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Prevention as an investment: analysis of costs and damages from forest fires in Bulgaria (2014–2024)

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Abstract. In the context of increasing climate change, forest fires present a growing risk to society, the economy, and biodiversity. Comparing funds invested in preventive measures with the damages caused by fires underscores the need for systematic and long-term financing of fire prevention activities. This study analyzes the relationship between investments in forest fire prevention and the damages caused in Bulgaria during 2014–2024. Based on statistical data, institutional reports, and European experience, the study evaluates prevention costs and fire-related losses. The main contribution of this research is the development of an integrated methodological framework for assessing forest fire damage, combining environmental, economic, and social indicators. Results show that prevention is economically justified, with long-term savings significantly exceeding initial investments. The study concludes with recommendations for sustainable financing, improved institutional coordination, and the implementation of a unified national methodology.

Key words: forest fires, damage assessment, prevention, sustainable management, fire risk.

Introduction

Forest ecosystems are increasingly threatened by natural disturbances such as forest fires, whose frequency and intensity have risen due to climate change, land-use changes, and human activity. Bulgaria is among the countries with high fire vulnerability, with over 60,000 hectares of forest areas affected during 2014–2024.

Beyond timber loss, forest fires disrupt key ecosystem services, including carbon sequestration, water regulation, soil protection, biodiversity conservation.

Despite existing policies, Bulgaria still lacks a comprehensive and integrated methodology for assessing forest fire damage. Current approaches focus mainly on direct economic losses, underestimating broader environmental and social impacts.

The main contribution of this study is the development of an integrated framework for assessing forest fire damage, combined with an analysis of prevention costs and damages. The study aims to support the development of scientifically grounded policies for sustainable forest management under increasing fire risk.

Materials and methods

The analysis is based on data from:

- Ministry of Agriculture and Foods (MAF)
- Executive Forest Agency (EFA, 2024)
- National Statistical Institute (NSI)
- Ministry of Environment and Waters (MoEW, 2024)
- European Forest Fire Information System (EFFIS)

The study compares:

- annual prevention costs (equipment, infrastructure, training)
- fire-related damages (burned area, economic losses).

The analysis is conducted over the period 2014-2024, using comparative and trend-based approaches.

Results

Forest resources and Fire risk context

Forests and forestry play an important role in the socio-economic development of the country. Through their ecological, economic, and social functions, they contribute to sustainable development and the well-being of society.

As of 2024, forest areas in Bulgaria cover 4.28 million ha, representing approximately one-third of the national territory. The diversity of the terrain and the transitional position between different climate and vegetation regions result in rich species diversity. The largest areas of forest are occupied by naturally distributed species such as oak (*Quercus* sp.), beech (*Fagus* sp.), hornbeam (*Carpinus* sp.), Scots pine (*Pinus sylvestris* L.), black pine (*Pinus nigra* Arnold), spruce (*Picea abies* (L.) H. Karst), and fir (*Abies alba* Mill.). To restore degraded terrain and combat erosion, over 1.5 million ha of artificial plantations, mainly of Scots and Black pine, have been created in the last century. The increasing share of vulnerable coniferous plantations and climate-induced stress factors contribute to rising fire risk.

Forest fire prevention costs

Analysis of publicly available financial information shows that during the period 2014–2023, investments in forest fire prevention activities by state-owned enterprises (varied between €0.51 million and €1.074 million annually, with a peak in 2015. (Fig. 1).

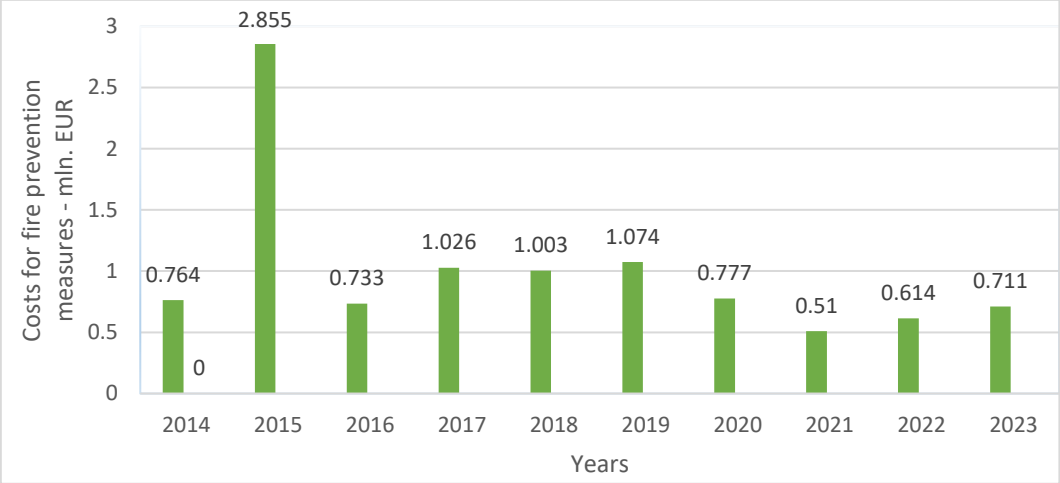

Fig. 1. Expenditures for fire prevention measures by State-Owned Enterprises in Bulgaria for the period 2014–2023, in million €.
Source: MAF, 2025.

The funds were used for:

- firebreaks and silvicultural barriers
- observation infrastructure
- equipment and vehicles

On average, the annual plan includes the construction of 2,140 km of mineralized strips, 790 km of silvicultural barriers, and fire prevention observation towers (MAF, 2025). The Forest Investment Fund annually purchases transport vehicles and specialized forestry equipment to improve access to forests and to build and maintain the infrastructure necessary for fighting fires and ensuring access to forest areas.

All efforts to ensure the human, financial, and technical capacity of state-owned enterprises to perform this socio-ecological function are carried out by the enterprises and their divisions. In addition, they spend significant financial resources on purchasing equipment for fighting forest fires and maintaining automatic observation stations. Financing comes entirely from their own revenues, without assistance from the state budget for these important functions, which have a direct and significant impact on biodiversity protection, minimizing greenhouse gas emissions from forests, and protecting forests with recreational functions.

Currently, forestry and hunting enterprises have 126 all-terrain vehicles equipped with systems for initial fire attack (MAF, 2025). Over the years, these vehicles have proven effective due to their high cross-country ability and capacity to cover large distances quickly, enabling rapid res-

ponse at the initial stage of fire development. State-owned enterprises also possess heavy equipment for extinguishing forest fires - 16 tracked bulldozers and 24 wheeled excavators – which are used to a more limited extent (MAF, 2025).

In addition to state-owned enterprises, funding sources include the national budget and a limited number of pilot programs and projects funded by the EU, but their share is not large. The existing fire-fighting infrastructure, especially in remote and hard-to-reach areas, is often inadequate for actual needs and risk dynamics. This affects both response times to incidents and the effectiveness of early warning and monitoring.

The data show a long period of underinvestment followed by a recent policy shift toward strategic prevention.

A significant shift occurred in 2023–2024 with the launch of a large-scale investment program (€86.92 million), introducing modern monitoring systems and improved response capacity. This investment program will be implemented jointly by the Ministry of Environment and Water (MoEW) and the Ministry of Interior (MI).

The main activities include:

• purchase of specialized extinguishing equipment and field access;

• introduction of remote monitoring and fire risk prediction systems;

• training of employees from forestry and firefighting structures, focusing on coordination, early response, and field safety;

• creation of response bases in key vulnerable regions.

The costs are planned to be allocated within a multi-annual investment framework, linked to performance indicators such as reduction in the number and area of burned areas, improved response time, and increased institutional capacity.

There is also growing interest at the municipal level in integrated prevention measures, including the creation of firebreaks, provision of water sources, construction of observation towers, and activation of voluntary groups.

These results highlight the need for sustainable and strategically targeted funding, based on risk analysis and prioritization of actions in the most vulnerable areas. Additional efforts should be made to improve the assessment of prevention effectiveness through the use of quantitative indicators and regular monitoring of the impact of the measures taken.

Analysis of shortcomings in previous policies

Despite measures taken over the past decade, several structural and institutional weaknesses in forest fire risk management continue to hinder effective prevention:

• Fragmentation of responsibilities: Prevention and extinguishing activities are divided among various institutions – the Ministry of Interior, the Executive Forestry Agency, the Ministry of Environment and Water, municipalities, and State Enterprises with their territorial divisions (SFEs and SHEs) - without clearly defined mechanisms for coordination and data sharing (Stoyanov, 2025).

• Lack of sustainable financing: Until 2023, there was no permanent budget line to guarantee annual resources for prevention activities. Expenditures are often planned after serious incidents rather than based on risk assessment and a long-term strategy.

• Outdated firefighting infrastructure: Much of the available equipment is outdated, especially in the highest-risk areas. There is a lack of clearings, water reservoirs, and communication facilities in critical locations.

• Weak integration of spatial and prognostic data: Although Geographic Information Systems (GIS) and access to European platforms such as the European Forest Fire Information System (EFFIS) and Copernicus Emergency Management Service (CEMS) are available, they are rarely used systematically to assess fire risk or guide preventive activities.

• Limited participation of local communities: Awareness, preparedness, and participation of the local population in prevention efforts are low. Where voluntary formations exist, they are underfunded and underdeveloped.

• Lack of monitoring of effectiveness: There is no mechanism for assessing the impact of invested funds – no performance indicators exist, making analysis and justification for future planning difficult.

Damage from forest fires

Damage from forest fires includes:

• Direct economic damage – loss of timber, destroyed infrastructure, costs of extinguishing and restoration;

• Indirect damage – loss of ecosystem services (soil retention, water cycle), biodiversity, damage to tourism, and health and social impacts such as losses to the population, lost jobs, and reduced viability of affected areas.

Analysis of official statistics for the period 2014–2024 (https://system.iag.bg) shows that the average annual direct damage from forest fires in Bulgaria amounts to about €1.087 million (Fig. 2). However, these values vary greatly depending on climatic conditions and the number and scale of fires each year. Higher damage occurs during prolonged droughts combined with high temperatures and strong winds, which favor the rapid spread of fire in hard-to-reach forest areas.

Peak years characterized by particularly high material losses include:

• 2024 — one of the most severe years in the period under review, with 595 registered forest fires covering 17,116 ha of forest areas. Damage reported by the EFA amounts to €4.293 million, which is over half the total value for the previous ten years – €8.046 million.

• 2016 – Despite approximately the same number of fires (584), the total affected area was 6,340 ha, but the damage was significant €3.044M.

• 2017 – The area affected by forest fires was 4,569 ha, with damage totaling €2.039M.

During the period 2014–2024, 43,910 em-ployees and 14,975 vehicles from state-owned en-terprises and their territorial divisions participa-ted in extinguishing forest fires, with several fatal cases unfortunately occurring.

The data shown in Fig. 2 include only the costs incurred within the forest system for extinguishing fires and losses from burned wood, stands, and saplings. The actual damage, if the costs of fire safety and population protection authorities are added, as well as environmental damage (loss of carbon capacity and ecosystem services, reduced recreational value and tourism revenue, erosion, deterioration of the water regime, soil degradation, etc.) and socio-economic damage (social costs, burden on security systems, health care, etc.), is much greater, but such figures have not yet been calculated or reported.

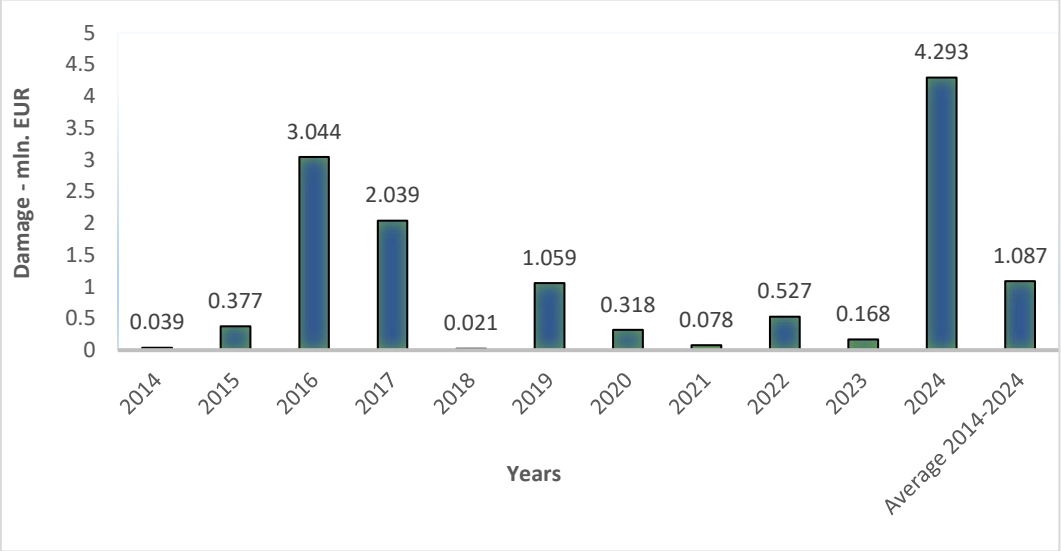

Fig. 2. Damage from forest fires for the period 2014–2024 in million €.
Source: http://system.iag.bg

Studies show that Bulgaria still lacks a unified, officially accepted methodology that comprehensively measures and evaluates damage from forest fires, including economic, environmental, and social aspects. Often, assessments are based on practical costs and expert opinions, without a harmonized national standard. Direct damage to forest areas in Bulgaria during periods of active fires amounts to millions, but the figures vary significantly depending on the data source and assessment method. Damage assessments have been made based on base prices of forest properties and actual costs incurred to determine the differences between normative and practical values (Georgieva, 2011).

Comparison of prevention costs and damages

A comparison of annual investments in forest fire prevention and the value of recorded damage from 2014 to 2023 shows that prevention costs exceed damage, but costs are trending downward (Fig. 3).

The analysis shows that in 2016 and 2017, the amount of damage significantly exceeded prevention costs. The findings confirm that effective prevention is economically justified, especially given increasing climate risks and the growing vulnerability of forest areas.

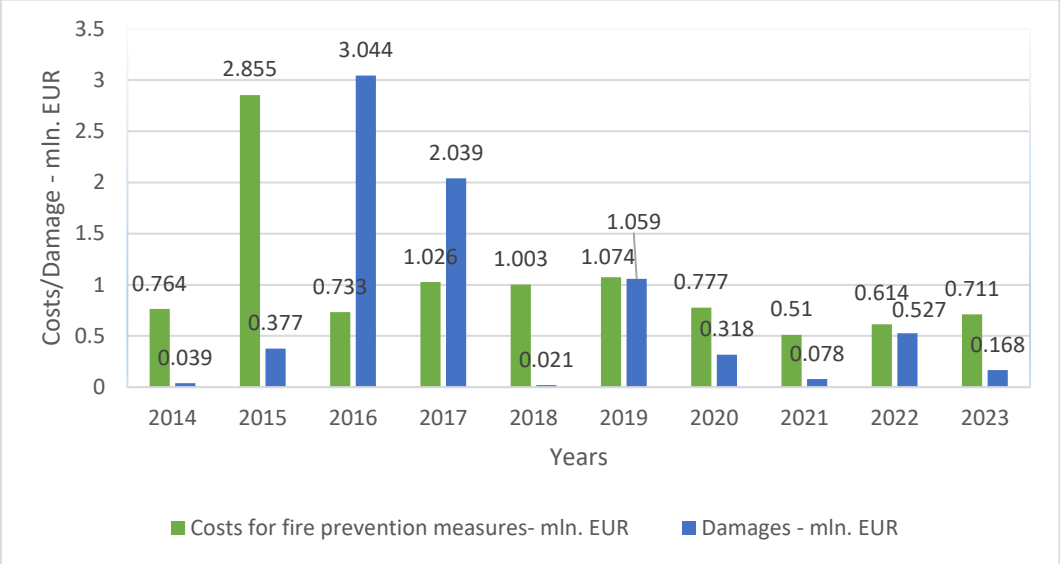

Fig. 3. Comparison of costs incurred for fire prevention measures and reported damage for the period 2014–2023, in million €.
Source: MAF, 2025; http://system.iag.bg

Key conclusions from the comparison:

Economic effectiveness of prevention: Available data show that for every €0.51 invested in preventive measures, between €1.53–4.09 are saved in damage over the long term. This range varies according to terrain characteristics, the type of forests affected, proximity to settlements, and the level of institutional preparedness. In areas with improved coordination and developed infrastructure, the effect of prevention is significantly more pronounced.

Insufficient funding and consequences (2014–2020): During this period, with average annual fire prevention costs below €1.02 million, numerous serious incidents occurred, with limited opportunities for timely response, lack of equipment, and insufficient field capacity. The consequences included not only material losses but also deterioration of ecosystem functions and long-term social costs for affected communities.

Changing trend after 2023: In 2023–2024, with the implementation of a large-scale investment project (€86.92 million), a positive transformation in prevention policy began. The purchase of equipment, personnel training, and the introduction of monitoring through GIS and remote sensors marked qualitative progress in risk management. However, the full results of these investments will be visible after 2025, following the completion of infrastructure activities and the accumulation of operational capacity.

Certain dependencies:

In years with higher investments in prevention (e.g., 2023–2024), initial indicators point to faster mobilization, better localization of fires, and reduced containment time, especially in regions with functioning observation systems.

In contrast, during periods of underfunding, the damage far exceeds the recovery capabilities of affected institutions and municipalities using their own resources.

The comparison highlights the need for a long-term, sustainable investment framework based on risk analysis and impact forecasting (Borisova et al., 2024). Prevention should not be seen as a cost, but as an economically justified investment

with a high return – not only economically, but also socially and environmentally.

Proposed framework for assessing forest fire damage

Rationale

Bulgaria lacks a unified methodology integrating economic, environmental, and social damage from forest fires and current assessments are partial and expert-based. This leads to underestimation of losses and limits effective policy planning.

In the European Union (EU), through EFFIS, various modules and methodologies have been developed for assessing the risk and damage from forest fires, which include (Copernicus, 2026; Sedano et al., 2012, 2013):

1) Fire Danger Assessment
2) Rapid Damage Assessment, which includes:
   - Active fire detection
   - Fire severity assessment
   - Land cover damage assessment
3) Emissions Assessment and Smoke Dispersion
4) Potential Soil Loss Assessment
5) Vegetation Regeneration

In EFFIS, harmonized procedures for damage assessment are being developed, based on satellite data, GIS, and comparative indices, allowing for more objective and comparable results. Harmonization of assessments in the EU is an advantage, especially in cases of transboundary fires or trend analysis.

Analysis of the prerequisites, causes, and factors for the occurrence of forest fires leads to the conclusion that Bulgaria, in terms of forest fire risk parameters, is approaching the traditionally dangerous Mediterranean region. The main problem is that all forest fires cause serious environmental damage, negatively affecting society, economic activity, and human life. At the same time, it is extremely difficult to assess the potential damage from fires, as many sectors of the economy are affected, and conducting a comprehensive assessment requires collecting a large amount of data. Damage assessment is also complicated by the fact that some effects may appear years after the fires.

Even more importantly, much of the damage remains only partially valued due to the lack of methodologies for the quantitative assessment of intangible impacts. This creates a risk of underestimating the real scale of the damage when making decisions on compensation, restoration activities, and strategic planning.

In this context, the need for integrated assessments – combining environmental, economic, and social parameters – becomes particularly important. Developing a unified methodology for damage assessment will allow for a more realistic valuation of losses, taking into account the functions of forest areas, their vulnerability, and their importance to society.

Structure of the Framework

The lack of strategic vision and insufficient prioritization of prevention are leading factors for the high level of damage from forest fires in the country. Overcoming these weaknesses requires systemic change: integrated policies, secured financing, spatially oriented planning, and active participation of all stakeholders. It is essential to develop and implement a methodology for assessing forest fire damage, which will support accurate evaluation and determination of the effectiveness of funds invested in forest fire prevention.

A model for developing a methodology for assessing forest fire damage is shown in Fig. 4.

The proposed model consists of three main components:

1. Input Data - Satellite data (Copernicus, EFFIS), Statistical data (EFA, NSI) and Field observations.

2. Assessment Modules - Economic damage: timber loss, infrastructure, firefighting costs; **Environmental damage:** carbon loss, biodiversity, soil degradation **and Social damage:** health impacts, economic disruption, loss of ecosystem services.

3. Assessment Levels - Rapid assessment (immediate post-fire,), Detailed assessment (field-based) and Long-term impact evaluation.

Relationships Between Components

Input data are processed through the three modules, generating integrated damage estimates. These outputs support: policy development, resource allocation and risk forecasting.

Practical Application

The methodology can be applied by national institutions (MoEW, EFA), regional authorities and municipalities. It enables more accurate da-

mage valuation, improved prevention planning and better justification of public investments. The interaction between these components allows integrated damage assessment and improved prioritization of preventive measures.

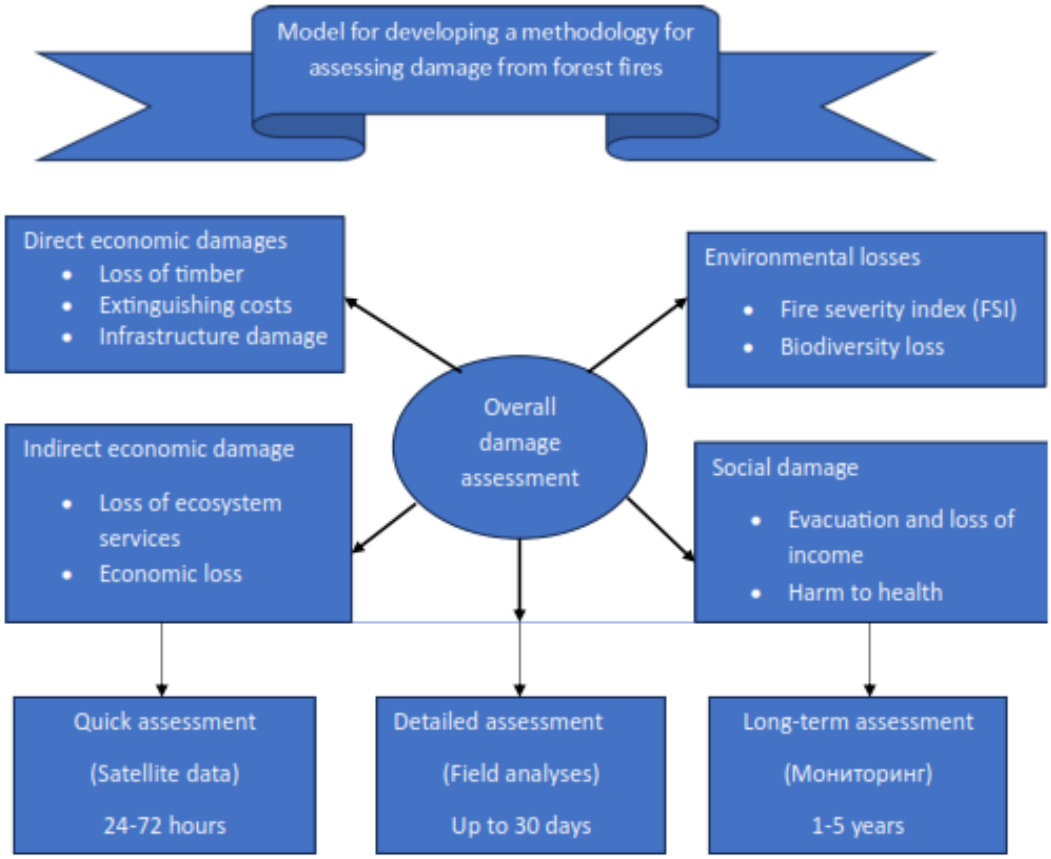

Fig. 4. Model for developing a methodology to assess damage from forest fires.

Discussion

Prevention costs include not only equipment and infrastructure but also training, early warning systems, and public campaigns. In Bulgaria, these costs are traditionally underestimated, and fire damage is viewed mainly in terms of wood loss. International experience (Spain, Italy, Greece) shows that sustainable investments in prevention reduce both risk and extinguishing costs (Mauri et al., 2023; Copernicus, 2023; San-Miguel-Ayanz et al., 2024; OECD, 2023; Verde et al., 2024). A change in the regulatory framework and the creation of a model for forecast financing and valuation of ecosystem services is necessary.

The analysis of public spending on forest fire prevention in Bulgaria over the last decade highlights structural deficiencies in the approach to risk management. Although positive trends have been reported in the last two years, the previous period was characterized by insufficiently coordinated and partial efforts that do not correspond to the actual degree of fire vulnerability in forest areas.

Institutional fragmentation is a key problem. Management and operational functions are distributed among different departments (MI, MoEW, EFA, SFEs/SHEs, municipalities) without a clear mechanism for joint planning, data exchange, or strategic synergy. This leads to inefficient resource allocation and delayed crisis response.

From 2014 to 2020, there was a lack of sustainable and predictive financing. Prevention spending was not based on risk assessment but was often undertaken reactively, after large-scale fires had occurred. The allocated funds (under €1 million per year) are extremely insufficient for building modern fire-fighting infrastructure in vulnerable regions, especially in remote and difficult-to-access areas.

A significant challenge is the limited use of modern analysis and planning tools, such as GIS, forecasting models, and satellite monitoring. Despite access to platforms such as EFFIS and CEMS, they are rarely integrated into local or national strategies.

Local community participation also remains weak. In most regions, voluntary groups lack the necessary equipment, training, or resources. The absence of awareness campaigns and the underestimation of preventive training contribute to the vulnerability of the population in rural and forest areas.

Finally, there is no comprehensive mechanism for monitoring the effectiveness of preventive measures. Quantitative indicators are not used to track the return on investment or identify good practices. This limits opportunities for adaptive management and for motivating long-term financing.

Currently, in Bulgaria, only portion of the direct economic damage from forest fires is assessed, which is highly insufficient. It is necessary to develop and implement a national methodology for comprehensive assessment of forest fire damage, drawing on global experience and that of European Union countries. This will enable a thorough evaluation of forest fire damage and provide an opportunity to assess the effectiveness of funds invested in forest fire prevention.

Using the proposed methodology, with the help of satellite data obtained during and immediately after the fire is extinguished, a preliminary rapid assessment of forest fire damage can be made. After the fire, a comprehensive assessment can be conducted based on a detailed examination of the affected terrain. Finally, using the results of risk assessment, long-term evaluations can be performed, preventive measures can be planned, and forecasts of potential damage can be developed.

The proposed framework addresses these gaps by introducing a structured and comprehensive approach to damage assessment.

A key issue remains the lack of performance indicators to evaluate prevention effectiveness. Without such metrics, long-term planning and funding remain constrained.

Conclusions

This study demonstrates that forest fire prevention is both economically efficient and environmentally necessary. The study's results highlight the need for a systematic and multifaceted approach to forest fire risk management in Bulgaria. Although strategic documents and a regulatory framework exist, the practical implementation of preventive measures has, until recently, been characterized by low funding, institutional fragmentation, and limited integration of scientifically based risk assessment tools.

Recent investments (2023–2024) mark a positive shift, but long-term success depends on sustainable financing, institutional coordination and implementation of a unified methodology.

The proposed framework for assessing the damage and consequences of forest fires can support both strategic planning and the implementtation of specific management decisions. Integrating economic, environmental, and social indicators provides a more realistic picture of the impacts, which is essential for correctly prioritizing interventions given limited resources and increasing climate risks.

It is recommended to:

- establish permanent funding mechanisms
- develop and adopt a national damage assessment methodology
- strengthen inter-institutional coordination
- integrate GIS and satellite-based systems
- promote local community involvement

Further development of the methodology should include pilot implementation in different forest areas, improvement of performance indicators, and closer integration with the processes of forming forest policy at national and regional levels.

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