Smart Forests will save Greece

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Introduction & background:

Every summer, Greece is severely affected by wildfires, a phenomenon that has become increasingly frequent and intense due to rising temperatures, prolonged droughts, and climate change. These wildfires destroy vast areas of forests and natural ecosystems, leading to significant biodiversity loss, soil degradation, and long-term environmental damage.

Forests play a crucial role in regulating the Earth's climate by acting as carbon sinks, absorbing atmospheric carbon dioxide (CO_2) through photosynthesis while producing oxygen. When forests burn, this essential ecological function is disrupted. In addition, wildfires release substantial amounts of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$) into the atmosphere. These emissions contribute to global warming, deteriorate air quality, and pose serious risks to both environmental and human health.

Given the increasing occurrence of wildfires in Greece, there is an urgent need to develop innovative, sustainable, and effective solutions for wildfire prevention, early detection, rapid response, and post-fire ecosystem restoration. Reducing the frequency and impact of these events is essential for protecting forests, preserving biodiversity, and mitigating the effects of climate change.

This table lists the statistics of fires in Greece over the last two decades.

YEAR	Burned Area(ha)	Number of fires
2006	16294	22
2007	271715	139
2008	24988	46
2009	42807	46
2010	6472	21
2011	35713	80
2012	52487	83
2013	19762	32
2014	14815	31
2015	11613	27
2016	31707	52
2017	20041	57
2018	12037	33
2019	10736	53
2020	14915	88
2021	130744	85
2022	22480	66
2023	174773	56
2024	41948	86
2025	47819	69
2026	12072	26

Info(EFFIS)Copernicus

Wildfires have become one of the most significant environmental challenges in Greece over the last two decades. According to the Copernicus European Forest Fire Information System (EFFIS), the country has experienced several extreme wildfire seasons, with 2007, 2021, and 2023 being among the most destructive years on record.

In 2007, approximately 271,700 hectares of land were burned, making it one of the worst wildfire disasters in modern Greek history. Although burned areas fluctuated during the following years, the occurrence of extreme wildfire seasons has become increasingly frequent. In 2021, more than 130,000 hectares burned, while in 2023 the burned area exceeded 175,700 hectares, making it one of the largest wildfire seasons ever recorded in the European Union.

Scientific evidence indicates that climate change has increased the likelihood of prolonged heatwaves, severe droughts, and extreme fire-weather conditions, creating an environment that favors the ignition and rapid spread of wildfires. Rising temperatures, reduced soil moisture, and stronger winds significantly increase fire intensity and make suppression efforts considerably more difficult.

As we all know with these high numbered fires there are a lot of consequences: Wildfires have severe environmental, economic, and social consequences. Forest destruction leads to habitat fragmentation and biodiversity loss, threatening numerous plant and animal species. Burned vegetation can no

longer function effectively as a carbon sink, reducing its capacity to absorb atmospheric carbon dioxide (CO_2).

During combustion, forests release significant amounts of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO), and nitrogen oxides (NO_x), as well as fine particulate matter ($PM_{2.5}$). These emissions contribute to climate change, decrease air quality, and increase respiratory and cardiovascular health risks.

Furthermore, the removal of vegetation exposes the soil to erosion, increases the probability of floods and landslides, reduces groundwater recharge, and accelerates desertification processes. The economic impact is also substantial, affecting agriculture, tourism, infrastructure, and local communities. Consequently, effective wildfire prevention and rapid detection have become critical priorities for sustainable environmental management.

Existing Wildfire Management Framework in Greece:

Currently, Greece applies several strategies and technologies for wildfire prevention, monitoring, and emergency response. The existing wildfire management system combines meteorological forecasting, satellite monitoring, emergency communication systems, aerial surveillance, and firefighting operations.

One of the main tools used for wildfire monitoring is the European Forest Fire Information System (EFFIS), which operates through the Copernicus Emergency Management Service. EFFIS provides real-time information about active fires, fire danger levels, burned areas, smoke dispersion, and post-fire damage assessment. These data support authorities in evaluating wildfire risks and improving emergency response planning.

In Greece, the 112 emergency warning system is also used to provide rapid alerts to citizens during dangerous situations, including wildfires. Through mobile notifications, authorities can send evacuation instructions and safety recommendations to affected areas.

Additionally, wildfire prevention relies on traditional methods such as patrols, firefighting aircraft, ground forces, forest management activities, and risk assessment based on weather conditions. In recent years, Greece has also increased the use of new technologies, including drones equipped with thermal cameras, digital monitoring platforms, and advanced observation systems to improve early detection.

However, despite these measures, several challenges remain. Current systems often detect fires after ignition has already occurred, meaning that valuable time

may be lost before firefighting forces arrive. Furthermore, Greece's mountainous terrain, fragmented forest areas, extreme weather conditions, and increasing temperatures make wildfire prediction and rapid intervention particularly difficult.

Therefore, there is a need for innovative solutions that can provide earlier detection, more accurate risk prediction, and faster response capabilities in order to reduce the environmental and social impacts of wildfires.

Based on these limitations, this project proposes an innovative approach that aims to improve wildfire prevention and early detection in Greece.

Before implementing the proposed solution, it is essential to identify and analyze the areas in Greece that are most vulnerable to wildfires. This can be achieved by combining data from satellite monitoring systems, such as the Copernicus Emergency Management Service, with Geographic Information Systems (GIS).

The first step of the project would involve the development of a wildfire risk heat map, which would integrate multiple environmental parameters, including temperature, drought conditions, vegetation density, land cover, historical wildfire occurrences, and climatic data. This spatial analysis would allow the identification of high-risk areas and provide a better understanding of where wildfire prevention measures should be prioritized.

By using GIS-based analysis, it would be possible to determine the regions with increased wildfire susceptibility and evaluate the factors that contribute to fire ignition and rapid spread. This information would serve as the foundation for the implementation of targeted prevention strategies and the deployment of monitoring technologies in the most critical areas.

Therefore, the creation of a detailed wildfire risk map represents the first and most important step towards developing an effective wildfire prevention and early detection system for Greece.

System Overview:

Proposed Concept

Autonomous Solar-Powered Wildfire Prevention Station (ASWPS)

Each station is an independent monitoring and prevention unit installed inside high-risk forest areas. The station performs three main functions:

- Continuous environmental monitoring
- Wildfire ignition probability assessment
- Automatic preventive response and emergency alert generation

1. Environmental Monitoring Module

The station continuously measures the most critical wildfire-related parameters.

Parameter	Purpose
Air Temperature	Detects heat accumulation
Relative Humidity	Indicates fuel moisture conditions
Wind Speed	Determines fire spread potential
Wind Direction	Supports propagation modeling
CO Concentration	Early combustion indicator
CO_2 Concentration	Supports combustion detection
PM2.5 / PM10	Detects smoke particles
Soil Moisture	Evaluates drought conditions
Surface Temperature	Identifies localized hot spots

These are the parameters for avoiding wildfires

2. Solar Power System

Is very important for these stations to charge automatically. This can be done with solar panels

Suggested configuration

- Solar panel: 150–250 W
- Battery: 12V / 100 Ah $LiFePO_4$
- Autonomy: 5–7 days without sunlight
- Charge controller: MPPT

With these configurations the stations can operate throughout the summer without connection to the electricity grid. We understand that we need to use the energy from the sun wisely.

3. Station Spacing

A technical approach is needed here. The distance depends on the terrain and the density of the forest. So with qgis we can analyze forests terrain with the aim of correctly placing the stations so that they cover the entire area of the forests.

indicative distances:

Flat or gently sloping terrain

- 1 station per 1 km^2
- Approximate spacing: 1,000 m

Moderate terrain

- 700–900 m

Mountainous / dense forest areas

- 400–700 m

Greece: Mediterranean forest deployment Recommended spacing for Mediterranean forests:

≈ 800 meters between stations:

This provides overlapping sensor coverage and keeps communication links reliable.

Coverage radius per station:≈ 400–500 m

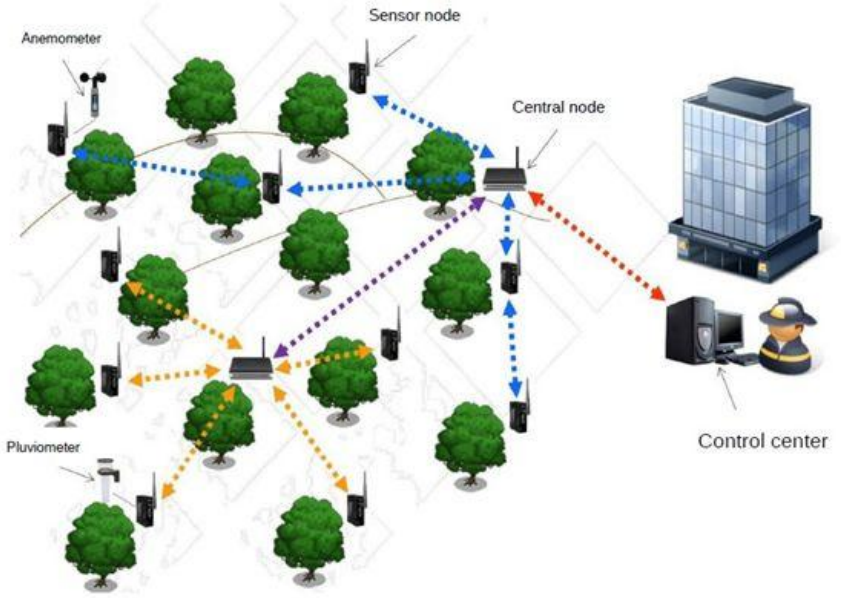
Effective monitored area:≈ 0.5–0.8 km^2

With this distance, there is also overlapping coverage, so that if one station breaks down, it is covered by the next one. With these technique we prevent wildfires in a more efficient way.

4. Communication Between Stations

Communication Between Stations is one of the most important parts of ASWPS.

The stations communicate not only with the center but also with each other. With Ais help(we can manage to code it for our usage) the stations will send signals to the nearest fire department to prevent as fast as possible the wildfire. Furthermore the stations will communicate with each other In order If one node fails, data are rerouted through neighboring nodes.



Station A ↔ Station B ↔ Station C

If one node fails, data are rerouted through neighboring nodes.

Communication technology: LoRaWAN Mesh.

5. Fire Risk Assessment:

Instead of waiting for smoke to appear, each station calculates a Wildfire Risk Index (WRI).

WRI=0.35T+0.30W−0.25RH-0.10SM (The result ranges from 0 to 100)

T = normalized temperature

W = normalized wind speed

RH = relative humidity

SM = soil moisture

WRI	Risk Level
0–30	Low
31–60	Moderate
61–80	High
81–100	Extreme

With this method we will prevent wildfires faster and in a more efficient way.

6. Preventive Water Cooling Module:

The activation process follows a dual-stage protocol:

1. **Stage 1 (Alert & Pre-Conditioning):** When environmental variables breach pre-defined critical limits (e.g., $T > T_{threshold}$, $RH < RH_{threshold}$, and $\theta < \theta_{threshold}$), indicating an extreme risk of auto-ignition or rapid flammability, the system automatically transmits high-priority telemetry data to the relevant authorities (Fire Services & Civil Protection).
2. **Stage 2 (Automated Physical Intervention):** Simultaneously, the system activates a localized precision micro-sprinkling (or water misting) mechanism.

Physical Mechanisms of Prevention

The localized discharge of water aims to suppress fire formation through two primary thermodynamic and physical pathways:

- **Sensible Heat Release & Thermal Reduction:** Water possesses a high specific heat capacity ($c_p \approx 4.184$ J/gcdot^circC) and latent heat of vaporization ($h_{fg} \approx 2260$ kJ/kg). The fine mist or water droplet spray absorbs significant thermal energy from the immediate atmosphere and surrounding vegetation, rapidly reducing the local microclimate temperature.
- **Fuel Moisture Content (FMC) Elevation:** Dry surface fuels (leaves, needles, small twigs) absorb the applied moisture, increasing the Fuel Moisture Content (FMC). By raising FMC above the critical "extinction moisture content" threshold, the energy required to ignite the biomass exceeds the thermal energy available from environmental sources or ambient sparks, effectively preventing ignition.

System Architecture / Flowchart

- **[IoT Sensor Node]** (Measures: Temp, Humidity, Soil Moisture) →
- **[Edge Processing / Threshold Evaluation]**
    - *Option A (Normal conditions):* Return to Loop.
    - *Option B (Critical Thresholds Exceeded):*
        1. → **[Telemetry/LoRaWAN/GSM Module]** → Dispatch Alert to Fire Department & Civil Protection Services.
        2. → **[Actuator Relay]** → Activate Automated Water Sprinkling/Misting Pump.

Sustainable Water Supply: Integration with Constructed Wetlands (CWs)

To ensure system viability and environmental sustainability without depleting local potable water resources, the water supply infrastructure relies on **Constructed Wetlands (CWs)** for decentralized wastewater treatment and reuse.

Circular Resource Recovery

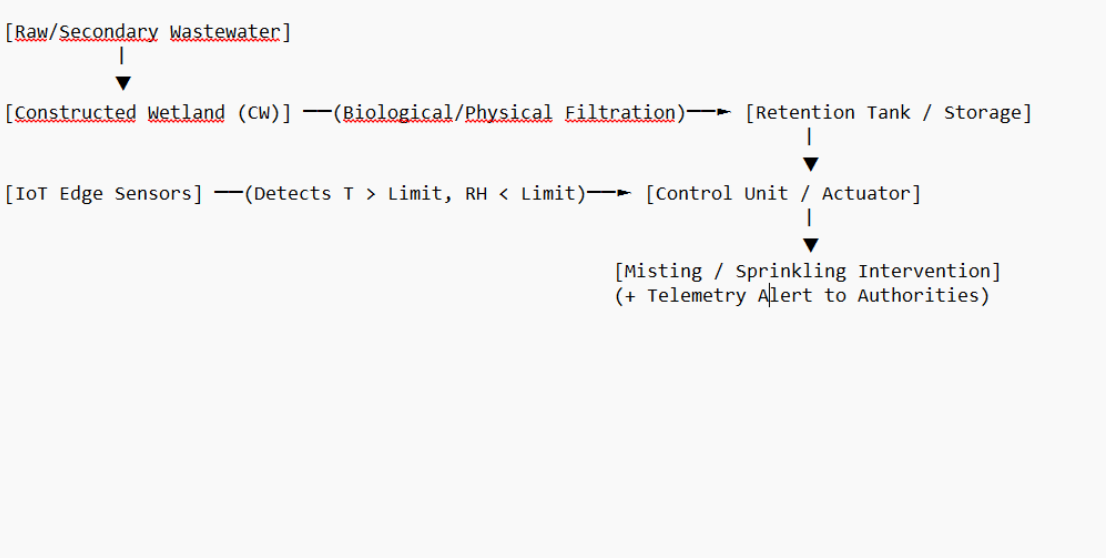
Instead of relying on conventional groundwater extraction or municipal grid connections, the system utilizes secondary-treated municipal or

agricultural wastewater. This wastewater undergoes biological and physical purification through horizontal or vertical sub-surface flow Constructed Wetlands (SSF-CWs).

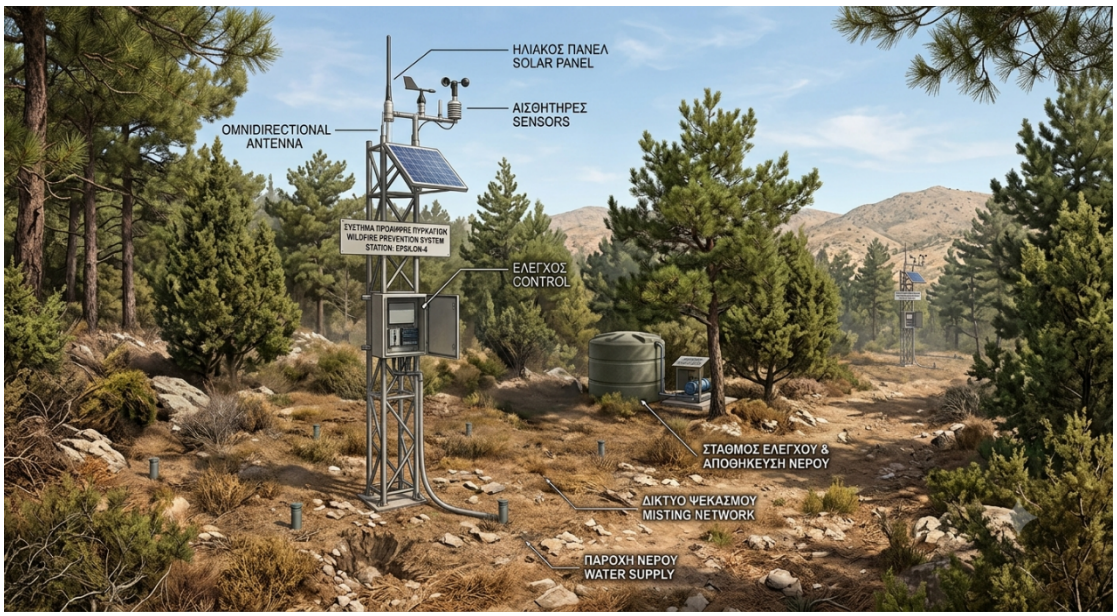
- **Phytoremediation & Filtration:** Aquatic vegetation (e.g., *Phragmites australis*, *Typha latifolia*) combined with gravel/sand filter beds reduces organic load (BOD/COD), suspended solids, and pathogens, producing effluent suitable for environmental applications (Class A/B non-potable reuse standards).
- **Decentralized Storage:** The treated effluent is stored in integrated retention basins or underground storage tanks located adjacent to high-risk forest zones, acting as dedicated water reservoirs for the automated conditioning system.

Ecological & Operational Advantages

1. **Resource Efficiency:** Capitalizes on non-conventional water resources, aligning with Circular Economy principles.
2. **Thermal Buffering:** Water retained within wetland micro-ecosystems maintains a lower ambient temperature, enhancing the cooling effect upon dispersal.
3. **Continuous Availability:** Ensures a constant, renewable supply of water during high-risk drought periods, independent of the primary water supply network.



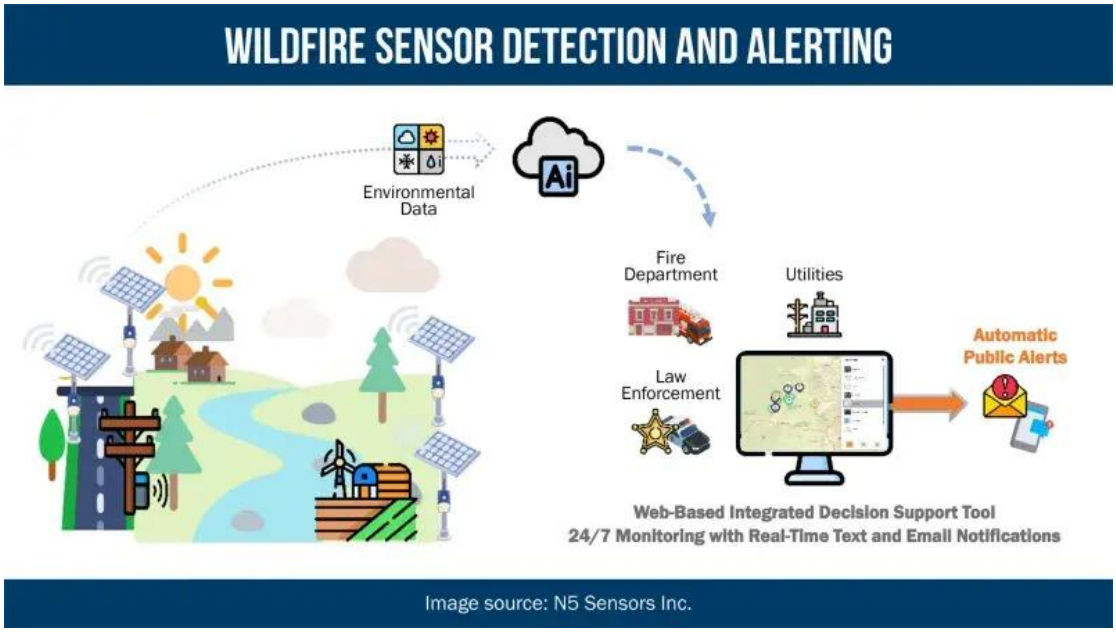
The purpose is not to extinguish a fire, but to increase local fuel moisture and reduce the surface temperature. Until the firefighters arrive.



Conceptual CAD Rendering of the ASWPS Station

7. Emergency Alert Mechanism:

Once a potential ignition is detected:



The transmitted packet includes:

- GPS coordinates
- Timestamp
- Sensor values
- Thermal image
- Risk level
- Confidence score

Alert delivery time:

Less than 10 seconds.

8. Why This Is Different:

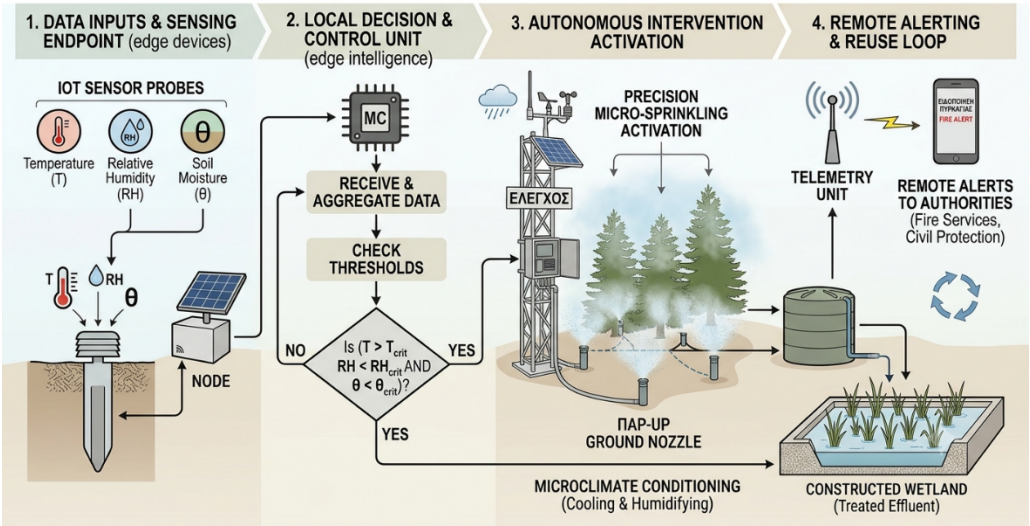
Unlike conventional wildfire monitoring stations that only collect environmental data, the proposed Autonomous Solar-Powered Wildfire Prevention Station introduces an active prevention mechanism. By integrating real-time risk assessment with an automated localized cooling system, the station is capable of reducing ignition probability before a wildfire occurs, transforming wildfire management from a reactive to a proactive approach.

Visual Framework and Comparative Paradigm Analysis

To synthesize the functional mechanics and validate the core value proposition of the proposed system, the architectural and operational logic is formalized in Figures 1 and 2 below.

Figure 1 details the **Integrated System Architecture**, illustrating the end-to-end data pipeline from physical sensing to autonomous microclimate actuation and notification loop. Figure 2 presents a **Paradigm Comparison Matrix**, directly juxtaposing the traditional reactive wildfire response framework against the proposed proactive microclimate conditioning approach.

FIGURE 1: INTEGRATED SYSTEM ARCHITECTURE FOR PROACTIVE MICROCLIMATE CONDITIONING



The innovation of the proposed system is further elucidated through two conceptual visualizations. Figure 1 details the **Integrated System Architecture**, illustrating the closed-loop logic from data acquisition to autonomous intervention. It demonstrates how the edge-computing node processes localized sensor inputs (Temperature, Humidity, Soil Moisture) and uses threshold-based logic to simultaneously activate two critical responses: precise micro-sprinkling for physical conditioning and digital telemetry alerts for authorities. This diagram confirms the system's ability to operate independently of human intervention during the critical pre-ignition window.

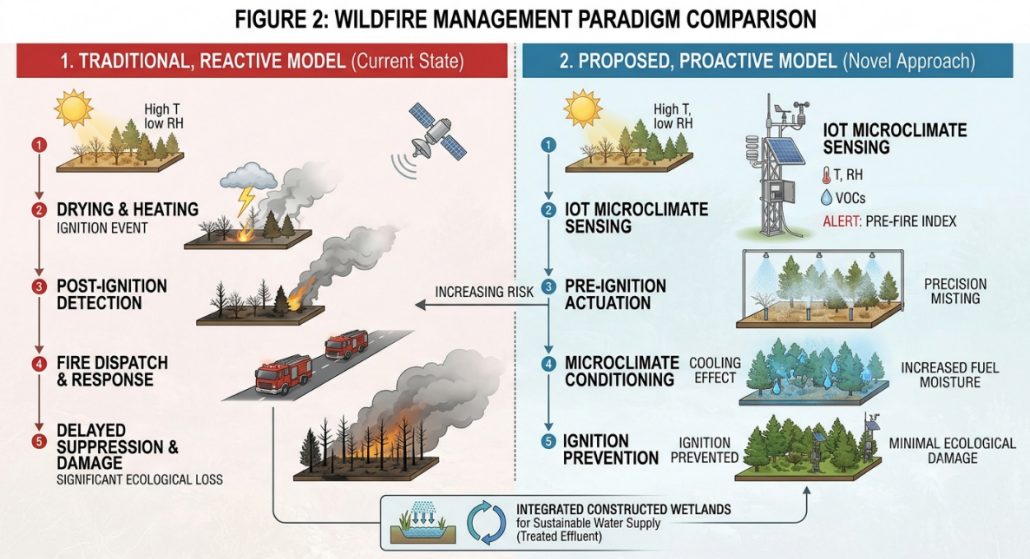


Figure 2 presents a **Paradigm Comparison Matrix**, aligning the proposed proactive approach against traditional reactive wildfire management. While conventional systems are activated only *after* ignition, the proposed model utilizes the high-risk drying phase for preventative microclimate conditioning. By dynamically elevating Fuel Moisture Content and lowering ambient temperatures before an ignition event can occur, the system introduces a novel technological barrier. This visualization confirms that the distinction lies not just in earlier detection, but in active prevention, thereby minimizing ecological damage and maximizing fire suppression efficiency.

Conclusion:

This study presented a proactive, closed-loop framework for wildfire risk mitigation designed specifically for vulnerable Mediterranean ecosystems. By bridging IoT edge-sensing with an autonomous precision micro-sprinkling system, the proposed solution shifts the operational paradigm from post-ignition firefighting to preventive microclimate conditioning. The integration of decentralized Constructed Wetlands (CWs) addresses the critical constraint of water availability in remote forest zones, establishing a sustainable, circular resource recovery model. By actively maintaining Fuel Moisture Content (FMC) above critical ignition thresholds and depressing ambient thermal loads prior to combustion, this methodology provides a continuous physical barrier against wildfire inception while providing automated telemetry alerts to emergency services.

Future Work:

To advance this conceptual framework toward physical deployment, future research will focus on the following key areas:

- **Algorithmic Risk Modeling:** Integrating machine learning models (e.g., Random Forest or LSTM networks) to process real-time microclimatic streams and dynamically predict site-specific ignition probabilities, thereby optimizing water discharge timing and volume.
- **Hydraulic and Nozzle Network Optimization:** Conducting fluid dynamics simulations to optimize the spatial distribution, pressure head, and spray trajectory of pop-up nozzles under varying canopy densities and ambient wind fields.
- **Pilot Scale Field Testing:** Deploying a prototype node network in a high-risk Wildland-Urban Interface (WUI) to empirically measure the rate of Fuel Moisture Content elevation and evaluate sensor durability in real-world forest environments.

Matthews, S. (2014). *Dead fuel moisture research: 1991–2012*. International Journal of Wildland Fire, 23(1), 78-92.

Purtill, J., et al. (2021). *IoT-based microclimate monitoring for early wildfire threat assessment*. Journal of Environmental Management, 285, 112100.

Vymazal, J. (2011). *Constructed wetlands for wastewater treatment: Five decades of experience*. Environmental Science & Technology, 45(1), 61-69.

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