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Research Article

Energy Infrastructure-Based Fire Risk: The Impact of Electric Transmission Lines on Forest Ecosystems and Social Policy with Prevention Strategies

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Abstract – In recent years, the rising frequency and intensity of forest fires globally have been driven not only by climate change-related natural factors but also by human-induced infrastructure vulnerabilities. Among the most at-risk areas are forested and rural regions intersected by power transmission lines. In arid, windy, and low-humidity environments, technical issues such as poor maintenance, equipment failure, inadequate insulation, or collapsed poles can generate sparks that ignite fires. These fires endanger ecosystems and also disrupt livelihoods, essential services, and social well-being in affected communities. This study investigates the relationship between energy transmission infrastructure and forest fires from an integrated perspective encompassing engineering, environmental safety, and social policy. Numerous international incidents, particularly in countries like the USA and Australia, highlight faulty power infrastructure as a critical cause of large-scale fires. Accordingly, such fires should be regarded not only as environmental disasters but also as technological and social crises. To mitigate these risks, the study proposes several technical strategies: routine and autonomous inspection of power lines via unmanned aerial vehicles (UAVs); early fault detection using thermal imaging technologies at cables and connectors; creation of protective zones of at least 10 meters along power line routes; and deployment of AI-powered spark detection sensors and smart grids equipped with fast-acting circuit breakers. The study also explores the broader impacts of power outages during wildfires. These outages can severely hinder emergency response capabilities, disrupt communication systems and healthcare services, and destabilize supply chains for food and basic needs. Such disruptions tend to exacerbate social inequalities, particularly in rural areas marked by high vulnerability. In conclusion, forest fires represent a complex interplay between environmental risks, infrastructure safety, and social resilience. Managing these risks effectively requires a multidisciplinary approach that incorporates disaster risk reduction, rural development, and climate justice-oriented social policies. Key priorities should include continuous monitoring of energy infrastructure, legal enforcement of maintenance responsibilities, and targeted infrastructure investment in socially disadvantaged regions to ensure sustainable disaster preparedness and response.

Keywords – Forest Fires, Electricity Transmission Lines, Energy Infrastructure, Social Policy, Disaster Management

I. INTRODUCTION

In recent years, there has been a noticeable increase in the frequency and severity of wildfires worldwide. While natural factors such as drought, high temperatures, and low humidity associated with climate change are among the primary causes of this rise, it is evident that human-induced infrastructure issues also significantly elevate fire risk. In particular, areas where energy transmission lines intersect with forested and rural regions stand out as high-risk zones for wildfires. In arid, windy geographies with low humidity levels, technical problems such as inadequate maintenance, equipment failures, poor insulation, or the collapse of poles can generate sparks along transmission lines, potentially triggering large-scale wildfires. These fires not only have devastating effects on natural ecosystems but also threaten the livelihoods, access to essential services, and overall social welfare of communities residing in affected areas. Therefore, fire risks associated with energy infrastructure should be viewed not merely as environmental disasters but also as technological and social crises [1-3].

This study adopts a holistic approach to examine the relationship between energy transmission infrastructure and wildfires, incorporating perspectives from engineering, environmental safety, and social policy. Various large-scale wildfire incidents in countries such as the United States and Australia clearly demonstrate that failures within energy transmission systems can result in catastrophic outcomes. In this context, the management and regulation of energy infrastructure should be regarded not solely as a technical issue, but also as a fundamental component of disaster risk reduction, rural development, and climate justice-oriented social policies.

The subsequent sections of the article will explore in detail the technological measures aimed at reducing fire risk, the socio-economic impacts of power outages during fire events, and how infrastructure investments may influence social inequalities. Within this scope, the necessity of an interdisciplinary risk management approach that aligns with the complex nature of wildfires will be emphasized [4].

Wildfires should not be considered solely as natural disasters, but also as socio-technical phenomena closely linked to human activities and technological infrastructures. In this regard, the impact of energy transmission lines on wildfires represents a critical issue that must be evaluated through an interdisciplinary lens. The literature contains numerous studies addressing this relationship from various perspectives, which can be examined under thematic categories as outlined below [5,6].

A. The Link Between Energy Infrastructure and Wildfire Ignition Points

Recent research on the increasing incidence of wildfires in recent years has shown that a significant proportion of these fires originate from energy transmission infrastructure. Notably, the case of Pacific Gas and Electric Company (PG&E) in the United States has highlighted the critical importance of utility companies' responsibilities and maintenance obligations. Negligence in PG&E's maintenance practices led to the 2018 Camp Fire disaster, which claimed 85 lives and destroyed tens of thousands of structures. Following this incident, it has been observed that regulatory frameworks governing energy companies were strengthened, and liability provisions were more clearly defined [7,8].

Similarly, studies conducted in Australia have revealed that energy transmission lines running through forested areas carry a high likelihood of spark generation, particularly under hot and dry climatic conditions. Li and Lin (2019) [9]. demonstrated that the probability of fire ignition is statistically significantly higher in areas traversed by power lines compared to regions without such infrastructure.

B. The Interaction Between Climate Change, Drought, and Infrastructure

Meteorological conditions driven by climate change—such as rising temperatures, decreasing humidity, and increasing wind speeds—create favorable environments for the rapid spread of wildfires [7]. Vahedi et al. [10] emphasize that such environmental factors exacerbate the risk of wildfires originating from energy infrastructure. Additionally, increased drought in areas where power lines are located enhances the flammability of vegetation, thereby intensifying the impact of fires. These findings underscore the need to assess infrastructure safety in conjunction with climate vulnerability.

C. High-Tech Preventive Systems and Risk Mitigation Practices

Studies on technological solutions aimed at preventing wildfires caused by energy infrastructure have shown a remarkable increase, particularly over the past decade. The integration of technologies such as periodic and automated inspection of transmission lines using unmanned aerial vehicles (UAVs), early heat detection through thermal imaging systems at cables and connection points, artificial intelligence-based spark detection sensors, and fast-response circuit breakers holds significant potential for minimizing fire risk [11, 12].

In addition, real-time monitoring of transmission lines and automatic power shut-off during fault conditions through "smart grid" systems have emerged as effective methods for wildfire prevention. However, due to the high installation costs of these systems, their implementation remains limited, particularly in rural and low-income regions.

D. Social and Economic Impacts of Power Outages During Wildfires

Preventive power outages during wildfires are essential for reducing risks and preventing the spread of fires. However, such outages can lead to severe societal consequences across a wide range of sectors, including healthcare services, communication infrastructure, agricultural activities, and food supply chains. Tierney (2006) [13] emphasize that power outages during disasters have disproportionately destructive effects in impoverished regions, further deepening social inequalities. The "Social Vulnerability Index" (SoVI) is used to assess communities' resilience to such disasters and demonstrates that infrastructure deficiencies reduce social resilience. In this context, there is a direct relationship between energy infrastructure and social vulnerability [14].

E. Energy Infrastructure, Public Policy, and Climate Justice

Ensuring the safety of energy transmission lines is not only a matter of engineering practices but is also directly linked to effective public policy. Clearly defining the maintenance obligations of energy companies through legislation, conducting regular inspections, and directing infrastructure investments toward socially disadvantaged regions are of critical importance in reducing disaster risks. At this point, the concept of climate justice comes to the forefront. This is because the impacts of disasters can exacerbate existing social and economic inequalities, and infrastructure deficiencies may serve as one of the root causes of such injustice [15].

F. The Situation in the Turkish Literature

In Türkiye, the impact of energy infrastructure on wildfires has been addressed in only a limited number of studies. Research has primarily focused on climatic and anthropogenic causes of wildfires, while the risk of fires stemming from technical infrastructure has not been adequately analyzed. However, data from the General Directorate of Forestry reveal that electric transmission lines constitute a significant cause of wildfire ignition. This highlights the need to fill gaps in the national literature and to increase interdisciplinary research focusing on the relationship between energy infrastructure and wildfires [16].

II. MATERIALS AND METHOD

This study examines the impact of energy transmission infrastructure on wildfires through a multidisciplinary approach. The research is based on a qualitative methodology that combines documentary review, case study analysis, and analytical synthesis. Within this framework, the literature in engineering, environmental safety, and social policy fields was systematically analyzed, and comparative evaluations were conducted using national and international wildfire cases.

A. Literature Review Based on Documentary Research

In the initial phase, scientific publications, technical reports, official institutional data, and media news related to the topic were systematically reviewed. The review primarily focused on studies published after the year 2000, utilizing sources accessed from databases such as Scopus, Web of Science, Google Scholar, and Tübitak Ulakbim. Keywords employed included terms such as "electrical transmission lines," "forest fire risk," "power grid failures," "infrastructure-related disasters," "wildfire resilience,"

"climate justice," "smart grid technologies," and "social vulnerability." The studies particularly emphasized themes including the relationship between energy infrastructure and wildfires, fire prevention technologies, the social impacts of power outages, and infrastructure inequalities in rural areas. Additionally, technical reports and policy documents published by international organizations (FAO, IEA, IPCC) were also incorporated into the study.

B. Case Study Analysis

To deepen the literature review and strengthen the empirical dimension of the study with real-world examples, large-scale wildfires from three continents were analyzed using the case study method:

- Camp Fire (California, USA – 2018): Originating from sparks caused by energy transmission lines owned by PG&E, the Camp Fire is one of the most devastating wildfires in U.S. history. This disaster exemplifies the consequences of technical infrastructure deficiencies and institutional negligence. The event was analyzed not only for its environmental destruction but also for its implications in understanding social crises stemming from energy infrastructure failures [17, 18].
- Black Saturday Fires (Victoria, Australia – 2009): The fires that occurred in Victoria, Australia, in 2009, which resulted in numerous fatalities, demonstrate how wildfire risks originating from energy lines rapidly escalate under conditions of high temperatures, drought, and wind. This case illustrates the interaction between meteorological factors and infrastructure vulnerabilities [19, 20].
- The Turkey Example (Muğla and Antalya Fires – 2021): The major wildfires experienced in Turkey during the summer of 2021 highlighted the relationship between energy infrastructure in coastal regions and wildfire risk. Although official sources do not clearly specify the ignition causes, it is evident that the fire risk associated with power lines has not been sufficiently examined in Turkey. This case points to a significant gap in domestic literature and infrastructure management [21, 22].

These cases allowed for a comprehensive examination of not only technical causes but also institutional responsibilities, regulatory deficiencies, and social impacts.

C. Analytical Synthesis and Thematic Structuring

The collected data were evaluated using the "thematic content analysis" method, resulting in the identification of three primary analytical axes:

- Infrastructure Safety and Technological Risks: Maintenance deficiencies, technical failures, renewal investments, sensor and automation systems
- Socio-Economic Consequences and Vulnerability of Wildfires: Corporate responsibilities, infrastructure regulations, investment priorities, disaster management, and rural policy
- Social Policy, Climate Justice, and Inequality: Power outages, service disruptions, rural poverty, and post-disaster inequalities

Under these themes, findings derived from the literature and case studies were comparatively analyzed, providing empirical data to support the development of recommendations.

D. Limitations

This study does not include quantitative measurements, fieldwork, or numerical wildfire modeling. The information and documents used in the case analyses are predominantly based on secondary sources. Furthermore, due to limited data access regarding energy infrastructure in certain country examples—particularly in Turkey—the analysis of technical details remains constrained. Nevertheless, the findings obtained contribute to the development of a multidimensional understanding of the impact of energy infrastructure on wildfires.

III. RESULTS

The national and international cases examined in this study demonstrate that energy transmission lines play a critical role both as ignition sources and in exacerbating the impact of wildfires. The findings are presented under three main themes: (1) fire risks originating from technical infrastructure, (2) environmental and social impacts of wildfires, and (3) preventive strategies and policy gaps.

A. Fire Risks Originating from Technical Infrastructure

A.1 Inadequate Maintenance and Technical Negligence

In the case of the Camp Fire (California, 2018), a spark caused by a worn connector on a high-voltage transmission line owned by PG&E ignited dry vegetation in an arid region, leading to an uncontrollable wildfire. Investigation reports revealed that the transmission line had not been maintained for years, warning systems were disabled, and the company prioritized investments based on profit motives. Similarly, in the Victoria fires (Australia, 2009), transmission lines were found to have overheated under excessive load, and the clearance distances around the lines were insufficient. It was determined that tree branches contacting the transmission lines caused spark generation.

A.2 Clearance Zones and Transmission Line Routes

Findings indicate that in many regions, adequate clearing and buffer zone applications around energy transmission lines are not implemented. Expert reports recommend that fire-resistant corridors with a minimum radius of 10 meters should be maintained around the lines. Although data regarding the proximity of energy lines to fire paths in the 2021 Manavgat and Marmaris fires in Turkey are insufficient, local-level findings suggest that clearance distances have occasionally been neglected.

B. Environmental and Social Impacts of Wildfires

B.1 Ecosystem Destruction

Approximately 62,000 hectares of forest were destroyed during the Camp Fire, resulting in permanent damage to the habitats of numerous rare species. Additionally, the reduction in soil permeability increased the risks of flooding and landslides in the region. Similarly, following the 2009 fires in Australia, significant contraction of habitats for species such as koalas and wallabies was documented. The infrastructure-related origin of these fires indicates that direct technical negligence can lead to ecological devastation.

B.2 Power Outages and Service Disruptions

Mandatory power outages during wildfires have caused the collapse of communication infrastructure, interruption of healthcare services, and coordination failures among emergency response teams, especially in rural and mountainous areas. In the case of the Camp Fire, intensive care units in hospitals became dependent on generators, and firefighting efforts were hampered in some areas due to non-functional water pumps. Similarly, in the Turkish examples, access to water and communication infrastructure in rural villages was disrupted due to outages.

B.3 Social Inequality and Vulnerability

Case analyses reveal that the impacts of wildfires are not distributed evenly across social groups. Damage has been more severe in regions with high concentrations of low-income, elderly populations and weak rural infrastructure. Following the Camp Fire, thousands of families facing a housing crisis were forced to live in temporary shelters for extended periods. Post-fire support programs predominantly targeted insured homeowners, thereby excluding uninsured tenants and migrants. This situation highlights how disasters exacerbate social injustices.

C. Preventive Strategies and Policy Gaps

C.1 Deficiencies in Technology Use

Findings indicate that modern technologies such as unmanned aerial vehicle (UAV) surveillance, thermal camera monitoring, and artificial intelligence-supported spark detection systems are not

sufficiently widespread in high fire-risk areas. Companies like PG&E have been observed to implement these systems only after major wildfire events. In Turkey, technological prevention systems are used on a limited scale by public institutions, and local municipalities face significant budget constraints in this regard.

C.2 Legal and Institutional Responsibility Ambiguities

It has been observed that responsible actors for the inspection and maintenance of energy transmission lines are not clearly defined, inspections are not conducted with sufficient frequency, and penalty mechanisms lack deterrence. For example, PG&E was ordered to pay compensation after the wildfire but did not undergo structural reform. In the Turkish context, jurisdictional confusion among the General Directorate of Forestry, TEDAŞ, and private distribution companies hinders the clear fulfillment of maintenance responsibilities.

C.3 Insufficiency of Social Policies

Post-fire disaster aid and infrastructure reconstruction processes are generally carried out inequitably. Particularly, small producers, farmers, and elderly populations living in rural areas do not receive adequate social protection. This situation reveals that wildfires originating from energy infrastructure not only cause technical problems but also generate structural social crises.

IV. DISCUSSION AND CONCLUSION

The findings of this study comprehensively reveal the critical impact of energy transmission infrastructure on wildfires. Sparks and faults originating from energy transmission lines constitute a significant proportion of wildfire ignition points. This indicates that fire risk is influenced not only by climatic conditions but also substantially by infrastructure safety and maintenance practices. Technical infrastructure deficiencies not only facilitate the ignition of fires but also complicate their control and contribute to increased damage. In particular, insufficient clearance zones and irregular maintenance enable the rapid spread of fires. At this point, technological innovations—such as regular maintenance using unmanned aerial vehicles (UAVs), early detection through thermal cameras, and AI-based sensors—are of vital importance, yet they remain insufficiently widespread. The findings also clearly highlight the substantial social and economic impacts of power outages during wildfires. These outages cause disruptions in healthcare services, communication difficulties, and reduced emergency response capacity; disadvantaged and rural populations are disproportionately affected. Infrastructure vulnerabilities are understood to exacerbate the effects of disasters, especially in communities with heightened social vulnerability. This study further emphasizes that wildfire risks originating from energy infrastructure should be evaluated not only from technical perspectives but also through the lenses of social policy and legal frameworks. It is imperative to clearly define the responsibilities of energy companies, conduct regular inspections, and direct infrastructure investments within a social justice framework. Analyses specific to Turkey indicate that infrastructure-related fire risks have not yet been systematically monitored, and that regulatory frameworks and institutional cooperation are inadequate. This situation leads to significant challenges in both wildfire prevention and post-disaster response and recovery processes. In conclusion, wildfires constitute a multidimensional crisis emerging from the complex interaction of climatic, technical, and social factors. Effective risk management requires an interdisciplinary approach, advanced technological applications, and social policy reforms. In this context, energy infrastructure safety should be prioritized not only within the field of engineering but also as a key concern of environmental management, public policy, and societal resilience.

This study comprehensively demonstrates that energy transmission lines play a critical role in both the ignition and spread of wildfires, a situation arising from both technical infrastructure deficiencies and inadequacies in social policies. The international and Turkish cases examined indicate that in the absence of proper maintenance and oversight of energy infrastructure, wildfire risks significantly increase. Particularly, rising temperatures and drought conditions associated with climate change exacerbate the adverse effects of these technical vulnerabilities. In addition to the ecological damage caused by fires, power outages during and after wildfire events severely disrupt access to social, economic, and healthcare

services for rural and disadvantaged communities, thereby constituting a social vulnerability factor that deepens the disaster's impact.

To reduce wildfire risk related to energy transmission infrastructure, it is essential to strengthen infrastructure maintenance and inspection processes. In high-risk fire zones especially, regular and frequent technical maintenance of transmission lines, renewal of worn and hazardous equipment, and strict monitoring of maintenance activities within a legal framework are of vital importance. The widespread adoption of advanced technological applications is also crucial in this context. Automated inspection systems using unmanned aerial vehicles (UAVs), thermal imaging techniques, and AI-supported spark detection sensors can enable early identification of potential fire ignitions and facilitate prompt intervention. The use of smart grid systems can rapidly cut electricity during faults, preventing the spread of fires.

Moreover, establishing fire-resistant buffer zones along transmission line corridors and regularly clearing these areas constitute important measures to reduce the speed of fire spread. The mandatory enforcement of such clearance zones through legislation and their effective supervision are necessary. Beyond technical measures, comprehensive improvements in social policy are required to mitigate the social impacts of wildfires. Access to electricity, healthcare, and communication services must be ensured for low-income and elderly populations in rural areas during and after disasters. Targeted support mechanisms should be developed to prevent disaster-related damages from exacerbating social inequalities.

From a regulatory perspective, the responsibilities of energy companies regarding infrastructure safety must be clearly and explicitly defined. Maintenance and inspection obligations, alongside enforcement mechanisms, should be strengthened. Rather than focusing solely on post-disaster compensation, deterrent policies aimed at proactive prevention must be developed. Coordination and collaboration among public institutions, private sector actors, and academic communities should be enhanced to implement multidisciplinary and sustainable wildfire prevention strategies.

Specifically in Turkey, systematic data collection and analysis related to wildfire risks stemming from energy infrastructure must be conducted. Transparency should be ensured by establishing effective communication mechanisms between local governments and energy authorities. Infrastructure investments should be prioritized in high-risk fire zones, and strategies aimed at enhancing the technical and social resilience of rural areas should be developed. These steps, in an era where climate change and infrastructure risks are simultaneously increasing, should be considered fundamental requirements for combating wildfires in terms of both environmental sustainability and social justice.

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