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Powerlines and Wildfires: Overview, Perspectives, and Climate Change

Could there be more electricity blackouts in the future?

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Overhead powerlines cross extensive areas of forest and grasslands, and these areas are often flammable and can burn. Wildfire is a natural phenomenon important to many ecosystems around the globe, but also capable of considerable damage to people and communities. As a result of human activity in natural spaces, people have altered wildfire regimes over time, and wildfires have become a threat to people, to their property, and infrastructure. To examplify this, Figure 1 shows the thousands of wildfires detected by satellite around the globe during seven days of early September 2021; the image gives an indication of the planetary magnitude of the phenomenon. Powerlines represent both a way in which human activity has changed the natural wildfire regimes (i.e., an ignition source), and vital infrastructure vulnerable to fire.

The interaction of powerlines with high winds or vegetation can initiate wildfires, such as the 2018 Camp Fire in California that killed 85 people. While there are other more sophisticated ways to mitigate the ignition risk posed by powerlines, one method employed by utility companies is to shut off lines to prevent any possible ignition during periods of high winds and high fire danger. These preventive shutoffs have multiple negative consequences and can interfere with the operation of critical infrastructure like hospitals or food supply.

Wildfires can also damage powerlines when the intense heating from the flames or large quantities of smoke deteriorate the lines and impair their performance. Wildfire damage to power networks also impacts critical infrastructure and communities. While preparing this article in September 2021, a fire at an interconnector in the UK caused the power supply to cease for nearly a week and is expected to operate at a reduced capacity for six months. According to the BBC, the fire resulted in a 19% electricity price increase the day after. Considering the close integration of human activity with wildland ecosystems, and that ecosystems and the climate are changing, the question arises whether interruptions of electric power as a result of wildfire (or threat of wildfire ignition) could become more frequent in the future.

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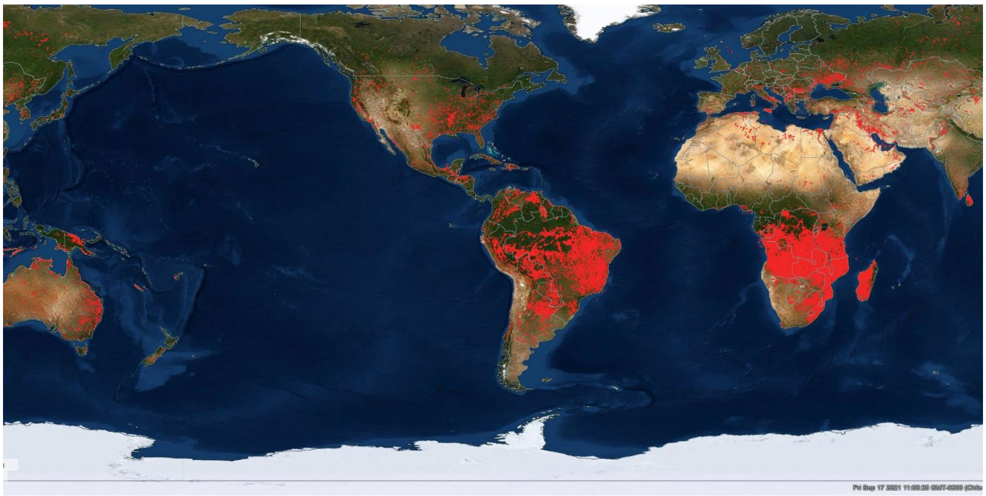

Figure 1: Fires and thermal anomalies around the world during seven days in early September 2021. (Visible Infrared Imaging Radiometer Suite image taken from NASA Fire Information for Resource Management System-https://firms.modaps.eosdis.nasa.gov/)

============== Box 1 - Camp Fire ==

One recent large-loss wildfire started by power distribution equipment is the 2018 Camp Fire in Butte County, California which started on the 8th of November. CAL FIRE (California state wildfire service) later reported that the fire burned over 153,000 acres, destroyed over 18,000 structures, and resulted in 85 civilian fatalities. It was determined that the fire was caused by electrical power lines owned and operated by Pacific Gas and Electric (PG&E). Dangerous fire conditions - strong winds and dry fuel from warm weather and low humidity allowed the fire to grow rapidly through wildland and urban areas. This fire is the deadliest wildfire in recorded California history and at the time was also the most destructive in California. According to detailed fire investigation reports led by NIST, fallen power poles and other electrical equipment blocked multiple streets, impairing evacuation and response activities.

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The risk wildfires pose to infrastructure and communities depends on several factors. To determine this risk, an objective against which consequences can be evaluated needs to be defined. In a remote region with a very low population, a wildfire might burn large areas without damaging infrastructure. It might, however, still cause severe damage to the ecosystem. In general terms, risk is the product of the severity of an event (the damage caused), and the probability of its occurrence (the frequency). Powerlines influence the risk in two distinct, but not mutually exclusive ways: Powerlines can cause (ignite) wildfires, influencing the risk wildfires pose to communities by increasing frequency. Alternatively, powerlines can be affected by passing wildfires, increasing the risk wildfires pose to infrastructure by increasing the damage produced.

Powerlines and Wildfires

Ignition Involving Overhead Powerlines

Nearly all accidental wildfire ignitions *caused* by overhead powerlines involve an electrical fault resulting from some combination of wind or a foreign object (e.g., tree, wildlife, mylar balloon, and so on) interacting with the powerlines. These causes, in turn, can result in varied, but also overlapping ignition mechanisms. At the same time, there are also major contributing factors, such as drought and elevated temperature, which can dramatically change the likelihood of ignition.

Wind plays an outsized role in causing powerline-involved wildfires by either directly interacting with the lines, or indirectly causing foreign objects to interact with them. One direct wind-powerline interaction is conductor clashing (also known as *line slap*) where two conductors make contact, allowing current to flow between them, heating the powerlines to the point of melting and even localized boiling of the molten material (this process is illustrated schematically in Fig. 2a). Heated solid particles or molten droplets of conductor material may then be ejected. Depending on the material (e.g., aluminum), these particles or droplets may also exhibit flaming combustion. When falling onto the ground, they may ignite fine fuels if the conditions are right. Typically, the larger or more energetic the particle is, the greater its ability to ignite fuel. The particle's energy is a result of its temperature, energy stored through melting, and chemical energy released through combustion or surface oxidation reactions.

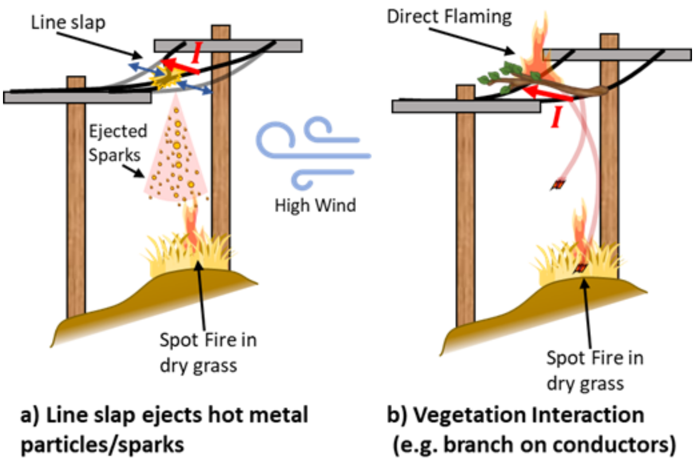

Figure 2: A schematic illustration of ignition caused by powerline failure. The two main mechanisms are interactions between conductors (a) and interactions of vegetation and conductors (b).

Conductor clashing occurs when powerlines sag sufficiently, so that the wind can cause them to swing into electrical contact. One mechanism which may cause lines to sag is the thermal expansion of the conductor material due to elevated temperatures. The heating can be the result of a combination of extreme weather (elevated temperature) and electrical heat generation in the wires. Extreme weather with high winds and high temperatures, such as extreme cases of Santa Ana winds in California, may in some cases provide the conductors' sag and winds needed for this to occur while also facilitating ignition and fire spread.

Because of this (ignition under extreme weather conditions), powerline-ignited wildfires tend to be especially intense and destructive. Changes brought about by climate change may produce similar effects in other regions or make weather phenomena such as the Santa Ana winds worse.

Wind can also indirectly cause wildfires by causing vegetation-driven faults in powerlines, as illustrated in Fig. 2b. Toppled trees or large broken branches can break the powerlines, causing the line to fall to the ground and ignite vegetation from its electrical discharge. The broken conductor can also come into contact with other conductive material (telecom lines, support wires, etc.), resulting in conductor clashing. Less forceful vegetation interactions, such as a tree leaning on a powerline or a branch laying across conductors, may not catastrophically break the lines, but instead, provide a path for electrical current to flow through and, in turn, ignite the vegetation. This vegetation may burn with a flame of sufficient size to spread to other nearby fuels, or it may act as a firebrand falling and igniting combustible material below.

Electrical transformer oil fires and explosions constitute a third ignition mechanism for wildfires. These fires are typically a consequence of electrical faults with the most common cause being lightning. Faults from high wind, weather, and interactions with trees can also cause explosions that result in fires. During such events, droplets of burning oil can contact and ignite fuels in a process similar to ignition by hot metal particles or firebrands. In other cases, burning oil may fall and form a pool fire which may then ignite other fuels. Finally, hot or molten conductor material may be ejected, potentially igniting fuels similar to the molten metal droplets produced during conductor clashing. A selection of important wildfires caused by powerlines is provided in Table 1. The relative importance of these fires is indicated by the destructiveness highlighted in the last column.

***Table 1**: List of selected large-loss wildfires started by power lines*

Fire	Region	Deaths	Burned Area (ha)	Structures	Notes
Camp Fire (2018)	Butte County, California, USA	85	62,053	18,804	Most destructive & deadly fire in CA history. (source: CAL FIRE)
Witch Fire (2007)	San Diego County, California, USA	2	80,124	1,650	7th most destructive Fire in California (source: CAL FIRE)
Black Saturday Brushfires (2009)	Victoria, Australia	173	450,000	>3,500	Composed of 15 fires, with 5 caused by powerlines. Worst bushfire disaster in Australia (Source: National

					Museum of Australia)
Bastrop County Complex Fire (2011)	Bastrop County, Texas, USA	2	13,903	1,685-1,731	Most destructive wildfire in Texas history (Sources: NFPA, USFS)
Attica Fires (2018)	Attica Region, Greece	102	1,431	>4000	2nd deadliest wildfire worldwide since 2001 (Source: news reports)

Risk of Disruption to Powerlines by Wildfires

Wildfires can disrupt power distribution systems by damage from the flames directly, the smoke, or even some fire suppression activities. High-intensity wildfires propagating through the canopy of dense woodlands can produce flashover (short-circuit between conductors) due to the increased electric conductivity of the hot combustion products or deposition of soot particles on suspension insulators. The inorganic content of plants, typically dominated by alkali and alkaline earth metal species, ionizes at high temperatures, providing free electrons to sustain electric current. Increased conductivity is estimated to occur as high as 15 m above the canopy, reaching the height of typical power lines.

Flames near conductors can also provide a conductive path through the ionized gas species present in the flame, promoting electrical flashover. Wildfire can heat powerlines, causing the conductors to sag which, combined with wind, can cause conductor clashing. Wooden poles can burn during fires, severely damaging power networks. Similarly, aluminum conductors may melt during wildfires due to the low melting point of aluminum (~640°C). Fire retardants dropped from aircraft can cause power lines to foul, limiting their performance.

Experience tells us that wildfires are more likely to spread in dry and warm climate conditions. Intuitively this leads to the hypothesis that climate change manifestations of drought and higher temperatures could have an important impact on wildfire activity. The nature of this impact (i.e., frequency of fires, size of fires, or type of fires, etc.) on wildfire activity is less intuitive, however the data from reports of large destructive wildfires over the past several decades show strong clear evidence of increased wildfire severity and size.

Climate Change and Wildfires

Weather extremes around the globe are only confirming what has been the consensus among climate scientists: the climate is changing. Human influence on this change is substantial and cannot be denied. Large amounts of greenhouse gas emissions and overexploitation of essential ecosystems have overcome the natural resilience of the planet and are causing changes in the climate. The latest Intergovernmental Panel on Climate Change report (August 2021) states “it is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred."

Especially in the Northern Hemisphere, climate change is expressed through consistently higher temperatures (during the past century, global average temperatures have risen by about 1° C) and extended periods of drought. In general, weather phenomena become more extreme. While overall rainfall has not been necessarily diminished, it occurs in shorter, more intensive events. An example is the extensive flooding that devastated large areas of Central Europe and Southeast Asia during the early summer of 2021. The preceding heatwave, which produced unprecedented temperatures in several locations across Europe (e.g., 35° C in Ireland) completes the picture.

Climate change results from a positive feedback loop. An example is the temperature-induced melting of ice caps in the polar regions. The Northern Siberian permafrost region contains important extensions of peatland, which upon thawing provides fuel for smouldering fires that further emit carbon dioxide. While forest fires are in theory carbon neutral (carbon dioxide released during the fire will be re-absorbed as the vegetation grows back), peat fires are a net contributor to carbon emissions. It was estimated carbon dioxide emissions from the 1997 peatland fires in Indonesia corresponded to up to 40% of fossil fuel emissions during the same year. Carbon dioxide-driven climate change thus self-accelerates and indirectly contributes to increased carbon dioxide emissions, which in turn further accelerate climate change.

One consequence of higher average temperatures resulting from climate change is the decrease of ambient humidity which causes a decrease in vegetation moisture levels. This in turn makes the vegetation easier to ignite and burn more intensely. Thus, climate change is likely to result in an increase in wildfire activity.

A recent study published in the research journal *Earth's Future*[1] presented evidence confirming such a link, identifying an increase in the areas consumed by wildfires in California as the atmospheric water vapor pressure deficit (VPD - a proxy for drier vegetation) increases. The graph in Fig. 3 shows this increase, and also establishes a link between increased VPD and climate change since higher VPD has occurred predominantly during the past two decades (illustrated by the orange and red data points). Similar trends are observed in Eurasia and Canada, especially in the arctic and sub-arctic regions. The enhanced propensity to burn could, in turn, indicate elevated risk to power networks.

A 2009 study found a close correlation between drought indexes and the area burned by wildfires. It was also found that areas experiencing extreme drought periods have been expanding over Eurasia in the 20th century. Climate change can cause longer, or more intense drought conditions punctuated by events of more significant rainfall. This poses the risk of allowing fine ("flash") fuels to grow and then dry. The Mediterranean region constitutes an interesting exception in that sense, as the burned area has decreased slightly since the mid-1980s.

1 Williams et al., Observed Impacts of Anthropogenic Climate Change on Wildfire in California, Earth's Future, 2019.

There is also evidence that the global wildfire weather season is lengthening as a consequence of climate change, i.e., that the number of days in the year with weather conditions favorable to sustain wildfires has increased.

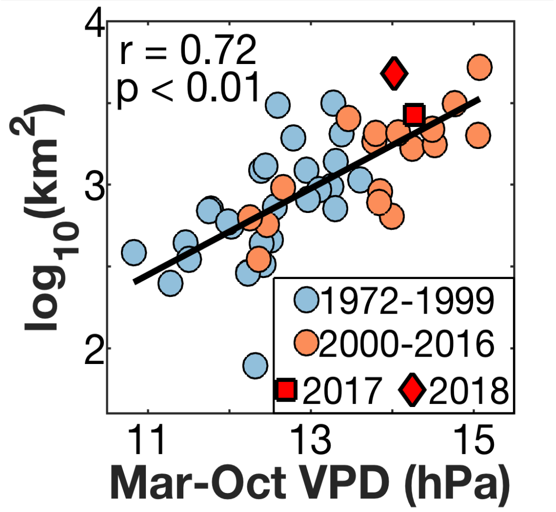

Figure 3: A summer-burned area in California compared to climate indicators. The atmospheric water VPD is used as a proxy for drier vegetation. (Source: Williams et al., Earth's Future, 2019, with permission)

While the burned area has increased during the last decades in many ecoregions around the globe (Fig. 4b), the overall number of fires follows a less intuitive trend. Data from the California Department of Forestry and Fire Protection (CAL FIRE) indicate that wildfires have decreased in numbers since 1985, although the trend has been reversed in the past 15 years (Fig. 4a). This leads to the conclusion that individual fires are, on average, increasing in size, i.e. wildfires are burning larger areas.

=============Side Box 2 - Fire Paradox ====================================

One of the many explanations for the increase in the burned area even with lower fire frequency is “the fire paradox.” To prevent catastrophic wildfires in the past, an effort (particularly in the US) was made to aggressively suppress all fires. Without periodic burning, dead plant material (solid fuel) accumulated over the years. The increased fuel load caused wildfires to be more likely to grow out of control and more severely affect the ecosystem. From that grew a shift in fire control efforts. Now, allowing low-intensity fires to burn and using controlled burning have become important wildfire management strategies.

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There are, of course, other factors that contribute to increased wildfire activity. Some of them are also triggered by climate change, including altered wind patterns, longer fire seasons, earlier snow melt, and longer snow-free seasons. But humans can also have a more direct impact on changes in wildfire activity. Growth in population at the wildland-urban interface (WUI) increases the probability of accidental wildfire ignition and exposes a larger number of people to the consequences of wildfires. Changes in land use and forest management also impact both wildfire numbers and total area burned (Box 2 – Fire Paradox). Invasive vegetation altering the natural ecosystem constitutes another factor of importance in terms of wildfire frequency and extension (e.g., invasive annual grasses in the Mojave Desert in the western United States, or increased tree density due to timber production in Chile).

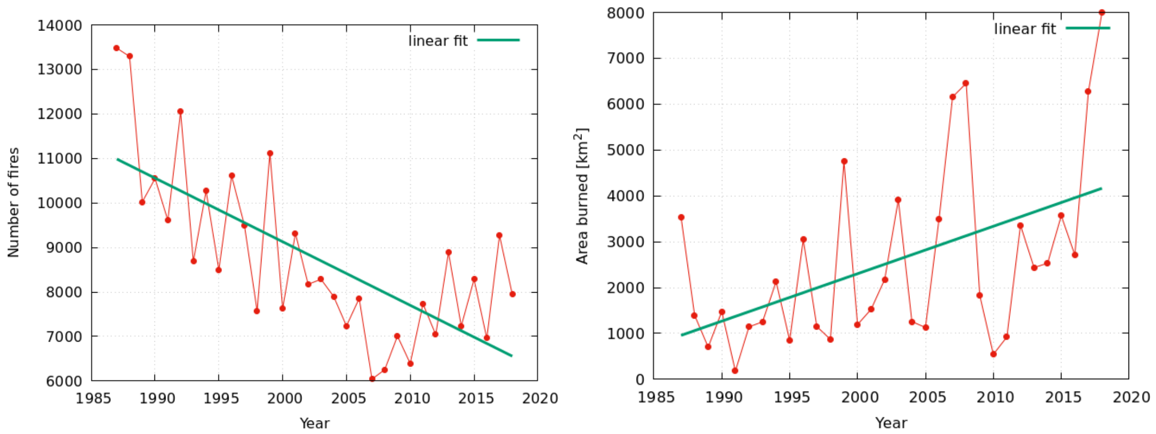


Figure 4: The evolution of frequency and burned area over time in California. Note that the number of fires is generally decreasing with time, but there may be a slight increase with time over the past decade. National US trends also do not show increases in the number of fires, but increases in the area burned.(Source: CAL FIRE)

Whether the risk wildfires pose to power networks has increased due to climate change is difficult to establish. There is a lack of indicators and data about the risk of wildfires. Wildfire frequency and area burned (such as those for California shown in Fig. 4) are the proxies typically invoked to describe the risk, but it is unclear whether these indicators translate into actual risk to power networks.

Information regarding fire severity would provide more insight into the potential for wildfires to damage power infrastructure. Observations of flame length, the estimated rate of heat release, or the presence of flames in the canopy of trees would be more telling indicators, but these are not reported consistently and are difficult to measure. Other indicators, such as flammability and fuel load, however, could be included in climate change studies related to wildfires for a better understanding of the link between climate change and wildfire activity.

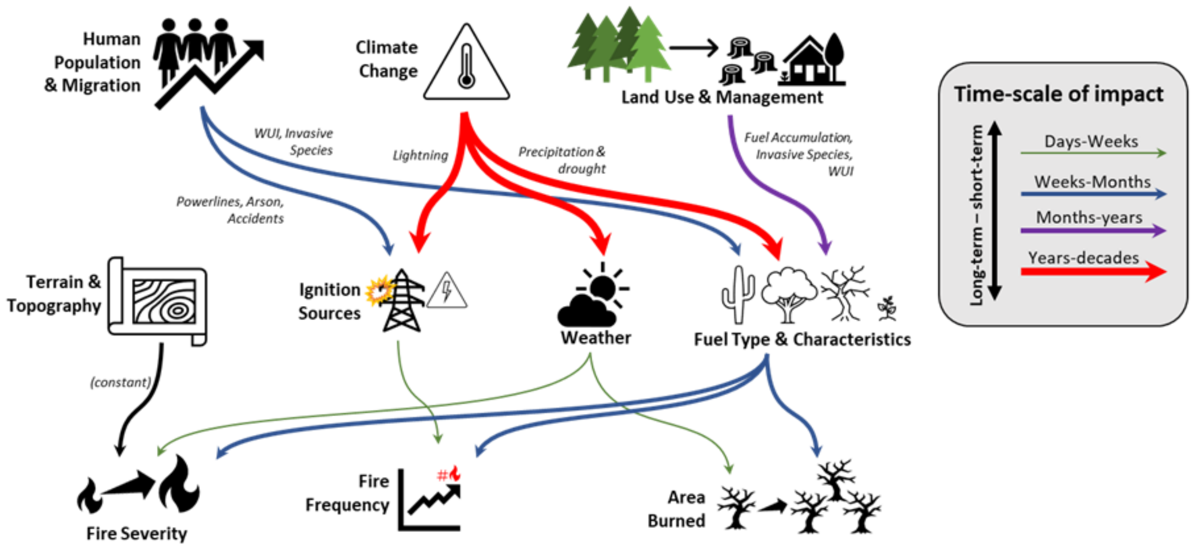
Furthermore, no published studies were found discussing the relationship between the risk posed to power networks by wildfires and climate change directly. However, an increased Forest Fire Danger Index (based on temperature, wind speed, drought, and relative humidity) positively correlates with an increased loss of houses due to wildfires. This suggests the risk posed to power networks by wildfires has increased, especially when considering that powerlines tend to be concentrated near human settlements.

The risk wildfires pose to overhead power networks is not constant in time. Change in land use and the associated change of vegetation can result in a change of wildfire frequency and intensity or even fires started by powerline interactions with vegetation. It has also been speculated that, if wildfire activity is increasing, vegetation in some regions might change (e.g., predominant species, prevalence, etc.) over the long term, because it cannot grow back at the same rate it is consumed. This means that wildfire activity might increase for a short time (a few years) in a certain region, but in the long term, it might decrease due to a change in vegetation that leads to a lack of fuel. This is valid only at a regional level as wildfires would then happen where the vegetation density and type remain favourable.

In summary, there is abundant evidence that points toward a direct link between climate change and increased wildfire activity. Combined with changes in land use due to human activity, and a growing WUI as a result of people moving to semi-rural areas around cities, there seems to be potential for increased wildfire activity affecting communities, including power infrastructure, in the future.

However, there also are claims suggesting that wildfire activity has not increased significantly, especially when considering much longer time scales. Researchers from Swansea University, UK[2], for example, found that the global biomass burned during the past century is lower than any time in the past 2000 years. They recognise the influence of climate factors on wildfire, but question the general conclusion of a global upward trend in wildfire activity and intensity. It is argued that time scales in the context of global changes are generally much longer than those considered in many studies, and long-term data do not support such a claim. The perceived increase in wildfire activity might be mostly due to raised awareness and extended media coverage of iconic wildfire events.

What is clear is that the climate is changing globally, and that a link between climate and wildfire activity exists. There seem to be more wildfires at regional levels, but extrapolation to a global scale does not seem to follow. To understand the different, interconnected factors influencing the occurrence of wildfires (qualitatively illustrated in Fig. 5), and to assess the potential of an increase in fire-related breakdowns of power transmission, a closer look at the interaction between power transmission system design and the dynamics of wildfires is necessary. This includes details on how wildfires start and which characteristics of the fire contribute to damaging power networks.



2 Doerr and Santin, Global trends in wildfire and its impacts: perceptions versus realities in a changing world, Phil. Transactions B, 2016.

Figure 5: The factors influencing changes in wildfire aspects, color, and arrow thickness designate approximate time scale of change.

Wildfire Dynamics

For a wildfire to occur, two conditions must be met simultaneously. There must be fuel that can support continuous fire spread, and there must be an ignition source strong enough to start the fire. It is unlikely that a fire would start from igniting the thickest part of a tree trunk. A dead twig or dried leaf is significantly more likely to catch fire and then spread to surrounding vegetation. This intuitive fact is the consequence of the physics that governs combustion processes.

Solid fuels do not burn directly. What burns are the gases liberated by the thermochemical degradation of the solid fuel when it is sufficiently heated. The degradation of woody biomass, known as pyrolysis, in very simple words, converts the organic (hydrocarbon) chemical compounds of wood into gaseous hydrocarbon fuels and char while leaving behind minerals in the ash. The energy necessary for this process comes from an external heat source (spreading flame or ignition source), and it must be sufficient to first heat the solid fuel to a temperature where pyrolysis reactions will produce gaseous fuel. This may also require heat to drive the evaporation of moisture held by the fuel, and then ultimately produce the fuel.

The morphology of the fuel is very important. In particular, the larger the surface to volume ratio of a fuel package (trunk, twig, leaf, etc.), the easier it is to ignite. In the wildland fire context, the reason for this is two-fold. First, fine fuels (which have a higher surface area to volume ratio) can be heated more quickly than larger fuels. Similarly, these fuels will respond more quickly to changes in the local moisture levels, allowing them to dry more quickly under drought conditions. Wildland fuels can be characterized as 1-hr, 10-hr, 100-hr, and 1,000-hr fuels. The time rating corresponds to how fast these fuels respond to changes in atmospheric moisture, such as a drought. As a result, some of the easiest fuels to ignite are the quickest to dry in drought, further increasing their ability to ignite and facilitate fire spread.

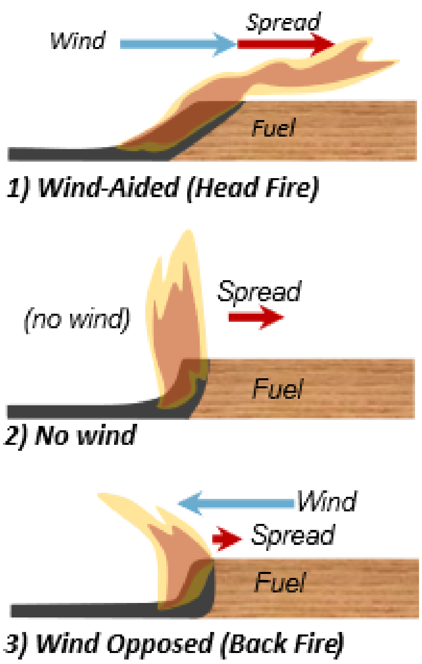


Figure 6: Effect of wind direction on fire spreading over a generic fuel. Faster fire spread is achieved in situations where the wind can bring the flame into better thermal contact with the unburned fuel.

Once a fire is ignited, the heat flux necessary for pyrolysis comes from the flame that results from the combustion of the gaseous pyrolysis products. A positive feedback loop is thus established: Heat from the flame is transferred onto the surface of the fuel package, providing the energy for pyrolysis. The gases produced by pyrolysis mix with the surrounding air and, under certain circumstances, produce a flammable mixture that burns, feeding the flame.

The spread of fire can be thought of as a continuous ignition process of unburnt fuel ahead of the reaction zone, where the feedback cycle dominates. Consequently, the rate of fire spread will depend on the effectiveness with which heat is transferred to the virgin fuel. The mode of heat transfer from the combustion zone to the surface is dominated by some combination of radiation and convective heating.

The geometry of the flame and its relative position to the fuel are crucial parameters in both heat transfer mechanisms. The heat transferred by radiation is a direct consequence of the projected flame surface area “seen” by the fuel. For convective heating, increased contact between the flame or hot combustion gases leads to faster fire spread, this impact is very strong in fire spreading through fine fuels. In general, the larger the flame and the more aligned it is with the fuel surface, the higher the rate of heat transferred via that mechanism. Under no-wind conditions, the flame position is driven by buoyancy (hot gases are less dense and rise), the flame tends to be in a vertical position. A strong wind can cause the flame to tilt either toward the unburned fuel or the burned fuel (Fig. 6).

A similar effect can occur if the fire is spreading on an incline (Fig. 7). In both cases, the fire spread is strongly driven by the thermal contact between the flame and unburned fuels (i.e., distance from flame to fuel) and the size of the area in front of the fire heated by the flame.

These factors explain why a flame spreading with the wind is faster than against, and why uphill fire spread is faster than on a horizontal plane. If the terrain where the wildfire spreads is irregular with valleys and peaks, the spread velocity may be further enhanced due to re-radiation from opposite sides. Terrain geometry, wind, and fuel characteristics are thus the three dominating parameters that determine the rate of spread of a wildfire.

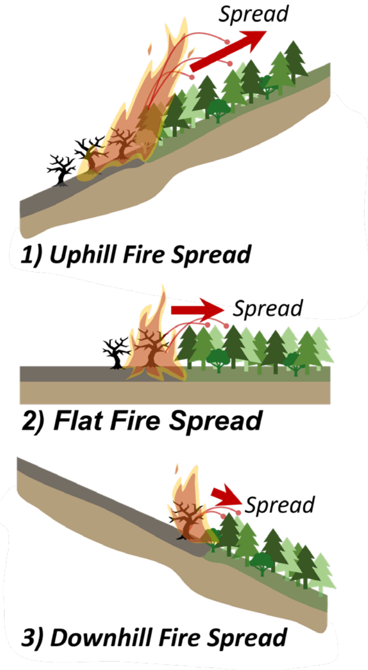


Figure 7: Effect of slope on fire spread. Buoyancy causes flames to align vertically which in uphill fire spread causes more effective fuel heating from the flame.

But not all fires prosper. Unburnt fuel must be close enough to the burning region to receive sufficient heat flux from the flame to produce enough gaseous fuel through pyrolysis reactions. If the feedback cycle is locally interrupted, the flame may extinguish and further spread is prevented. But even if the flames extinguish, combustion may still occur at the surface of the char left behind by the pyrolysis (similar to charcoal in a barbecue). The heat produced is much less, but if conditions are favourable (small heat losses and enough oxygen), it might be enough to maintain pyrolysis. In porous fuel beds, such as grounds covered by pine needles, or in peat soils, such smouldering fires can survive and grow for long periods. If conditions again change, the pyrolysis gases can re-ignite and transition to flaming may take place, such as happened in the Oakland Hills Fire of California in 1991.

Ignition of Wildfires

As described, a series of physical processes must take place to ignite a wildfire. Sustained ignition can only be achieved if the heat from the flame produces more gaseous fuel by heating more solid fuel (in simpler words, the fire must then be able to spread). Even under very favorable conditions (e.g., Santa Ana winds in California), about half of ignited fires have limited spread and do not grow to become large wildfires.

Natural ignition sources are limited to lightning and volcanism. Self-heating of natural fuels, such as peat, may also cause ignition. Since peat is a porous organic material, air can penetrate the soil and cause spontaneous exothermic oxidation. This oxidation process is very slow at ambient temperatures, but since heat cannot escape, temperature builds up and ignition of self-sustained smouldering combustion may occur.

However, according to a 2017 article in *Proceedings of the National Academy of Sciences* by Balch et al, the predominant cause of ignition around the globe (>80%) is a consequence of human activity. The ignition can be due to arson, negligence, or accidents. Among the latter, powerlines play an outsized role. Powerline-involved wildfires typically occur under worse fire conditions (high winds, low moisture/humidity) resulting in rapid growth. As a result, powerline-caused fires are typically larger and faster spreading compared to the average wildfire.

Types of Wildfires

Since vegetation (live or dead) feeds wildfires, the nature of the resulting fires is as diverse as vegetation itself. A fire spreading over grasslands will produce shorter flames than one propagating through densely packed shrubs. The rate of propagation, on the other hand, will be significantly higher than in the latter. This results in a shorter residence time, which reduces the time larger objects are exposed to heat. This fact is crucial for the characteristics of wildfires propagating in woodlands and forests, where large trees co-exist with shrubs and smaller vegetation and where the ground is covered with combustible material that has fallen from the trees. The wildfire type is also important in terms of the risk it poses to power networks, as not all fires would potentially produce the same damage.

Surface Fires

If wildfires occur regularly in woodlands and forests, consuming the dead organic matter accumulated over a relatively short time, they will spread quickly over the dry fuel lying on the ground and have a low intensity (short flames and a low rate of heat release as shown in Fig. 8). If such a fire passes below powerlines, it is less likely to cause significant damage to them, as it does not interact closely enough with the conductors.

Larger shrubs and trees require more heat to ignite. Their size also allows the vegetation to retain moisture longer than smaller fuels, such as dry grass or twigs.

Figure 8: A low intensity surface fire (back fire set by fire fighters to contain fire). Short flames and high spread velocity cause little damage. (Photographer: Philip Pacheco - www.philippachecophoto.com, used with permission).

A variety of reasons, however, can lead to intensified ground fires, such as drought periods that lower the moisture content of shrubs and other larger vegetation. Another reason could be poor land management causing accumulation of dry organic matter with a consequently larger energetic content. There is evidence that weather extremes, such as abundant rain followed by prolonged drought, can result in excessive vegetation with very low moisture content, which is a hazardous combination in terms of wildfire.

Canopy (Crown) Fires

When surface fires, which under normal circumstances do not pose a problem to trees or powerlines, grow in intensity, their flames may bypass trunks and ignite thinner twigs and leaves in the canopy. Despite their relatively high moisture content, intense burning is possible due to the favourable geometric configuration (thin components surrounded by sufficient air). Recent research has shown that for live fuels, such as green foliage in the forest canopy, the moisture also contains sugars and other organic species that can promote ignition. While the underlying propagation mechanism of canopy fires is the same as ground fires (pyrolysis induced by heat from the flame), flames are considerably longer and enhance the propagation speed. The strong convective forces induced by the large flames add a new, discontinuous propagation mechanism that often poses severe challenges to fire management. Glowing embers/firebrands (small branches, twigs or cones) are broken off the tree and carried away by rising gases from the fire. Depending on their aerodynamic characteristics, these firebrands can travel kilometres and ignite spot fires (small fires) ahead of the fire front. Canopy fires are more capable of severely affecting power networks, as the flames can interact directly with conductors.

Figure 9 A high intensity canopy fire. Flames are long enough to directly interact with the conductors of powerlines, causing them to flashover (Photographer: Mike Eliason, Santa Barbara County Fire-Public Information Officer, used with permission).

============= Box 3 ==

Fire Characteristics Based on Land Use

The terms “wildfire” and “wildland fire” commonly describe fires that occupy land with significantly different usage, fuel loading, and modes of spread. In the wildfire research communities, the terms are used more narrowly. The main distinction is between wildland fires (nearly all natural fuels) and WUI fires. Unlike wildland fires, WUI fires burn through a combination of - or between wildland and urban fuels (e.g., structures, vehicles, ornamental/agricultural vegetation, etc.). The difference in the fuel loading can be seen in Figure 10 which shows satellite images of WUI and non-WUI areas. The WUI areas can either be interface-WUI or intermix-WUI fires, the difference being in how separated (or intermixed) the urban and wildland fuels are.

Figure 10: Examples of overhead power lines in different WUI and non-WUI land. (Source: Google © 2021)

Wildland fires often pose little or no threat to communities and are on many occasions ignited by lightning. In some remote areas, such as the western United States, these fires are allowed to burn. In contrast, WUI fires intrinsically occur near communities. Wildland fire can spread into a community and become a WUI fire. Power line-involved fires occur near communities and thus are most commonly WUI fires likely accompanied by structure loss.

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Wildfire Management: Prevention and Response

If there is a tendency of wildfires to become more intense due to climate change, it is advisable to put effort into decoupling the effects of climate change from increased wildfire activity, and to prevent power disruptions and powerline caused ignition. This can be done, at least partially, by effective and efficient wildfire management.

General Prevention and Response

Wildfire management can be grouped in terms of preventative measures and response measures. Wildfire prevention consists in avoiding the initiation of any wildfire that cannot be readily controlled by managing the forest itself, like fuel reduction or prescribed burning, and removing accidental ignitions, like forbidding bonfires or shutting down powerlines. Wildfire response involves fire containment, evacuations, and structure defense. The goal is to achieve containment of the fire. This is done by creating a perimeter using natural features (e.g., bodies of water), infrastructure (e.g., wide roads/highways), and firebreaks created in advance, by ground crews or fire retardant from aircraft. Ground crews create firebreaks by clearing vegetative fuels or starting a low-intensity fire that spreads into the wildfire front.

During WUI fires, first responders focus on orderly evacuation from areas at risk. Inadequate paths out of affected areas or lack of evacuation planning can lead to significant loss of life as seen in wildfires around the world. Finally, fire crews can perform structure defense activities by spraying water on structures and surrounding vegetation to limit ignition.

Over-reliance on fire response is not an effective long-term solution to wildfire management. It can reinforce the “fire paradox” (Box 2 – Fire Paradox) and involve substantial resources (people, equipment, etc.). During particularly bad fire seasons, relevant agencies responding to fires can be constrained in their ability to deploy fire crews to different locations.

In contrast, wildfire prevention includes many actions that can be taken by the broader community, including landholders such as utility companies. These actions prevent or limit spread by creating fire/fuel breaks around and within communities, clearance distances between structures and large or highly flammable vegetation, and adoption of appropriate fire and building codes. Communities can also develop fire shelters, providing emergency supplies to victims during events.

Controlled burning is an important preventative tool to mitigate losses from wildfires. During controlled burning, low-intensity fire is carefully, intentionally, and regularly set on managed land to reduce the fuel load, especially fine fuels which are easier to ignite and spread the fire. Finally, a crucial aspect of wildfire mitigation is community planning, ensuring that major roadways have sufficient capacity to allow egress of evacuating vehicles.

Powerlines Prevention and Response

While power utilities can take part in some of the activities described above, there are also specific actions they should take to prevent fires. First is the monitoring and clearing of vegetative encroachment near power transmission lines. This can limit the risk of interactions between powerlines and vegetation, but also the risk of ignition by controlling the types of fuel below the conductors. Similarly, regular inspection and maintenance of power transmission equipment are important. Several recent large loss wildfires in the United States have been attributed to a lack of appropriate equipment maintenance.

There are also important technological approaches to wildfire prevention. One method is the adoption of fault detection strategies to limit the ignition risk from tree-powerline interactions. Another approach is hardening powerlines, typically by burying them. Recently Pacifica Gas & Electric, the largest power utility in California, announced it would bury 10,000 miles of lines over the next decade. Similar approaches were taken in Australia following the 2009 Black Saturday Fires.

Another approach is public safety power shutoffs where power is intentionally shut off during periods of significant fire danger. However, shutoffs can also have dangerous consequences to local health care and food supply. To address this, there have been recent efforts to place critical services onto microgrids that can continue to operate during such events. There are of course newer and emerging technologies to address the impact of wildfires on power distribution systems.

Conclusions

The threat of wildfires poses a significant risk to the safe operation of power networks. If the fuel and weather conditions are right, wildfires can damage power infrastructure. Overhead power lines are a potential ignition source of wildfires and are sometimes shut off to avoid this during high winds. To determine how the future could be for power line involvement with wildfires, this article examines how climate change affects wildfire characteristics as well as how power line faults may cause wildfires.

While climate conditions undoubtedly affect wildfire behavior, it is difficult to determine exactly how wildfire behavior will be influenced based on previous fires. There is evidence that in some regions, wildfire activity has increased as a result of climate change during the past decades. In other regions, the evidence is less conclusive due to a decreasing number of fires but increased overall burned areas.

One issue is that fire intensity itself (rate of released heat, flame length, etc.) is not generally reported, so it is not possible to determine whether it has increased as a result of climate change. Other factors also influence wildfire behavior, and it is usually not possible to separate the contributing factors from each other. Changes in land use and human migration are happening simultaneously to climate change, and their effects are often similar, making their relative influence difficult to establish. As a result, a fundamental problem in establishing a direct link between an increased number of failures in power networks and climate change is the lack of data for a satisfactory proxy for fire intensity.

Understanding the dynamics of wildfires may contribute to a clearer idea of what might occur in the future and provide tools to avoid unfavorable scenarios in terms of power outages caused by wildfires. Drought, intense winds, and other extreme weather phenomena play into the hands of intensifying wildfires, and an increased risk to the operation of overhead power networks seems a realistic possibility for the near future. Adequate wildfire management, including the creation of fuel/fire breaks and prescribed burning, can help to interrupt the feedback loop that results in high-intensity fires and contain wildland fires within their natural domain of occurrence.

Further Reading

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