

ENVIRONMENTAL EDUCATION AND FOREST FIRE PREVENTION IN ENERGY TRANSMISSION NETWORKS

EDUCAÇÃO AMBIENTAL E PREVENÇÃO DE INCÊNDIOS FLORESTAIS EM
REDES DE TRANSMISSÃO DE ENERGIA

EDUCACIÓN AMBIENTAL Y PREVENCIÓN DE INCENDIOS FORESTALES EN
REDES DE TRANSMISIÓN DE ENERGÍA

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ABSTRACT

This article explores the importance of environmental education in the prevention of forest fires, especially in areas under the influence of electric power transmission networks. Through a literature review, the study highlights how educational actions aimed at local communities, managers, and operators of the electrical system can reduce the risk factors associated with fires and strengthen the resilience of transmission systems. Statistical data show that in 2017, 21.3% of transmission line outages in Brazil were caused by forest fires. The highest incidence of fires occurs in the Northeast, Southeast, and Central-West regions of Brazil, in areas dedicated to sugarcane cultivation and in anthropized cerrado areas. Environmental education emerges as a strategic tool in environmental risk management and the promotion of sustainability.

Keywords: Sustainability. Risk Management. Community Awareness. Transmission of electric energy.

RESUMO

O artigo destaca a relevância da educação ambiental na prevenção de incêndios florestais, com foco especial em áreas sob influência de redes de transmissão de energia elétrica. Por meio de uma revisão de literatura, evidencia-se que ações educativas direcionadas a comunidades locais, gestores e operadores do sistema elétrico podem reduzir fatores de risco associados aos incêndios e aumentar a resiliência dos sistemas de transmissão. Dados estatísticos revelam que, em 2017, 21,3% das interrupções em linhas de transmissão no Brasil tiveram como causa incêndios florestais, sendo as regiões com maior incidência o Nordeste, Sudeste e Centro-Oeste, em áreas de cultivo de cana-de-açúcar e cerrado antropizado. Assim, a educação ambiental é apresentada como estratégia fundamental para a gestão de riscos e promoção da sustentabilidade.

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Palavras-chave: Sustentabilidade. Gestão de riscos. Educação ambiental. Transmissão de energia elétrica.

RESUMEN

El artículo resalta la importancia de la educación ambiental en la prevención de incendios forestales, especialmente en áreas bajo influencia de redes de transmisión de energía eléctrica. A través de una revisión bibliográfica, se evidencia que las acciones educativas dirigidas a las comunidades locales, gestores y operadores del sistema eléctrico pueden reducir los factores de riesgo asociados a los incendios y fortalecer la resiliencia de los sistemas de transmisión. Los datos estadísticos muestran que, en 2017, el 21,3% de las interrupciones en las líneas de transmisión en Brasil fueron causadas por incendios forestales, principalmente en las regiones Nordeste, Sudeste y Centro-Oeste, en zonas de cultivo de caña de azúcar y áreas de cerrado antropizado. Por lo tanto, la educación ambiental se presenta como una herramienta estratégica para la gestión de riesgos y la promoción de la sostenibilidad.

Palabras clave: Sostenibilidad. Gestión de riesgos. Educación ambiental. Transmisión de energía eléctrica.



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INTRODUCTION

Environmental education is a crucial tool in addressing contemporary sustainability challenges, playing a significant role in the prevention of forest fires, which pose severe threats to environmental balance, population safety, and critical infrastructure. In Brazil, where electric power transmission systems traverse extensive vegetation areas, forest fires not only affect ecosystems and biodiversity but also directly impact the reliability of electricity supply, resulting in line outages and economic and social losses.

In this context, this article seeks to explore the intersections between environmental education and forest fire prevention, focusing on its application in areas under the influence of electric power transmission networks. To this end, it conducts a literature review aimed at mapping studies, methodologies, and practices that highlight how awareness and societal engagement can contribute to mitigating fire risks and their impacts. The proposal is to demonstrate how educational actions aimed at local communities, managers, and operators of the

electrical system can reduce the risk factors associated with fires and strengthen the resilience of transmission systems.

Forest fires are multifaceted, with causes ranging from natural factors to human interventions, with the latter being predominant in several regions of the country. Among the challenges faced, the lack of adequate maintenance in safety corridors and the coexistence of agricultural activities near transmission lines stand out. Environmental education thus emerges as a transformative element by providing technical and social knowledge about the consequences of fires and stimulating behavioral changes for environmental preservation and the protection of electrical infrastructure.

The article is structured in sections that initially address the characteristics and challenges of electric power transmission systems, followed by an analysis of the impacts of forest fires on these systems, and finally, a discussion on the role of environmental education. By compiling data and analyses from various academic and institutional sources, the aim is not only to understand current dynamics but also to propose ways to integrate educational practices into the planning and operation of transmission networks.

Thus, this study aims to contribute to the advancement of research on sustainability and environmental risk management, highlighting education as a strategic tool for mitigating environmental impacts and promoting safer and more efficient electric power transmission systems.

METHODOLOGY

The method adopted for this research was a literature review, based on a comprehensive examination of existing literature. Initially, to define the topic and the problem, a search was conducted for works related to the Brazilian electrical system, forest fires, and environmental education. The selection of works was based on keywords such as "education", "fires", and "energy transmission".

To conduct the research in a detailed and specific manner, three main databases were used: the Scientific Electronic Library Online (SciELO), Google Scholar, and the CAPES journal platform. These databases provided robust support for the research.

A sampling was conducted in the three mentioned databases, resulting in a total of 90 selected works. This sampling process aimed to ensure a diversity of perspectives and approaches on the topics of interest.

The selected works were predominantly published between 2000 and 2024. This time frame was chosen to ensure the relevance and timeliness of the information. Works focusing on engineering, human sciences, and applied social sciences, areas that frequently explore the intersections between education and the impact of forest fires on the electric power transmission system, were included. The selection encompassed works written in Portuguese and English, allowing for the inclusion of a wide range of relevant studies. Works prior to 2000 were excluded, except for those addressing fundamental concepts and definitions of sustainable development. Works not directly related to the study's theme or not in the specified languages were also excluded.

The initial analysis of the documents was conducted through the reading of abstracts. This step allowed for the identification of the relevance of the works to the proposed topics. After reading the abstracts, the works considered relevant were subjected to a more detailed examination, which included a complete reading of the main textual elements, such as the introduction, methodology, results, and discussions.

The choice of a literature review as the primary method is justified by its ability to provide a broad and diverse view of the topic, as highlighted by Gil (2019). The literature review allows for the compilation and synthesis of established knowledge, identifying gaps and opportunities for new investigations (Creswell, 2009). Additionally, the use of renowned databases such as SciELO, Google Scholar, and the CAPES journal platform ensures the quality and credibility of the selected sources (Lakatos & Marconi, 2021).

LITERATURE REVIEW

In this section, we will discuss electrical systems and their characteristics, the performance of electric power transmission lines subjected to forest fires, and the impact of education on the prevention and control of forest fires. We will also discuss the Brazilian electrical system in terms of governance and expansion planning, and the impacts related to forest fires.

Electric Power

In Physics, work is the result of the product of an applied force and the displacement produced. In turn, energy is defined as the variation of work. The concept of energy is subject to a universal rule that knows no exceptions: the law of conservation of energy. According to this law, energy is not created but transformed (Halliday, Resnick, & Walker, 2016).

Energy is an essential element of modern society (Pavão & Leal, 2016).). Without energy, society as we know it would not exist. Energy can be found in various forms: kinetic, potential, thermal, photovoltaic, electrical, etc. (Reis, 2011; Reis & Santos, 2015). The conversion of various forms of energy is an essential factor for our civilization.

Although we do not use it directly, energy in the form of electricity is what allows for long-distance transport with minimal losses (Queiroz, 2010). Due to this property, electric power is of utmost importance in our society.

The simple act of turning on a light bulb can demonstrate the complexity and importance of electric power. The energy that makes the bulb function is certainly being produced at a distant point, often hundreds of kilometers away. The origin of the energy may come from a rotating machine that converted kinetic energy into electrical energy. In this form, the energy was guided by a system until it reached its destination. This occurs almost instantaneously, as electrons travel at speeds very close to that of light (Hayt Jr., 1994).

According to Daniel Kammen, the electrical grid that makes this possible has been considered the most complex machine humanity has ever built. It is the largest, most extensive, has the most parts, and possesses a magnificent simplicity (McCabe, 2017).

What is an Electrical System

An electrical grid is a collection of interconnected elements in a specific manner (Johnson, Hilburn, & Johnson, 1994). These grids are commonly referred to as electrical systems and are divided into transmission systems and distribution systems.

Transmission and distribution systems are distinguished by their energy transport capacity and capillarity. Transmission systems are designed to transport large blocks of energy over long distances (Pereira & Spritzer, 2007). This transport is done point-to-point, with low capillarity. Distribution systems, although of lower transport capacity, are extremely capillary, connecting

each consumer to the electrical system (Garcia, França, González, Yoshimoto, & Lyra Filho, 2003).

Technically, transmission and distribution systems are distinguished by the voltage levels at which they operate. Depending on the system, these values are different, but the voltage levels of the transmission system are always higher than those of the distribution system. In Brazil, voltages greater than or equal to 230 kV are considered for energy transmission (EPE, 2024). For comparison, a residence in Brasília is supplied at a voltage of 220 V, more than a thousand times lower than the levels used in transmission.

Higher voltage levels imply lower current values to transmit the same power. The main losses in electrical systems, the Joule effect, are proportional to the square of the current (Johnson et al., 1994). Therefore, lower currents mean lower losses. Thus, to transmit large blocks of energy, higher voltage levels are used.

Therefore, the function of the electrical system, whether transmission or distribution, is to transport energy.

The Brazilian Electrical System

The way in which society obtains the energy it demands for its development is a crucial factor for future success or failure. According to Amado (2017), only development that observes the pollution support capacity of ecosystems, respecting the permanence of natural resources, will be sustainable, in order to maintain good standards of environmental quality.

Obtaining energy sustainably necessarily involves the use of renewable sources, and in this regard, Brazil stands out internationally, with an average of 49.1% of its energy matrix coming from renewable sources, while the global average is 14.7%, considering consolidated data from 2023 (EPE, 2024).

By the end of 2016, Brazil's transmission system comprised 252 contracts across 159 concessionaires, covering 130,000 km of transmission lines (138–800 kV), around 500 substations, and an installed transformation capacity exceeding 320 GVA (Aneel, 2016; Costa et al., 2017).

Performance of the Brazilian Electrical System

The performance of the Brazilian electrical system is monitored by the Integrated System for Recording Disturbances – SIPER –, owned by the ONS. This system collects, classifies, and verifies the consistency of data on forced outages and disturbances occurring in the SIN, for statistical purposes and calculation of performance indicators (ONS, 2016).

SIPER has been operating since 2013 and has valuable databases for the analysis of outages in the transmission system.

Outages Caused by Forest Fires

According to Jian et al., (2013), forest fires always cause the interruption of the operation of transmission lines, which is why the study of the phenomenon is of utmost importance. This occurs because overhead transmission lines have their insulation significantly reduced by the presence of high-temperature gases and suspended particulate matter, which, combined, cause the flashover of electrical circuits (Yi-Shi Yue, Yan-Hui Zou, Fu-Yong Huang, Zheng-Xiong Gong, & Cheng Wang, 2017).

Pu et al., (2015) demonstrated that temperature, flame conductivity, and ash are the main factors leading to the breakdown of air dielectric strength. In the same work, laboratory tests showed that the resistivity of air under fire conditions is reduced to about 20% of that under pure air.

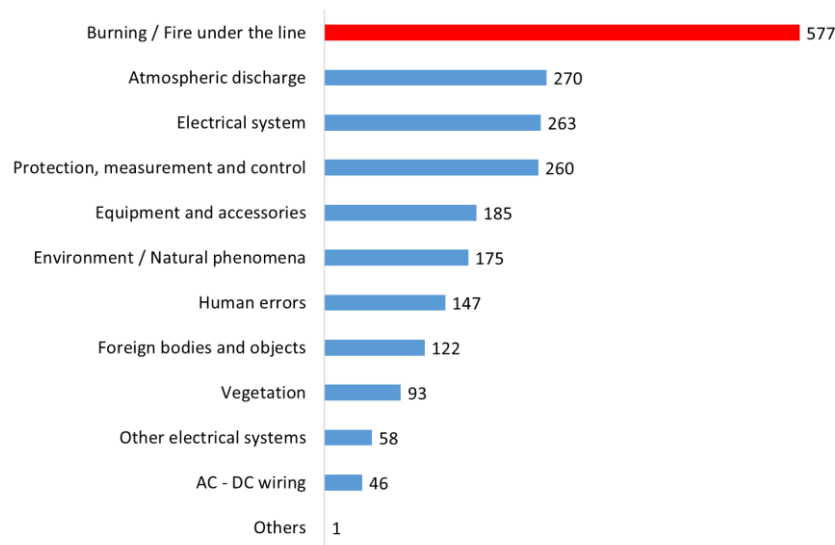
Fonseca et al., (1990) highlighted that even after a forest fire has ceased, there is a deposit of particulate matter on the surface of insulators, which can cause an undesirable increase in conductivity, leading to new outages of transmission lines.

In 2017, 21.3% of transmission line outages in Brazil were caused by forest fires (ONS, 2018). For comparison, South Africa, with a transmission system of 28,000 kilometers, had 22% of its transmission system forced outages caused by forest fires between 1993 and 2009 (Minnaar, Gaunt, & Nicolls, 2012).

From July to December, considering the dry season in most of Brazil, the incidence of forest fires increases significantly, being the main known cause of unplanned transmission outages in the country. Figure 1 shows the relationship between the causes of outages and their absolute quantities in the second half of 2017.

Figure 1

Main known causes of forced outages in transmission lines, from July/2017 to December/2017



Source: Operador Nacional do Sistema Elétrico – ONS (2016)

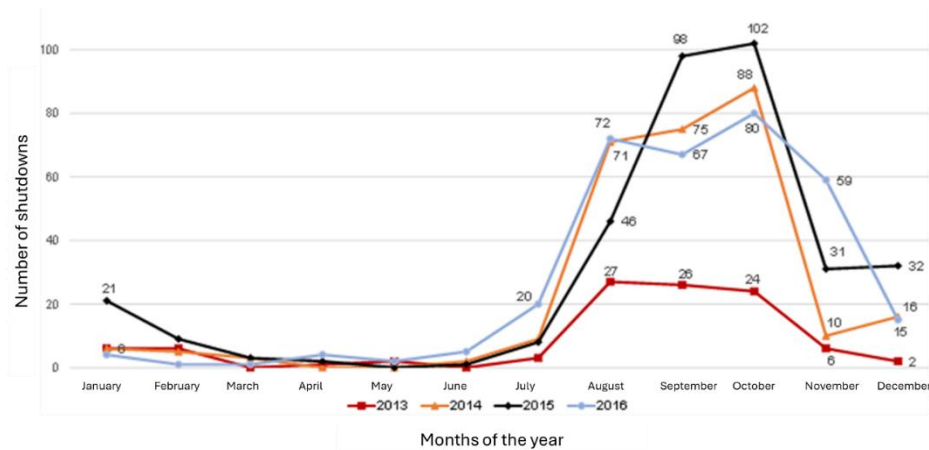
According to ANEEL inspection studies (2018) the highest incidence of forest fires occurs in the Northeast, Southeast, and Central-West regions of Brazil, respectively in areas of the Zona da Mata dedicated to sugarcane cultivation and in anthropized cerrado areas.

The incidence of forest fires in the safety corridors of Regional Interconnections represents a serious risk of forced outages of these lines, a situation that, depending on the configuration and operating point of the electrical system, can cause blackouts with serious consequences for the electrical system. This was the case on August 28, 2013, when a large-scale forest fire reached the safety corridor of the 500 kV Ribeiro Gonçalves / São João do Piauí line, part of the North/Northeast Interconnection, and shut down both circuits simultaneously, causing a blackout throughout the Northeast region and part of the North region of Brazil (Guido Jr. et al., 2018).

Figure 2 shows the monthly distribution of forced outages of transmission lines caused by forest fires recorded from 2013 to 2016. It is observed that this is a seasonal phenomenon, with a higher concentration of forced outages between the months of July and December each year (dry season).

Figure 2

Forced outages caused by forest fires in all transmission lines of the Basic Network and Complementary Network from 2013 to 2016



Source: Agência Nacional de Energia Elétrica – Aneel (2016)

One of the factors that significantly increase the risk of forced outages of transmission lines due to forest fires is the existence of medium/large vegetation within the safety corridors. It is the obligation of transmission companies to maintain the safety corridors in adequate conservation conditions, observing the restrictions imposed by environmental agencies. However, due to the high costs involved in carrying out these activities, the cleaning of safety corridors (maintenance of low vegetation) is not always carried out adequately, often resulting in delays in the execution of services, causing the safety corridors to enter the dry season with large masses of vegetation inside (Guido Jr. et al., 2018).

Fonseca et al. (1990) reported that under fire conditions, the safety distances of the conductor to ground in 500 kV transmission lines should be increased from 9.5 to 13.5 meters (an increase of 42%) and in 230 kV transmission lines, the increase should be from 8 to 10 meters (an increase of 25%). In the case of distances between conductors of different phases, the increase should be from 9 to 11 meters (an increase of 22%) in 500 kV transmission lines and from 6.5 to 8 meters (an increase of 23%) in 230 kV transmission lines.

For a 70 kV transmission line, Robledo-Martinez, Guzman, & Hernandez (1991) found that the dielectric strength of air is reduced by half under forest fire conditions, compared to pure air conditions.

The Role of Environmental Education in Forest Fire Prevention

The UN's 2030 Agenda, through SDG 4, promotes inclusive and equitable education that fosters sustainable development by integrating environmental education into school curricula to transform students' relationship with the environment (Nações Unidas, 2024).

Reigota and Soares (2004) emphasize that environmental education should go beyond information transmission, encouraging active citizenship and linking scientific knowledge to local realities. Similarly, Gonçalves, Oliveira and Gonçalves (2022) highlight the need to adapt educational practices to regional and cultural contexts, stressing interdisciplinarity and the dialogue between science and local knowledge in addressing challenges such as climate change and biodiversity loss.

Loureiro (2003) critiques traditional approaches and advocates for a dialogical environmental pedagogy that values prior knowledge and local contexts, fostering a more inclusive and contextualized educational practice.

Next, we will present works related to environmental education and forest fires at the international level and in Brazil.

The Relationship Between Environmental Education and Forest Fires at the International Level

Ryan (2012) explored the impact of landscape preference and environmental education on public attitudes toward wildfire risk reduction strategies in the fire-prone pine barrens of the northeastern United States. To understand these issues, a sample of 233 residents living at the urban-wildland interface of Long Island, New York, and southeastern Massachusetts were interviewed with a photographic questionnaire containing scenes of different forest management strategies, as well as an educational section describing the environmental implications of forest management near their homes. The results of this study showed that knowledge about native ecosystems had a significant impact on local residents' support for management strategies, such as prescribed fire to reduce wildfire risk and promote native plants.

For Papaspiliou, Skanavis and Giannoulis (2014), forest fires, like all natural disasters, have the potential to seriously affect both the environment and the social structure of a local community. Unlike some natural disasters, such as hurricanes, tornadoes, and tsunamis, which

are unpredictable, the phenomenon of forest fires can be easily predicted and controlled, as the causes are mainly anthropogenic. Their study deals with the significant role that Civic Ecology Education plays in promoting resilient societies in Greece. The study argues for the need for successful environmental education for resilience, in order to avoid similar tragedies. Increasing social tolerance to natural risks and directing community efforts toward strengthening sustainable development in their area should become a priority everywhere.

For Yustina and Kapsin (2017), land and forest fire issues require a comprehensive effort, one of which is through the dissemination of educational values, such as scientific education. The authors conducted a study with 7th-grade science students to assess knowledge about forest and land fires.

Colaço, Rego and Cartea (2018) reported that fires are the greatest threat to Portuguese forest spaces and are mostly a social problem. With the aim of understanding whether the skills provided in various university courses in the forestry area meet the various labor demands of these professionals and the challenges of the 21st century, a survey of the training needs of technicians was conducted, comparing them with the different professional activities and their university education at the undergraduate and master's levels. From this analysis, it was found that there are various new functions mainly related to social components, such as in the area of environmental education and awareness. Thus, it was concluded that the greatest discrepancies between what is important for professional performance and the preparation of technicians are mostly in the human dimension of forest resource management, particularly in the integration of the social component of risk perception by the population in management.

For Xiong et al. (2020), forest fires are a recurring and serious problem that raises major environmental, economic, and social concerns. Information on the temporal-spatial distribution of ignition probability and the identification of the factors driving the pattern of forest fire occurrences are the most challenging issues in the world. In this study, the spatial distribution and temporal variation in forest fire occurrence were examined by applying the Maximum Entropy (Maxent) algorithm. Redundancy analyses were used to determine the contributions of the determining factors (forest fire policy, human interventions, and biophysical variables) to forest fire occurrences. The results suggest that we should strengthen administrative capacities to prevent forest fires and improve publicity and education on fire prevention among residents living near the national border and/or in low population density areas to increase awareness and compliance of local residents with forest fire policies.

For Parajuli et al. (2022), every year, forest fires cause enormous damage to forest ecosystems and the landscape of Nepal. For active community engagement at the landscape level, policymakers must take into account the interests of local forest managers to increase social acceptability. This research explores the perception of community forest managers, who are constantly managing forests at the grassroots level, to understand the relationship between their priorities, needs, and attitudes toward forest fire management. Most respondents agreed with the activities under the forest fire management strategies and actions section, followed by forest fuel management and infrastructure.

Andrew (2022) found that in the last two decades, there has been an increase in investments in exotic forests and commercial forest plantations in Tanzania. However, fire has repeatedly been pointed out as the number one risk to investments in forest plantations, and improved management is urgently needed to reverse the trend and ensure the sustainable supply of forest products. To effectively control fires, it is important that forest policy is enforced, fire education and awareness are enhanced, local community support is promoted, and fire prevention and suppression are strengthened in Tanzania.

For Noviana et al. (2023), disaster education remains crucial in building resilient communities, especially in disaster-prone areas. An essential element of the educational strategy in this article involves the integration of local wisdom into teaching and learning processes. The set of teachings, moral values, social norms, and cultural practices that guide the daily life and behavior of people within the Malay community forms the basis for knowledge and didactic transposition in disaster education to emphasize the prevention of floods, landslides, droughts, and forest and land fires. The authors conclude that the meanings of these values need further academic exploration to create a more comprehensive understanding and preservation.

Brazilian Experiences in Forest Fire Prevention Through Environmental Education

Medeiros and Fiedler (2004) showed that most of the causes of fires in the Serra da Canastra National Park (50%) are of human origin, despite the large number of fires caused by lightning (44%). Among the human causes, most are criminal, originating from arsonists (47%).

There is a high concentration of fires caused by lightning in the rainy season and the transition from dry to rainy season and a concentration of human-caused fires during the dry season, mainly between June and October. However, lightning fires usually burn small areas (less

than 500 ha), while human-caused fires are more catastrophic, affecting larger areas. To reduce forest fires within the Park, fire control through prevention actions, little disseminated in the region, is essential, mainly through environmental education and fuel isolation through firebreaks (Medeiros & Fiedler, 2004).

Cavalca and Cavalca (2018) highlighted the importance of forming environmental awareness in the population through education, aiming at the prevention of forest fires. A bibliographic research was conducted, demonstrating through statistical data that a large part of forest fires occurs due to human causes. For the authors, the use of environmental education as a working tool for forest fire prevention is fundamental, acting on the causes, preventing fires from starting.

Matsuo and Silva (2021) developed work with the aim of analyzing the profile of schools and the approaches to Disaster Risk Reduction Education (DRRE) adopted in 127 practices enrolled in the #LearnToPrevent Campaign. In the purpose of educating in societies of risk and socio-environmental disasters, the authors presented some reflections: i) denaturalize disasters and understand them as a social and cultural construction; ii) form critical and resilient societies, capable of dealing with life's uncertainties; iii) adopt a local perspective; and iv) recognize schools as producers of knowledge.

Felipe and Bernardi (2023) developed the Pequi Pedagogical project, which deals with the teaching of Probability and Statistics, anchored in forest fire prevention, using as technological resources geoprocessing, multimodal virtual tools, virtual teaching environments, video conferencing platforms, action simulation, and indication of pedagogical possibilities. We conclude that the proposed interaction mechanisms promote the active participation of the student in the entire teaching process, enabling dynamic and contextualized learning, based on dialogue and criticality.

Santos et al. (2023) conducted a study with the objective of verifying the existence of an interface between the actions of Civil Protection and Defense (CPD) and Environmental Education in schools, for the prevention of burns and forest fires, in the municipality of Palmas-TO. The investigation was based on bibliographic, documentary, and qualitative research through interviews. The results showed that burns and forest fires present themselves as a problem that negatively impacts the population of Palmas and the school community. However, there are educational actions that can be developed in these teaching environments and that have the

potential to contribute to the reduction of risks of these events and the minimization of their impacts.

For Fernandes, Santos and Oliveira (2024), the impacts caused by burns and fires in the Atlantic Forest are an old case, and environmental education is one of the tools capable of stopping and reducing this impact. To support their findings, the authors analyzed the perception of visitors about fires in the Pedra Branca State Park and about Environmental Education. The work was done through a survey with visitors to the Pedra Branca State Park, using a semi-structured questionnaire with 17 questions, which aimed to verify whether visitors have contact with Environmental Education, have knowledge about burns and forest fires and the impacts caused by these events, and whether there is a relationship between EA and knowledge about the events and the impacts of burns.

CONCLUSION

Environmental education plays a fundamental role in the prevention of forest fires, especially in areas under the influence of electric power transmission networks. This study highlighted the importance of integrating educational actions aimed at local communities, managers, and operators of the electrical system, aiming to reduce the risk factors associated with fires and strengthen the resilience of transmission systems.

Statistical data show that in 2017, 21.3% of transmission line outages in Brazil were caused by forest fires. Additionally, the highest incidence of forest fires occurs in the Northeast, Southeast, and Central-West regions of Brazil, in areas dedicated to sugarcane cultivation and in anthropized cerrado areas. The monthly distribution of forced outages of transmission lines caused by forest fires recorded from 2013 to 2016, evidences the seasonality of the phenomenon, with a higher concentration of outages between the months of July and December each year.

Through awareness and societal engagement, it is possible to mitigate environmental impacts and promote a safer and more efficient energy supply. Therefore, environmental education should be seen as a strategic tool in environmental risk management and the promotion of sustainability. This study aims to contribute to the advancement of research on sustainability and environmental risk management, highlighting education as an essential tool for mitigating environmental impacts and promoting safer and more efficient electric power transmission systems.

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