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Wildfire Modelling and Artificial Intelligence

Report of an International Workshop

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The InterAcademy Partnership (IAP) is a global network of 150 academies of science, engineering, and medicine. With its four regional networks—in Africa (Network of African Science Academies NASAC), the Americas (the InterAmerican Network of Academies of Sciences, IANAS), Asia/ Oceania (the Association of Academies and Societies of Sciences in Asia, AASSA) and Europe (the European Academies Science Advisory Council, EASAC), IAP provides a platform for mobilising regional and national expertise on wide ranging issues of global importance, and for facilitating cooperation with other key stakeholders and potential partners. IAP's secretariat offices are hosted by The World Academy of Sciences in Trieste, Italy, and the National Academy of Sciences in Washington, DC, USA. More information is available at **www.interacademies.org.**

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Executive Summary

On 17-18 March 2025, the InterAcademy Partnership (IAP), in collaboration with the Royal Spanish Academy of Sciences and with support from the US National Academies of Sciences, Engineering, and Medicine, convened an international workshop on Wildfire Modelling and Artificial Intelligence.

The workshop brought together global experts in modelling and tool development to assess state-of-the-art wildfire prediction models, explore strategies to mitigate wildfire impacts on built environments, and identify key challenges, gaps, and opportunities for international collaboration. The workshop aimed to advance wildfire risk mitigation by focusing on three key objectives. First, it sought to evaluate existing wildfire models, their accuracy, and computational requirements, when possible, as well as their application to capture wildfire damage and risk. Second, it aimed to close the gap between technical fire simulations and their practical use in shaping policies. Finally, the workshop addressed challenges in scaling models and standardising data across national boundaries to support coordinated and effective fire management strategies.

The workshop focused primarily on the impact of wildfires on the built environment, especially within the wildland–urban interface (WUI). The workshop brought together 26 experts from ten countries, including Australia, Chile, France, Italy, New Zealand, Portugal, Spain, and the United States.

The workshop's sessions (see Appendix A for the workshop agenda) explored a spectrum of approaches—physics-based, semi-physics-based, and empirical/AI-driven modelling—each with distinct strengths and limitations. Physics-based models such as the Fire Dynamics Simulator (FDS) developed by the U.S. National Institute of Standards and Technology (NIST) and Nek5000 spectral element, a highly scalable computational fluid dynamics code, offer high accuracy and detailed analysis of fire behaviour mechanisms, making them essential for policy development and structural planning; however, their computational intensity, expertise requirements, and limited accessibility restrict broader operational use. Semi-physics-based models, including AGNI-NAR and urban hybrid models, balance physical realism with efficiency by integrating simplified physics into probabilistic frameworks, offering faster run times and adaptability for planning and training, though they face challenges in generalisability, adoption, and stakeholder awareness. Empirical, statistical, and AI-driven models—such as Cell2Fire and vulnerability mapping tools—leverage historical and environmental data to deliver scalable, accessible wildfire risk assessments ideal for strategic planning and public engagement, though they lack real-time predictive capacity and may underperform under shifting climate conditions. Together, these model types form a complementary toolkit for advancing wildfire understanding and preparedness, with workshop participants emphasising the need for international collaboration, training, and targeted investment to optimise their use in diverse operational contexts. The workshop did not explore the uncertainties associated with these models, and not all presenters provided numerical information on the prediction and accuracy of the models, highlighting potential areas for further discussion.

Workshop participants explored the following concrete opportunities for advancing wildfire modelling efforts:

1. Harmonise and standardise data and terminology in wildfire modelling
2. Enhance interoperability across wildfire modelling platforms
3. Integrate local context with regional wildfire modelling
4. Integrate human behaviour into wildfire models
5. Leverage wildfire modelling to inform policy, planning, and community protection
6. Strengthen wildfire modelling credibility through ethical practice and collaborative development
7. Communicate uncertainty transparently and in an appropriate format to support informed decision making
8. Strengthen training and communication to operationalise wildfire modelling tools
9. Advance integrated wildfire risk modelling through targeted data and research investments
10. Strengthen global collaboration to advance wildfire modelling
11. Build a global repository of wildfire events
12. Strengthen multinational coordination and logistics to support model-driven fire response

This report summarises the presentations and discussions that took place during the workshop. It is authored by Dr. Hussam Mahmoud of Colorado State University and now at Vanderbilt University, who served as the workshop chair and rapporteur. The report captures key insights from the sessions, outlines proposed priorities for advancing wildfire modelling capabilities and applications, and identifies proposed next steps for research and collaboration.

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INTRODUCTION

On17-18 March 2025, the InterAcademy Partnership (IAP), in collaboration with the Royal Spanish Academy of Sciences and with support from the U.S. National Academies of Sciences, Engineering, and Medicine, convened an international workshop on Wildfire Modelling and Artificial Intelligence. The workshop brought together global experts in modelling and tool development to assess state-of-the-art wildfire prediction models, explore strategies to mitigate wildfire impacts on built environments, and identify key challenges, gaps, and opportunities for international collaboration.[1]

The workshop focused primarily on the impact of wildfires on the built environment, especially within the wildland–urban interface (WUI). While acknowledging ecological and public health dimensions, discussions centred on advancing understanding of damage mechanisms, improving modelling accuracy, and developing effective mitigation strategies for residential and urban areas bordering flammable wildland landscapes.

The workshop brought together 26 experts from ten countries, including Australia, Chile, France, Italy, New Zealand, Portugal, Spain, and the United States. Participants were nominated by IAP member academies and identified through other scientific and professional networks based on their expertise in wildfire modelling and artificial intelligence (AI). All experts played an active role in the workshop discussions and activities. Appendix A shows the workshop agenda and Appendix B includes brief biographical information on the invited experts and background literature highlighting their relevant work. The background literature provides context for the expertise each participant brought to the discussion and offers readers an opportunity to explore the foundational and emerging literature that informed the workshop.

Participants drew on wildfire events from their own regions or countries to illustrate response challenges, mitigation strategies, and the performance of predictive models. Examples included are listed in Box 1.

This report summarises the presentations and discussions that took place during the Wildfire Modelling Workshop. It was authored by Dr. Hussam Mahmoud of Colorado State University and now at Vanderbilt University, who served as the workshop chair and rapporteur. The report captures key insights from the sessions, outlines proposed priorities for advancing wildfire modelling capabilities and applications, and identifies proposed next steps for research and collaboration.

1 The role of the National Academies of Sciences, Engineering, and Medicine (National Academies) was limited to providing staff support for the workshop. The National Academies had no role in authoring, reviewing, or approving this report, and the content does not necessarily reflect the views of the National Academies.

Box 1: Wildfire events discussed at the workshop

- **Portugal, 2017 wildfires:** A series of four initial wildfires erupted across central Portugal within minutes of each other, resulting in at least 117 deaths and 204 injuries.
- **Greece, 2018 Mati wildfire:** Burned more than 4,000 homes and resulted in 104 fatalities.
- **United States, 2018 Camp Fire (Northern California):** Caused 85 fatalities, displaced more than 50,000 people, and destroyed more than 18,000 structures.
- **Australia, 2019–2020 Black Summer fires:** Burned over 17 million hectares, destroyed more than 3,000 homes, and caused 33 deaths. An estimated 3 billion animals were killed or displaced.
- **United States, 2021 Marshall Fire (Boulder, Colorado):** Caused the evacuation of 37,500 people, killed two people, and destroyed more than 991 structures.
- **Spain, 2022 wildfire season:** Burned approximately 315,000 hectares across the country.
- **Canada, 2023 wildfire season:** Burned about 5% of the entire forest area of Canada and killed eight firefighters. Smoke caused widespread air quality alerts and evacuations in Canada and the United States.
- **South America, 2024 wildfires:** Affected Bolivia, Brazil, Chile, Colombia, Ecuador, and Peru, burning over 85 million hectares and causing significant deforestation of the Amazon rainforest.
- **Portugal, September 2024 wildfires:** Burned more than 135,000 hectares and led to at least nine fatalities.
- **United States, January 2025 wildfires (Southern California):** Burned over 23,000 hectares, destroyed more than 18,000 homes and structures, and resulted in at least 30 deaths.

1.1 Opening Remarks

The workshop began with opening remarks from three participants who set the stage for the presentations and discussions that followed.

Dr. Ana Crespo, President of the Royal Spanish Academy of Sciences, emphasised the growing frequency and severity of wildfires globally, including in Spain. She highlighted the crucial role of science in understanding and mitigating wildfire risks, particularly at the WUI. Dr. Crespo pointed to urban expansion into forested areas and the abandonment of agricultural land as key drivers of increased wildfire vulnerability. She underscored the societal value of scientific modelling, noting that predictive tools capable of identifying high-risk zones can strengthen early warning systems and support informed decision making by emergency services. Stressing the responsibility of the scientific community, she called for integrated, science-based, and policy-driven responses to the growing complexity of natural disasters.

Dr. Ourania "Rania" Kosti, Executive Director of IAP, introduced IAP's mission as a global network of academies of science, medicine, and engineering committed to knowledge exchange and addressing regional and global challenges, including those posed by natural hazards such as wildfires. Dr. Kosti emphasised the workshop's aim to foster new partnerships and build a global network of wildfire researchers. She called for collaborative frameworks to support data sharing and model integration and stressed the importance of engaging interdisciplinary expertise to address the complex, multi-scale impacts of wildfire.

Dr. José Manuel Moreno, Emeritus Professor of Ecology at the University of Castilla-La Mancha and Fellow of the Royal Spanish Academy of Sciences, provided an operational overview of the workshop, including venue logistics, recording protocols, and support personnel assignments. As a fire ecologist and liaison with the host academy, he noted the increasing convergence of natural and built environments and the challenges this presents for managing wildfire risk.

Following the opening remarks, Dr. Hussam Mahmoud, Professor of Civil and Environmental Engineering at Colorado State University, and now at Vanderbilt University, and chair of the workshop, introduced the goals of the meeting. In his role as chair, Dr. Mahmoud led the development of the workshop agenda and the selection of speakers in coordination with the host academy and IAP. He emphasised the urgency of addressing fire vulnerability in WUI communities and highlighted the persistent disconnect between land management practices and structural fire policies. Despite recent advances in fuel mapping and weather forecasting, he noted that significant gaps remain in translating these data into actionable strategies for risk mitigation.

Dr. Mahmoud outlined three core goals for the workshop:

- Identify barriers to model integration and assess their real-world applicability.
- Bridge the gap between fire behaviour simulations and policy implementation.
- Understand the challenges related to model scalability and data standardisation across national boundaries.

His remarks framed the workshop as a critical convergence point for global experts to co-design practical, collaborative solutions to the escalating challenges posed by wildfires.

1.2 Wildfire Modelling Paradigms and Data Integration

Dr. Mahmoud elaborated on the need to reconcile diverse modelling approaches—ranging from physics-based to AI-driven methods—which vary widely in resolution, scope, and usability. He noted that while some models are capable of structure-level analysis, others operate at coarser scales, posing challenges for aligning model outputs with policy and operational needs across scales. To address this complexity, the workshop sessions were intentionally structured to explore modelling diversity while identifying opportunities for integration and cross-scale policy harmonisation.

Dr. Mahmoud presented a scenario-based approach that assumed comprehensive access to weather, fuel, and structural data. Even under this idealised condition, Dr. Mahmoud questioned whether existing models on wildfire behaviour, both for wildland and community contexts, are sufficient to effectively inform policy. This rhetorical framing, illustrated in **Figure 1**, underscored the complexity of translating research outputs into actionable strategies within real-world decision-making constraints.

Figure 1: *Rhetorical framing presented by Dr. Hussam Mahmoud, United States, illustrating the challenge of devising comprehensive wildfire mitigation policies—even when critical data are available—due to the absence of community-level wildfire behaviour models.* SOURCE: Dr. Hussam Mahmoud, Colorado State University and now at Vanderbilt University

Highlighting systemic inefficiencies, Dr. Mahmoud pointed to the disconnect between wildfire policy domains—specifically land-based fire management and structural fire protection. This siloed approach, which is common in the United States, hinders the development of cohesive strategies for WUI. He cited the growing number of structural losses in recent wildfires, arguing that reversing such trends needs to be a policy priority.

Dr. Mahmoud noted that the workshop offered a rare opportunity to realign model development with practical mitigation strategies. Participants were encouraged to critically examine how their respective models could support vulnerability reduction and to identify the operational barriers that impede implementation on the local and national scale.

1.3 Session Architecture and Thematic Focus

The workshop's technical sessions were divided into five distinct tracks, beginning with wildfire propagation in natural systems (Session 1) and moving toward increasingly applied modelling approaches. Other sessions included: physics-based simulations (Session 2), semi-empirical models (Session 3), statistical and AI-based frameworks (Session 4). The workshop culminated with a guided breakout discussion (Session 5). This structure enabled a comprehensive examination of the modelling-to-action continuum. The breakout session (Session 5) was used to synthesise insights from earlier sessions and evaluate model efficacy in real-world scenarios. Participants of sessions 1–4 were asked to discuss modelling strengths and limitations, use cases, and barriers to broader deployment. Their observations were compiled into slides and presented in the final plenary.

On the topic of data sharing, Dr. Mahmoud recognised the absence of standardised, real-time data platforms as a critical barrier. He proposed that participants highlight these issues during breakout sessions, even if they could not be fully resolved within the workshop timeline. He emphasised the need for a separate initiative dedicated entirely to developing unified wildfire data architecture. He concluded by stressing that continued funding support reflects both recognition of the problem's urgency and a shared responsibility for its resolution. The workshop, he reiterated, was not only a technical exchange but a call to action for global interdisciplinary collaboration in wildfire risk management.

1.4 Keynote Perspective on Wildfire Early Warning, Monitoring, and Risk Assessment

Dr. Jesus San-Miguel, speaking on behalf of the European Commission's Joint Research Centre (JRC), opened his keynote with an acknowledgment of global wildfire challenges and the European Union's (EU's) growing role in both research and operational support. His presentation outlined the current state of wildfire monitoring, early warning, and risk assessment, offering insights into data standardisation, decision support systems, and international cooperation. Dr. San-Miguel noted that the JRC's primary role is to inform policy development in the EU by addressing data gaps and promoting harmonised methodologies. Although rooted in European priorities, the European Commission's initiatives are increasingly global in scope due to the transboundary nature of wildfire risks and their intensification due to climate change.

Wildfires, while historically part of natural ecosystems, have changed drastically in scale and impact. According to Dr. San-Miguel, 96% of fires in Europe are now human-induced, with many occurring in areas that historically did not experience fire activity. Current global datasets underestimate the extent of burned areas, particularly in tropical and temperate forests. For example, MODIS-based satellite data underrepresent fire impact by up to 80% in some regions. Climate change has amplified wildfire frequency and severity, with increasing incidents in North and South America, Australia, and across Europe. Events such as the 2023 wildfires in Canada and the unprecedented 2024 fire season in South America highlight the global dimension of this threat. Dr. San-Miguel noted a clear link between fire activity and rising global temperatures.

To address wildfire risk globally, a joint initiative of the European Commission and the Group on Earth Observations was launched in 2021 to gather and share harmonised information on wildfires at the global level. This initiative resulted in a Global Wildfire Information System (GWIS), which is an international platform designed to provide global-scale information on wildfires, supporting fire risk assessment, early warning, and long-term monitoring **(Figure 2)**. The key features of this platform are to track active fires using satellite data, produce global fire danger forecasts (e.g., fire weather index), and analyse fire behaviour and burned area estimates.

Figure 2: *GWIS applications—fire danger forecast.* SOURCE: Dr. Jesus San-Miguel, Joint Research Centre, European Commission

The EU currently utilises the Canadian Fire Weather Index (FWI) to assess fire ignition potential, spread, and intensity. Short-term forecasts (up to nine days) are complemented by experimental medium- and long-range forecasts (up to six months). These forecasts are shared with civil protection agencies to support pre-positioning of emergency resources. However, challenges remain in harmonising fire danger indices across countries. Despite collaborative efforts among 43 nations, reaching consensus on models and terminology remains difficult. The JRC continues its work on standardisation in partnership with global entities such as the United Nations and the World Meteorological Organization.

Dr. San-Miguel emphasised two distinct approaches to fire monitoring: long-term trend analysis and near real-time tracking. Long-term monitoring relies on satellite imagery, and its accuracy is limited by cloud cover and data availability. The European Commission is advancing the use of Sentinel-2 satellite data that provides 20-meter resolution imagery and anticipates further improvements with future satellite generations.

Real-time systems are critical for decision making and public safety. Currently, Europe and parts of the globe receive daily updates on wildfire activity, with some regions receiving data refreshed as frequently as every five minutes. These systems are increasingly enhanced by AI to process and classify large volumes of incoming satellite data. Dr. San-Miguel noted that the JRC has developed a decision support system that models fire progression, predicts perimeters, and estimates impacted populations and infrastructure. This system supports the European Emergency Response Coordination Centre in allocating aerial firefighting resources and other emergency response measures. Similar systems are being piloted for global application through international collaborations. A key limitation in modelling fire behaviour is the lack of standardised fuel data, particularly in WUI zones. Dr. San-Miguel noted that although efforts are ongoing to address this through several projects supported by Horizon 2020, the EU's flagship research and innovation funding programme, coordination across initiatives remains a concern. These include FirEUrisk, aiming to better understand how vulnerable communities are to wildfires and which are the best practices to adapt, and FIRE-RES, aiming to develop an integrated fire management strategy to efficiently and effectively address extreme wildfires events in Europe.

Despite improved data and models, implementation of fire-related policies remains inconsistent. Many countries possess risk assessments but lack enforcement mechanisms. Dr. San-Miguel stressed the need for a sustained and unified European research strategy, similar in scope to the U.S. LandFire programme. In his view, without consistent funding and long-term planning, fire science risks becoming fragmented and reactionary.

In closing, Dr. San-Miguel called for better integration between wildland fire science and structural fire safety research. Current funding structures and institutional silos hinder comprehensive understanding of how wildfires affect the built environment. He concluded by affirming that wildfires are a growing global threat requiring coordinated scientific, operational, and policy responses. The European Commission is taking significant steps to build integrated systems for forecasting, monitoring, and response. However, in his view, long-term success will depend on harmonised data standards, continuous investment, and international collaboration.

1.5 Discussion on the Keynote Presentation

A participant raised a question about the accuracy of fire progression predictions and prioritization systems. Dr. San-Miguel confirmed that validation efforts are underway, using historical fire progression data to train and evaluate the models. He emphasised that model refinement and validation are continuous processes which are informed by annual fire data from numerous large wildfire events. Another participant sought clarification regarding the satellite data used in near-real-time fire progression mapping. Dr. San-Miguel confirmed that his team at JRC uses Sentinel-2 imagery (20-meter resolution) for burnt area mapping rather than hotspot detection. Additionally, questions were asked about whether JRC's fire progression modelling tools were AI-based or physical. It was noted that the current tools rely on a semi-empirical modelling (notably FARSITE) and that incorporating AI or stochastic methods in the future is a possibility, particularly in order to overcome limitations in fuel mapping.

A participant expressed frustration with the outdated national wildfire datasets available in Spain, pointing out that the most recent data available in the national database date back to 2015. This was described as a bottleneck for modern fire research and deemed unacceptable given current scientific and operational needs. This limitation was acknowledged by others and was attributed to the slow and fragmented process of data collection from regional authorities, followed by lengthy validation and standardisation procedures before publication in national wildfire databases.

When asked whether burn probability modelling, like that developed at the Forest Service's Missoula Fire Lab in the United States, had been implemented at the European level, Dr. San-Miguel responded that such approaches were being explored but had not yet been fully adopted. The integration of burn probability metrics is viewed as a valuable future step.

Participants raised concerns about the ongoing divide between wildland fire and structural fire research communities in both funding and academic spheres. A participant argued that this division prevents a comprehensive approach to addressing WUI fire impacts. Many participants agreed and pointed out the lack of a coordinated research strategy in Europe. They also highlighted gaps in past EU funding cycles that have disrupted continuity and long-term planning.

In closing, Dr. San-Miguel acknowledged the complexity of building a cohesive fire research agenda across the EU's 27 member states. While some progress has been made, such as increased civil protection funding and the appointment of a dedicated fire officer in the European Commission, still there is no strategic framework comparable to that in a single country, such as the United States, where interagency governance and coordination is prioritised. For example, the National Wildfire Coordinating Group (NWCG) includes representatives from the U.S. Forest Service, Department of the Interior, the Federal Emergency Management Agency, state fire agencies, and the Wildland Fire Leadership Council, which provides strategic direction for wildland fire policy across federal, tribal, state, and local governments. Participants agreed that a sustained, wide research and policy strategy in Europe is essential.

-2-
WILDLAND FIRE BEHAVIOUR AND OBSERVATION

The session on Wildland Fire Behaviour and Observations (Session 1 in the meeting agenda as shown in Appendix A), explored the dynamics of wildfires, including their causes, patterns, and processes associated with their propagation as well as the impact of global climate on shifting fire regimes. It was moderated by Dr. Andrey Krasovskiy, International Institute for Applied Systems Analysis.

2.1 Integrating Science and Technology in Fire Management

Dr. Ilkay Altıntaș, University of California San Diego, described her lab's mission to bridge fire science with practical management by translating scientific findings into actionable decision-support tools. This approach integrates multimodal data streams with advanced models, enabling near real-time execution for operational use by decision makers at various levels. Dr. Altıntaș highlighted the need for model flexibility, noting that fire management requirements vary by context. For example, initial attack scenarios call for rapid models with minimal complexity capable of delivering results within minutes. As fire management scenarios shift from emergency response to strategic initiatives—such as fuel optimization, community risk assessment, prescribed fire planning, and ecological sustainability—model complexity and computational requirements increase. Dr. Altıntaș's lab adapts fire models to fit specific needs, using platforms like FIREMAP and BurnPro^{3}D to simulate high-resolution fire behaviour in 3D environments.

To support beneficial fire practices such as prescribed burns and tribal fire use, her team developed custom 3D modelling tools. These tools operate in immersive digital twin environments that support policy education, public engagement, and fire personnel training. A digital twin is a virtual representation of a physical system or environment that uses real-time data, simulations, and algorithms to mirror and predict behaviour of the real system. In wildfire management, digital twins can simulate fire spread, infrastructure vulnerability, and emergency responses to support planning, training, and decision making.

The FireMap platform was developed as a decision-support tool. It integrates multimodal data—including satellite imagery, aircraft sensors, and camera feeds—into a centralised system that provides fire behaviour predictions within five minutes of ignition. Developed in collaboration with California emergency services, FireMap represents a significant advancement in initial fire attack capabilities. During recent firestorms in Southern California, traditional wildland fire models underperformed as fires rapidly moved to urban areas. In response, Dr. Altıntaș's team experimentally modeled homes as combustible timber. Although this approach is considered a gross approximation, the model produced surprisingly accurate results, highlighting the need for urban–wildland coupled models. Responding to extended attack scenarios requires different workflows than responding to initial attacks.

Tools like ELMFIRE (Eulerian Level Set Model of FIRE spread) incorporate probabilistic modelling with adapted communication strategies for resource planning several days in advance. This shift necessitates tailored user interfaces and closer collaboration with emergency management leadership to ensure the tools align with operational decision-making needs. BurnPro 3D was developed to optimise prescribed fire planning at scale, addressing the limitations of traditional wildfire tools that were often misapplied for prescribed fire contexts. BurnPro 3D leverages fast-simulation models and voxel-scale (1-meter) data, integrating land cover, forest inventory, and species characteristics to produce high-resolution, risk-informed burn plans. Using LiDAR and aerial imaging, Dr. Altıntaș's team created immersive forest environments where users can walk through simulations, observe fire behaviour, and interact with predictive models (Figure 3). This immersive approach supports not only fire personnel but also scientific validation, education and training of emergency personnel, and policymaking. Dr. Altıntaș noted that the fire modelling field is data-rich but also faces significant challenges in standardisation, multi-scale data integration, and temporal dynamics (4D modelling). She emphasised the need for rapid, adaptable solutions and sustainable data infrastructures. To address these challenges, her team launched the Wildfire Science and Technology Commons. This initiative promotes open data, model sharing, AI readiness, and collaborative tool development. It aims to build a sustainable marketplace and cloud-compatible environment that supports global fire science innovation.

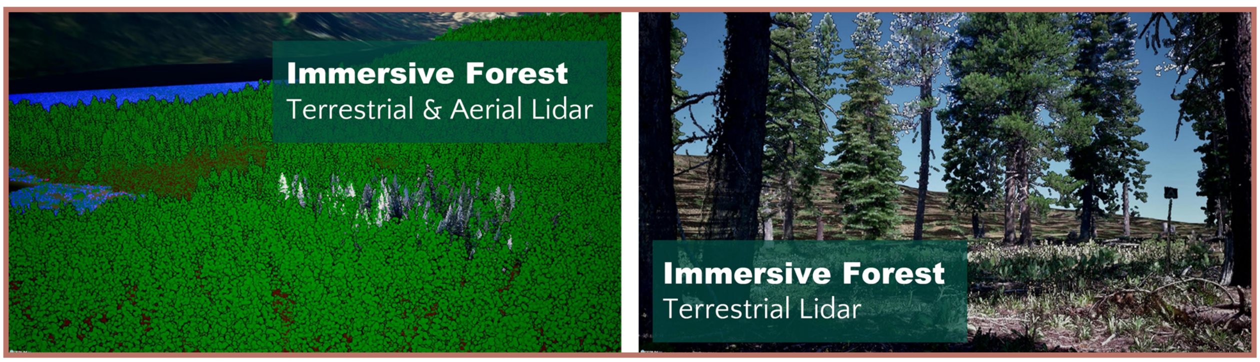


Figure 3: *Immersive forest environment using LiDAR and aerial images.* SOURCE: Dr. Ilkay Altıntaş, University of California, San Diego

Dr. Altıntaș noted that partnerships with organisations such as San Diego Gas & Electric and the California Governor's Task Force have produced valuable data hubs and predictive tools. These platforms support vegetation management, infrastructure protection, and power outage predictions, demonstrating real-world applications of open science. Dr. Altıntaș's team developed innovative deep learning models that integrate physics principles to simulate fire dynamics—a difficult domain traditionally underserved by AI. These physics-guided models represent a cutting-edge frontier in wildfire prediction research and have gathered significant recognition from the scientific community.

Dr. Altıntaș concluded by emphasising the importance of cultural change, collaboration, and a commitment to open science. She advocated for a multi-model ecosystem designed to address specific problems, called for greater access to and understanding of how fire modelling works, and encouraged community-led model development. By bridging the gap between research and practice, she argued, wildfire science can deliver more effective and scalable solutions in the face of a changing climate.

2.2 Overview of Wildfire Trends in Spain and the Mediterranean

Dr. José Moreno, Royal Spanish Academy of Sciences, presented a comprehensive analysis of wildfire behaviour and policy in Spain, offering insights relevant to the broader Mediterranean region. He began with a review of wildfire trends, highlighting a significant rise in the number of fires during the 1970s and 1980s, followed by a steady decline beginning in the mid-1990s as shown in **Figure 4**. A major turning point came in 1994, which marked one of the worst wildfire episodes in the country's history, with nearly half a million hectares burned and more than 400 major fires recorded. The 1994 events in Spain mobilised both government and society, leading to strengthened fire management policies and a noticeable reduction in both fire occurrence and area burned.

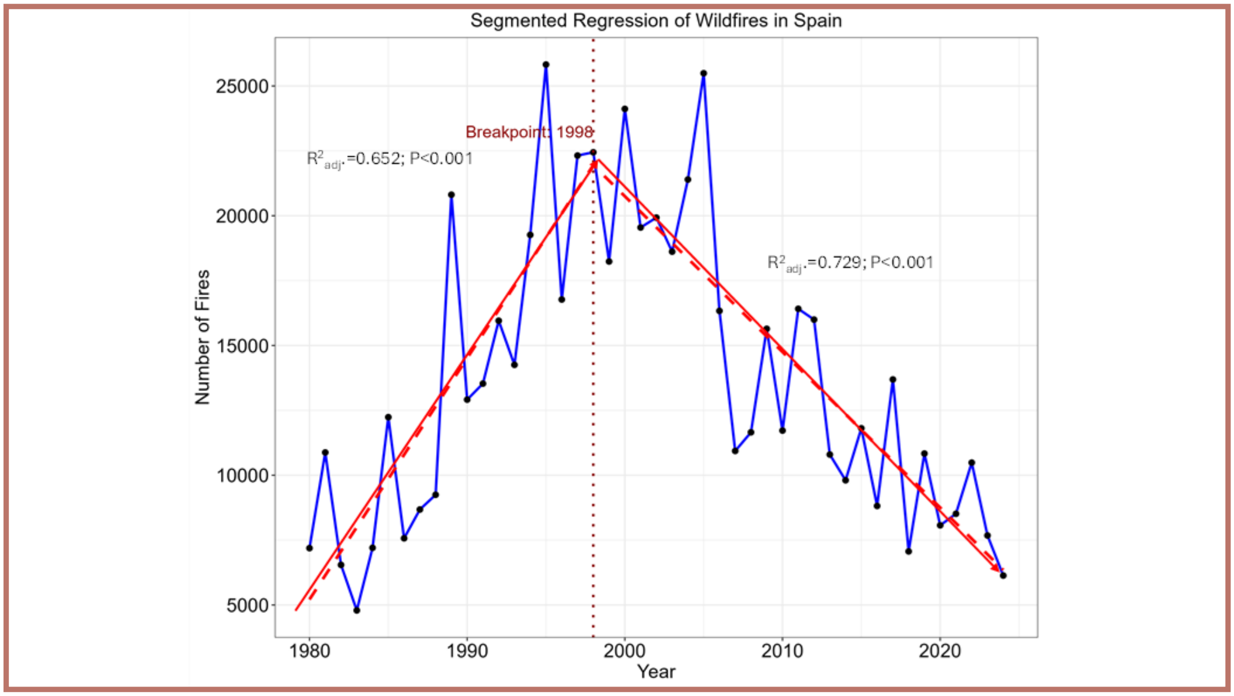


Figure 4: *Wildfire trends in Spain from late 1970s until 2023.* SOURCE: Dr. José Manuel Moreno, Emeritus Professor of Ecology at the University of Castilla-La Mancha and Fellow of the Royal Spanish Academy of Sciences

Despite the overall reduction in fire incidents, Dr. Moreno pointed out an increase in treeless burned areas, indicating a shift in the type of landscape affected by wildfires. The average fire size and the 95th percentile fire size have declined over time. Meanwhile, forest coverage in Spain has increased since the 1940s, partly due to land abandonment, leading to greater fuel availability. These ecological changes have contributed to the continued change in fire risks in the region.

Dr. Moreno also emphasised the expanded use of firefighting resources, particularly the growth in aerial suppression capabilities since the 1990s. The deployment of aircraft and helicopters to nearly every fire has greatly improved suppression efforts. Combined with enhanced ground support, these efforts have contributed to the overall decline in the burned area. While fewer fires are occurring, the incidence of civil protection interventions—such as road closures, power line disruptions, evacuations, and infrastructure damage—is increasing. This paradox reflects the growing encroachment of fires into urbanised and infrastructure-dense areas, especially along the Mediterranean coast in regions like Catalonia, Valencia, and Murcia.

Dr. Moreno also reported a decline in firefighter fatalities, which is primarily due to improved safety and aerial operation protocols. In contrast, civilian deaths have nearly doubled, often resulting from entrapment, heart attacks, or injuries sustained while fleeing fires. This trend underscores the growing threat to communities near WUI areas. He presented data showing a strong correlation between wildfire activity and climate indicators, particularly the FWI and drought severity metrics. Rising temperatures and prolonged dry periods are contributing to longer, more intense fire seasons. The summer of 2022 stood out as a historic extreme, with record-setting temperatures and FWI values across much of Spain.

Using statistical models, Dr. Moreno and his team demonstrated a strong relationship between climate variables and wildfire occurrence across southern Europe and western North America. Projections under high-emission scenarios (RCP 8.5) indicate a 100–300% increase in fire danger across regions such as Portugal, northern Spain, and the central Iberian Peninsula. He cautioned that even under lower-emission scenarios, significant increases in fire danger remain likely.

Dr. Moreno ended his presentation with a powerful example from his own campus, where a fire approached dangerously close, underscoring the proximity and reality of the threat. Dr. Moreno emphasised that firefighting alone will not be sufficient to address future climate-driven wildfire extremes. He called for a paradigm shift toward integrated landscape management that includes fuel reduction, especially near the wildland–urban interface; use of fire as a tool, including prescribed burns and cultural practices; and better preparedness for extreme events, recognising that response systems may be overwhelmed, as it happened in 2022.

2.3 Panel Discussion on Wildfire Behaviour and Observation

Dr. José Moreno responded to a question about projected increases in the burned area by clarifying that the key variable is ignition frequency. He argued that under extreme weather conditions, even a single ignition could trigger large, uncontrollable fires. Suppression systems often become overwhelmed, as was evident during Spain's 2022 fire season. Dr. Moreno stressed that reducing ignitions is the most direct and effective approach to managing fire size and frequency. He also highlighted the need to integrate wildfire into broader multi-risk climate adaptation frameworks, especially in regions prone to other hazards like earthquakes and flooding. Participants discussed the value of combining data from different hazards—such as fire, debris flows from landslides, and floods—into unified models. U.S.-based researchers described how airborne LiDAR data have supported debris flow prediction following wildfires, feeding into emergency response planning. Similar approaches are being applied to earthquake and flood modelling, using life-cycle analysis to assess the vulnerability of buildings exposed to multiple hazards.

Several speakers stressed the importance of cultivating a culture of risk awareness. They noted that in many regions, the public lacks basic preparedness for wildfires, floods, or earthquakes. By contrast, in places like California, residents often receive hazard-specific education and evacuation guidance by fire authorities within a town or a city. Mediterranean communities, however, frequently lack this foundational knowledge and are unsure how to respond during extreme events. To address this gap, participants called for improved communication, regular community drills, and expanded risk education initiatives.

The discussion also addressed model limitations in capturing extreme fire behaviour, particularly at night, a critical window for successful fire suppression. However, during Spain's 2022 fires and Australia's 2019–2020 fire season, nighttime humidity and temperatures did not drop significantly, removing this key opportunity for fire suppression. California's fire services have developed nighttime aerial suppression systems, but such innovations remain isolated and not widely adopted. There was agreement among several participants that scientific tools and fire models must evolve to better predict and manage these new extremes and better support real-time decision making.

Panellists acknowledged that suppression-based strategies are no longer sufficient strategies. Prevention, especially through the expanded use of fire as a management tool (e.g., prescribed or managed burns), need to play a larger role. However, Europe—unlike the United States or Australia—still lacks widespread policy backing and cultural acceptance for these practices. Some participants called for a paradigm shift, urging the development of scientific tools that can guide risk reduction strategies and support informed decisions around the use of managed fire.

A discussion on the progress U.S. wildfire programmes have made, although limited, raised questions about their replicability in other regions. Speakers emphasised the need for long-term collaboration, open data sharing, and the formation of public–private partnerships such as those currently formulated across the western United States between local fire departments, emergency management offices, and public utility companies. They pointed to U.S. wildfire database initiatives, such as LandFire, as a successful model for integrating science, policy, and operational coordination, an effort built over decades. LandFire produces geospatial data on fuels, vegetation, and fire regimes that support fire behaviour modelling, fuel treatment planning, and ecosystem risk assessments. Participants called for similar initiatives in Europe but acknowledged the difficulties posed by fragmented national policies and limited funding.

The session concluded with a practical discussion on grazing as a fuel management strategy. Participants shared examples of successful grazing trials in Spain and the United States, especially in areas where mechanical treatment, where machines and tools are used to reduce vegetation, is restricted. Grazing was framed not only as an ecological solution, but also as a cost-effective service to support rural economies while reducing wildfire risk. Participants stressed that grazing is impactful and needs to move beyond small pilot projects. Achieving this will require targeted policy support and sustained public investment.

-3-
PHYSICS-BASED WILDFIRE MODELLING

Session 2 of the workshop, titled Modelling Wildland–Urban Interface Fires with Physics-Based Approaches (as listed in the meeting agenda in Appendix A), focused on the application of computational fluid dynamics (CFD) to simulate localised fire behaviour and fire spread within communities. The session was moderated by Dr. Miguel Almeida of the University of Coimbra, Portugal.

Presentations in this session featured models such as the Fire Dynamics Simulator (FDS) which was developed by the U.S. National Institute of Standards and Technology and simulates key fire propagation mechanisms: radiation, convection, and ember spotting. FDS solves a form of the Navier-Stokes equations tailored for low-speed, thermally driven flows involving combustion. In addition, participants discussed a Nek5000 spectral element model designed to simulate ember dynamics both near the ground and in the air. This model employs large-eddy simulation and Lagrangian particle tracking to represent ember transport processes. It accounts for multiple physical forces influencing ember behaviour, including drag, gravity, collisions, and wind.

3.1 Modelling Fire Behaviour Using Computational Fluid Dynamics

Dr. Craig Weinschenk, Fire Safety Research Institute, highlighted the evolution and integration of FDS capabilities for modelling complex fire behaviours in WUI environments. FDS, originally developed to model structural fires, has undergone significant modifications to support wildland fire dynamics. Dr. Weinschenk detailed how the tool's vegetation modelling components, once separate under the Wildland Fire Dynamics Simulator (WFDS), have been integrated into the main FDS framework to provide a unified modelling platform for diverse fire scenarios. A key strength of FDS is its robust validation infrastructure, which includes hundreds of verification and validation cases which are regularly tested on dedicated computing clusters.

Weinschenk emphasised that verification routines ensure mathematical consistency, while more comprehensive validation is typically reserved for major software releases. FDS models vegetation using Lagrangian particles, enabling detailed simulations of pyrolysis and combustion processes. Vegetative fuels are represented as discrete elements with specific thermal degradation characteristics to simulate flame spread, crown fires, and ember generation under varying environmental conditions. The model incorporates multiple flame spread mechanisms, including level set, boundary fuel, and particle-based methods, giving researchers the flexibility to select the most appropriate approach for the fire scenario being studied, whether in grasslands, shrublands, or forest canopies. Dr. Weinschenk presented modelling results produced by NIST from the Camp Swift experiments in Texas, where controlled burns were used to collect empirical data for model calibration. These experiments included drone-based infrared mapping, ground thermocouple arrays, and heat flux sensors to capture fire behaviour at high resolution. This experiment demonstrated the feasibility of using FDS for high-resolution wildland fire modelling and highlighted its computational intensity. The current version of FDS, 6.10.1, includes support for multi-step pyrolysis chemistry, enhancing the model's ability to simulate key thermal degradation processes such as fuel moisture evaporation, char formation, and gas-phase ignition. These advancements improve the fidelity of simulations, particularly in capturing the transition from smouldering to flaming combustion.

Dr. Weinschenk identified limitations in how oxygen availability is computed for combustion reactions in FDS. In previous versions of FDS, the software assumed full oxygen concentration in adjacent cells, where each cell represents volume of space in the computational domain, leading to unrealistic rapid flame acceleration. To address this, a mass balance approach was introduced, resulting in more accurate simulation of flame spread behaviour. FDS simulations are sensitive to grid resolution, especially when modelling flame spread. However, finer grids do not necessarily yield more accurate results due to the complex interplay of wind behaviour, combustion chemistry, and particle interactions. Wind modelling remains a major limitation in FDS.

While FDS can generate and loft firebrands, significant challenges remain in being able to predict the accumulation of fire brands on surfaces and the ignition potential they pose. This current gap limits the model's effectiveness in capturing ember-driven ignition and spot fire development in communities.

3.2 Community-Scale Vulnerability Assessments in France

Dr. Éric Maillé, French National Research Institute for Agriculture, Food and Environment (INRAE), delivered a presentation on behalf of his colleague Dr. Anne Ganteaume, also from INRAE, who was unable to attend the workshop. The presentation offered a detailed exploration of vulnerability assessment at the WUI using a combination of laboratory experiments, two-dimensional simulations, and full CFD modelling. This approach emphasised operational goals, aiming to provide practical insights for land managers and policymakers rather than focusing on theoretical modelling advancements alone. He presented a detailed application of physics-based modelling to assess wildfire vulnerability and inform fuel management strategies in WUI settings. Representing Anne Ganteaume, Dr. Maillé framed the institute's work around operational priorities such as aiming to support decision makers in evaluating community fire resilience amid global climate changes, land use, and vegetation patterns. What distinguishes this work is its strong emphasis on real-world application, using simulation tools not only to study fire dynamics but also to assess the effectiveness of vegetation clearance policies and fire-resistant landscaping practices.

Dr. Maillé began by outlining the regulatory framework in France, where a 50-meter vegetation clearance around homes is mandated by law. However, the real-world effectiveness of this measure—particularly when accounting for slope, wind conditions, and the presence of exotic or ornamental plant species—remains uncertain. The project's overarching goal is to inform fire-resilient landscaping and urban planning policies by integrating laboratory data, field observations, and advanced modelling techniques such as FDS.

The first phase of the project focused on developing a database of plant flammability characteristics across multiple scales—from particle-level combustion properties to full-plant outdoor burn tests. These experiments revealed that roofs, rather than walls, are often the primary point of fire penetration into homes, especially when vegetation reaches or exceeds the level of the eaves. Additionally, the tests demonstrated that slope and wind—factors not currently considered in vegetation clearance regulations in France—have significant influence on fire behaviour and building exposure.

Dr. Maillé outlined three successive modelling steps. The first step involved using a 2D flame propagation model derived from the SWIFFT model to simulate fire spread in gardens as shown in **Figure 5**. Although the model provided useful preliminary insights, it lacked the ability to capture vertical fire spread through ladder fuels—where fire spreads vertically through vegetation into tree canopies.

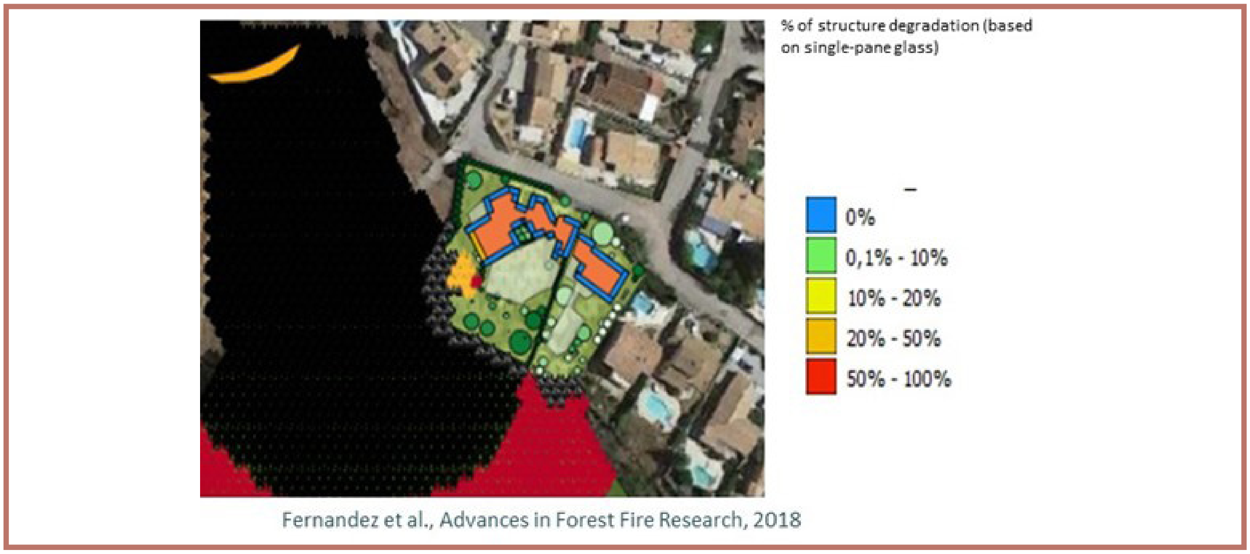


Figure 5: *FIREWUI model derived from raster-based fire spread model SWIFFT accounting for thermal degradations of structures, wildland and ornamental vegetation, leading to damage to building.* SOURCE: Fernandez, R., Planas, E., Pastor, E., & Álvarez, J. (2018). Advances in forest fire research. In D. X. Viegas (Ed.), Advances in Forest Fire Research 2018. Imprensa da Universidade de Coimbra

In the next step, FDS was used to simulate seven scenarios representing a range of vegetation configurations from bare lawns to gardens with large trees adjacent to houses. These simulations showed a twofold difference in heat release rates between treated (cleared) and untreated vegetation plots. They also revealed significant variation in radiant heat fluxes on building surfaces depending on the presence, size, and placement of trees. However, Dr. Maillé acknowledged that modelling wind accurately at this fine scale remains a technical challenge. Moreover, certain plant species, particularly ornamental varieties, displayed fire behaviours that were not adequately represented in existing vegetation models, underscoring the need for further refinement.

The third step included Dr. Maillé's own research which focuses on integrating real terrain data, including topography and vegetation types, into larger-domain FDS simulations. Intermittent wind conditions were also introduced to more accurately reflect real-world fire scenarios. The goal was to assess the spatial relationship between vegetation fuel and vulnerable geographical structures (buildings) to assess the "global risk" at a local scale. These simulations successfully reproduced observed fire paths and validated the effectiveness of fuel treatment strategies. However, some discrepancies remained, particularly in complex scenarios, such as fire spread through hedgerows.

Dr. Maillé concluded by emphasising the value of simulation tools in assessing fire mitigation strategies. His findings underscored the need to revise existing vegetation clearance regulations—demonstrating that a three-meter buffer between trees and homes is often insufficient, particularly on sloped terrain. He also stressed the importance of improving vegetation moisture content modelling and expanding flammability databases to include ornamental species, which are commonly found in residential landscapes but remain underrepresented in current fire behaviour models.

3.3 Performance-Based Design in WUI Contexts in Spain

Dr. Eulàlia Planas, Polytechnic University of Catalonia, presented research on applying performance-based design (PBD) methodologies—commonly used in structural fire safety—to assess building vulnerability in the WUI. Her work addresses the limitations of current prescriptive regulations by proposing a more robust, flexible, and physics-informed framework. Using CFD, specifically the FDS, she evaluates how residential structures withstand wildfire exposure under various conditions. Dr. Planas began by acknowledging the widespread use of PBD in conventional fire safety engineering, particularly for complex structures such as tunnels and high-rises where prescriptive codes may be inadequate. PBD methodologies involve defining performance objectives, selecting relevant fire scenarios, and validating the design through fire modelling. The core principle is to ensure safety not merely through code compliance but by demonstrating that the building performs reliably under realistic fire conditions. Planas argued that this approach can be effectively applied to WUI contexts, where fire behaviour is highly variable and complex.

Dr. Planas outlined a multi-stage methodology tailored for applying performance-based design in WUI settings. The process begins with setting the project's scope and objectives, such as protecting human life, preventing structural damage, or using a building as a temporary shelter. Next, quantitative performance criteria are defined, followed by the selection of representative fire scenarios. Building performance is then evaluated using CFD simulations. A key component of the approach is the identification of performance thresholds, such as maximum allowable window temperatures or structural integrity limits, to determine whether a building can withstand wildfire impacts under the modeled conditions.

To demonstrate this approach, Dr. Planas presented a case study involving a house exposed to different types of vegetation-fueled fires. Three scenarios were modeled: (1) a high-frequency, low-consequence fire starting in nearby hedgerows; (2) a low-frequency, high-consequence fire involving large trees adjacent to the structure; and (3) a special scenario involving ignition of porch furniture near the building facade. In all cases, CFD simulations revealed that fire exposure resulted in window breakage and subsequent fire penetration, as illustrated in **Figure 6**, thus failing to meet the defined performance criteria. In response, mitigation measures—such as installing solid aluminum shutters—were evaluated and shown to be effective in preventing fire entry.

Figure 6: *Fire Dynamics Simulator (FDS) analysis of a house with failure of porch window.* SOURCE: Dr. Eulàlia Planas, Polytechnic University of Catalonia

A critical insight from the study was the significant role of the building's immediate surroundings on fire vulnerability, especially ornamental vegetation and artificial fuels like stacked firewood, garden furniture, and propane tanks. Dr. Planas highlighted the limited availability of data on the flammability and thermal behaviour of these elements, emphasising the need for further research and material characterisation to improve simulation accuracy. Improving the representation of such components in fire simulations is essential for enhancing the accuracy and reliability of performance-based assessments in WUI environments.

In addition to fire entry modelling, Dr. Planas also discussed the use of CFD for assessing the building's capacity to serve as a shelter during wildfire events, especially under smoke-filled conditions. She also addressed the application of simulation tools to evaluate evacuation strategies in WUI environments. Her team has also examined the effectiveness of defensible space mitigation measures and related regulations, such as buffer zones around homes, under varying terrain and vegetation conditions, helping to inform more context-sensitive fire mitigation strategies.

In conclusion, Dr. Planas's work offers a structured, scenario-driven framework that enables engineers and policymakers to make informed decisions about building design and retrofitting in wildfire-prone areas. By leveraging the precision of CFD simulations and the flexibility of PBD, the methodology presented by Dr. Planas advances the field toward more resilient, data-driven approaches for wildfire risk management both at the individual plot level and across broader community scales.

3.4 Modelling Ember Storms at the Wildland–Urban Interface in Australia

Dr. Jason Sharples, University of New South Wales, Australia, shifted the focus from flame-based fire behaviour to the less-studied but highly destructive phenomenon of ember storms in WUI fires and discussed this within the Australian context. Dr. Sharples began by contextualising current mitigation strategies in Australia, namely Asset Protection Zones (APZs) and the building standard AS 3959, both of which primarily aim to reduce exposure to radiant heat through vegetation clearance and prescriptive building materials. Dr. Sharples highlighted a critical shortcoming in these frameworks: they inadequately account for dynamic fire behaviour and the risk posed by ember attack, which can lead to ignition well beyond cleared zones and protected perimeters.

Drawing on historical events like the 2003 Canberra fires, Dr. Sharples showed how entire neighbourhoods were devastated by ember attack even while the main flame front remained over 100 meters away. In these cases, embers ignited homes directly or set ablaze surrounding vegetation, triggering secondary fires that rapidly overwhelmed urban areas. These examples underscored the critical need to address ember behaviour as a distinct and potent driver of structure loss in WUI fire events.

To advance understanding and modelling of ember storms, Dr. Sharples and his team developed a new computational framework that departs from traditional approaches. Unlike traditional models that treat embers as ballistic particles following parabolic trajectories, Dr. Sharples' team focused on aeolian-driven behaviour—embers that are lofted and carried at low altitudes across the ground by wind turbulence. Using the spectral element solver Nek5000, the team simulated embers as Lagrangian particles interacting dynamically with airflow patterns around buildings and vegetation as shown in **Figure 7.** This approach captures more realistic ember behaviour and dispersion, particularly in complex WUI environments.

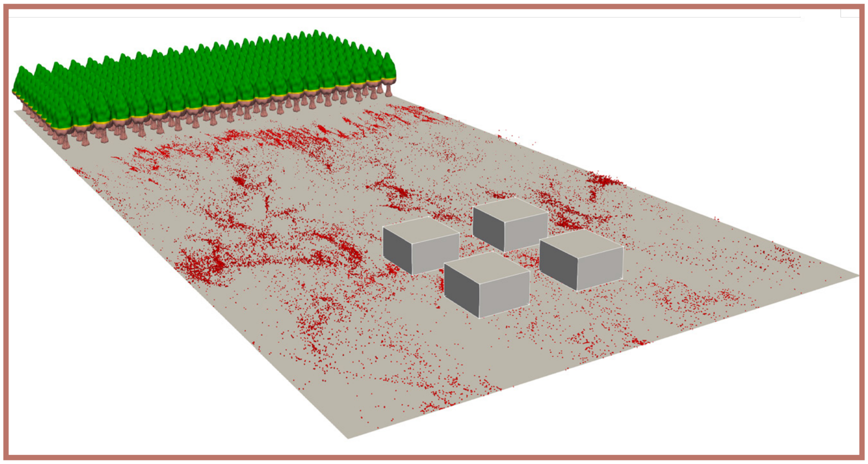


Figure 7: *Modelling aeolian-driven ember storms at the WUI.* SOURCE: Dr. Jason Sharples, University of New South Wales, Australia. Simulation conducted by Tanvir Saurav, PhD Scholar.

The model developed by Dr. Sharples and his team incorporated four core elements: forest canopy dynamics, wind fields, urban infrastructure, and ember movement. Simulations showed that embers tend to accumulate behind the first row of houses, locations that frequently contain ignition-prone materials such as wooden decks, stacked firewood, and garden furniture. This makes these areas especially vulnerable during ember storms. The model also revealed that dense forest canopies could trap embers in localised vortices, limiting their dispersion and keeping them closer to their source. In contrast, sparse canopies allow embers to travel farther and more rapidly, increasing the risk of spot fires ahead of the front of the main flame.

Through a series of simulations and experiments, varying factors such as building density, fire weather intensity, and forest structure, Dr. Sharples demonstrated how ember distribution patterns shift in response to both environmental and built-environment parameters. These findings not only affirm observational data from past wildfires but also provide a foundation for rethinking community-level fire mitigation strategies. By capturing the complex interplay between landscape features and ember behaviour, the research supports critical tools to better anticipate, visualise, and mitigate the destructive potential of embers in future wildfire scenarios.

Dr. Sharples concluded by challenging the adequacy of house-by-house risk assessments, advocating instead for a broader, suburb-level approach to wildfire resilience. He called for the integration of landscape architecture and urban planning principles to design communities that inherently limit ember exposure pathways. His work underscores the need to revise building codes and APZ design principles, emphasising the complexity and unpredictability of ember behaviour under extreme fire conditions.

3.5 Summary of the Panel Discussion on Physics-Based Models

The discussions focused on how ember particle density is represented and modeled in different tools, comparing established platforms like FDS with emerging ember storm models. Dr. Sharples clarified that the ember model he and his team have developed was currently exploratory and not yet calibrated with field data or directly compared with FDS. Its primary aim is to identify ember accumulation zones near structures and offer a new perspective on spatial vulnerability in WUI environments.

A major theme of the discussion was the challenge of translating research models into practical tools for engineers and decision makers. While advanced tools are increasingly available, concerns were raised about accessibility, ease of use, and the risks of potential misuse without proper training. Participants noted the importance of education, professional licensing, and professional standards to ensure ethical and effective application of fire modelling in the built environment.

Concerns were also raised about inconsistent results when different users apply the same model—a common problem in CFD modelling. Dr. Weinschenk noted that the FDS development team is addressing this by working on best practice guidelines and plans to establish a wildland fire modelling equivalent to the MACFP (Modelling and Analysis of Complex Fire Phenomena) initiative, which has proven effective in promoting consistency and rigor within the structural fire community.

The panel also engaged in an in-depth discussion on evaluating which fire models are best suited for specific tasks. Participants expressed the need for comparative studies across modelling platforms (e.g., FDS, WFDS) and for better documentation of input sensitivities and model limitations. A recurring theme was the importance of developing actionable models and balancing model output with computational cost, particularly for time-sensitive or large-scale applications.

Several participants pointed out that insurance companies continue to rely on overly simplistic wildfire models even as wildfire losses grow. Although there is growing interest within the insurance industry in using advanced modelling for pricing risk, many insurers remain cautious and rarely disclose the methodologies they use. Panellists advocated for better alignment between community-level wildfire risk assessments and insurer methodologies, arguing that such alignment could drive more informed land-use decisions and influence building policy in high-risk areas.

There was strong agreement among workshop participants around the urgent need for better real-world fire data, especially during extreme wildfire events. Participants emphasised that although experimental burns provide valuable insights, they cannot fully replicate the complexity and unpredictability of catastrophic wildfires. They called for dedicated fire intelligence teams to collect high-quality data during live fire events using advanced technologies such as LiDAR, thermal imaging, and multispectral sensors. While PBD was discussed as a valuable tool, its reliance on scenario-based approaches (rather than probabilistic ones) was flagged as a limitation—particularly in the context of climate-driven fire extremes. Panellists highlighted the growing uncertainty in future fire conditions and argued for the development of more realistic models and adaptive decision-making frameworks that can account for this increasing variability in fire behaviour.

Discussions touched on how individual buildings contribute to community-level fire spread, with participants urging a shift from isolated vulnerability assessments to network-based risk analysis. Dr. Mahmoud noted that some structures, despite having low individual vulnerability, can act as "super spreaders" due to their location and potential to ignite neighbouring buildings. Participants emphasised the need for new empirical studies on pyrolysis, ember behaviour, and building ignition and noted that much of the foundational data remains decades old. Even with advanced modelling techniques, without updated material and fire behaviour data, the predictive power of simulations remains limited.

The session concluded with reflections on the importance of collaboration, continued model validation, data sharing, and integration of fire modelling into real-world policy and planning. While participants were not tasked with identifying a single best path forward, there was a general agreement on the need for a shared community effort to improve modelling accuracy, accessibility, and applicability in wildfire risk management and policy development.

3.6 Physics-Based Modelling: Strengths and Limitations

At the final session of the workshop, panellists from Session 2 convened to discuss the strengths and limitations of physics-based wildfire models. These models offer high-fidelity representations of wildfire behaviour and allow for the isolation of specific variables such as ember transport, wind interactions, and heat flux. This capability makes them particularly valuable for in-depth scenario testing and advancing scientific understanding. Key strengths identified by the panellists included

- High accuracy in modelling fire dynamics at fine spatial and temporal scales
- Ability to isolate variables, enabling targeted analysis of individual fire-driving mechanisms
- Relevance to policy development, particularly in areas like evacuation planning, structural design standards, and defensible space regulations

However, the group also identified significant limitations:

- High computational demands, which limit scalability and real-time application
- Steep learning curves and the need for expert knowledge to operate and interpret models
- Sensitivity to input data, especially wind fields, can affect model accuracy
- Limited accessibility, as results are often difficult for non-specialists to interpret or apply

Despite these challenges, physics-based models continue to play a crucial role in shaping wildfire policy and preparedness. In the aftermath of Australia's Black Saturday fire in 2009, the country invested heavily in advanced wildfire modelling. These efforts contributed to changes in public behaviour and institutional response, leading to significant reductions in fire-related fatalities in subsequent fire events, including the 2019–2020 Black Summer bushfires.

While not suitable for all contexts, CFD models are especially effective for specific, high-stakes applications such as simulating fire exposure at the structure level. The group concluded that these models need to be strategically deployed where their details add significant value and that greater collaboration between model developers and public agencies is essential to bridge the gap between research capabilities and operational needs.

-4-
SEMI-PHYSICS BASED WILDFIRE MODELLING

Session 3 of the workshop, titled Modelling Wildland–Urban Interface Fires with Semi Physics-Based Models (as listed in the meeting agenda in Appendix A), focused on the use of models that incorporate simplified representations of physical processes to simulate fire behaviour and spread in communities. The session was moderated by Dr. Georgios Boustras, Director of the Centre for Risk and Decision Sciences in Cyprus.

In this session, three models were discussed. The first uses a stochastic differential equation approach to simulate turbulent fire spread. The model is inspired by jet engine ignition models where particles represent energy carriers that move via random walks through a gridded terrain using cellular automata. The second model, called AGNI-NAR, uses graph theory to model interaction between structures and vegetation. The nodes in the graph represent the geospatial location of buildings and vegetation and the links between the nodes represent the different fire propagation mechanisms—convection, radiation, and ember spotting. The third model is an urban empirical-physical hybrid model designed for urban planning and evacuation impact. The model uses radiant heat flux calculations from wildfire fronts (used as a proxy for exposure) based on a Japanese physics-based fire propagation.

4.1 Stochastic Wildfire Spread Modelling in the Wildland-Urban Inteface (WUI) Using a Hybrid Lagrangian-Cellular Automata Model

Dr. Savvas Gkantonas, University of Cambridge, introduced a novel stochastic model inspired by turbulent combustion modelling principles to model wildfire behaviour in the WUI, a topic that has received limited attention. His framework uses virtual particles to simulate stochastic flame spread in a computationally efficient manner, representing fire behaviour through random walks governed by wind, fuel characteristics, and energy decay functions. Originally developed in the context of jet engine research, this approach enables detailed simulations of complex fire environments, such as the ones found in the WUI and urban conflagrations. The model uses cellular automata to represent the grid-based nature of the flammable terrain, and virtual lagrangian particles to simulate firebrand motion, hot gas transport and radiative ignitions in a probabilistic manner.

Dr. Gkantonas explained that each cell in a simulated landscape acts as both an emitter and a receiver of energy and can be modelled at ultra-fine resolution, allowing the model to capture heterogeneous fire spread dynamics, including ember transport and wind-driven spotting. The model's core relies on stochastic differential equations, which simulate the movement and energy decay of virtual fire particles, accounting for highly inhomogeneous and turbulent wind fields shaped by both the natural terrain and built environment. These influences are directly embedded in the particle dynamics, enabling realistic interactions with the underlying landscape and urban fabric. These particles carry an assigned energy or "burning status," depending on their type (e.g., a firebrand of particular size) and propagate through a discretised terrain grid, igniting new cells based on predefined flammability functions and energy thresholds. These functions can be sourced directly from fire behaviour databases such as LANDFIRE or rapidly estimated for unstudied areas using transfer learning and real-time data assimilation.

Dr. Gkantonas emphasised the importance of accurate parameterization, particularly in representing the ignition delay and burn duration of structure and structure-adjacent fuels as well as wildland vegetation. To achieve this, his team uses high-resolution remote sensing and machine learning algorithms informed by reconstructions of historical wildfire events. They are able to resolve flammability at a fine spatial scale of 1–2 meters, which is then systematically upscaled to meet any computational efficiency requirements. To validate their modelling approach, Dr. Gkantonas and his team applied it to many real-world WUI wildfire events, including the 2021 Marshall Fire in Colorado **(Figure 8)** and the 2018 fire in Mati, near Athens, Greece. These case studies demonstrated the model's capability to resolve structure-level fire spread in the WUI by integrating stochastic firebrand movement, ignition probability, and localised wind behaviour, underscoring its potential for practical applications in wildfire risk assessment and mitigation.

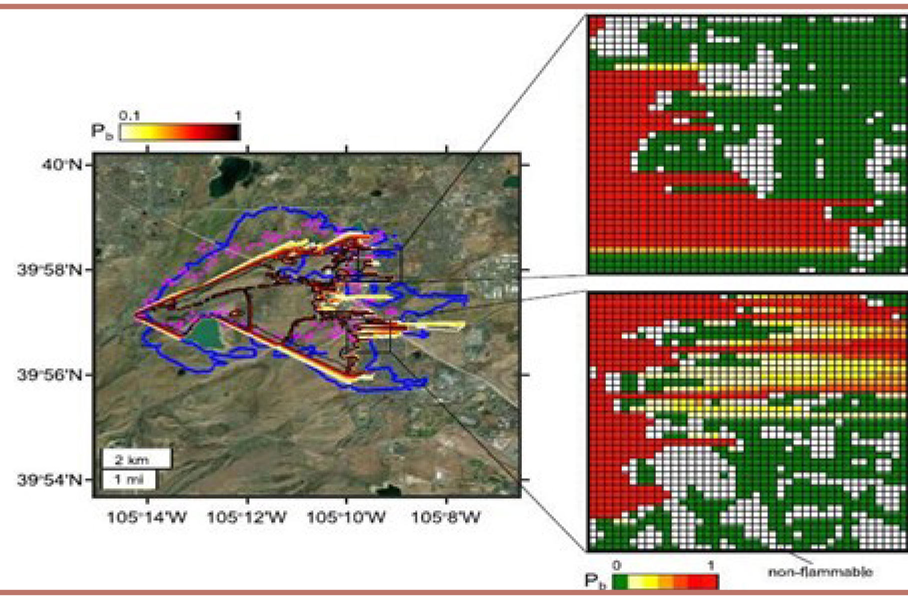


Figure 8: *Probabilistic output of the hybrid Lagrangian-cellular automata wildfire spread model, showing the burn probability of individual buildings and land parcels during the 2021 Marshall Fire. On the left, burn probability isolines are shown 14 hours after ignition. On the right, two zoomed-in panels highlight fine-scale resolution: non-flammable cells are white. flammable cells with zero burn probability are green, and those with certainty of burning are red. Maps like this enable detailed, probabilistic assessments of asset vulnerability at high spatial resolution and can be computed in just a few seconds.* SOURCE: Efstathiou, C., Viegas, D. X., Varela, V., & Oliveira, R. (2023). A methodology for assessing building exposure to wildfires using a probabilistic framework. Fire Safety Journal, 138, 103795Scholar.

Despite its relative simplicity, the model proved particularly effective in simulating cascading ignitions and directional flame progression under wind-driven scenarios, offering a promising alternative to computationally intensive CFD models. Building on this research, Dr. Gkantonas co-founded a spin-off company, Pine Peak, which integrates the stochastic fire model into web-based tools designed for insurance and emergency planning. These platforms, which are available for purchase through a specific licensing agreement, allow users to explore hypothetical ignition points, simulate fire spread, and assess risks using a user-friendly interface. Applications of the platform include asset-specific vulnerability analysis, optimization of mitigation strategies, and probabilistic forecasting under varying weather conditions. The commercial implementation of this model bridges the gap between academic research and industry needs, particularly in the realms of climate adaptation and insurance underwriting contexts.

4.2 Asynchronous Graph Model for Simulating Built Environment Damage in the Wildland–Urban Interface

Dr. Hussam Mahmoud, presented his research on modelling the spatial distribution of building damage during wildfires on the community scale. His work focuses on the WUI where vegetation and built environments intersect. Dr. Mahmoud highlighted that while fire propagation in the wildland is well studied, far less attention has been given to how fires behave once they enter communities. His group aims to bridge this gap using an asynchronous graph-based model that simulates fire spread and damage at the building level. The model, named AGNI-NAR, represents a community as a network of nodes—wherein each node corresponds to a home or vegetation patch—connected by directed links that represent heat transfer pathways such as convection, radiation, and embers. These connections simulate both direct and indirect interactions between fuels, allowing the model to capture fire spread from vegetation to homes, from home to home, and across complex spatial relationships.

Dr. Mahmoud emphasised the model's capability to determine the "most probable fire paths," enabling the model to establish likely fire boundaries and to assess the relative vulnerability of individual structures. This is achieved through probabilistic analyses that consider various ignition and exposure sources, with particular attention to features like building material, roof type, and spacing between homes. The model has been successfully applied to real-world wildfire events, including the 2022 Marshall Fire in Colorado. By comparing simulation outputs to observed damage, the model achieved boundary prediction accuracy of 95% and structural damage prediction accuracy of 85% in some cases. **Figure 9** illustrates the model's damage prediction for the 2018 Camp Fire in Northern California, showcasing its ability to replicate observed destruction patterns across complex WUIs.

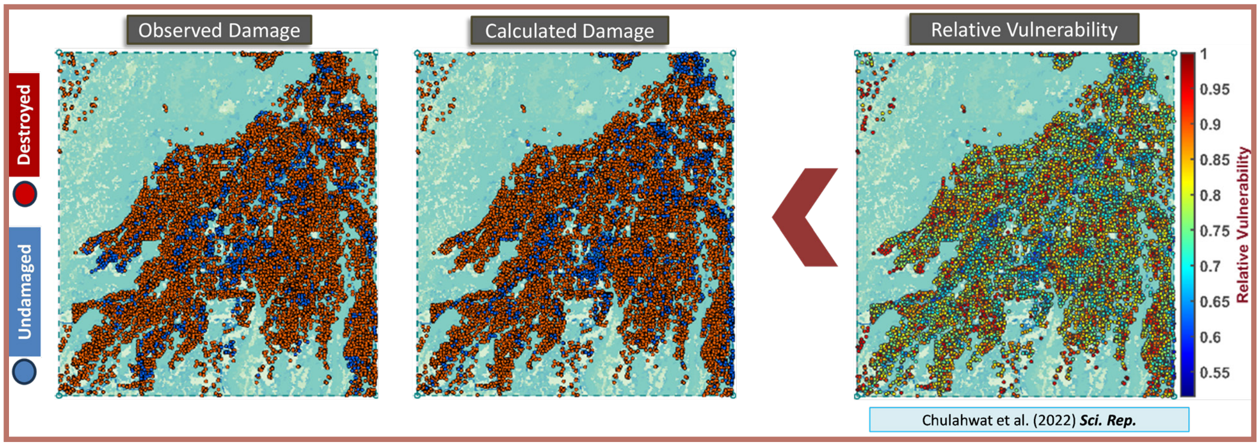


Figure 9: *Camp Fire Damage Comparison. The left image shows observed damage states (blue represents undamaged/minimally damaged and red represents significantly damaged structures). The right image shows the vulnerability of buildings relative to each other calculated using the AGNI-NAR model. The top middle image shows the calculated damage states by converting the vulnerability plot into discrete damage states using a cutoff vulnerability value to mark damage versus undamaged states (blue represents undamaged/minimally damaged and red represents significantly damaged structures).*
SOURCE: Dr. Hussam Mahmoud, Colorado State University and now at Vanderbilt University

A key strength of the AGNI-NAR model is its computational efficiency. It can simulate the fire spread across thousands of structures within seconds to minutes, making it well suited for ensemble analyses and scenario testing. Dr. Mahmoud demonstrated how the model can be used to evaluate the effectiveness of various mitigation strategies on the community scale. For example, a scenario involving the removal of 25% of surrounding vegetation combined with structural hardening of 75% of buildings resulted in a reduction of mean vulnerability by over 50%. These findings underscore the model's value as a decision-support tool for prioritising risk-reduction investments and informing land-use and resilience planning.

The AGNI-NAR model also incorporates data from the LandFire database and applies probabilistic thresholds to distinguish between damaged and surviving structures. It can identify the impact of low-vulnerability homes that, if left untreated, can act as catalysts for broader community-level fire spread and damage. This insight moves beyond simplistic metrics like distance to wildland fuels and offers a more nuanced understanding of risk based on spatial relationships and network effects.

Dr. Mahmoud's research has attracted strong interest from a range of stakeholders in the United States, including fire authorities, municipalities, and insurance companies. His team collaborated with several communities across Colorado, California, and Washington State to develop tailored mitigation strategies. The model's rapid simulation capability and actionable outputs support real-time applications and policy decision making by offering insights into optimal fuel treatments and defensible space design.

In conclusion, Dr. Mahmoud's asynchronous graph model represents a significant advancement in modelling fire dynamics at the community level. By combining computational efficiency, flexibility, and physical realism, AGNI-NAR provides a scalable tool for predicting fire behaviour, assessing structural vulnerabilities, and informing effective wildfire mitigation and adaptation strategies.

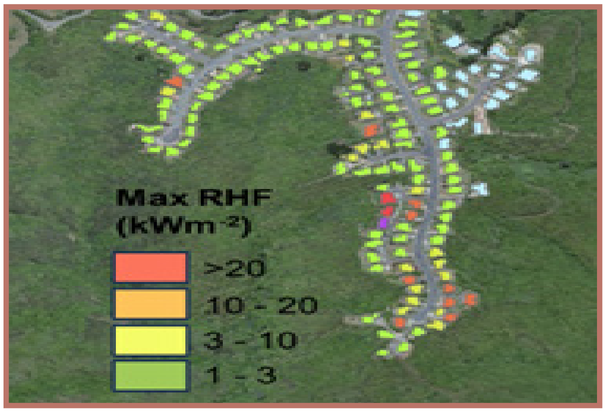
4.3 Multi-Hazard Integration and Visualisation Platforms

Dr. Andrés Valencia, University of Canterbury, New Zealand, presented his interdisciplinary approach to quantifying the impacts of wildfires on urban environments. His work centres on developing a modelling framework that integrates wildfire behaviour, community infrastructure vulnerability, and population evacuation to support decision making and climate adaptation planning.

Dr. Valencia began his presentation by outlining the key characteristics of WUI fires: direct and indirect exposure of buildings and infrastructure, complex multi-modal evacuation scenarios, building-to-building fire spread, and highly variable fire behaviour due to local weather and topography. Recognising that wildfires are expected to become a more significant threat under climate change, despite currently being relatively rare in New Zealand, his aim is to develop tools that are both scientifically robust and accessible to decision makers.

His model integrates several research streams. In collaboration with Scion (New Zealand Forest Research Institute) and as part of the research programme "Extreme fires, are we ready?", his team studied large-scale observational studies during prescribed burns to gather high-resolution data on fire spread, turbulence effects, and flame behaviour. This is complemented by laboratory-based flammability experiments, where variables such as moisture content, vegetation type, and fuel structure are assessed to understand how different landscapes and vegetation influence fire intensity and duration.

Dr. Valencia's model also addresses the vulnerability of built structures by integrating empirical data from targeted fire exposure experiments. His team performs targeted experiments exposing building elements to controlled fire conditions in the laboratory and the field to develop fragility curves based on materials and construction types as illustrated in **Figure 10**. These curves quantify the probability of ignition or structural failure under varying levels of fire exposures, enabling more precise risk assessments for urban communities.



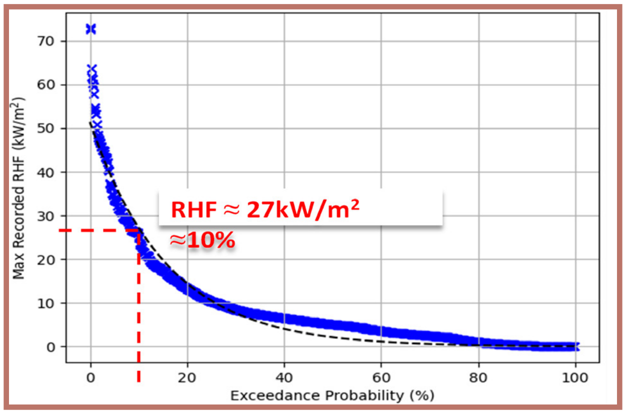


Figure 10: *Research streams and wildfire modelling outcomes. Result from single fire modelling: Exposure of several buildings after passage of fire front (left). Result from probabilistic ensemble modelling: Probability of exceeding heat flux (RHF) thresholds as an indication of exposure (right).* SOURCE: Dr. Andrés Valencia, University of Canterbury, New Zealand Simulation conducted by Tanvir Saurav, PhD Scholar.

A standout feature of Dr. Valencia's team's work is the integration of wildfire modelling with a dynamic evacuation tool. As part of the Horizon Europe funded "Minority Report" project (Grant Agreement Number: 101147385), a loosely coupled modelling approach is being developed whereby hazard outputs from either flooding or wildfire feed into a micro-scale transport simulation model developed within SUMO (Simulation of Urban MObility). This model allows simulation movements within the transport network via a variety of methods including walking, personal vehicle, and public transport.

To support real-world applications, Dr. Valencia team's modelling outputs are embedded within a multi-risk decision-support platform known as the "Resilience Explorer," which was developed by the partnering entity Urban Intelligence. This tool is currently used by several municipalities in New Zealand and allows stakeholders to visualise exposure to a range of natural hazards, including wildfire and the rise of sea level. Users can select specific assets, such as hospitals, roads, or schools, and evaluate their vulnerability under different hazard scenarios providing critical insights for urban planning and climate resilience strategies.

In conclusion, Dr. Valencia's presentation showcased a comprehensive, scalable, and multidisciplinary approach to wildfire risk modelling. By combining empirical data, remote sensing, vulnerability analysis, and decision-support tools, his work equips city planners, emergency managers, and policymakers with actionable tools to better anticipate, mitigate, and adapt to future wildfire threats.

4.4 Summary of the Panel Discussion on Semi-Physics Wildfire Modelling

The panel discussion offered an in-depth and multi-perspective examination of fire spread models, addressing issues of model fidelity, calibration, limitations, stakeholder use, and future development. A key question challenged how accurately the models capture fire dynamics, particularly the fire front shapes and convective behaviour. Panellists acknowledged that while many models offer valuable insights, they often prioritise computational efficiency over full physical detail. As a result, limitations remain in simulating buoyancy and the nuanced curvature of fire fronts. However, they emphasised ongoing efforts to improve model realism, particularly through hybrid approaches and better integration of experimental data, while maintaining scalability for operational use.

The panel also explored how model parameters are defined, specifically whether they are manually tuned or systematically optimised. Some panellists acknowledged using manual parameter settings for simplicity, while others incorporate AI-driven optimization and remote sensing. Some models showed high predictive accuracy even with limited calibration. For example, AGNI-NAR model achieved up to 95% accuracy in predicting fire boundaries and 85% accuracy in structural damage outcomes for the Camp Fire. These results were validated through simulations of the 2018 Camp Fire in Northern California and the 2021 Marshall Fire. The discussion also addressed how fire spread models represent different fuel types (e.g., houses, vegetation) and their interactions. Panellists confirmed that their models differentiate structure-to-structure, vegetation-to-structure, and vegetation-to-vegetation transmission pathways. These interactions are modeled using a variety of heat transfer mechanisms including radiation, convection, and direct flame contact to capture the complexity of real-world fire spread.

A recurring concern centred on ember generation and its role in structure ignition. Panellists acknowledged the difficulty in modelling ember production and deposition due to limited empirical data. To address this, many models incorporate probabilistic ember dispersion using random walk particle techniques. They also noted that house-to-house ignition is a major, evolving focus, with some fires driven almost entirely by structural transmission.

Questions about computational efficiency revealed that some models are capable of simulating thousands of wildfire scenarios within only a few hours. Their fast runtimes and modular designs make them well suited for Monte Carlo simulations and decision support, even if they are not yet optimised for real-time emergency operations.

The open-source status of wildfire models varies. Some tools are publicly available or freely licensed for academic use, supporting broader research collaboration and transparency. Others remain proprietary, often due to venture funding or concerns about misuse such as the potential weaponization of fire simulation capabilities. Across the panel, there was strong agreement that transparency and model explainability are critical, especially for insurance and public-sector applications.

Participants raised questions about the temporal and spatial granularity of the models. Some models operate with 15- to 30-minute timesteps, though these can be adjusted to capture more dynamic fire behaviour when needed. Spatial resolution commonly reaches 8–10 meters, enabling detailed simulations at the community scale. These resolutions are supported by data aggregated from high-resolution remote sensing, drone imagery, and computer vision techniques, providing accurate representations of fuel, terrain, and built environments.

Panellists emphasised the importance of model explainability, especially for consumer-facing industries like insurance where transparent risk assessments are essential for trust and accountability. They noted growing demand in community-scale vulnerability mapping and optimising mitigation within budget constraints. There was also agreement on the need for broader data sharing, more robust data validation, and interdisciplinary collaboration moving forward.

4.5 Strengths and Limitations of Semi-Physics Based Models

At the final session of the workshop, panellists from Session 3 met to evaluate the role of semi-physics-based wildfire models, which aim to balance model fidelity with usability and computational efficiency. These models integrate simplified physical principles within probabilistic or stochastic frameworks, enabling rapid simulations across a wide range of scenarios while maintaining a degree of physical realism and transparency.

Participants of Session 3 highlighted several key strengths of semi-physics-based models:

- Computational efficiency, allowing faster run times and broader scalability.
- Lower data requirements, making them accessible in regions with limited high-resolution inputs.
- Flexibility for use in scenario planning and training, supporting emergency preparedness exercises and stakeholder engagement.
- Transparency, enabling clearer communication of assumptions and results to non-specialist users.

However, several limitations were also discussed:

- Lack of generalisability, as many models are region-specific and require extensive recalibration when applied to different ecosystems or fire regimes.
- Limited adoption, in part due to their relative novelty and a lack of institutional familiarity.
- Barriers to implementation, including insufficient funding, inadequate technical infrastructure, and limited awareness among potential users such as municipalities and emergency services.

Despite these challenges, semi-physics-based models are gaining traction in wildfire risk assessment and policy design due to their balance between performance and practicality. Session 3 participants emphasised that these tools have strong potential to fill a critical gap between high-fidelity physics-based models and faster empirical approaches—if appropriate support mechanisms are put in place. To unlock their full value, the group called for increased investment in model dissemination, user training, and interface development. Enhancing accessibility for key stakeholders—such as local governments, insurance providers, and civil protection agencies—will be essential to realising the models' strengths in speed, adaptability, and usability across diverse operational contexts.

-5-

EMPIRICAL, LOGIC, STATISTICAL, AND ARTIFICIAL INTELLIGENCE ANALYSIS IN MODELLING WILDLAND–URBAN INTERFACE FIRES

Session 4 of the workshop, titled Empirical, Logic, Statistical, and Artificial Intelligence Analysis in Modelling Wildland–Urban Interface Fires (as listed in the meeting agenda in Appendix A), examined how various data-driven and logic-based approaches can be used to assess community vulnerability to wildfires. Presentations explored the application of artificial neural networks, statistical models, and empirical methods to identify relationships between key variables influencing wildfire risk at the community scale. The session was moderated by Dr. Fermín Alcasena, Universidad Pública de Navarra, Spain.

The models described in this session included a low-complexity risk assessment model that segments the interface into 25-meter units and computes risk as a composite of three components: hazard, exposure, and vulnerability. In addition, a Cell2Fire platform was discussed that represents a stochastic, cellular-automaton-based wildfire simulator coupled with operations research and machine learning modules. The Cell2Fire platform is developed to support landscape optimization, emissions control, and firefighter training. Moreover, a machine learning-based wildfire susceptibility model was presented that applies random forest classifiers at pan-European and national scales. Using decades of burn area data and detailed land cover information, the model identifies areas of heightened flammability based on vegetation type and continuity. Lastly, the fuzzy logic vulnerability model was presented which focuses on WUI property-level assessments. Designed as a self-assessment tool for residents, this model combines expert knowledge and fuzzy inference systems to evaluate building and site-specific vulnerabilities.

5.1 Socioeconomic Vulnerability and Human Dimensions

Dr. Maria Chas, University of Santiago de Compostela, provided a complementary perspective by examining socio-economic vulnerability to wildfires in Galicia, Spain. Her research focuses on the human dimensions of fire risk, including population exposure, the role of law enforcement, and the underlying socio-economic drivers. Using econometric models, she investigates how factors such as poverty, aging, rural depopulation, and institutional weaknesses contribute to both wildfire incidence and the effectiveness of suppression efforts.

By correlating ignition patterns with socio-demographic indicators and enforcement trends, her work reveals strong associations between intentional wildfires and regions marked by low institutional presence, aging populations, and underdeveloped infrastructure. These insights are critical for developing targeted prevention and education campaigns in the most vulnerable areas.

Dr. Chas's recent survey of elderly individuals found that while many are aware of wildfire risks, a significant number lack knowledge of effective protective measures. This underscores the need for community-level education and capacity building, particularly among vulnerable demographic groups. Using official fire records and census data, Dr. Chas demonstrated a strong connection between intentional fires and underlying social drivers. Her findings suggest that reducing wildfire incidence in rural regions requires more than ecological interventions but also targeted investment in community services, education, and strengthened law enforcement presence.

Dr. Chas's team developed fire exposure maps which incorporate land use patterns, proximity to forest edges, and settlement density. These maps were overlaid with socio-economic vulnerability indices enabling civil protection agencies to identify priority areas for intervention and to guide public investment in fire-resilient infrastructure. Her research also examined disparities experienced by socially vulnerable populations. The results showed that even under similar hazard conditions, communities with fewer resources suffered greater losses and faced longer recovery times. These findings support the integration of social equity considerations into wildfire risk reduction frameworks.

Through household surveys conducted among elderly residents in wildfire-prone areas, Dr. Chas found that while 69% of respondents acknowledged high wildfire risk within the next five years, over 40% reported having no knowledge of self-protection measures. This gap in preparedness highlights the urgent need for inclusive public education. According to Dr. Chas, effective risk communication needs to account for age, digital access, and cognitive diversity. Dr. Chas advocated for the development of tailored educational materials, in-person workshops, and neighbourhood drills to ensure that all demographic groups—particularly the most vulnerable—can participate in resilience-building and emergency response efforts.

5.2 Fuzzy Logic Tools for Plot-Level Risk Assessment

Dr. Elsa Pastor, Polytechnic University of Catalonia, Spain, presented a comprehensive approach to evaluating wildfire vulnerability at the home and property level. Her work focuses on the development of a vulnerability assessment tool that integrates expert knowledge and fuzzy logic to quantify the risk of wildfire penetration into homes based on structural and environmental characteristics.

Dr. Pastor framed her research around the widely accepted components of fire risk: hazard, exposure, and vulnerability. Her team focuses on the "home ignition zone"—the 30-meter radius surrounding a structure that plays a critical role in determining its susceptibility to ignition. The vulnerability assessment tool is designed to evaluate this zone by analysing factors such as ornamental vegetation, the presence of man-made and natural fuels, proximity to wildland, and building characteristics. This approach provides a systematic way to identify and mitigate risks at the property scale.

At the core of Dr. Pastor's methodology is the fault tree analysis (FTA), a risk-assessment technique commonly used in high-stakes industries like nuclear energy and chemical manufacturing. In the context of wildfire vulnerability, the "top event" is fire entering a building. The fault tree traces all possible scenarios and failures that could lead to this outcome, considering variables such as fuel presence near structures, ventilation points, window glazing, roofing materials, and ember accumulation zones. Logical gates (AND/OR) are used to model how these factors interact and compound vulnerability. A visual representation of the fault tree is shown in **Figure 11**.

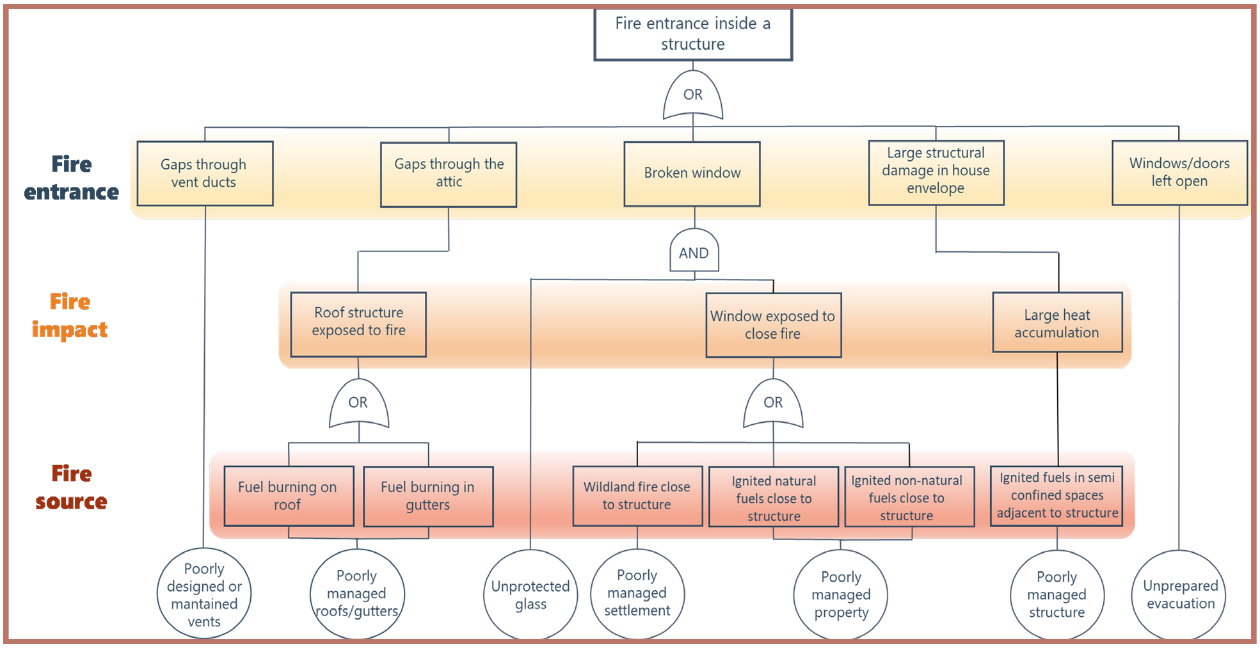


Figure 11: *Fault tree with logical (AND/OR) gates used to determine the pathways through which vulnerability is compounded.*
SOURCE: Dr. Elsa Pastor, Polytechnic University of Catalonia, Spain

To quantify these probabilities, Dr. Pastor's team used fuzzy logic—an approach well-suited for translating expert linguistic assessments (e.g., "highly flammable," "poorly maintained") into numerical values. This approach allows for the modelling of uncertain or subjective factors based on expert judgment. For example, the combination of a poorly maintained roof and the use of highly flammable materials may result in a high likelihood of ignition. A suite of fuzzy rules and membership functions is used to assign probabilities to these basic events, which then feed into the broader FTA model.

The tool was validated through application in multiple real-world scenarios. In Spain and Portugal, Dr. Pastor's team assessed homes that had experienced varying levels of wildfire damage. Properties with low vulnerability scores did not burn, while those identified as highly vulnerable frequently suffered structural losses. In one case, a home with an estimated 81% probability of fire entry was destroyed in a 2022 wildfire. The tool has also been adopted by fire agencies in Catalonia to evaluate the suitability of homes for horizontal confinement, a protective strategy where at-risk residents are directed to shelter in the most resilient nearby structures.

The tool is currently being enhanced through the EU-funded project FIREPRIME aimed at expanding its scope and usability. Enhancements include integrating broader European building typologies, linkage to hazard maps for a complete risk score (not just vulnerability) and delivering personalised recommendations. Most notably, the tool is being developed as a user-friendly mobile application. Homeowners will be able to answer a series of simple questions about their property and receive a vulnerability rating along with tailored mitigation suggestions to reduce their wildfire risk.

Dr. Pastor concluded by emphasising that the tool serves not only as a technical assessment tool but also as a means of raising awareness and supporting preparedness within WUI communities. By empowering residents to understand and take responsibility for their own fire risk, the tool effectively bridges the gap between fire science and practical community resilience, promoting proactive engagement in mitigation efforts.

5.3 Wildfire Spread Modelling and Risk Management in the Mediterranean

Dr. Michele Salis, National Research Council of Italy, presented a detailed overview of wildfire risk modelling with a focus on the Mediterranean region. He emphasised that while most wildfires are relatively small, only 1–2% of them—often extreme events—account for most of the damage, especially in WUI areas. These high-impact fires tend to occur under severe weather and fuel moisture conditions and often involve spot fires and simultaneous ignitions, which quickly overwhelm fire suppression capabilities.

Dr. Salis noted the growing complexity of wildfire risk in the Mediterranean due to factors such as land abandonment, an aging population, climate change, the expansion of WUI zones, and limited fire management budgets. Together, these dynamic factors challenge the implementation of effective and economically sustainable risk mitigation strategies. He explained that wildfire spread models can support policymakers by quantitatively assessing risk. In this context, wildfire risk is defined as the product of fire probability and potential consequences, the latter shaped by fire intensity and the susceptibility of exposed assets, such as buildings and infrastructure. Dr. Salis underscored that risk is not a fixed index but a dynamic measure that varies with fire behaviour, weather conditions, topography, and fuel characteristics.

To effectively model wildfire risk, Dr. Salis argued that relying solely on historical fire data is inadequate. Instead, simulation-based approaches—especially Monte Carlo methods— provide a more robust framework by generating thousands of potential fire scenarios under varying environmental and ignition conditions. He presented research conducted in Sardinia where his team used a calibrated minimum travel time (MTT) algorithm to simulate wildfire behaviour across extensive landscapes. The MTT model efficiently identifies the most likely and fastest pathways for fire spread, enabling the calculation of burn probabilities, fire intensity, and spread potential. This approach supports more nuanced and proactive risk assessments, particularly in complex Mediterranean environments.

Dr. Salis further elaborated on applying wildfire models to WUI areas. By creating buffers or "ignition zones" around buildings, his team intersected simulated fire perimeters with built infrastructure to assess the exposure of homes and communities. This method helps prioritise mitigation efforts by identifying zones of high vulnerability based on annual burn probability, flame length, and fire size. Dr. Salis underscored that current wildfire models still face challenges with simulating house-to-house fire spread—a significant issue in WUI fire events. Nevertheless, his team's modelling work has been effectively used to support real-world fire risk mitigation planning. For example, in cooperation with the Sardinia Forest Service and other local authorities in Sardinia, simulation outputs such as flame line intensity (illustrated in **Figure 12**) were used to guide the design of fuel treatments and the development of emergency response plans for the municipality of Bonorva in Northern Sardinia.

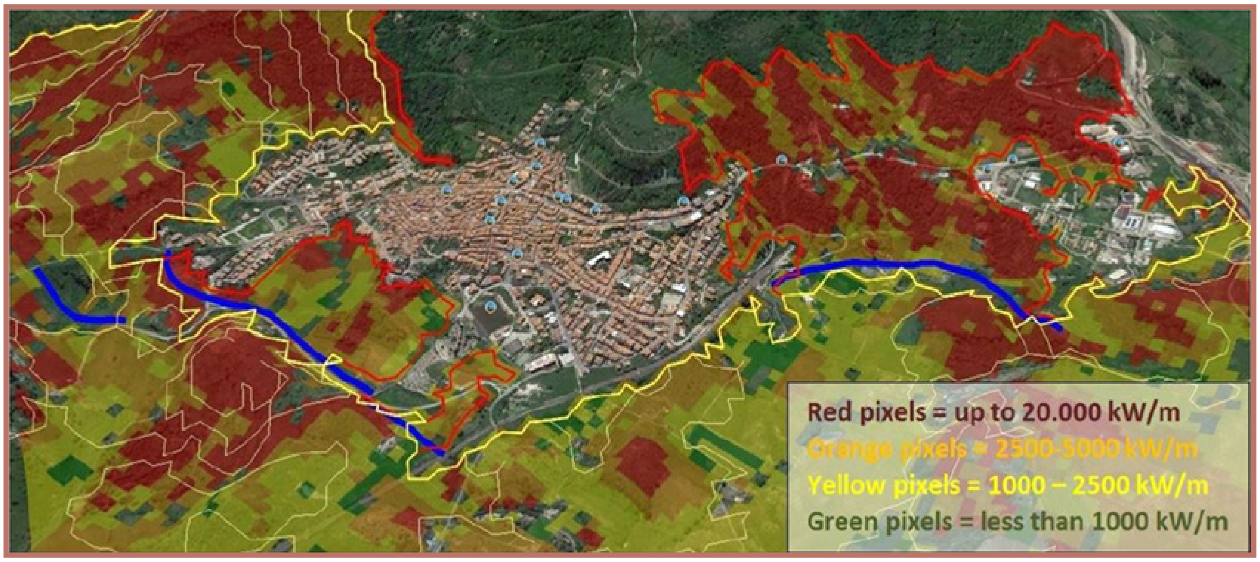


Figure 12: *Fire line intensity results, measured in kW/m, for identifying high-intensity areas and planning and testing fuel management activities to promote prevention and resilience to wildfires in the municipality of Bonorva. Blue lines indicate priority fuel treatment zones, determined based on fire behaviour simulation outcomes.*
SOURCE: Arca B, Casula F, Tesei G, Zuccarelli G, Pedes F, Bacciu V, Salis M, Pellizzaro G, Casula A, Maltoni S, Casula M (2023). Design of landscape preparation plans for wildfire prevention: a climate change perspective. Presented at the SISC 11th Annual Conference "SISC2023: Mission Adaptation!", Milan (Italy), 22–24 November 2023.

In conclusion, Dr. Salis advocated for the integration of wildfire spread modelling into risk governance, particularly in Mediterranean regions. His work demonstrates that spatially explicit modelling, combined with accurate environmental data and scenario analysis, is essential for prioritising fuel treatments and optimising resource allocation. This approach is particularly critical when budgets are limited, enabling more strategic and efficient wildfire risk management.

5.4 Risk Assessment Implementation in Portugal

Dr. Yannick Le Page, Agency for the Integrated Management of Rural Fires, presented a risk assessment model developed to support the 2020–2030 national wildfire strategy in Portugal. With 60% of its land covered by forests and shrublands, the country faces high wildfire risk due to fuel accumulation, rural abandonment, extended dry summers, and a large proportion of privately-owned land divided in small parcels, complicating vegetation management efforts. These conditions prompted a national shift in wildfire prevention strategies following the devastating 2017 wildfires. Recognising these risks, the national strategy emphasises both wildland fire containment and the protection of people and infrastructure, dedicating over 50% of its budget to prevention efforts.

Dr. Le Page's goal is to implement an actionable, low-complexity model that can effectively prioritise and monitor fire prevention measures, particularly in WUI zones where wildfire risk is on the rise. His team explored several risk assessment methodologies, including high-resolution fire propagation models and advanced simulation techniques. However, these methods proved too computationally intensive for nationwide application, and many stakeholders questioned implementation barriers, in particular the substantial capacitation needed for implementation at regional/local level, and evaluation studies to support integration in decision making. Thus, there was a clear need for a simpler, yet robust method that could guide decision making at all levels of governance and be easily updated to account for landscape dynamics, fuel treatments, and development of the WUI while also being intelligible to promote awareness and communication efforts.

The proposed model divides the WUI into 25-meter segments and calculates a composite risk index by integrating three components: hazard, exposure, and vulnerability. Each segment is analyzed using updated cartographic data, including land cover (derived from Sentinel imagery), wildland fire hazard, population data, and infrastructure. The hazard component is broken down to three spatial scales: direct Hazard, which assesses hazard within 500 meters of each segment based on the proximity, extent, and type of flammable vegetation; local Hazard, which evaluates the likelihood of incoming fires within a 5 km radius, and Regional Hazard which considers large-scale fire threats within a 20 km radius that could potentially overwhelm suppression efforts.

These inputs are combined using a weighted formula derived from stakeholder workshops where municipal and national authorities debated and assigned importance to different variables through an Analytical Hierarchy Process. This participatory approach not only enhanced the model’s acceptance but also allowed flexibility, enabling users to tailor the risk index or its three components based on specific operational or planning needs. Dr. Le Page emphasised the system’s dynamic nature. It supports regular monitoring of land use change, vegetation growth, and treatment progress. The model is currently being evaluated through feedback from municipalities and comparisons with historical fire data. Early results are promising, with affected areas from past fires strongly correlating with the high-risk segments predicted by the model. This validation, along with user feedback from six municipalities, has confirmed the model's practical value in supporting real-world decision making.

In conclusion, Dr. Le Page’s low-complexity, high-utility risk assessment model provides a scalable and adaptable tool for wildfire prevention in WUI areas. By balancing scientific rigor with operational usability, the model addresses the pressing need for more efficient intervention planning and resource allocation across Portugal’s fire-prone landscapes.

5.5 Simulation and Optimization Tools in Chile

Rodrigo Mahaluf, Institute for Complex Engineering Systems, presented a suite of advanced analytics tools for wildfire prevention, rooted in simulation and optimization techniques. His team contributed to the development of Cell2Fire and are the developers of Cell2Fire+World, an improved version of Cell2Fire adapted to simulate Canadian fuel systems, Scott and Burgan (USA and EU), and KITRAL (Chile).

Cell2Fire+world enables the execution of thousands of wildfire simulations, which are cross-referenced with values-at-risk to optimise firebreak locations, assess infrastructure vulnerability, and support firefighter training. The model’s modularity supports integration with machine learning tools and decision-making platforms, enabling real-time or pre-season strategic planning. The model is actively used in Chile, Canada, Italy, Portugal, and Spain. They also developed a QGIS toolbox that allows users to perform simulations, calculate risk metrics, and locate firebreaks using optimization algorithms that they developed specifically for this purpose. In Fermont, Italy, it supports augmented reality training for future firefighters, where it has also been used for real-time fire forecasting.

Dr. Mahaluf emphasised that effective wildfire prevention requires coupling fire spread modelling with optimization techniques. For example, strategically placing firebreaks across just 5% of a Catalonian landscape yielded an over 35% reduction in expected wildfire losses. The approach underscores how data-driven planning can reduce exposure while minimising landscape disturbance. Dr. Mahaluf also presented collaborative efforts with a Chilean electrical utility and the main national trade association for companies, SOFOFA. In the first case, the tool is used to assess both the risk of power lines being affected by wildfires and the potential damage that a fire starting from the line could cause to the surrounding landscape. This information guides targeted vegetation treatments and equipment upgrades helping to reduce ignition likelihood and enhance public safety.

A project with SOFOFA aims to spatially map and minimise wildfire-related emissions of greenhouse gas and particulate matter. By optimising fuel treatments in high-risk zones, the project supports both climate change mitigation and air quality improvement. These collaborations highlight the versatility of empirical models in addressing not only wildfire risk but also its broader ecological and economic risk implications.

Dr. Mahaluf concluded with a forward-looking proposal, introducing the concept "smart landscape design" as a wildfire mitigation philosophy. Inspired by natural features such as beaver dams, which have been observed to withstand wildfires due to their high moisture content, he proposed manmade landscape features that maximise ecosystem services and reduce flammability. These multifunctional landscapes could support biodiversity, retain water, and prevent soil erosion—as well as simultaneously function as natural firebreaks. This vision illustrates the potential of empirical modelling to move beyond fire behaviour simulation, informing holistic land-use planning and the development of resilient infrastructure.

5.6 Artificial Intelligence for Fire Susceptibility Mapping in Italy

Dr. Paolo Fiorucci, CIMA Research Foundation, Italy, showcased the use of machine learning—specifically Random Forest algorithms—to generate wildfire susceptibility maps across multiple spatial scales. His team initially analyzed historical wildfire data from the Liguria region, identifying key variables influencing ignition and fire spread. While early models relied on traditional statistical methods, the team shifted to machine learning for its greater flexibility, scalability, and ability to capture complex variable interactions. Random forest models outperformed previous approaches in predictive accuracy. The team found that key drivers of fire susceptibility were vegetation type, slope, and patterns of human disturbance.

Dr. Fiorucci's team expanded their machine learning models beyond Liguria to cover all of Italy and eventually the entire Mediterranean basin. This scaling effort was supported by pan-European datasets from the European Forest Fire Information System (EFFIS), incorporating inputs such as topography, climate, vegetation, and fire history. The resulting high-resolution maps produced at a 100-meter scale provided detailed assessments of wildfire susceptibility. Vegetation was classified into four functional fuel types—grasslands, broadleaves, shrublands, and conifers/eucalyptus—reflecting their distinct fire behaviour. These fuel types were linked to risk levels based on historical burn frequency and fire spread dynamics, producing a susceptibility index designed to guide fire management and urban development planning.

To demonstrate the practical value of the susceptibility maps, Dr. Fiorucci presented a case study from southern Italy, where a pine forest near a popular beach resort was identified as a high fire-risk area. Although the site had experienced only small ignitions in the past, its fuel continuity, topography, and potential for extreme weather conditions indicated a serious risk of rapid-fire escalation. Simulations showed that under high winds and low humidity, wildfire could reach the residential perimeter in under three hours, posing a significant threat to thousands of tourists and local infrastructure. This case study emphasised the importance of integrating fire modelling with evacuation planning, public awareness campaigns, and seasonal occupancy assessments in coastal Mediterranean communities.

In collaboration with Italy's Civil Protection Agency, Dr. Fiorucci's team has developed an AI-powered predictive platform to estimate next-day aerial suppression needs. By combining historical wildfire data with high-resolution meteorological forecasts, the platform produces daily risk maps that highlight regions where aircraft support is most likely to be required. By anticipating aerial suppression demand, this platform enhances readiness by enabling resource pre-positioning, especially during peak fire periods. Although still under evaluation, its first-year implementation showed high predictive accuracy, suggesting that operational forecasting can benefit from machine learning–based approaches when integrated with existing risk management systems.

Dr. Fiorucci emphasised the potential of AI and virtual reality as tools to engage the public and increase wildfire awareness. He presented AI-generated imagery of families living amid forest fires, demonstrating how visual storytelling can evoke emotional and cognitive responses more effectively than statistics alone. While cautioning against the overuse of fear-based messaging, Dr. Fiorucci suggested that combining immersive technologies with simulation-based training could help households better understand wildfire behaviour, evacuation protocols, and structural hardening strategies. This experimental approach aims to foster meaningful behavioural change by enabling people to learn through simulated experience rather than abstract instruction.

Dr. Fiorucci also highlighted that fuel continuity, not just vegetation type, is a critical determinant of wildfire severity. He explained that strategic landscape planning and design can significantly disrupt fire spread. Building on this insight, Dr. Fiorucci proposed that policymakers shift their attention from reactive fire suppression to proactive fuel reconfiguration through agroforestry, prescribed burns, and native vegetation restoration, all designed to reconfigure fuel patterns and reduce fire intensity. Such ecological interventions, when guided by empirical models, offer scalable strategies to mitigate wildfire risks across communities and regions.

5.7 Summary of the Panel Discussion on Empirical, Logic, Statistical, and AI Analysis Modelling

A significant portion of the discussion centred on the interpretation of wildfire cause statistics, particularly in Spain and Portugal. In Spain, for example, up to 75% of fires are classified as intentional, though the term encompasses a wide range of motivations ranging from illegal land clearing to deliberate acts of arson. Participants noted that many of these so-called "intentional" fires are likely misclassified incidents of negligence or mismanaged agricultural burns. This ambiguity underscores the need for a standardised categorization system to improve the accuracy of cause attribution and enable meaningful international comparisons.

A question was raised about the apparent high wildfire risk in fuel-managed regions such as Finland, pointing to a limitation in current European-scale risk maps. Dr. Fiorucci explained that the models used do not currently integrate localised fuel management data due to the lack of high-resolution data on the continental scale. As a result, some areas with active fuel treatments may appear overestimated in terms of risk. Despite overestimations in certain areas, civil protection protocols prioritise over-warning rather than under-warning to ensure preparedness and safeguard communities.

Several speakers emphasised the importance of distinguishing between WUI "interface" and "intermix" zones, as they involve different structural and vegetative configurations and require distinct modelling and policy approaches. While some tools rely on U.S. definitions, participants agreed on the need for a standardised, Europe-wide classification system. However, Dr. Mahmoud argued that for practical purposes in fire modelling and response, the precise label of these zones may be less important than understanding and addressing the specific risk behaviours they present. Later in the discussion, it was also noted that these technical terms often lack resonance with the general public. To improve communication and community engagement, some participants suggested adopting clearer, hazard-based terminology that better conveys the nature, urgency, and scale of wildfire risks to residents.

Dr. Pastor discussed concerns about data privacy in household-level fire risk apps, noting the challenge of balancing user privacy with the need to share valuable vulnerability data with local authorities. To address these concerns, pilot studies are currently underway in Spain, where volunteer-based data verification and follow-up are being tested to assess the feasibility and public acceptance of such tools.

The panel explored the growing role of AI in wildfire modelling and decision making. Panellists generally agreed that AI, including machine learning and deep learning, has significant potential, particularly in data-rich contexts, but they also raised critical concerns. Among these concerns were the limited interpretability of AI models and the potential of lack of public trust, especially in life-critical situations such as evacuation planning. Participants called for the need for further maturity in the field and closer integration between AI tools and human judgement.

Evacuation planning emerged as a complex and often contentious issue. While models can support strategic planning, first responders in Europe remain cautious about relying on automated systems, citing concerns over liability fears and the unpredictable nature of Mediterranean wildfire behaviour. In regions with limited road access, such as parts of Sardinia, sheltering in place is often considered safer than attempting large-scale evacuations. Participants noted the legal and ethical implications of model-driven evacuation decisions, emphasising the need for careful, context-sensitive implementation that complements, rather than replaces, human judgment.

Several speakers stressed that lack of risk awareness among residents in fire-prone areas remains a major barrier to effective wildfire mitigation. Without effective communication strategies, even the most advanced models and data may fail to drive meaningful mitigation action. The discussion concluded that building wildfire resilience requires more than technical tools—it depends on empowering communities and delivering tailored, locally relevant public messaging that motivates preparedness and behavioural change.

The discussion also touched on AI's potential as a communication and educational tool, beyond its role in analytical modelling. Some speakers advocated for AI-assisted applications to improve evacuation logistics or to simulate wildfire scenarios to improve public understanding and preparedness. Others cautioned that broad implementation needs to be paired with robust validation, transparent process for the development and sharing of the algorithms and codes, and user training to ensure effectiveness and trust. The conversation also highlighted critical, yet often underutilised, factors in vulnerability modelling, such as population characteristics. Variables like age distribution, tourism patterns, and seasonal residency can significantly influence risk. For example, the presence of tourists unfamiliar with fire protocols has been shown to elevate risk in Mediterranean coastal regions.

The panel discussion also examined the role of fuel loads versus fuel moisture in extreme fire behaviour. Citing studies from Australia, several participants noted that under severe weather conditions, fuel dryness may be a more significant factor in crown fire propagation than the total fuel mass present. This insight suggests a shift in modelling priorities from purely mapping fuel accumulation to incorporating environmental conditions such as temperature, humidity, and wind.

5.8 Strengths and Limitations of Empirical, Logic, Statistical, and AI Analysis Modelling

At the final session of the workshop, panellists from Session 4 convened to discuss advantages and disadvantages of empirical, logical, statistical, and AI analysis modelling. These models rely on historical data, environmental conditions, and exposure variables to assess wildfire risk and are increasingly valuable for pre-season planning, vulnerability mapping, and mitigation strategy, especially in resource-limited settings.

Participants of Session 4 highlighted several key strengths of empirical and AI-based models:

- Integration of diverse data sources, including social vulnerability, infrastructure exposure, and historical fire occurrence—features not always captured by physics-based models.
- Scalability, allowing for use at national or continental levels.
- Speed and accessibility, making them suitable for rapid assessments and for institutions without access to high-performance computing resources.
- Effectiveness in risk communication, supporting land-use planning and educational outreach.

However, panellists also identified important limitations:

- Inability to simulate fire behaviour in real time, limiting their use in operational firefighting.
- Limited predictive capacity for rare, high-impact events, particularly under novel climate or fuel conditions.
- Dependence on historical patterns, which may reduce reliability as wildfire regimes shift due to climate change.

Despite these constraints, empirical models are already in use by several national and regional agencies. For instance, they have been used by Portugal's National Guard to prioritise fuel treatments verification operations, while Italy's civil protection services use empirical models to plan aerial suppression strategies. These cases demonstrate how empirical modelling supports resource allocation, training, and operational decision making. In addition, empirical tools have been applied to protect critical infrastructure, such as electrical grids and archaeological sites, and to support hazard zoning, educational campaigns, and public–private coordination. Session 4 participants emphasised that as AI techniques become more sophisticated, empirical models can be further enhanced through machine learning to improve pattern recognition and scenario analysis, provided transparency and validation remain priorities.

-6-
OPPORTUNITIES FOR ENHANCING WILDFIRE MODELLING AND ITS APPLICATION

The final session of the wildfire modelling workshop served as a synthesis point, bringing together participants to summarise key insights, address implementation challenges, and outline future priorities. Through a combination of breakout group discussions and summary presentations, participants distilled outcomes from earlier discussions and explored concrete opportunities for advancing wildfire modelling efforts. Twelve opportunities are discussed in the following sections. These are:

1. Harmonise and standardise data and terminology in wildfire modelling
2. Enhance interoperability across wildfire modelling platforms
3. Integrate local context with regional wildfire modelling
4. Integrate human behaviour into wildfire models
5. Leverage wildfire modelling to inform policy, planning, and community protection
6. Strengthen wildfire modelling credibility through ethical practice and collaborative development
7. Communicate uncertainty transparently and in an appropriate format, to support informed decision making
8. Strengthen training and communication to operationalise wildfire modelling tools
9. Advance integrated wildfire risk modelling through targeted data and research investments
10. Strengthen global collaboration to advance wildfire modelling
11. Build a global repository of wildfire events
12. Strengthen multinational coordination and logistics to support model-driven fire response

6.1 Harmonise and Standardise Data and Terminology in Wildfire Modelling

Participants stressed the need for data harmonisation and standardised terminology at both regional and global levels. The lack of consistent definitions—especially around concepts like WUI—creates confusion across jurisdictions. Initiatives like the EFFIS were cited as essential for developing shared datasets and protocols that support interoperability across countries. There was broad agreement across participants that areas defined as "WUI" must be revisited to reflect today's rapidly evolving fire regimes, which are increasingly characterised by high-speed, high-intensity fires capable of traveling long distances and causing urban conflagrations. Participants advocated for adaptive, context-specific definitions of WUI that improve both modelling accuracy and risk communication.

Such updates are critical not only for technical consistency but also for fostering clearer public understanding and more effective policy responses.

6.2 Enhance Interoperability Across Wildfire Modelling Platforms

A recurring suggestion was the need to enhance interoperability across wildfire modelling platforms. Rather than relying on a single modelling paradigm, participants emphasised the potential of hybrid approaches—combining elements of AI, semi-physics-based models, and CFD—to improve performance across different spatial scales and operational contexts. To support such integration, standardisation of data formats, model inputs, and output structures was deemed to be essential.

The potential of AI to enhance wildfire modelling—across ignition, spread, and risk assessment—was explored in depth. While AI is not a replacement for physics-based simulations, it can augment them by accelerating pattern recognition, integrating multi-source datasets, and uncovering complex, non-obvious relationships in ignition dynamics and risk clustering. Participants advocated for hybrid modelling approaches that leverage AI's speed and adaptability alongside the scientific rigor of physical models. For example, machine learning could be used to preprocess inputs such as wind, vegetation, and exposure data for CFD models, or to estimate probabilities within scenario trees used for community-scale planning and decision support.

Participants called for the development of shared protocols that enable models to work together seamlessly. In particular, "model chaining"—for example, linking fire behaviour models with evacuation simulators or social vulnerability calculators—was seen as a promising path toward more comprehensive, systems-level risk assessments. To move from concept to practice, the group proposed launching workshops and pilot projects aimed at testing and refining these integrated workflows in real-world settings.

6.3 Integrate Local Context with Regional Wildfire Modelling

A recurring theme throughout the workshop was the importance of multi-scale wildfire models. Large-scale models are essential for identifying regional wildfire hotspots and projecting future fire risk under climate change scenarios and informing national-level resource allocation. At the same time, local-scale, high-resolution models are crucial for community-specific assessments and for guiding infrastructure-level mitigation strategies. Participants also noted that models developed in one region are often difficult to adapt in another region due to differences in built infrastructure, land ownership patterns, and vegetation types. This challenge reinforces localised modelling frameworks that draw on region-specific data and context, while still maintaining the ability to interface with broader-scale climate and hazard models.

6.4 Integrate Human Behaviour into Wildfire Models

A key theme that emerged from the workshop discussions was the need to better integrate human behaviour into wildfire modelling. Public responses to evacuation orders, mitigation incentives, and risk communications play a critical role in fire outcomes, but these behavioural dynamics are often overlooked in technical models. Participants emphasised that incorporating behavioural science—via tools such as agent-based modelling, decision trees, or social vulnerability indices—could improve scenario planning and emergency management. This is especially important in rapidly expanding

WUI zones with heterogeneous populations and uneven risk awareness which complicate response strategies. Modelling human behaviour alongside physical fire dynamics offers a more realistic and actionable foundation for both preparedness and policy design.

6.5 Leverage Wildfire Modelling to Inform Policy, Planning, and Community Protection

Wildfire models are playing an increasingly influential role in shaping policy decisions—from zoning regulations and building codes to vegetation management strategies and insurance reforms. Presenters shared real-world examples where empirical modelling has been used to prioritise fuel treatments, guide retrofitting structure programmes, and inform risk-based incentives for homeowners and insurers. To be effective at the policy level, however, models must be timely, accessible, and integrated into formal planning processes. This includes providing outputs in formats that are understandable to non-technical stakeholders and aligned with planning timelines. Greater collaboration between modelling teams and planning authorities is essential, supported by shared evaluation metrics that track the effectiveness of interventions over time. Importantly, access to modelling tools and outputs needs to be equitable to ensure that communities—that are at higher risk and with fewer resources—are not left behind in planning and mitigation efforts. Embedding wildfire modelling into early-stage policy development can help protect these populations and promote more resilient, fire-adapted communities.

6.6. Strengthen Wildfire Modelling Credibility Through Ethical Practice and Collaborative Development

Panel discussions emphasised that wildfire modelling is not purely a technical endeavour; it carries significant ethical and social responsibility. These models influence public policy, land use decisions, insurance practices, and emergency response protocols, all of which directly affect risk exposure and the allocation of resources. To maintain credibility and trust, participants stressed the importance of transparency in model limitations and cautioned against overstating accuracy or certainty. A key suggestion was to involve end users—including fire services, public agencies, and community stakeholders—in the development and validation of models. Doing so helps ensure that tools reflect on-the-ground realities, are contextually grounded, and are more likely to be accepted and applied in real-world settings. This collaborative approach can also help prevent unintended consequences and enhance the model’s relevance and trustworthiness.

Institutional resistance remains a significant barrier to adoption, particularly in high-stakes or legal contexts where concerns about liability and reliability are elevated. To address this, participants proposed a phased implementation strategy: begin with low-risk applications such as training, public awareness, and scenario planning, and expand use as confidence grows. Building trust through co-development, transparency, and validation is essential to making wildfire models both operationally useful and ethically responsible.

6.7 Communicate Uncertainty Transparently and in an Appropriate Format to Support Informed Decision Making

Across all modelling approaches, participants highlighted the importance of communicating uncertainty clearly and responsibly. Wildfire models are inherently simplifications of complex systems and carry both epistemic uncertainty (stemming from incomplete knowledge) and aleatory uncertainty (due to randomness in natural processes). If not properly communicated, these uncertainties can lead to overconfidence or misinterpretation by end users. To address this, participants suggested that sensitivity analyses—particularly for key variables such as wind conditions, fuel moisture, and ember transport—need to be embedded directly into model interfaces. Additionally, reporting of confidence intervals, underlying assumptions, and known limitations was seen as essential to building user trust and supporting informed, risk-aware decision making.

6.8 Strengthen Training and Communication to Operationalise Wildfire Modelling Tools

Even the most advanced wildfire models have limited impact if end users cannot understand or apply them effectively. Training for fire services, urban planners, and local government officials in model interpretation is crucial to ensure informed decision making. To some extent this has been successfully done in countries such as Italy and Portugal where models have been successfully integrated into firefighter training, resource planning, and pre-deployment strategies. Participants noted that tools need to feature user-friendly interfaces and communication aids like interactive dashboards, summary statistics, and automated reporting functions. Interactive platforms and online training modules can support broader adoption. Cross-sector workshops that bring together scientists, emergency managers, and community leaders are critical to align model outputs with real-world operational needs.

6.9 Advance Integrated Wildfire Risk Modelling Through Targeted Data and Research Investments

While the primary goal of the workshop was not to identify research priorities, participants nonetheless highlighted several critical areas for further investigation to improve wildfire risk modelling, including enhanced ignition probability modelling, real-time dynamic vegetation mapping, and forecasting of post-fire ecological recovery. Progress across all model types also depends on the development of new datasets, particularly related to firebrand behaviour, community-scale wind dynamics, and human evacuation patterns. Further research is essential to understand the compound hazards associated with wildfire events—such as post-fire flooding, landslides, and smoke exposure. To address these interconnected threats, integrated risk modelling platforms must evolve to capture cascading impacts in a warming climate.

6.10 Strengthen Global Collaboration to Advance Wildfire Modelling

Several speakers emphasised the value of sustained international collaboration in wildfire modelling. Sharing case studies, datasets, and model code across countries accelerates innovation, improves model generalisability, and strengthens collective preparedness. Fire-prone countries in the southern hemisphere called for greater inclusion in global research dialogues. To foster this collaboration, participants proposed exchange programmes, joint simulation exercises, and virtual forums as mechanisms for building a distributed global network of wildfire modelers. Such initiatives rely on alignment with national political priorities to move forward effectively. When that alignment exists, they can successfully support knowledge transfer, facilitate model co-creation, and help adapt tools to a range of ecological and governance contexts.

6.11 Build a Global Repository of Wildfire Events

A central issue raised at the workshop was the urgent need for standardised, robust protocols to collect, curate, and share wildfire incident data. High-quality post-incident data are essential for calibrating and validating models across all levels of complexity. Participants emphasised the value of establishing an international repository for wildfire datasets, underpinned by consistent metadata standards to ensure global interoperability. Open access to critical data types—including remote sensing imagery, suppression activities, damage reports, and environmental conditions—would accelerate the development, refinement, and cross-border collaboration of wildfire modelling efforts.

Participants noted that it is particularly important that extreme fire events are well represented in the repository, as these relatively infrequent events are responsible for a disproportionate share of human, economic, and environmental losses. These "black swan" fires need to be treated as critical learning opportunities. Participants emphasised the need to systematically analyze and share data on fire intensity, behaviour, and suppression outcomes from such events to inform future preparedness and response. To this end, establishing clear protocols for collecting, validating, and disseminating post-fire data was considered essential. Building a global repository of extreme wildfire events could enhance model calibration, support the development of AI training datasets, and strengthen early-warning systems, particularly in regions with limited historical data but growing fire risk.

6.12 Strengthen Multinational Coordination and Logistics to Support Model-Driven Fire Response

Effective wildfire response increasingly depends on cross-national coordination and agile logistics, especially as climate models predict more severe fire seasons. Smaller countries with limited firefighting capacity may benefit from pre-positioned equipment and personnel via multilateral agreements. These arrangements can be informed by modelling outputs that forecast high-risk areas and conditions, enabling proactive resource deployment. To support this, workshop participants noted that enhanced logistics platforms are needed to coordinate rapid deployment of aerial and ground resources in response to forecasted extreme fire conditions. Additionally, some participants from Europe proposed a firefighter exchange programme to allow personnel from northern countries to train in Mediterranean climates to gain critical experience in the types of fire behaviour projected by climate and risk models.

Future modelling platforms will likely need to integrate multiple hazard domains, including fire, floods, smoke, and heatwaves. Several presentations highlighted the cascading effects of wildfires, from degraded water quality to transportation disruptions and energy grid failures.

Interdisciplinary models that couple fire behaviour with infrastructure and social system dynamics will provide more holistic risk assessments. These platforms require collaborative governance, modular architecture, and funding mechanisms that span traditional agency boundaries.

-7-
WORKSHOP IMPACT AND NEXT STEPS

The workshop served as a catalytic moment for the research wildfire modelling community from across disciplines and regions to engage and set priorities for advancing evidence-based wildfire resilience. To sustain this momentum, participants proposed a follow-up meeting in two years to assess progress, strengthen international partnerships, and expand participation—particularly from emergency services, land management agencies, and underrepresented regions such as the Global South. There was also a collective commitment to produce a joint publication (separate from this report) to summarise key modelling insights, implementation challenges, and research priorities across approaches. Together, these actions mark the emergence of a globally connected wildfire modelling community focused on innovation, operational relevance, and long-term collaboration.

Appendix A:
Workshop Agenda

DAY 1: March 17

9:00 AM – 10:00 AM	**Coffee and Networking**
10:00 AM – 10:45 AM	**Welcome Remarks** *Brief Introductions of Workshop Participants* **Ana Crespo,** Royal Spanish Academy of Sciences **Ourania (Rania) Kosti,** InterAcademy Partnership Secretariat, U.S. National Academies of Sciences, Engineering, and Medicine (USA) **José M. Moreno,** Royal Spanish Academy of Sciences
10:45 AM – 11:10 AM	**Workshop Goals** *Overview of the Agenda* **Hussam Mahmoud,** Colorado State University (USA)
11:10 AM – 11:40 AM	**Perspectives on Wildfire Early Warning, Monitoring, and Risk Assessment** **Jesus San-Miguel,** European Commission Joint Research Center
11:40 AM – 12:00 PM	**Coffee Break** *Picture with Workshop Participants*
12:00 PM – 12:40 PM	**Session 1: Wildland Fire Behaviour and Observations** *This session will explore the dynamics of wildfires, including their causes, patterns and processes associated with their propagation as well as the impact of global climate on shifting fire regimes.* Moderator: **Andrey Krasovskiy,** IIASA (Austria) **1.1** *Right model, right data, right time: An open science workflow approach for actionable fire modelling* **Ilkay Altintas,** University of California San Diego (USA) **1.2** *Wildfires in the rural environment of Spain at the crossroad of increased severe weather and fire hazard due to abandonment* **José M. Moreno,** Royal Spanish Academy of Sciences

DAY 1: March 17 (cont.)

12:40 PM – 1:10 PM	**Session 1 Discussion**
1:10 PM – 2:30 PM	**Lunch**
2:30 PM – 3:45 PM	**Session 2: Modelling Wildland–Urban Interface Fires with Physics-Based Approaches** *This session will explore the use of computational fluid dynamics to simulate localised fire behaviour and the spread of fire in communities.* Moderator: **Miguel Almeida,** Universida de Coimbra (Portugal) **2.1** *Using Fire Dynamics Simulator (FDS) to model wildland and urban interface fires* **Craig Weinschenk,** Fire Safety Research Institute (USA) **2.2.1** *Fire behaviour at the WUI using physics-based models* **2.2.2** *Multicriteria assessment of WUI buildings' vulnerability* **Eric Maillé,** French National Institute for Agriculture, Food, and Environment (France) **2.3** *Assessing dwelling vulnerabilities with CFD simulations* **Eulalia Planas,** Polytechnic University of Catalonia (Spain) **2.4** *Dynamic fire propagation and extreme wildfire development* **Jason Sharples,** University of New South Wales (Australia)
3:45 PM – 4:15 PM	**Session 2 Discussion**
4:15 PM – 5:00 PM	**Reflections and Discussion on the Day's Sessions**
	ADJOURN DAY 1

DAY 2: March 18

9:00 AM – 10:00 AM **Coffee**

10:00 AM – 10:05 AM **Welcome**

Overview of Day 2

Hussam Mahmoud, Colorado State University (USA)

10:05 AM – 11:15 AM **Session 3: Modelling Wildland–Urban Interface Fires with Semi Physics-Based Models**

This session will explore the use of physics-based models with simplified representation of the physical processes to describe fire behaviour and spread in communities.

Moderator: **Georgios Boustras,** Centre for Risk Decision Sciences (Cyprus)

3.1 *A new granular and scalable model for stochastic WUI fire spread behaviour, risk assessment, and optimisation of extinction resources*
Savvas Gkantonas, University of Cambridge (UK)

3.2 *AGNI-NAR: An asynchronous graph model for simulating built environment damage in the wildland urban interface*
Hussam Mahmoud, Colorado State University (USA)

3.3 *Modelling Wildfire Impacts on Cities: Quantifying Threats to Buildings, Infrastructure, and Population Evacuation*
Andres Valencia, University of Canterbury (New Zealand)

11:15 AM – 11:45 AM **Session 3 Discussion**

11:45 AM – 12:10 PM **Break**

DAY 2: March 18 (cont.)

12:10 PM – 1:00 PM

Session 4: Empirical, Logic, Statistical, and Artificial intelligence Analysis in Modelling Wildland–Urban Interface Fires

This session will explore how different logic and data interpretation approaches can be used to understand communities' vulnerabilities to wildfires. The session will also explore the use of artificial neural networks and statistical models to capture the relationship between dependent and independent variables to vulnerability to wildfires at a community scale.

Moderator: **Fermín Alcasena,** Universidad Pública de Navarra (Spain)

4.1 *Socioeconomic analysis of the wildland–urban interface: Designing resilient societies for wildfire risk*
Maria Luis Chas, University of Santiago de Compostela (Spain)

4.2 *Evaluating wildfire vulnerability of dwellings using fuzzy logic and expert judgement approaches*
Elsa Pastor, Polytechnic University of Catalonia (Spain)

4.3 *Application of wildfire spread modelling to quantify wildfire impacts at WUIs*
Michele Salis, National Research Council (Italy)

1:00 PM – 2:30 PM

Lunch

2:30 PM – 3:30 PM

4.4 *Implementing low-complexity risk assessment models to monitor and prioritise WUI fire prevention in the Portuguese 2020–30 National Plan for Integrated Fire Management*
Yannick Le Page, Portuguese Integrated Rural Fire Management Agency (Portugal)

4.5 *Advanced analytics tools for the protection of wildland–urban interface against wildfires*
Rodrigo Mahaluf, Institute for Complex Engineering Systems (Chile)

4.6 *Can artificial intelligence enhance wildfire risk awareness?*
Paolo Fiorucci, CIMA Research Foundation (Italy)

DAY 2: March 18 (cont.)

3:30 PM – 4:00 PM	**Session 4 Discussion**
4:00 PM – 4:20 PM	**Break**
4:20 PM – 5:15 PM	**Session 5: Breakout Guided Discussion** **Q1:** *What do you see as the major advantages and disadvantages of the modelling approach discussed in your session?* **Q2:** *To the extent of your knowledge, how has the modelling approach discussed in your session been used for assessing or reducing wildfire vulnerability and risk reduction?* **Q3:** *Has the implementation of this modelling approach been successful (i.e., are there any success stories) and what are the barriers towards full implementation?*
5:15 PM – 5:40 PM	**5-Minute Reporting per Breakout**
5:40 PM – 6:00 PM	**Meeting Recap & Adjourn**

Appendix B:

Expert Biographies and Background Literature

Fermín Alcasena

Fermín Alcasena is a Senior Researcher at the Public University of Navarre, where he focuses on wildfire risk management and environmental policy. He holds an M.Sc. in Wildland Fire Science and Integrative Management, as well as a Ph.D. in Forest and Environmental Management. He began his research career at the CMCC Foundation in Italy, serving as a Research Assistant for a year before completing a three-year postdoctoral fellowship at Oregon State University under the USDA Forest Service J-1 International Visitor Program. Dr. Alcasena's main research interests include extreme fire modelling, landscape treatment optimization, and wildland–urban interface (WUI) mapping, and he has published more than 35 peer-reviewed papers that have collectively garnered more than 1,000 citations. He has delivered more than 10 oral presentations at premier international conferences in wildfire science, participated in multiple international research projects, performed 40 peer reviews for 19 publications, and served as a reviewer for national research project calls in Spain and Portugal. In addition to his research endeavours, he has taught as a lecturer in forestry and landscape restoration and management at the Universitat Politècnica de Catalunya and the Universitat de Lleida in Spain. Prior to his academic career, he gained practical experience as an operations manager in a logging company, significantly contributing to public forest management in northern Spain. Drawing on this blend of hands-on expertise, advanced modelling techniques, and real-world data, Dr. Alcasena continues to advance wildfire science and forest management, effectively bridging academic research with practical applications.

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Miguel Almeida

Miguel Almeida holds a Ph.D. in Natural and Technological Risks (2011) from the University of Coimbra, where he focused on wildfire spread through spotting. He previously earned an M.Sc. in Environmental Management and Policies (2005) from the University of Aveiro, analysing fire propagation in heterogeneous fuel beds, and a degree in Environmental Engineering (1998) from the same institution. He is a senior investigator at the Association for the Development of Industrial Aerodynamics, where he is a Member of the Board of Directors. Since 2021, he has been an Invited

Assistant Professor at the University of Coimbra. Every two years, he contributes to the organisation of the Boom Festival as Safety Director and is also a certified trainer at the National Firefighters School in Portugal. Since 2011, he has been an integrated member of LAETA: Associated Laboratory of Energy, Transports, and Aeronautics. Additionally, he is an expert member of the ISO42 Technical Committee on wildland–urban interface fire risk for building protection. His research is dedicated to fire behaviour and fire safety, with a particular focus in recent years on wildfire risk management in the wildland–urban interface. He has authored 32 journal articles, 31 book chapters, and two books. His academic contributions include organising 21 scientific events and co-supervising two PhD theses and 17 MSc dissertations. He has also played key roles in numerous research projects, serving as Principal Investigator in three, Co-Principal Investigator in three, and a researcher in 23 projects.

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İlkay Altıntaş

İlkay Altıntaş, at the University of California San Diego, is the Chief Data Science Officer of the San Diego Supercomputer Center as well as a Founding Faculty Fellow of the Halıcıoğlu Data Science Institute at the School of Computing, Information and Data Science. With a specialty in scientific workflows and systems, she leads collaborative teams to deliver impactful results and sustainable solutions through making computational data science and artificial intelligence (AI) work more reusable, programmable, scalable, equitable, and reproducible. She is the Founding Director of the Workflows for Data Science Center for the development of methods and workflows for computational data science, and the WIFIRE Lab on AI methods for an all-hazards knowledge cyberinfrastructure. She is the principal investigator (PI) of the National Science Foundation (NSF) National Data Platform and other diverse NSF grants to develop scalable computing, AI and data systems at the digital continuum from edge to HPC. Altıntaş Ilkay received a Ph.D. degree from the University of Amsterdam and holds a joint appointment at Los Alamos National Lab. She serves as a Member of the Founding Boards of two community-oriented non-profits—"Data Science Alliance" and "Climate and Wildfire Institute." Among the awards she has received are the 2015 IEEE TCSC

Award for Excellence in Scalable Computing for Early Career Researchers and the 2017 ACM SIGHPC Emerging Woman Leader in Technical Computing Award. Ilkay serves on the elected Board of Governors for the IEEE Computer Society, and was appointed by California Governor Newsom to the Wildfire Technology Research and Development Review Advisory Board.

María Luisa Chas Amil

María Luisa Chas Amil is Professor of Applied Economics at the University of Santiago de Compostela (USC). She holds a Ph.D. in Economics from the USC and an M.Sc. in Forestry from the University of Wisconsin-Madison. Her research career has primarily focused on studying environmental issues driven by economic factors, particularly within the forestry, energy, and fishing sectors. More recently, her research has focused on disaster risk reduction management with a particular emphasis on economic and social analysis of forest disturbances, such as wildfires. She also examines stakeholder participation in decision making and the strategic behaviour of natural resource users in both temporal and spatial context. She collaborates with interdisciplinary teams, using a range of statistical and econometric techniques to address environmental challenges. Her research aims to bridge the gap between economic analysis and environmental management, providing insights into the impacts of economic activities on natural resources. Additionally, her work emphasises how stakeholders can be better engaged in decision-making processes to promote sustainable resource management.

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George Boustras

George Boustras is a Professor in Risk Assessment at European University Cyprus, Director of the Centre of Risk and Decision Sciences (CERIDES—Excellence in Innovation and Technology) and Visiting Researcher at the National Observatory of Athens. He is a Member of the EU Mission: Adaptation to Climate Change. He is a Special Advisor in Civil Protection and Crisis Management to the President of the Republic of Cyprus Nikos Christodoulides. He is Scientific Director of Civil Protection Programs under Prime Minister of the Hellenic Republic, Kyriakos Mitsotakis. George has a Ph.D. in Probabilistic Fire Risk Assessment from CFES at Kingston University London (2003), he was Honorary Research Fellow at CPSE at Imperial College London (2003–2005), and KTP Research Fellow at FSEG at the University of Greenwich (2009). He has advised Governments in Civil Protection reforms and has worked with World Bank, European Commission and Expertise France. George is Editor-in-Chief of Safety Science (Elsevier, IF 6.392) and Member of the Editorial Board of Fire Technology (Springer Nature) and the International Journal of Critical Infrastructure Protection (Inderscience). He (co-)supervises five PhD students; ten of his students are now Ph.D.s. In May 2024 he received the Distinguished Researcher Award at the Annual Awards for Excellence in Research 2024 of European University Cyprus.

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Paolo Fiorucci

Paolo Fiorucci is a wildfire expert with extensive experience in risk assessment, prevention strategies, and emergency response coordination. He currently serves as the Associate Director at the CIMA Research Foundation where he leads projects focused on wildfire prevention, sustainable forest management, and the development of early warning systems, particularly in the Mediterranean region. Throughout his career, Paolo has contributed to several initiatives and projects, developing risk mapping tools, policy recommendations, and capacity-building programmes for local authorities and first responders. He collaborates with multidisciplinary teams to integrate scientific research, technology, and community engagement into effective wildfire mitigation strategies. His recent research focuses on the application of artificial intelligence (AI) in wildfire risk mapping, prediction and management. By leveraging machine learning models and remote sensing data, he has contributed to the development of AI-driven tools that enhance fire risk assessment, optimise resource allocation, and improve decision-making processes for emergency response teams. These innovative approaches are helping to improve the accuracy of fire spread models and provide real-time insights for more effective wildfire suppression strategies. Paolo has also been actively involved in knowledge dissemination, contributing to scientific publications, technical reports, and training activities aimed at strengthening wildfire preparedness at local and international levels. His work bridges the gap between research and operational needs, ensuring that scientific advancements translate into practical solutions for wildfire risk reduction.

Savvas Gkantonas

Savvas Gkantonas is a visiting researcher at the University of Cambridge and the Chief Executive Officer of Pinepeak, a University of Cambridge spinout developing predictive technologies and data-driven solutions for wildfire risk assessment. Before founding Pinepeak, he was a Senior Research Associate in the Department of Engineering at Cambridge. Savvas has authored or co-authored more than 40 peer-reviewed articles in leading journals and conference proceedings. Known for his expertise in advanced numerical simulations of turbulent reacting flows, he has worked extensively with computational fluid dynamics and low-order methods to tackle fundamental and applied challenges in transport, power, human health, and the environment. In the field of wildfire, he co-invented a stochastic Lagrangian model to capture fire propagation in inhomogeneous terrains, including the wildland–urban interface (WUI), drawing inspiration from turbulent reacting flow modelling and jet engine ignition research. Savvas holds a Ph.D. from the University of Cambridge and a double degree in engineering from the Aristotle University of Thessaloniki and Centrale Supélec.

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Andrey Krasovskiy

Andrey Krasovskiy is a versatile mathematical modeler with expertise in simulations, control problems, and optimization, applied across a broad range of ecosystems and domains, including economics, technology, and the social sciences. His research primarily focuses on land use and forest modelling with a particular emphasis on global wildland fires under climate change. Dr. Krasovskiy's career at the International Institute for Applied Systems Analysis (IIASA) began in 2006 when he was awarded the prestigious Mikhalevich Award. In 2012, he transitioned to the former Ecosystem Services and Management Program, and he now leads the FLAM team within the Agriculture, Forestry, and Ecosystem Services Research Group, contributing significantly to the Biodiversity and Natural Resources Program. As the primary developer of the Wildfire Climate Impacts and Adaptation Model, a mechanistic fire model integrated into the IIASA biophysical model cluster, Dr. Krasovskiy plays a key role in projecting and assessing fire risk hot spots and burned areas combined with the evaluation of fire adaptation strategies in the context of climate change. His current focus is on improving modelling accuracy through the integration of remote sensing observations and ground data, alongside the use of artificial intelligence technologies for model calibration and validation. His research interests also extend to dynamic optimization of economic growth and investment models, the evaluation of REDD+ offset programmes with financial benefit-sharing mechanisms, wildlife population modelling, and permanence modelling.

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Rodrigo Mahaluf

Rodrigo Mahaluf is a Senior Scientist at the Complex Systems Engineering Institute (ISCI) and the General Manager of Fire Management and Advanced Analytics, ISCI's research team focused on wildfire management. He holds a degree in Industrial Engineering from the University of Chile and has extensive experience in developing analytical tools to support decision making in wildfire risk management. He actively participates in the European FIRE-RES project, representing ISCI in efforts to enhance wildfire resilience through innovative technologies and methodologies. His research integrates simulation, optimization, and artificial intelligence to develop cutting-edge decision-support systems that help anticipate, prevent, and mitigate wildfire impacts. A key focus of his work is ensuring that state-of-the-art scientific research is effectively transferred into real-world applications. He collaborates closely with industries—such as electrical utilities—to improve risk assessment models, helping them reduce fire hazards associated with power infrastructure. He also works with forest agencies and emergency management organisations, providing them with advanced simulation and planning tools that enhance preparedness and response strategies. In addition to international collaborations, he has contributed to national research initiatives, including the FONDEF project "Diseño de paisajes resistentes a incendios forestales integrando modelos de simulación, optimización e inteligencia artificial," which aimed to design fire-resilient landscapes using advanced modelling techniques. Through his leadership, he strives to bridge the gap between cutting-edge research and operational decision making, ensuring that scientific advancements translate into actionable solutions for fire-prone regions worldwide.

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Hussam Mahmoud

Hussam Mahmoud is the Craig E. Philip Endowed Chair of Engineering at Vanderbilt University and is the Director of the Vanderbilt Center on Sustainability, Energy and Climate (VSEC). Previously he was the George T. Abell Professor in Infrastructure in the Department of Civil and Environmental Engineering at Colorado State University. Dr. Mahmoud's research focuses on sustainable and resilient infrastructure and communities, emphasising developing socio-physical models to capture the recovery of systems as influenced by human behaviour and socio-economic policies. He is an international authority on infrastructure and community resilience and an advisor to the World Bank, the International Science Council, the United Nations, insurance companies, and other agencies on such topics. His recent work on predicting wildfire vulnerability to the built environment is set to provide a new paradigm for wildfire mitigation worldwide, and he has recently received significant funding from the Gordon and Betty Moore Foundation to support this effort. He has authored more than 300 publications and given more than 180 presentations, including 140 invited talks at national and international conferences and workshops, distinguished lectures, and keynotes. He has chaired and served on numerous technical committees, including the ASCE Committees on Fire Protection and Multi-hazard Mitigation. Dr. Mahmoud is a Fellow of the American Society of Civil Engineers, Fellow of the Structural Engineering Institute, and is the recipient of various awards. He has been invited to various symposia by the U.S. National Academies of Sciences, Engineering, and Medicine; the Royal Academy of Engineering; and the Royal Institute of International Affairs. His research has received media coverage through citations and interviews in numerous venues, including Nature Computational Science, Nature Climate Change, the US National Academy of Engineering, Smithsonian Magazine, CNN, Forbes, and The New York Times.

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Eric Maillé

Eric Maillé, Ph.D., is a Research Engineer in the INRAE/Aix-Marseille University joint research unit "Risks, ecosystems, Environment Resilience (RECOVER)" at Aix en Provence, France. He specialises in global wildfire risk modelling at the wildland–urban interface at a local scale by integrating both hazard and vulnerability components. His work notably involves developing WUI spatial analysis models aimed at relating spatial WUI structures, representing the intrication of fuel vegetation classes and vulnerable anthropogenic objects (e.g., buildings, infrastructures) to experienced impacting fire events. He also develops multi-criteria models and tools to assess physical and anthropogenic vulnerabilities in built-up areas and local territories at the forest–urban interface. His third research topic is to develop spatial models of WUI dynamic aimed at anticipating future change in fire risk at the local scale in the context of climate change. He notably developed these research topics in several European projects including FireParadox (2007–2010), FUME (2010–2013), MEDSTAR & INTERMED (2018–2022), and now MEDSTAR II (2025–2028). Dr. Maillé also has an important activity in transferring research results to decision makers by providing valuable information for long-term planning in regions where urban development and natural landscapes converge and by developing tools and web services implementing the specified research models (e.g., WUIMAP II, VULNINTERMED). He will mainly present some of the works of Dr. Anne Ganteanme, Research Director in the same research unit, whose works focus on fire behaviour physical modelling at WUI, fuel vegetation fire traits assessment, and fire ecology.

José M. Moreno

José M. Moreno is Emeritus Professor of Ecology at the University of Castilla-La Mancha and Fellow at the Royal Spanish Academy of Sciences. He is a terrestrial ecologist by training, and his interests are focused on understanding wildfire's effects on the ecosystem and landscape and the impacts of climate and global change on them. He has worked mainly on Mediterranean-type ecosystems.

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Elsa Pastor

Elsa Pastor is a Full Professor in the Department of Chemical Engineering at the Universitat Politècnica de Catalunya (UPC). For more than 20 years, she has been dedicated to advancing teaching and research in safety and risk analysis, with a particular focus on fire risk assessment in the wildland–urban interface (WUI). Dr. Pastor has led numerous projects across both the private and public sectors, developing innovative methodologies for WUI fire prevention, mitigation, and risk management. She has coordinated several European research projects funded by the European Commission's Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG-ECHO), including WUIVIEW (Wildland–Urban Interface Virtual Essays Workbench, 2019–2021), WUITIPS (Wildland–Urban Interface Fire Tourist Infrastructure Protection Solutions, 2023–2025), and FIREPRIME (European Program for Wildfire-Prepared Communities, 2024–2026). She has authored 70 peer-reviewed articles in high-impact international journals and contributed to more than 100 scientific conferences worldwide. Additionally, she has co-authored 10 specialised books and supervised 10 doctoral theses, playing a key role in shaping the next generation of researchers in fire risk analysis.

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Yannick Le Page

Yannick Le Page is a wildfire knowledge and innovation expert at the Portuguese Integrated Fire Management Agency (AGIF) since 2020. The agency was created in the aftermath of the 2017 fire season and tasked to (1) develop a new national strategy to prevent devastating fires, and (2) coordinate its implementation. Yannick works to ensure that the strategy is driven by the best available science and knowledge. He is particularly involved in implementing risk assessments, developing interactive analytical tools to support informed decision making and communication campaigns, as well as identifying opportunities from innovation and through a lessons learned process applied to recent fire events. His scientific experience is grounded in a forestry Ph.D. at the University of Lisbon, and more than 10 years of research. This includes a scientist position at the Joint Global Change Research Institute (Washington, DC, United States) which provides future societal scenarios to the IPCC. Yannick was involved in a range of multi-disciplinary projects with a core focus on improving the representation of vegetation dynamics in the model and exploring their interaction with societal, economic, and policy decisions. He also developed the Human-Earth System Fire model (HESFIRE) to evaluate future fire regimes under changing environmental and socio-economic conditions.

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Eulàlia Planas

Eulàlia Planas is a Professor in the Department of Chemical Engineering at the Universitat Politècnica de Catalunya (UPC) and the Head of the Centre for Technological Risk Studies (CERTEC). She holds a degree in Industrial Engineering (1993) and a Ph.D. in Chemical Engineering (1996). Her main research areas include the study of hydrocarbon pool fires, the mathematical modelling of major accidents, risk analysis related to the transportation of hazardous materials, and the assessment of natural hazards impacting industrial facilities (NaTech), with a particular focus on wildfires. In wildfire research, Dr. Planas has developed infrared image processing systems to quantify fire progression metrics such as rate of spread, fire intensity, and flame geometry, as well as to evaluate the effectiveness of aerial fire suppression. She is also advancing systems to deliver fire behaviour forecasts for decision-making purposes, leveraging data assimilation and inverse modelling techniques. Her work in wildland–urban interface (WUI) fires focuses on developing methodologies using computational fluid dynamics modelling to study the effects of burning wildland and residential fuels on structures. These studies incorporate performance-based criteria to evaluate house vulnerability and sheltering capacity. Dr. Planas is extensively involved in experimental fire research, further enriching her contributions to the field.

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Michele Salis

Michele Salis, Ph.D. in Agrometeorology and Ecophysiology of Agricultural and Forestry Systems (2008) at the University of Sassari. From 2008 to 2018, post-doc, research assistant and researcher at University of Sassari, Euro-Mediterranean Center on Climate Change, and National Research Council of Italy. Visiting Researcher at the USDA Forest Service in 2010. In 2018 he became Permanent Research Scientist, and then Senior Research Scientist (2020) at the National Research Council. In 2023, he obtained the National Academic Qualifications as Full Professor and as Associate Professor on Science and Technology of Wooded and Forest Ecosystems (07/B2). His main research fields focus on: a) fire spread and behaviour modelling; b) fire hazard, exposure and risk evaluation; c) fire management strategies. He has been and is currently involved in several European, National, and regional research projects as scientific coordinator, local team coordinator and researcher; in these projects, he also was/is Module or Task leader. He was and is also member of the Advisory Board of some projects and served as scientific expert for the evaluation of competitive research projects in EU and North America. Lecturer and invited speaker at various national and international courses on wildfires. He participated as speaker or invited speaker, as well as Member of Scientific and Organizing Committees at many scientific conferences in Italy and abroad. Tutor or co-tutor of Ph.D. and Master students in Italy and Spain, and scientific supervisor of several post-doc, Ph.D., Master and foreign students at the University of Sassari and the National Research Council. Author and co-author of several scientific articles, book chapters and technical reports, he has the following indicators of scientific productivity (SCOPUS, February 2025): 48 indexed works, h-index 22, 1480 citations.

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J. San-Miguel-Ayanz

J. San-Miguel-Ayanz works at the European Commission Joint Research Centre and is in charge of the development and operation of the European Forest Fire Information System (EFFIS) and the Global Wildfire Information System (GWIS). Currently, he leads the development of an artificial intelligence–based Global Wildfire Decision Support System in collaboration with EU and U.S. experts. He holds a Ph.D. (1993) and a M.Sc. (1989) in Wildland Information Science, with majors on Remote Sensing and Geographic Information Systems by the University of California-Berkeley, Berkeley, California, and a Forest Engineering Degree (1987) by Polytechnic University, Madrid, Spain. J. San-Miguel-Ayanz is co-chair of the Expert Group on Forest Fires in the pan-European region (EGFF - 43 countries) and the Expert Group on Forest Fires of Latin America and the Caribbean (EGFF LAC). Additionally, he acts as co-chair of the Global Observation of Forest Cover Fire Implementation Team (GOFC Fire IT) and leads the Group on Earth Observation (GEO) GWIS initiative. Publication list available at: https://scholar.google.it/citations?hl=en&user=I6t-LYgAAAAJ&view_op=list_works&sortby=pubdate

Jason Sharples

Jason Sharples is a mathematical scientist at the University of New South Wales (UNSW), Professor of Bushfire Dynamics and Director of UNSW Bushfire. As an internationally recognised expert in dynamic wildfire behaviour and extreme wildfire development, his research has extensively influenced policy and practice in Australia and internationally. He uses advanced mathematical and computational models to understand the dynamics of wildfire propagation and to pinpoint geographic features and weather conditions more likely to generate extreme wildfires. He is Operations Node Leader in the NSW Bushfire and Natural Hazards Research Centre and is further involved in various national and international research projects. He is a regular contributor to international wildfire science and professional dialogue. Jason has been elected a Fellow of the Australian Academy of Technological Sciences and Engineering, and the Royal Society of New South Wales. He also has a background working as a firefighter with the ACT Rural Fire Service and providing operational support and expert advice to the NSW Rural Fire Service, the NSW Coroners Court, and the Royal Commission into Natural Disasters in Australia.

María Olga Viedma Sillero

María Olga Viedma Sillero is a geographer with a Ph.D. in Environmental Sciences, specialising in Remote Sensing and Geographic Information Systems (GIS). She is a member of the "Fire Ecology and Other Disturbances in the Context of Global Change" (GLOBECO) research group at the Faculty of Environmental Sciences and Biochemistry, University of Castilla-La Mancha (UCLM). Currently, she works as an assistant professor at UCLM, where her primary research focuses on Landscape Ecology and Forest Fires. her work has been centred on: i) developing new methodologies for fire mapping using satellite imagery; ii) analysing spatio-temporal patterns of forest fires and fire hazard assessment; and iii) studying fire severity and post-fire regeneration through satellite and LiDAR data. Additionally, she serves as the Coordinator of the Official Master's degree in "Environmental Sustainability in Local and Territorial Development," offered by the Faculty of Environmental Sciences and Biochemistry at UCLM.

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Andres Valencia

Andres Valencia is a Senior Lecturer at the University of Canterbury, Department of Civil and Natural Resources Engineering, and current director of the fire engineering postgraduate programme. His research focuses on numerical and experimental studies of wildfires and aims to develop new engineering principles for reducing wildfire risk, particularly in urban areas, to build more fire-resilient communities. Current research includes investigating the potential harm of wildfires in the wildland–urban interface (WUI) in New Zealand as part of the ongoing MBIE Endeavour

Research Project "Extreme Fire Behaviour: Are we ready?" and the EU Horizon Project "Minority Report." These projects involve field, laboratory, and numerical experiments on New Zealand vegetation and its impact on urban settlements. Andres Valencia also consults on various wildfire risk projects and is currently developing a series of modular training courses specifically designed for US emergency services personnel to enhance their understanding and response capabilities to WUI fires. Previously, he served as a wildfire scientist at Urban Intelligence (NZ).

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Craig Weinschenk

Craig Weinschenk is a director of research with the Fire Safety Research Institute (FSRI), part of UL Research Institutes. He holds a Master of Science and a doctorate in mechanical engineering from the University of Texas-Austin. During his graduate studies, Craig worked with the Austin Fire Department on analysing firefighter compliance to changes in standard operating guidelines and on characterising the impact of forced ventilation on room-scale fires. Since joining FSRI, he has conducted full-scale residential fire experiments designed to characterise the thermal environment within the structure as well as exposed firefighter personal protective equipment. Craig is also a developer of the U.S. National Institute of Standards and Technology's Fire Dynamics Simulator (FDS) Version 6. He has used FDS to study the fire dynamics and thermal environment of fires that resulted in line-of-duty deaths and injuries to firefighters. Craig currently the principal investigator for the development of the National Emergency Response Information System (NERIS).

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