of dominant themes and subthemes related to community-wildfire-energy interactions.

Theme 1: Hazard familiarity, sectoral roles, and limited integration of social vulnerability
• Sector experiences and roles in managing POs and wildfire hazards • Social vulnerability and prioritization in emergency management
Theme 2: Cross-sector coordination and interdependence in PO and wildfire management
• Interdependence in fuels management and rights-of-way maintenance • Interdependence during response to POs and wildfire near energy infrastructure
Theme 3: Relational and structural conditions shaping coordination and collaboration
• Relationships as a coordination resource • Interorganizational system awareness as a coordination resource • Practices and structures shaping coordination • Influence of organizational mandate and culture

intersectoral system awareness and coordination, and how organizational mandates and cultures influence participation in these processes.

3.1. Theme 1: Hazard familiarity, sectoral roles, and the limited integration of social vulnerability

The first theme captures informants' perceptions of common hazards, wildfire-related and energy-related hazards, the associated health and safety risks to first responders and the public, and how these perceptions shaped their preparedness priorities and perceived responsibilities. Preparedness priorities reflected feedback-driven adaptation, whereby past hazard encounters reinforced attention to familiar risks and informed future planning. As a result, preparedness was strongest for hazards encountered frequently and perceived as falling within formal roles, while preparedness for less familiar hazards—such as co-occurring POs and wildfire or powerline-wildfire interactions—was uneven across sectors. While informants strongly emphasized their roles in protecting the public health and safety, risk was usually identified based on proximity to hazards and population density. Few systematic approaches to addressing social vulnerability to hazards were described; when social vulnerability was considered, it was primarily through actions undertaken during response rather than through mitigation/prevention or preparedness planning, and there was limited cross-sector collaboration to support these efforts.

3.1.1. Sector experiences and roles related to PO and wildfire hazards

Informants reported having more established '*playbooks*' for responding to hazards that they encountered frequently and considered to fall within their formal roles and responsibilities. These playbooks shaped

how risks are anticipated and managed and most references were oriented toward wildfire and POs as distinct hazards, rather than as interacting events.

> 'I guess particularly for fire, for me, it is a rare enough event that I do not have a real good playbook as to how to respond, and obviously fires have a mind to their own. They are going to do what they do. I do not typically know exactly what [the wildland firefighters] response is, what the what the intended response is' (P5-EU).

> 'I have not responded to extreme heat events. I do not have, like, a list of things in my head for that' (P6-HPH).

> 'We have yet to have anything that was quite directly in line of fire, for lack of a better term, to the facility itself. We usually get inundated with more of the smoke from the wildfires that might be in our area' (P11-HPH).

Experience with hazards varied across sectors. EU and FM informants had more direct experience with wildfire-energy system interactions as they related to their organizational operations. For example, some informants noted gaps in training and awareness among newer firefighters, indicating that knowledge of more complex or uncommon situations was not consistently embedded in preparedness practices. In contrast, HPH actors described a largely hypothetical and limited experience of these interactions and correspondingly limited preparedness or changes in practice in anticipation of them.

HPH informants usually focused their remarks on wildfire, wildfire smoke, or POs as distinct, non-interacting hazards, emphasizing their impact on people, property and their own operations. During POs, healthcare facility informants described managing backup power largely on their own, communicating with EUs or emergency managers primarily to assess outage duration or request prioritization. During wildfire events, HPH informants sought information about the location and spread of wildfires and wildfire smoke to anticipate staffing needs, operational disruptions, potential medical surge, or need for evacuation and interacted with the LFD or EM. Consideration of co-occurring POs and wildfire was limited; three informants from healthcare facilities indicated that they had never directly experienced co-occurring POs and wildfire, describing either limited drills for this scenario or planning for POs and wildfire as separate hazards. Public health informants described the implications of compound events for public messaging as largely hypothetical, while one hospital informant noted that co-occurring wildfire and POs could increase operational strain by prolonging outages and stressing backup power and air-handling systems.

HPH, FM, and LFD informants described impacts of wildfire smoke on the public and taking action to protect health, such as by monitoring air quality, setting up air quality monitors, and providing education about clean air or setting up a clean air room. However, one informant indicated that wildfire smoke was considered an expected occupational exposure for firefighters and they did not monitor exposure to air pollution. In general, FM and EU informants considered wildfire smoke to be primarily an operational constraint because it reduced visibility, making it difficult to fly or drive, and enabled electrical conduction from power lines to the ground, increasing the risk of arcing and electrical hazards during response. These risks resulted in increased monitoring of air quality, delays in response, and increased need for cross-sector coordination.

EUs were responsible for restoring power, communicating with the public and other organizations about power restoration times and coordinating infrastructure repair during POs. De-energization of power lines during wildfire response was frequently described as a protective strategy to reduce risks to firefighters, prevent new ignitions, and safeguard infrastructure. One EU informant indicated that they do not engage in planning preventive de-energizations (or turning the power off during wildfire conditions) because they '*do not typically see wind bad enough here*.' EUs were also responsible for maintaining power to infrastructure needed for response efforts, such as water pumps or airplane hangars.

Emergency managers tended to speak about hazards as they related to the specific sectors that they would need to engage, viewing their role as more supportive of the operations led by other organizations (e.g. FM, EU) through coordination and public communication. Emergency managers anticipated acting to protect public health primarily during large-scale, long-duration POs occurring in extreme cold. In these cases, informants reported actions such as opening shelters, first assessing the extent and anticipated duration of POs. In contrast, emergency managers did not describe comparable public health protection efforts during POs co-occurring with wildfires, smoky conditions, or extreme heat.

Community members and community-based organizations were often viewed as recipients of information, such as through notifications or public education efforts. When community involvement was mentioned, it was largely confined to narrow, functional roles during response. A few informants described residents as providing critical information during POs and emergency response. EUs depended

on community members to report routine POs and one ITM informant emphasized the importance of on-the-ground information provided by residents. An EM informant cited local amateur (ham) radio operators and community organizations active in disaster as sources of situational information. One EU informant said that it was important to coordinate with schools due to their role in providing shelter. Multiple informants described the military bases as being isolated and not sharing data or resources with other organizations, regardless of the hazard.

Overall, informants discussed conducting activities across all phases of emergency management (table 4). Emergency management stages were not always neatly distinguishable (e.g. informant discusses planning for back-up power while also reporting problems with back-up power during the response stages, monitoring during an ongoing incident to anticipate a change in response). There was generally more discussion on response activities, with comparatively less emphasis on preparedness, mitigation/prevention, and recovery (in that order). This emphasis reflected a tendency toward reactive rather than proactive coordination across sectors. HPH informants put more emphasis on preparedness and planning than other sectors, while EU informants focused primarily on response.

Prevention and mitigation activities were relatively limited and often sector-specific, such as fuels management or infrastructure hardening. Preparedness activities that involved planning activities—whether intra- or inter-organizational—and monitoring of conditions were common activities across all sectors. Data collection and development was most common among EM, FM, EU, and ITM informants, while HPH worked to access and interpret such data during both preparedness and response stages. While EM, FM, EU, LFD and ITM coordinated response efforts with other sectors, HPH contacted other organizations as resources to meet their own needs. However, HPH organizations also responded by managing medical surge and coordinating movement of patients with other organizations in the HPH sector.

3.1.2. Social vulnerability and prioritization in emergency management

Informants recognized that social and economic vulnerability shaped the impacts of POs and wildfires, though such considerations were often informal or reactive and based on available tools rather than systematically incorporated into planning. Informants described their conceptualizations of social vulnerability, how they collected data and acted on social vulnerability, information sharing, and public communication practices.

Many informants described individuals with medical equipment and older adults as being potentially more impacted by POs, and some informants from HPH and FM indicated that individuals with asthma or other chronic illnesses were most impacted by wildfire smoke. Children were not described as a priority population and one informant contrasted young people with older adults saying, '*if it is just a matter of extreme temperatures, young people will be just fine*' (P3-ITM). One healthcare informant described the vulnerability of people with limited English proficiency during POs and wildfire because of the impact to interpretive services which rely on cellular services. Two informants noted that low-income populations or populations with fewer resources could be more impacted during wildfires. One EM informant additionally indicated that sled dogs were a high priority population. One informant considered populations with limited access to technology as more vulnerable.

Socially vulnerable populations were not systematically identified. Organizations relied on opt-in data, and some organizations had no access to vulnerability data at all:

> We have had a couple of people in our area that have… They will call us, or they send this paperwork or come visit me and say 'Hey, if you respond, these people are on these machines or these things' right? (P16-LFD)

One EU informant indicated that they maintained a list of individuals who indicated during sign-up that they were reliant on electricity-dependent medical equipment, but that applied only to disconnections for non-payment; otherwise, communication about POs went to those directly impacted if contact information was available. Communication efforts were largely described in terms of the tools and platforms used (e.g. alert systems, websites, social media), with limited discussion of tailoring strategies to the needs of different populations.

In practice, prioritization during response was most often based on immediate physical exposure rather than underlying social or health vulnerability, or it was on a more case-by-case basis. Informants indicated that they emphasized efforts to address areas or sections of communities that were directly exposed to POs or wildfire:

Table 4. Activities identified across emergency management stages and their relative emphasis[a].

Emergency management stage	Prevention or mitigation		Preparedness or planning		Response		Recovery	
Overall emphasis	●		●●		●●●●●		○	
Sector emphasis	LFD	●●	LFD	●●●	LFD	●●●●	LFD	○
	FM	●●	FM	●●●	FM	●●●●	FM	○
	ITM	●	ITM	●●	ITM	●●●●●	ITM	○
	HPH	○	HPH	●●●●	HPH	●●●●●	HPH	○
	EM	○	EM	●●	EM	●●●●●	EM	○
	EU	●	EU	●	EU	●●●●●●	EU	○
Activities identified	- Fuels management in the rights-of-way. - Fuels management outside homes. - Grid hardening such as undergrounding power lines. - Long-term infrastructure changes (e.g. road upgrades to reduce entrapment risk). - Preventative de-energization (i.e. sensitive power line settings). - Planning for back-up power. - Community land use planning.		- Pre-incident planning (including daily briefings during fire season). - Exercises and drills. - Preparedness fairs. - Monitoring (e.g. wildfire encroachment, wildfire smoke). - Collecting data such as air quality. - Data collection or integration activities for dispatch or notification systems. - Data sharing agreements. - Weather forecasting and development of fire danger ratings. - Training for firefighters and lineman on interaction-specific hazards. - Maintaining contact information. - Household-level preparedness (e.g. provide education about need for HEPA filters).		- Operational planning such as coordinating response functions across multiple entities or partners. - Account for impacts on staffing and operational capacity. - Address immediate threats to life and property. - Develop and send alerts, notifications, and guidance. - Support evacuation, setting up warming or clean air shelters or connecting with shelter and emergency transport. - Calls/radio communication to/from community or agency partners. - Use emergent de-energization as a protective strategy for responders and infrastructure. - Manage re-energization of power lines. - Implementing work arounds for back-up power, communication, or resource needs.		- Rebuilding of power line infrastructure. - Integrating lessons learned during response stages into ongoing practice.	

[a] Dots represent relative emphasis of informants' statements on emergency management stages. They are informed by a quantitative assessment of coded segments and an interpretive judgment of each interview overall. Dots are used to avoid implying unwarranted precision, particularly given differences in segment length and that some informants described personal experiences in more than one sector.

> It hasn't been like—'hey, Bertha's out on, you know, Block 5 Street, Front Street or whatever, and she is an elder, so bring power over there.' it is really like—'hey, this section is out.' (P18-ITM)

> We (pause) who is most at risk? (pause) We, um, you know, we will just respond to the incident—we do not differentiate who is most at risk. (P3-FM)

> Certainly, if we were to do a disconnect for non-payment, those factors come into play…. And just inform people by any means possible; we post notices at post offices… on Facebook… (P5-EU)

More densely populated areas were prioritized and had more access to resources and support, although one LFD informant indicated that they lacked the ability to identify areas with higher population density.

Perceptions of the value of collecting such data varied. For example, EM informants for boroughs described more extensive collection of data for planning, while one informant serving in remote areas of Alaska, with dual roles in HPH and EM, perceived that formal planning for vulnerable populations was unnecessary because of the smaller population size of the villages. Some informants voiced an expectation that households or entire communities in rural areas would have back-up power generation due to the frequency of POs. While some data was described as holding relevance during response efforts (e.g. setting up shelters, anticipating medical surge), no one described using such data for prevention/mitigation or preparedness efforts.

No informants indicated that there was any type of interorganizational collaboration to identify those individuals who might need to be prioritized, either for educational/preparedness purposes or for resource allocation across the emergency management stages. The sharing of such data between agencies were viewed as essential first steps for collaboration. However, informants were often uncertain about what information on social vulnerability was being maintained by other organizations and there were no clear mechanisms for comparing the lists or data used by different organizations.

> I do not think there is any kind of interorganizational collaboration when it comes to making sure elders are taken care of […] I know the utilities are not keeping tabs on which area—there's no way that they are keeping tabs on which addresses that they are currently servicing, which are being inhabited by the elderly […] That information we could, we could easily respond to. (P13-ITM)

3.2. Theme 2: Cross-sector interdependence in PO and wildfire management

There was extensive interdependence during two key activities, including fuels management and rights-of-way maintenance and wildfire response, necessitating coordination across multiple sectors. Those sectors most interdependent were EU, FM, and LFD sectors, while HPH, community organizations, and landowners were relatively more peripheral.

3.2.1. Interdependence in fuels management/rights-of-way maintenance

The most common prevention/mitigation activity described was fuels management, which involved hazard identification, data sharing, vegetation reduction, and access management along EUs' rights-of-way, often well in advance of a crisis. The work was described as extensive and costly, requiring a 'boots on the ground' assessment, even when data provided by Light Detection and Ranging was available. However, the work done for fuels management of the rights-of-way was also described as supporting wildfire response efforts, such as by providing access to fight a wildfire in difficult terrain or an ideal location for a fuel break. This underscored the high interdependence between EU and FM:

> It is extremely expensive to maintain right-of-ways, and that our right-of-ways are recognized by all of these emergency response personnel as multi-factored mitigation. So, it is not just keeping a fire hazard out of the line. A lot of people assume that. Right-of-way clearing is so much more than that. So yes, obviously we are trying to keep a tree from growing in the line and starting a fire. We are also trying to keep a tree out of the right-of-way or near the right away-of-way from falling into the conductor. It is also a fire break, it is their redundant ingress and egress, they are emergency evacuation corridors, they are sometimes the only way emergency personnel can access remote firefighting areas is through our right-of-ways. (P19-EU)

Fuels management activities were primarily conducted by EU and FM; the department of transportation was cited as conducting fuels management along highways, and two informants also described landowners felling trees in the rights-of-way. However, despite the many actors engaged in fuels management (even in the same areas), collaboration varied:

> GIS layers, where they have done activities and treatments underneath their power lines are really important for us because those are potential control lines for wildfires. So, where they have gone in and masticated, mowed down, you know, all the vegetation

> underneath of their transmission lines, we find those extremely useful for controlling wildfires. We want to know where they are at. We share GIS layers. It was a really good thing. (P8-FM)

> And one of the things that would be I know that we are not doing that I think would be really good is none of this works coordinated with the utilities and I know they are out there doing right-of-way brushing periodically, and we are out there with the same equipment doing stuff literally adjacent to the power line, and we do not really talk to each other. (P15-FM)

One EU informant described involving multiple stakeholders in finding the right areas during 7 year clearing cycles. Some also reported the sharing of data about vegetation and infrastructure to support both prevention and response activities. However, not all EU service territories had rights-of-way, and not all EUs had the expertise or capacity to conduct their operations in such an in-depth or coordinated process. Two EU informants indicated fuels management involved more internal planning rather than coordination with external organizations:

> We just drive the lines, we know our area. And my line foremen will say, 'Hey, we need to clear this area' and we will look at it and say 'Yeah, it is hazardous. Let us get rid of it.' (P23-EU)

There were few mentions of landowners. One FM informant described engagement with individual landowners as inefficient, with it being more impactful to engage owners of larger tracts of land, while another described engaging with landowners as part of an interagency effort.

3.2.2. Interdependence during resonse to POs and wildfire near energy infrastructure

Wildfire and energy infrastructure interactions, whether wildfire was caused by powerlines, wildfire was encroaching on energy infrastructure, or there was a PO caused by de-energization or infrastructure damage, were serious events requiring cross-sector coordination. As incidents became more complex—particularly during wildfire-energy interactions—sectoral roles shifted from independent action to interdependent coordination. Which organizations took coordinating roles varied, depending on jurisdictional considerations, how they were impacted, and their organizational purposes or mandate. Although EUs handled routine POs internally or by coordinating with contractors or other EUs, during complex events they had to transition to a different pattern of communicating and coordinating with many more organizations. These included EM, FM, dispatch, and any entities impacted by outages or wildfire, such as health care facilities, life flight, and local community organizations that assisted with response.

While as a whole system, all sectors played a role in public health and safety during large incidents involving wildfire and energy infrastructure, EU, FM, and LFD sectors were most interdependent in managing them, with EM often playing a supportive role in communicating with the public. Emergency de-energization appeared to be a routine aspect of responding to active threats involving power lines and wildfires. EUs were responsible for emergently de-energizing power lines for wildfire response to reduce risks for FM, LFD and EU workers and to prevent risks from fire encroaching on EU infrastructure, including poles and substations, while EU relied on FM for safe access and re-energization after fires:

> When we show up and we basically hold there until the electric company shows up and tells us that the power is dead because we are not going to spray water on a fire if there's a live power line there, right? So, we are kinda at their mercy. We keep it from spreading. We keep back [….] We just hold back until we get confirmation from [electric utility] that the powers cut to that source. (P16-LFD)

> Once the fire was out and forestry had it under control, then we could respond and start our work. (P23-EU)

Coordination between these entities was described as critical to protect personnel, maintain service continuity, and prevent further damage. FM and LFD relied on communication from both gas and electric utilities in identifying hazards and safe working conditions and in de-energizing power lines when responding to fires near energy infrastructure or structures, and EU informants relied on FM for ensuring the safety of their line workers during re-energization after wildfire. Informants provided limited discussion of the impacts of POs resulting from emergency de-energization, except for impacts related to FM activities (e.g. ability to pump water).

EU informants often described coordinating with other sectors in the moment rather than proactively engaging others in planning to respond to an issue. For example, EU and FM informants

described the risks of PSPS (i.e. proactive or planned de-energizations) to critical infrastructure and emergency management activities. One EU informant indicated that such risks were too dangerous for communities and emergency services due to the level of coordination required. It was described as possible but improbable that they would need to turn the power off due to hazardous conditions, and that they would need to decide in the moment based on conditions; as such, they did not proactively plan for PSPS:

> That's one of the things about operations is, it is really our responsibility to assess the situation in the moment […] When you shut power down […] that would be shutting down significant portions of our service area. Then we would have to give thought to the emergency services that are dependent on that. So, we have cell phone provider—providers, we have hospitals, we have, you know, the first responders, and they all have redundant power systems, but you do not want to tax into those redundant power systems, you know, without really trying to coordinate with them. And so, because that would be a lot of effort we—we really try to avoid doing it. If the wind got bad enough we would do that, we would talk about it, but we just do not see winds like that here. (P19-EU)

The same informant later described using sensitive settings during critical fire conditions, such that the power would only be turned on after a crew checked on it rather than being turned on automatically. The informant indicated that when changing to sensitive grid settings, they conducted internal planning and communicated with emergency services about their plans.

Healthcare facilities were infrequently mentioned by EU informants, and they were more of an operational constraint in decisions around PSPS. The HPH sector tended to have weaker relational ties with organizations more directly involved in wildfire and PO management because they had no direct role or responsibility in managing such incidents.

3.3. Theme 3: Relational and structural conditions shaping coordination and collaboration

Theme 3 examines how relational and structural conditions shape coordination and collaboration across sectors. Relationships between agencies were considered foundational for an effective response because they supported the emergent sharing of information, resources, and expertise, fostered creative problem-solving in times of resource constraints, and provided a pathway for developing interorganizational system awareness. Several practices and structures were described as supporting interactions between organizations, facilitating strong relationships, interorganizational system awareness, and effective communication. Organizational mandates and cultures further shaped participation in these structures and interactions, influencing how coordination and collaboration were enacted.

3.3.1. Relationships as a coordination resource

Relationships were highly valued as a source of information, expertise, and physical resource sharing. Relationships were perceived as critical for effective response: '*it is all about relationships*' (P18-ITM). Having a smaller network, such as in rural areas, was viewed as resulting in higher vulnerability and a motivating factor for developing stronger relationships. Informants described leveraging these informal relationships to respond to emerging threats with creative problem solving and resource sharing:

> …Just there's sometimes nowhere else to turn and we—so we just kind of—it is all about relationships. So, like when [remote village] flooded last year, Alaska Energy Authority is kind of a state agency that was responding. They did not have an extra truck. They did not have the local contacts for linemen. So, we ended up sending—they brought some stuff up here on [place name]. We sent one of our drivers in a truck out to [small town] to assist them, then hooked them up with local linemen, and just kind of did that that matchmaking-slash-teamwork to figure out how we could all work together, get the power back on. Not an ideal situation, but we all just kinda try to make it work. (P18-ITM)

Participants who viewed their relationships with other organizations more favorably tended to report satisfaction with a higher frequency of communication. They also trusted other organizations to respond if they needed support. Conversely, informants noted that relationships had changed, or they wished for stronger relationships, particularly with EUs. Informants that had negative sentiments about relationships wished for improved information sharing and coordination:

> Again, I think that has a lot to do with the relationships that have changed, especially here with our local utility. There's, so there's three electrical utilities that serve the [borough], and all three of them, those relationships have changed. And it is not a bad thing. It just

> means that, you know, more than ever we are having to be proactive and insert ourselves for that initial engagement, well before the utility realizes that we should have had [the Office of Emergency Management] at the table in the beginning. (P1-EM)

Relationships and the sharing of resources and expertise were supported through both formal structures (e.g. an emergency manager having responsibility for specific municipalities) as well as more informal and voluntary efforts (e.g. collaborative groups and partnerships). Information and resource sharing both depended on and reinforced these relationships, with repeated exchanges contributing to trust and familiarity. These relationships also contributed to the development of interorganizational system awareness, as repeated interactions and familiarity with partners helped informants better understand roles, responsibilities, and communication pathways across the system:

> At times, there's the power companies who will do community events, and promote their service to the public. And a lot of times we are invited there to piggyback on that and help spread the fire prevention message with the power company… We get to talk to the responders from the power company as well—and again forming that relationship. And trying to get that synergy built between us. So, when an emergency does come, that we are a little bit more prepared for it. (P3-FM)

3.3.2. Interorganizational system awareness as a coordination resource

Building on these relationships, interorganizational system awareness was identified as a related coordination resource that enabled information flow and effective coordination during wildfire-energy events. Interorganizational system awareness was an understanding of the big picture of communication flow and how roles, responsibilities and procedures were different, yet interdependent, within the emergency response system. This awareness included knowledge of the system, such as how other organizations were impacted during POs and wildfire and how that might affect or change response efforts, the importance of engaging proactively with other partners, and how to communicate with contacts at other organizations (e.g. when to ask questions or provide information):

> There's just different levels to our experience. Some might have not responded to a power line fire before. They might run in there and think, 'Hey this is—we are going to put out a fire.' But there's a lot of precautions that we have to take, and just education on what that looks like, education and cooperation with their local provider. So that there's a good working relationship between the firefighters and the power companies—we know their process and we know 'Hey, this is a good contact number, this is what they need from us'—the information on the pole, so they can isolate it. (P3-FM)

This awareness developed over time through experiential knowledge and repeated interaction across organizations, requiring both relational familiarity and practical experience. While this resource was embedded in individuals rather than formal systems, its development was supported by structures and practices that enabled ongoing interaction. Due to attrition and changing environmental conditions, sustained engagement was necessary to maintain and rebuild this form of knowledge over time.

> ...there's a new guy in place and the level of communication is just different compared to what we have—the individual who is in place was there for years and years and years and now, I— they had a lot of needs before, they communicated a lot before I asked […] and I think they do not know what they do not know at this point in time, they're not, they'ree not sure what questions need to be asked, is, is really what comes down to. (P7-FM)

A greater baseline understanding and familiarity with other organizations was described as a resource that could be tapped during more complex and uncertain events (e.g. energy-wildfire interactions), involving a larger number of actors at different levels and across multiple jurisdictions. Conversely, when interorganizational system awareness was limited, coordination was constrained. Limited familiarity with other agencies' response approaches sometimes restricted planning efforts and contributed to delays during response. During interdependent response to wildfire and energy interactions involving EU, FM, and LFD organizations, uncertainty about how other organizations would respond contributed to delays and potential safety concerns.

Gaps in interorganizational system awareness also reflected operational and sectoral differences. For example, land and forest management and EU informants generally described actions of wildland fire management activities in an uncertain and hypothetical manner. Further, HPH informants indicated that organizations from other sectors lacked knowledge of their operations on both a routine (e.g. differences

between healthcare facility types and what type of care was provided) and emergency basis (e.g. how the actions or recommendations of HPH entities could be shaped by or shape the actions of other organizations, impacts of outages on healthcare operations). This sometimes resulted in misunderstanding during response and the need for additional communication and outreach:

> Sometimes where we have had frustrations, is that they do not understand what we can and cannot do during emergencies. So, they are like, 'why are you trying to send this person to the hospital, are not you a hospital?' (P20-HPH)

3.3.3. Practices and structures shaping coordination

Informants described practices and structures that supported coordination and collaboration, as well as the consequences of their absence. These processes increased organizational readiness, supported shared situational awareness, and helped build and maintain cross-sector relationships. They included shared meetings, information sharing agreements, communication triggers, authority and responsibility, formal coordination roles, and repeated interaction during prolonged responses. In contrast, the absence of these processes and structural conditions contributed to a more reactive, person-dependent, and memory-based approach to coordination and information sharing and a lack of interorganizational system awareness, preparedness, and planning.

Preparedness and planning activities, such as discussion-based tabletop exercises, drills, and planning meetings (e.g. to develop agreements of understanding, plan vegetation treatments), were described as structured opportunities that facilitated informal interaction. Informants noted that these activities supported the development of mutual understanding of roles and processes, and interorganizational dynamics, thereby improving interorganizational system awareness and mitigating gaps in communication and coordination:

> So just that two-way sharing of information, which I think you know one of the easiest way to do that is just to reach out once a year and say, 'Hey, is there any major changes? Anything that we need to talk about that's not covered in our operating agreement? We have had some turnover back here, and this gentleman is his name is so and so, and you would probably see him on the response' and just forming that good working relationship I think is really important. And something that I would just continue to recommend to all of our cooperators and us—it is again that it takes two to tango there. (P3-FM)

However, participation in these activities was often described as limited across sectors, particularly with EUs, reducing opportunities to build shared system awareness. For example, likely due to a lack of cross-sector planning, informants from FM and EU had some uncertainty about the methods used by EUs in their grids to prevent wildfire, and whether they were planning for PSPS or using fast-trip or sensitive settings during critical fire weather.

Bidirectional communication was often initiated when an event required coordination with other sectors. Informants were often ambiguous about the size or scale or complexity of events (e.g. when the fire gets big, when there is a big PO) that triggered bidirectional communication. Several informants attributed coordination problems to EUs having a lack of defined triggers for alerting other agencies. Instead, urgency spurred information sharing and it was more difficult to access information or coordinate prior to an emergency. EU were often described as more involved and easier to receive information from during response stages but not as collaborative during prevention/mitigation or preparedness stages. To address these gaps, formal internal triggers and agreements to share information and data were recommended by participants:

> …even though we have these plans in place, it is hard sometimes to get the electric companies to be the prompter or promptee. It is hard for them to remember to send that information out to us because they are so busy trying to get the power up, and then it usually means that I have to call them and remind them that we are looking for this information. (P4-EM)

> I think the biggest challenge is just remembering to work with them. [Chuckle] You get your POs and think 'Oh, I should have told them I forgot' type thing. It is more of that than—there's been no refusal by anybody there, we are all willing to work together. It is just… Or maybe get all your ducks in a row. (P23-EU)

Informants often relied on public resources such as outage websites, real time hazard maps, and social media pages when monitoring for potential risks. Agreements to share data was frequently identified as supporting shared situational awareness, even in the absence of communication:

> And so, I think we have worked out a pretty good system after running into the problem a couple of times, we have got a pretty good system for sharing that data from [the electric utility]…it all boils down to ahead of time, working out agreements; what are your security issues, how do I get this data we need to share, and then what are the limitations. (P2-LFD)

These agreements included the sharing of geospatial information, such as infrastructure, fuels, dynamic data involving the medical or demographic characteristics of those threatened by a wildfire, communication platforms, or integration of data sources. Interoperable communication systems, such as shared communication platforms and coordination between dispatch centers, were cited as an important facilitator of information sharing.

However, these systems were not uniformly established. One informant, who frequently emphasized political factors affecting emergency management, described frustration with local political dynamics that, in their experience, impeded efforts to develop interconnected dispatch systems. Data on fuels treatment was not standardized or integrated and data on power lines were often described as incomplete and/or inaccessible. In some cases, agreements to share information were developed reactively to address recurrent problems, rather than as part of coordinated planning. In addition, access to technical resources varied, with organizations in more remote areas reporting limited access to GIS expertise.

Gaps in institutional responsibility and information availability were also evident across sectors. In some cases, organizations described stepping beyond formal jurisdictional boundaries to collaborate when official mandates were insufficient. Informants described developing or implementing data collection in the absence of existing information and sharing these data with other organizations in the absence of established systems. For example, one informant expressed surprise at the absence of a systematic approach to mapping electrical infrastructure, noting that they had not been directed to produce the maps they were creating and sharing with communities. Similarly, one FM informant described establishing air quality monitors to address a critical gap but noted that no organization was responsible for their ongoing maintenance. These examples illustrate how essential functions were sometimes performed in service of other organizations through ad hoc, gap filling efforts rather than through clearly defined roles or institutional mandates.

Informants frequently referred to borough emergency managers as fulfilling an important role in bringing the different organizations together and as a conduit of communication between different organizations:

> When you start adding complexities to the PO like wildfires and stuff like that, we lean on our borough Emergency Operation Center for communications. (P11-HPH)

Public information officers were also important for relaying communication to the public and other organizations. Informants described employing liaison roles that would share information with other organizations during active incidents, sometimes in a face-to-face manner. One FM informant indicated that they thought there was need for a '*champion*' that would identify issues that could be addressed in the '*off season*' and bring different organizations together that do not normally work together, while a LFD informant thought there was the need for a '*central clearing house*' to integrate GIS data from different organizations.

Informants also described informal processes such as frequent interaction during a prolonged response effort that could also enable improved coordination. For example, one informant also described establishing relationships emergently during response efforts:

> A lot of times you have never met them before—until there's an incident and, all of the sudden, we become very, like best friends for a little while. (P12-FM)

However, benefits from frequent interactions in a crisis or from participating in preparedness activities could fade when relationship holders were lost due to attrition and/or there was a long length of time between interactions (e.g. once a year meetings). This underscored the need to create structures to support relationships.

3.3.4. Influences of organizational mandate and culture

Informants indicated that frequent interagency response to emergencies contributed to stronger relationships and greater familiarity with other organizations. While this suggests that improved coordination and interorganizational awareness might develop through repeated interactions and interdependence, it was not straightforward. Some informants described ongoing challenges in obtaining information or

coordinating with other organizations in both highly interdependent contexts (e.g. FM with EUs during fire response) and in situations where organizations depended on others for critical information (e.g. HPH accessing daily fire risk, locations, and wildfire smoke spread provided by FM organizations).

Preparedness and planning activities, such as pre-planning meetings, were described as potential mechanisms for strengthening relationships and building shared system awareness. However, participation in these activities and information sharing practices were often shaped by alignment of organizational roles and priorities:

> Occasionally [the EUs] come to some meetings, we talk to them but I do not think we have been very successful in working with them as a fire group… I know as a as agencies like, we have totally different missions. (P15-FM)

Informants described sustained collaboration among actors with shared operational responsibilities even across jurisdictional boundaries, particularly among landowners and fire and fuels agencies, where interdependence was more readily recognized. For example, one FM informant described the '*All Lands All Hands*' collaborative effort involving multiple landowners and agencies. At the same time, other sectors were less consistently engaged in these preparedness networks. Although EUs often played a key role during wildfire events, they were often described as absent and/or not invited to attend pre-planning events.

More peripheral sectors such as HPH were also not systematically included in meetings and this was attributed to differences in operational roles:

> There's just not always that inclusion unless you are like really trying hard knocking at the door, like making sure that you are involved in all these meetings… I thought everything was fine, and then later learn like there was this issue that we could have talked about a little differently… they have that whole incident command system, you know, you have got your emergency plan, but what other tangential pieces are not as clearly laid out but are still important to involve. (P17-HPH)

> When we get to preparedness level three, which would be high fire danger and above, we invite any of the fire chiefs or any of the departments that want to come and participate in our daily operations, briefing here at the station to do so. Some do, some do not, depending on how they are staffed, and how busy they are, too. […] they are a little more diverse in their response with medical and all kinds of other stuff that we do not have that responsibility for—we are just strictly wildland fire. (P10-FM)

Furthermore, HPH informants sometimes struggled to get the information they needed or were not directly notified of wildfire risk. At the same time, one HPH informant indicated that they shared plans with other facilities, acknowledging that they would be similarly impacted during incidents.

4. Discussion

In this study of cross-sector collaboration in managing wildfire-energy interactions in Alaska, we found that coordination among organizations was frequent during response but more limited and fragmented during prevention and preparedness stages. Collaboration tended to occur among actors with aligned operational responsibilities, while interdependence alone did not consistently translate to cross-sector engagement. At the same time, coordination often emerged adaptively through informal and self-organizing processes rather than through fully institutionalized structures. Finally, consideration of social vulnerability was limited and inconsistently integrated into decision-making, reflecting broader challenges in aligning public health objectives with infrastructure and hazard management priorities. Taken together, our findings suggest that there are numerous opportunities to strengthen cross-sector collaboration in the context of wildfire-infrastructure interactions, including through both technical and non-technical efforts.

Our study found that roles and responsibilities are considered in relation to hazards experienced historically and that are expected to be experienced in the future and are related to organizational operations or mandates. Practitioners are not proactively considering the possibility of compounding hazards such as POs and wildfires, wildfire smoke, or extreme heat. Public health response is activated only for POs during extreme cold temperatures and/or those of long duration, and not for POs during wildfire, wildfire smoke, or extreme heat or for shorter POs. Consistent with this, there is little evidence of proactive, cross-sector planning for POs in these contexts. At the same time, EUs consider PSPS as distinct

from POs resulting from fast-trip settings and emergent de-energizations, despite limited evidence that the impacts differ at the community level. Our findings may reflect the broader challenges in conceptualizing climate-related risks which involve uncertainty, complexity, and trade-offs, as well as unspoken risk tolerance and acceptance of losses [97], particularly those affecting remote areas or socially vulnerable populations.

Informants indicated that strong relationships and frequent interactions were considered essential for effective coordination, consistent with relational coordination theory which proposes that 'frequent, timely, accurate, and problem-solving communication supports relationships of shared goals, shared knowledge, and mutual respect' [117]. According to the literature on the Institutional Collective Action (ICA) theoretical framework, these relational processes serve as informal mechanisms that reduce coordination risks by facilitating information sharing and building mutual understanding across organizations [118]. We found that structural mechanisms, such as formal roles, agreements, and communication systems, create spaces and pathways for information exchange that complement informal relationships developed through repeated interaction. These mechanisms support the transition from initial information sharing to more coordinated action, enabling organizations to engage in adaptive and emergent forms of response. In this sense, our findings are consistent with research demonstrating that there is an 'interplay between the permanent and temporary' in emergency response operations [100], in which formal structures and emergent practices work together to support coordination under dynamic conditions.

Some organizations described self-organizing forms of coordination outside of hierarchical command structures to address institutional gaps [97]. Rather than being fully planned or institutionalized, coordination practices often evolved through feedback processes, with organizations adapting structures and practices in response to gaps revealed during incidents. For example, the '*All Lands All Hands*' interagency effort was developed in response to spruce bark beetles and subsequently expanded to address fuels management [119]. This is an example of interactions within one collaboration spurring additional collaboration [119]. However, despite overlapping jurisdiction and interdependence—at times conducting the same activity within the same spatial area, EUs are less involved in these efforts.

We observed that despite interdependence during both fuels management and wildfire response activities, EU and FM organizations do not consistently engage in cross-sector planning in either context, although coordination emerges during active response. Our findings both align with and diverge from prior research on organizational collaboration in wildfire risk governance in Oregon [86]. Consistent with this work, interdependence alone does not reliably produce collaboration, resulting in persistent collaboration gaps [86]. However, while the same research found greater collaboration in fire management compared to forest management, which was attributed to greater visibility and immediacy of benefits [86], we did not observe a similar pattern in collaboration between EUs and FM. These differences may be explained by the fact that the prior study did not include EUs. Future research should explore the factors contributing to these differences.

Our study uncovered a pattern of fragmentation in governance, which presents its own risks [120]. Sectoral siloes, organizational differences, and different priorities makes collaboration more difficult [121]. New and compounding hazards such as those involving wildfire-energy interactions and associated risks such as heat and wildfire smoke may present unique challenges because they may require collaboration among organizations that are less familiar with each other, have not built trust, and have not established structural supports, such as information sharing agreements [122, 123]. From an ICA perspective, these conditions reflect a moderate to higher-risk collaboration environment, characterized by a high degree of fragmentation and decentralization, a complex problem presenting a need for cooperation, heterogenous preferences among actors, and little history of collaboration [118]. Greater awareness of interdependencies among organizations [121] and shared learning [118] may support improved cross-sector collaboration and coordination.

In the context of wildfire-energy interactions, there appears to be limited recognition of interdependence with health care and public health organizations, which may reflect a lack of shared goals around safeguarding public health beyond immediate threats to life and property. This may help explain why consideration of social vulnerability in decision-making is limited and, where present, primarily focuses on immediate survival rather than addressing underlying and interrelated vulnerabilities (e.g. energy affordability). There is also limited shared understanding across organizations of how vulnerability is defined and addressed, which may contribute to a lack of coordinated efforts to promote equitable outcomes. Efforts to promote equitable energy resilience among populations at elevated risk during wildfires and/or POs, such as low-income, elderly, or disabled individuals, appear limited. There is a need to implement equitable solutions, including financial assistance for residential energy systems, such as battery storage, that could support the capability of individuals to meet their basic needs and to receive alerts for evacuation [62, 124]. Backup energy systems, such as generators or batteries, could

be appropriate in the Alaska context; however, the suitability of such solutions depends on user needs (e.g. ease of use), highlighting the importance of engagement to understand and address context-specific vulnerabilities [68].

Prior research has illuminated power differentials between PG&E and disabled customers in California, showing how vulnerability is differently defined across organizational and lived contexts, with institutional definitions often shaping how resources and protections are allocated [68]. Further, PG&E's responsibilities are often narrowly defined, focusing on the provision of programs or resources rather than their usability, while the technical complexity of these solutions poses significant challenges for affected individuals [68]. Addressing equitable energy resilience to wildfire–energy interactions will require intentional engagement—not only across sectors but also with affected communities—and explicit attention to how differing definitions of vulnerability and associated power asymmetries shape access to resources [68]. Should such efforts be undertaken, they should involve a wide array of organizations, such as 2-1-1, healthcare facilities, healthcare plans, senior centers, area agencies on aging, battery manufacturers and suppliers, and community groups that have different levels of power [68].

Although there is an increasing understanding that cross-sector collaborations are essential for improved community resilience [125, 126], they often fall short of expectations [95]. We propose that efforts to improve cross-sector collaboration with EUs and other organizations begin with long-term planning focused on mitigation/prevention and preparedness because: (1) research has shown that organizations are more open to 'diverse partners and novel information' during these stages compared to in the moment of crisis when the stakes are higher [127]; and (2) structural enablers such as training exercises and formal agreements can support cross-sector relationships and interorganizational system awareness that can, in turn, support non-linear and emergent action that are essential for dynamic response [126]. Creating space for dialogue can be helpful for identifying opportunities to collaborate [118]. Improving coordination may begin with addressing 'first-order' coordination challenges, such as information sharing and system awareness, before advancing to more complex forms of cooperation [118]. Whilst individual organizations have expertise within their own domains of responsibility, they should also understand how their areas of expertise interact with other organizations in the context of wildfire-energy interactions [128], and this may be supported by understanding the data other organizations use to make decisions. Data sharing platforms could be used as a part of joint planning efforts to facilitate a share understanding of data; stakeholders could periodically discuss the origins of the data including its collection, maintenance schedules, and relevant limitations, and identify and develop agreements for additional data sharing within and beyond the platform. If intentionally designed, such an intervention could also support the sharing of GIS expertise with practitioners in less resourced areas. These efforts should not assume that information or technology will solve coordination challenges alone; it should instead be used to foster shared understanding and stronger relationships.

One strength of this study is the diverse representation across sectors and geographies within Alaska. However, hazard exposures vary across the region, making it difficult to interpret statements from informants who reported that they had not experienced (or did not anticipate experiencing) wildfire or extreme heat. It is not possible to discern whether the underlying risk is truly low or simply perceived as such. Although extreme heat may appear to be less likely in the more mild climate of Alaska, very low thresholds of heat ($\geqslant$21.1 °C) has been linked to higher emergency department visits, underscoring the importance of adequate preparedness [129, 130]. Since we did not explicitly probe upstream systemic factors such as regulations, organizational mandates, or governance structures, additional influences remain unexamined. Future work should broaden participant perspectives by including community members, elected officials, and community-based organizations given their critical roal in shaping response and recovery to disruptions [131].

5. Conclusions

Our research highlights the importance of proactively fostering cross-sector collaboration to manage wildfire–energy incidents, particularly during mitigation and prevention stages and with a focus on public health and safety, including the needs of socially vulnerable households. New and compounding risks present opportunities for collaborations among organizations without a history of working together. Solutions are needed that enable organizations to better understand system interdependencies and strengthen both formalized relationships between organizations and informal interpersonal or lateral relationships among individuals across agencies. There are also opportunities for cross-sector partners to proactively promote equitable household-level energy resilience. Such efforts would require cross-sector collaboration with a wider range of perspectives and levels of power.

Ethical statement

This research was reviewed by the University of Alaska Anchorage and determined to be exempt from formal review as it involved minimal risk and did not include identifiable private information. The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable local statutory requirements. All informants gave verbal informed consent prior to participation, and consent was obtained for the use of anonymized quotations in publications.

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Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

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