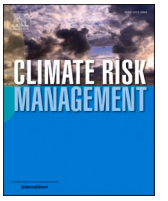
Climate Risk Management 45 (2024) 100638

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm



Fueling the fires – An exploration of the drivers and the scope for management of European wildfire risk under the Shared Socioeconomic Pathways

Eva Preinfalk [a,b,*], John Handmer [a,c]

[a] International Institute for Applied Systems Analysis (IIASA), Population and Just Societies Program, Laxenburg, Austria
[b] University of Graz, Wegener Center for Climate and Global Change, Graz, Austria
[c] Australian National University, Institute for Climate, Energy & Disaster Solutions, Canberra, Australia

ARTICLE INFO

Keywords:
Climate risk
Socioeconomic driver
SSP
Europe
Wildfire risk management

ABSTRACT

As socio-natural phenomena, wildfires are exacerbated by climate change and socioeconomic dynamics. However, the role of socioeconomic uncertainty in shaping future wildfire risk and management remains largely neglected. Building on the notion that risk emerges at the intersection of hazard, exposure and vulnerability, we conduct an integrative literature review to identify the most significant socioeconomic drivers of wildfire risk in the European geographical and institutional context and bring this together with the Shared Socioeconomic Pathways (SSP) perspectives on plausible socioeconomic dynamics. To our knowledge, this is the first study to bridge the gap between wildfire research and socioeconomic scenarios to establish a conceptual understanding of future wildfire risk. The resulting wildfire risk scenario space has two main applications: (i) it acts as a qualitative navigator for factoring socioeconomic uncertainty in model-based wildfire risk assessments, and (ii) it sets the boundary conditions for evaluating the feasibility of management strategies. Sustainable land use practices and profitable agricultural value chains can reduce future wildfire risk (e.g. *SSP1*), whereas land degradation (e.g. *SSP4*), and socioeconomic disparities (e.g. *SSP3*) may increase it. As a result, challenges to future wildfire risk management differ significantly across scenarios, leading to paradoxical situations. In scenarios where vulnerability reduction has significant potential to lower risk, socioeconomic challenges reduce the feasibility of implementing the necessary measures to achieve risk reduction. Similar dilemmas may arise in the context of hazard and exposure. By considering multiple plausible futures, this paper emphasizes the importance of accounting for socioeconomic dynamics in shaping wildfire risk and keeping the design of risk management strategies open and flexible in the face of changing circumstances.

1. Introduction

Through this century, hotter and drier conditions across Europe have led to more intense and long-lasting fire seasons, with

* Corresponding author.
E-mail address: preinfalk@iiasa.ac.at (E. Preinfalk).

https://doi.org/10.1016/j.crm.2024.100638
Received 8 February 2024; Received in revised form 16 July 2024; Accepted 17 July 2024
Available online 20 July 2024

wildfires[1] raging through cultural heritage and Natura2000 habitats (JRC, 2022), continuing to threaten lives and causing economic losses in the billions (Rego et al., 2018). While wildfires have long been considered integral to Mediterranean ecosystems (Pausas & Vallejo, 1999), with increasing frequency and intensity, they are now seen as a potential threat to the very existence of these habitats and the socioeconomic systems inextricably connected with them (Faiola & Labropoulou, 2023).

Considering future climate change, studies estimate an increase in fire occurrence and burned area for Southern Europe, especially under high warming levels, while expanding areas with low fuel moisture, pushing regions with moderate fire danger, i.e. a moderate likelihood for damaging fires to occur, further north (de Rigo et al., 2017). Despite increased investment in fire suppression[2] infrastructure, the increase in fires characterized by high intensities and high rates of spread (San-Miguel-Ayanz et al., 2013; Tedim et al., 2018) exhaust suppression capacities and create bottlenecks in the deployment of firefighting resources (OECD, 2023). This has raised concerns about the efficacy of holding on to what is referred to as 'zero fire policy', which prioritizes fire suppression, largely ignoring other approaches to risk reduction (Bacciu et al., 2022). Persisting with current management approaches focused on suppression and the restoration of burned settlements may lead to significant residual risk, especially in extreme wildfire situations (McWethy et al., 2019).

In addition to climate-driven changes to wildfire hazard, socioeconomic processes play a critical role in shaping wildfire risk (Lambrou et al., 2023). While studies focus on changes in fire occurrence and burned area under different climate scenarios, they largely disregard the complex and contemporary role (Essen et al., 2022) of socioeconomic dynamics and their impact on land use change, resource and vegetation management (de Rigo et al., 2017; Dupuy et al., 2020). This creates uncertainties regarding the long-term role of anthropogenic processes and the reliability of projections under various policy scenarios relevant for decision-making process (Dupuy et al., 2020). Bryant & Westerling (2014) demonstrated that in California, future changes in wildfire risk due to population growth, vegetation changes, and housing values have a greater impact on residential wildfire risk than variations in climate scenarios, highlighting the importance of considering socioeconomic factors in managing fires.

We address this gap by integrating empirical evidence on the socioeconomic drivers determining European wildfire risk, and establishing a conceptual understanding of the dynamics shaping European wildfire risk, by building on the notion that risk emerges at the intersection of hazard, exposure and vulnerability (IPCC., 2022). To our knowledge, this study presents a novel approach by conducting a review of recent literature to identify socioeconomic drivers of wildfire risk, which are then combined with relevant elements of the Shared Socioeconomic Pathways (SSP) literature to formulate plausible socioeconomic scenarios of future European wildfire risk. This aims to inform the integration of socioeconomic uncertainty in model-based wildfire risk assessments, going beyond climatic factors to highlight the interplay between socioeconomic processes and risk. This should help inform the design of future wildfire risk strategies.

Scenario analysis has become an integral tool in climate change research, using narratives to analyze and communicate climate impacts and adaptation (Ara Begum et al., 2022). Scenarios consider uncertainties in future dynamics (Kwakkel et al., 2010) and their long-term implications (Ebi et al., 2014; Riahi et al., 2017), supporting robust adaptation planning and strategy assessment (Haasnoot et al., 2012) (e.g. UK flood risk management under the Thames Estuary, or the Dutch Delta Programme (Bloemen et al., 2018)). With the first set of scenarios developed for assessing environmental change over two decades ago (Alcamo, 2001; Kok et al., 2007), scenarios have since evolved into global, national and local tools in climate change research (Rounsevell & Metzger, 2010). The global-scale SSPs are now widely used by the community, outlining potential trends in socioeconomic development throughout the 21st century through qualitative narratives (O'Neill et al., 2017) and quantitative projections (e.g., Dellink et al., 2017; Jiang & O'Neill, 2017; Riahi et al., 2017). SSPs were designed for broad applicability across sectors and geographic scales (Kok et al., 2019) and embody adaptation challenges, arising from societal or environmental conditions at any given level of climate change (O'Neill et al., 2014, 2017). Global SSPs have been adapted for regional and sector contexts, such as agriculture-focused SSPs for Europe (Mitter et al., 2020), West Africa (Palazzo et al., 2017) and Finland (Lehtonen et al., 2021). SSPs have also been extended to define possible futures for the global forest sector, accounting for uncertainties regarding land-use regulation, demand and supply-side changes, yet disregarding disturbances such as fires (Daigneault et al., 2019). The European-specific SSPs (EUR-SSPs) by Kok et al. (2019) and the detailed European agriculture and land use futures (Eur-Agri-SSPs) (Mitter et al., 2020) form the basis for the wildfire risk scenarios developed in this study. Building on and extending on this literature, this study uses the SSP framework, to align with and be applicable to the broader climate research community.

By bringing together wildfire risk with the broader literature on the use of socioeconomic scenarios in climate research, this work aims to bridge the gap between two highly related, yet largely disconnected, strands of literature. With a significant share of burnt area in Southern Europe[3], we draw on the experience and published work on these countries. However, recent decades have seen an increase in wildfire hazard conditions across Europe, extending into western, central, as well as northern regions (Bednar-Friedl et al., 2023). Authors have highlighted significant wildfire challenges in central and northern European countries (Stoof et al., 2024), with worse to come (Arnell et al., 2021; Forzieri et al., 2021). Therefore, our study adopts a European-wide perspective, aligning with the available scenario descriptions about alternative socioeconomic futures in Europe (Kok et al., 2019; Mitter et al., 2020). EU-wide policies on climate change, forests and landscapes play a critical role in shaping European wildfire risk and adaptation strategies,

[1] In this paper, the terms fires and wildfires are used interchangeably to refer to unplanned landscape fires. Wildfires are also known as forest fires, bushfires and veld fires, among other terms.

[2] 'Suppression involves extinguishing a wildfire, preventing or modifying the movement of unwanted fire, or managing a fire when it provides benefits like vegetation reduction or improved wildlife habitat.' https://www.doi.gov/wildlandfire/suppression (last access: 19.06.2024).

[3] https://www.eea.europa.eu/data-and-maps/daviz/burnt-forest-area-in-five-4#tab-chart_5(last access: 19.06.2024).

underscoring the relevance of a European focus. Relevant initiatives under the European Green Deal[4], such as the Biodiversity Strategy for 2030[5] and the New EU Forest Strategy for 2030[6], influence country-level land management and biodiversity conservation efforts, determining future wildfire risk and prominent management approaches (EC DG Env, 2021). National approaches for wildfire prevention and post-fire restoration are also determined by the Common Agricultural Policy[7] and the European Structural and Investment Funds (EC DG Env, 2021). While this paper focuses on the European scale, the proposed approach should be transferable to other regional contexts.

This paper is structured as follows. The next section introduces the definitions of wildfire risk, hazard, exposure, and vulnerability and categorizes common approaches for wildfire risk reduction. Section 3 outlines the methodological approach. Section 4 presents results from the review of recent literature and section 5 evaluates future wildfire risk using the qualitative directions provided by the SSPs and describes implications for management. Section 6 discusses and concludes.

2. Conceptual framing and current wildfire risk management

As a climate-related impact, wildfires occur against the backdrop of socioeconomic change (O'Neill et al., 2022). Throughout this paper, *socioeconomic* is used as an umbrella term for *"a wide range of aspects of societal, or more broadly, socioecological systems"*, including "*demographic, political, social, cultural, institutional, life-style, economic, and technological aspects, and the conditions of ecosystems and ecosystem services that have been affected by human activity such as air and water quality, biodiversity, and ecosystem form and function*", and explicitly exclude "*conditions related to future climate change itself*" (O'Neill et al., 2014, p.390). Thus, we consider the impact of regional socioeconomic dynamics on wildfire risk, independently from global changes in the climate system. We define a dynamic socioeconomic system as one that evolves over time, through changing and interacting variables.

2.1. Defining wildfire risk

This work builds on the notion that climate risk, or in our context, wildfire risk, results *"from the dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system"* (IPCC, 2022, p.132).

Determined by natural and anthropogenic processes, wildfires can be considered socio-natural hazards[8]. We define wildfires as unplanned landscape fires with the hazard coming from both the heat and flames of the fires and from the smoke they generate. For details on how fires spread and cause damage from flames, embers spotting ahead of the fire, and radiant heat see Sullivan (2017), for health impacts of smoke, see Gould et al. (2024). Most wildfires occurring across Europe are small in terms of burnt area and intensity, with only a small fraction exceeding local firefighting capacities (San-Miguel-Ayanz et al., 2013). Yet, these fires that are *"rare at a particular place and time of year"* (IPCC, 2022, p.2908), cause severe socio-economic and ecological impacts in the areas affected (Tedim et al., 2018).

The second, and location-specific dimension of wildfire risk, exposure, refers to the *"the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas."*[9]. The IPCC, 2022 (p.2908) goes beyond tangibles, mentioning also the presence of "*livelihoods; species or ecosystems, environmental functions, services and resources",* as well as *"cultural assets"*.

The third dimension of wildfire risk, vulnerability, is a socially constructed concept, changing with time and across communities and individuals (Jurgilevich et al., 2017; Kienberger et al., 2013). Following the UNDRR, vulnerability is understood as *"the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility […] to the impacts of hazards"*.[10] Research commonly assesses vulnerability to climate impacts or extreme weather on one-dimensional determinants (e.g. wealth & income (Hallegatte et al., 2020; Tasri et al., 2022), health (Chan et al., 2019), gender (Rahman, 2013), education (Muttarak & Lutz, 2014)), at the risk of disregarding the interactions among them (Versey, 2021). Originating from the work of Crenshaw (1989) in the field of black feminist and civil rights research, the concept of intersectionality can provide a more nuanced understanding of social vulnerability (Kuran et al., 2020). Spreading beyond ethnicity and gender, intersectionality has become established as a valuable concept for studying climate vulnerability (Kaijser & Kronsell, 2014), avoiding binary categorizations and enhancing understanding of the causes, and co-existence and synergisms, of multiple types of vulnerability (Kuran et al., 2020). This emphasizes the multidimensional and context-specific nature of vulnerability and the inability to capture it in a single or static measure (Thomas et al., 2019).

However, rather than considering vulnerability from the perspective of the individual, this paper considers the vulnerability of

[4] European Commission (2019), COM(2019) 640 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN (last access: 19.06.2024).

[5] European Commission (2020), COM(2020) 380 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380 (last access: 19.06.2024).

[6] European Commission (2021), COM(2021) 572 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0572(last access: 19.06.2024).

[7] European Commission (2020), Common Agricultural Policy for 2023–2027 https://agriculture.ec.europa.eu/system/files/2022–12/csp-at-a-glance-eu-countries_en.pdf (last access: 19.06.2024).

[8] UNDRR (2022a), *Terminology—Hazard* [Online post]. https://www.undrr.org/terminology/hazard (last access: 22.07.2019).

[9] UNDRR (2022b), *Terminology—Exposure* [Online post]. https://www.undrr.org/terminology/exposure (last access: 22.07.2024).

[10] UNDRR (2023), Vulnerability. In *UNDRR Terminology*. https://www.undrr.org/terminology/vulnerability (last access: 22.07.2024).

communities or groups of people sharing similar characteristics relevant to their vulnerability. This may include but is not limited to place-specific characteristics. We acknowledge that this insufficiently accounts for the heterogeneity of individual vulnerability to wildfires but is what can be achieved given the available SSP descriptions.

Fig. 1 illustrates wildfire risk, located in the intersection of hazard, exposure and vulnerability. Throughout this paper we refer to hazard, exposure and vulnerability as the dimensions of risk, or risk dimensions. Socioeconomic changes reshape each risk dimension over time, increasing or decreasing the overall level of risk.

2.2. Towards a risk-based approach to managing wildfires

European countries have responded to increasingly severe fire seasons by stepping up their emergency preparedness and response capacity (OECD, 2023). This includes a pledge to double the EU firefighting fleet to increase transnational suppression infrastructure (European Commission, 2023). Hazard reduction initiatives are fostering fire resilient landscapes (Ascoli et al., 2023), by restoring peatlands, implementing fuel breaks and supporting vegetation management (OECD, 2023).

Traditional practices used fire as a land management tool, which also reduced wildfire hazard (Vázquez-Varela et al., 2022). While the abandonment of land and tradition has led to a discontinuation of these practices in parts of Europe (Quintas-Soriano et al., 2022), they have now been re-introduced for a range of reasons including heritage, landscape aesthetics and biodiversity, as well as for being a practical way managing fire hazard (Vázquez-Varela et al. 2022). Economic incentives, such as subsidies for farmers for the provision of environmental services support the economic viability of such approaches (Wunder et al., 2023). Tweaking current practices in fuel management and landscape resilience may help to partially overcome potential limits to adaptation to extreme wildfire risk. Yet, the effectiveness of such approaches is increasingly debated for a future facing unpredictable fire behavior and longer more severe fire seasons (Eriksen et al., 2021; McWethy et al., 2019; Tedim et al., 2018).

Exposure-focused risk management approaches require the integration of wildfire hazard information with land-use decisions, to prohibit construction in areas where protection is impossible (Kocher & Butsic, 2017; OECD, 2023). However, high demand for residential areas and for tourism and recreation increases formal and informal expansion into fire-prone areas (Blandford, 2019). In these circumstances, wildfire risk reduction needs to include alternative ways for post-fire recovery, as returning the system to its condition before the wildfire occurred is becoming unsustainable (Schumann et al., 2020). This constitutes a fundamental change in dealing with wildfires. Instead of rebuilding destroyed assets as they were before, exposure-focused approaches acknowledge fires as natural phenomena, and actively account for this in zoning, infrastructure planning and management (McWethy et al., 2019). While the opportunity for such transformational approaches commonly presents itself during rebuilding decisions after a major event (Schumann et al., 2020), an emphasis on proactive adaptation, rather than recovery, may be more effective in mitigating the loss and suffering from wildfires (Moritz et al., 2014; Rego et al., 2018). This would require institutional efforts on land-use regulation (Montiel Molina & Galiana-Martín, 2016) and the establishment of asset-protection zones for emergency response (Rego et al., 2018).

An understanding of vulnerability and its links to local social, institutional and economic factors is key to wildfire risk adaptation (Rego et al., 2018). The transformation towards effective wildfire risk adaptation in an uncertain future will have to acknowledge and address underlying social and economic conditions determining differential vulnerabilities in the context of wildfires (McWethy et al., 2019; Schinko et al., 2023). In turn, this would require a shift towards a more inclusive and transparent engagement of those groups most at risk to work towards an even distribution of risk (Essen et al., 2022). During recovery and adaptation, insurance can serve as a solidarity mechanism (Schinko et al., 2023), yet, increasing wildfire occurrence is compromising insurance availability or affordability (OECD, 2023), threatening livelihoods and raising issues of asset stranding (Caldecott et al., 2021).

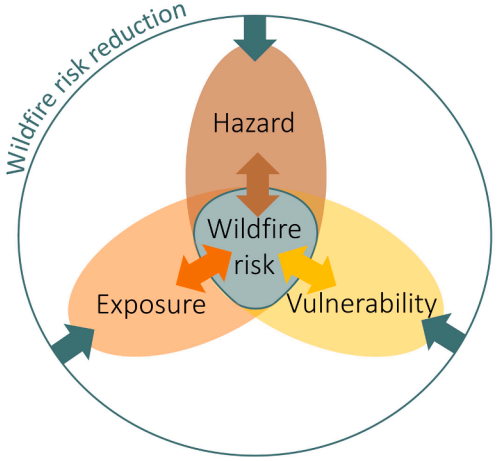


Fig. 1. Wildfire risk as the interaction between hazard, exposure and vulnerability. Illustration based on the risk framing in O'Neill et al. 2022, Figure 16.1. Arrows between wildfire risk and hazard, exposure and vulnerability indicate the socioeconomic dynamics determining the size of each risk dimension and the impact on shaping risk. Green arrows illustrate that risk can be reduced from measures encompassing all risk dimensions.

Fig. 1 illustrates the importance of considering each wildfire risk dimension by means of hazard-, exposure- and vulnerability-focused approaches of risk management. Moving away from the hazard-centered approaches currently dominating the European wildfire risk management landscape is indispensable for reducing risk. This is especially the case when risk is determined to a significant extent by the socioeconomic drivers of exposure and vulnerability.

3. Methodology

3.1. Identifying the socioeconomic drivers of European wildfire risk

To identify the socioeconomic dynamics determining European wildfire risk, we reviewed and synthesized the representative literature on the underlying drivers of wildfire risk by means of an integrative review (Torraco, 2005) of published peer-reviewed and grey literature. Integrative reviews synthesize the current state of knowledge on a topic, abstracting broader themes (Cronin & George, 2023).

For a first set of relevant literature, we developed a query that contained risk drivers as categorized in O'Neill et al. (2022, pp.2421–2422): *demographics*, *socioeconomic development including inequalities* and *ecosystem degradation*. Also, the query accounted for the climate impact in question and the geographical location of interest. We included Europe, the EU and five European countries explicitly (i.e. Spain, Greece, Italy, France, Portugal), as they accounted for a significant share of burnt area across Europe (e.g. 92 % of the 2017 burnt area in Europe was in these countries) (EEA, 2021). Thus, we expect a significant share of research on these regions. We allowed for flexibility in the wording and accounted for words commonly used synonymously. As our analysis is forward-looking, we have restricted our search query to include work published after 2012, to capture current and relevant dynamics related to wildfire occurrence in the last decade or two. The final search query used in SCOPUS is indicated in Fig. 2.

A total of 825 search results were screened based on their title and abstract, of which 16 were identified as suitable to be included for full-text analysis (see appendix A for a full list). The screening was split between the two authors, with an immediate check of the complete manuscript in case a document seemed relevant based on the title and abstract. Once a suitable document for full-text analysis was identified, the authors discussed the implications of the socioeconomic drivers mentioned on determining wildfire risk. Given the integrative nature of the review, this iterative exchange on identified drivers helped the authors identify relevant aspects and perspectives on the topic to inform the identification of additional literature and synthesis of findings.

For the analysis, the focus was put on empirical research of past events, excluding modelling studies and projections of future conditions, as these are based on ex-ante knowledge of relevant dynamics, without adding novel aspects regarding the underlying drivers themselves. Book chapters and conference contributions were not considered. Also, studies focusing primarily on impact assessment, management or recovery were excluded.

After a first screening and identification of drivers, suitable pieces of grey literature (OECD, 2023; Rego et al., 2018) were identified focusing on policy documents offering a broader perspective on European wildfire risk, to ensure that no significant drivers are overlooked. Based on the literature cited in these reports and the sample identified via SCOPUS, additional sources were added by means of backward induction, strengthening the evidence on relevant aspects mentioned in this first selection of documents (see appendix A for a full list).

The documents identified as relevant were imported as whole-text PDFs into Zotero. Within Zotero, relevant sections were highlighted and grouped according to their relevance to the driver categories: demographic, socioeconomic development including inequalities, and ecosystem degradation. These highlighted sections were then further coded by the authors to identify common topics within each category.

3.2. A common understanding of possible socioeconomic futures – The SSPs

With SSP narratives covering dynamics in demography, economic development, inequality and socioecological interactions, they offer a well-suited background for discussing plausible dynamics for the drivers of wildfire risk identified.

In *SSP1*, throughout this paper referred to as *Sustainable development*, effective environmental policies together with rapid technological and economic progress and low inequalities foster sustainable lifestyles (Kok et al., 2019). These environmental policies are in contrast to *SSP5*, referred to as *Fossil-fueled development*, where rapid technological and economic progress is supported by carbon-based fuels and environmental concerns have low priority (Kok et al., 2019). Low economic development and high levels of conflict and regional rivalry prevail across Europe in *SSP3* (*Rivalry*) with low levels of human capital investments and severe ecosystem failures (Kok et al., 2019). In *SSP4* (*Inequality)*, European society is fragmented with a low-income majority working in a low-tech labor-intensive economy, contrasted with a powerful business elite pushing towards high-tech solutions to solve environmental problems (Kok et al., 2019). Table A1 lists the key elements relevant in the context of wildfire risk for each scenario. In the absence of exhibiting

```
TITLE-ABS-KEY ( ( demograph* OR socioeconomic OR societal OR economic OR inequal*
OR ecosystem* OR biodiversity ) AND ( driver* OR determinant* OR dynamic* OR factor* )
AND ( wildfire OR forest AND fire ) AND ( europe OR eu OR mediterranean OR spain OR
greece OR italy OR france OR portugal ) ) AND PUBYEAR > 2012
```

Fig. 2. Scopus search string.

any distinctive trend with all elements changing only moderately, or as Kok et al. (2019, p. 645) put it, *"lacks its own 'identity'"*, we consider *SSP2* as a consistent reference scenario in which Europe remains on established paths, referred to as *More of the same*.

3.3. Bringing together wildfire risk drivers and the SSPs

In a first step, the drivers of wildfire risk identified during the literature review were categorized following O'Neill et al. (2022) into demographic factors, socioeconomic development (including inequalities) and ecosystem degradation. Next, these drivers were aligned with the three dimensions of wildfire risk based on their interaction with risk dimensions.

Subsequently, the identified wildfire risk drivers were matched with the relevant SSP dynamics, using appropriate SSP extensions to develop wildfire risk narratives contextualizing plausible scenarios of future wildfire risk. The EUR-SSPs developed by Kok et al. (2019) break down governance, social and economic aspects of the SSPs into the European context. For land use changes, we referred to qualitative indicators provided in Mitter et al. (2020) and Popp et al. (2017) (assuming Europe follows the description for high income countries). For indicators on human capital development and institutional support, we use Kok et al. (2019), as well as Mitter et al. (2020), with a focus on rural communities and the farming population. Directions and characterization of urbanization and land use regulation are provided in O'Neill et al. (2017) (assuming that Europe follows the descriptions for rich OECD countries). Throughout this paper, we focus on qualitative indicators to suggest possible directions, rather than quantifying trends.

To visualize future wildfire risk under different SSPs, we adjusted the risk propeller introduced in Fig. 1. Based on the qualitative directions from the combination of socioeconomic drivers and SSPs, each dimension is scaled up or down proportionally. This modifies the size of the intersection of hazard, exposure and vulnerability, resulting in a different risk level in each scenario.

4. The socioeconomic drivers of European wildfire risk

4.1. Demographics

Based on the literature review, we find that demographic trends significantly shape European fire ***hazard*** (Rodrigues et al., 2020). The abandonment of rural areas has increased landscape flammability by expanding shrubland and forest areas (Ganteaume et al., 2013; Nunes & Lourenço, 2017), connecting fuel loads and reducing landscape heterogeneity (Ascoli et al., 2021; Sil et al., 2019). This homogenization also leads to a loss in biodiversity and ecosystems (Quintas-Soriano et al., 2022). The main determinants of rural depopulation in Europe include lack of land governance (Spadoni et al., 2023) and unprofitable value chains for agriculture and forestry sectors (Rego et al., 2018). Viedma et al. (2015) note a shift from the abandonment of remote, less productive lands until the 1990s, to the abandonment of farms with low mechanization levels and with land-holders older than 55 years.

Rural abandonment has left ageing populations in villages and communities (Nunes & Lourenço, 2017; Rodrigues et al., 2022) with a false sense of security, who although experienced in living with fires, nevertheless underestimate changing fire intensities from land use change and climatic drivers (Rodrigues et al., 2022). At the same time, rural depopulation has affected local interactions and relationships (Uyttewaal et al., 2023), reducing levels of social cohesion from losing relationships with neighbors (Rodrigues et al., 2022; Uyttewaal et al., 2023). This increases ***vulnerability*** of the population residing in fire prone areas.

Unlike farmland abandonment, recent decades have seen the expansion of human settlements into areas covered by flammable natural vegetation, known as the wildland urban interface (WUI) (Colantoni et al., 2020), increasing the ***exposure*** of people and assets. Fires in these areas cause significant damage to and loss of private property, especially where human settlements and natural vegetation intermingle (Ganteaume et al., 2021; Vacca et al., 2020). Poor land-use planning has left parts of the urban–rural interface with scattered and sparsely clustered buildings among shrubby vegetation, prone to high-intensity fires (Beltrán-Marcos et al., 2023), particularly informal structures without permits. During the 2018 Mati wildfires in Greece, assets without building permits amounted to a significant share of building losses (Blandford, 2019; OECD, 2023). Also, unclear zoning and outdated hazard maps have contributed to settlement expansion into flammable landscapes, increasing exposure (OECD, 2023; Triantis, 2023).

4.2. Socioeconomic development including inequalities

As commonly raised in disaster risk management and development studies, risk is determined to a significant extent by socioeconomic status (Cutter et al., 2003; Hallegatte et al., 2020), including the context of wildfires (Preston et al., 2009). Empirical evidence for Europe is associating socioeconomic inequalities such as rural poverty, aging, financial deprivation, unemployment and deregulated urban expansion with fire ignition, intensity and frequency (De Diego et al., 2023; Ferrara et al., 2019), increasing wildfire ***hazard***. In some rural areas, the lack of preparation and awareness, poor risk literacy and lack of competences among authorities (Rodrigues et al., 2022) further contributes to fire risk by increasing the ***vulnerability*** of exposed communities.

In addition, institutional factors such as insufficient infrastructure development and in rural areas, incomplete land cadasters and land management conflicts are contributing to wildfire risk, by impeding the implementation of effective prevention policies (Skulska et al., 2020) fostering a reduction of **exposure** to damaging fires. A recent review by Lambrou et al. (2023) emphasizes the role of insufficient financial resources in exacerbating wildfire ***vulnerability*** in the absence of effective institutional support during response and recovery among the communities with low coping capacities.

Wildfire ***exposure*** is particularly high in rural economies (Rodrigues et al., 2023). When fires burn permanent crops such as olive orchards (Stougiannidou & Zafeiriou, 2021), or commercial forests (Alcasena et al., 2016) decades of revenue streams are lost, disrupting farm livelihoods and creating ***vulnerability*** among the affected population.

4.3. Ecosystem degradation

The literature also points to the relevance of ecological trends in determining wildfire risk. The replacement of natural vegetation with extensive monocultures of highly flammable non-native species alters wildfire ***hazard*** (Gómez-González et al., 2020; OECD, 2023). This has been observed in Portugal, where large-scale commercial eucalyptus plantations (Rego et al., 2013) have reduced landscape heterogeneity, fueling the occurrence of large scale fires (Barquín et al., 2022).

In addition to plantations for commercial objectives, large scale afforestation programs for biodiversity conservation, or the enhancement of carbon sinks (Anderegg et al., 2020; Gómez-González et al., 2020) are increasing landscape connectivity and fuel availability, facilitating extreme fires (Duane et al., 2021; Hermoso et al., 2021). This may become an important driver of European wildfire risk, as the objectives of current and future EU climate or biodiversity regulations may foster an increase of flammable fuel loads.

4.4. Drivers in the context of hazard, exposure & vulnerability

Table 1 generalizes the drivers identified in 4.1–4.3 into broader categories relevant in the context of European wildfire risk. Based on the mechanism through which each of the drivers discussed above is affecting wildfire risk, we differentiate between their relevance with respect to hazard, exposure and/or vulnerability. For further detail on the interaction between the drivers with the relevant wildfire risk dimension, see Table B1 in the appendix.

We see that hazard interacts with all drivers mentioned, with a large body of literature emphasizing the role of land abandonment and vegetation change on landscape flammability and thus, wildfire risk. With literature commonly highlighting the human influence on climate-induced risks on the dynamics of exposure and vulnerability (O'Neill et al., 2022), this well-established link between wildfire hazard, human landscape management and fire ignition, adds complexity to the assessment of wildfire risk.

Wildfire exposure is determined by the degree of settlement expansion into the WUI, characterized by areas in which tangible and intangible assets intermingle with natural vegetation (Radeloff et al., 2005), and exacerbated by insufficient management of highly flammable vegetation. Also, another aspect of exposure is the level of assets in agriculture and forestry at risk of sudden devaluation from fires.

Vulnerability to wildfires is driven by a loss of social cohesion among rural communities, limiting their coping capacities. Low levels of institutional support and infrastructure developments exacerbate vulnerabilities in communities challenged by poor socio-economic circumstances. Moreover, the reliance on revenue streams from agriculture and forestry increases the vulnerability of communities, particularly smallholders.

5. Future wildfire risk in a dynamic socioeconomic environment

By bringing together the literature on the drivers shaping wildfire risk (see 4.1–4.4) and their possible directions under different SSP trajectories (see 5.1), this section discusses future wildfire risk in different socioeconomic scenarios and management implications.

5.1. Drivers of future wildfire risk drivers in line with SSP indicators

Tables 2–4 indicate how the drivers wildfire hazard, exposure and vulnerability were matched with corresponding indicators in the SSP descriptions provided in Kok et al. (2019), Mitter et al. (2020), O'Neill et al. (2017) and Popp et al. (2017). Qualitative directions

Table 1
Drivers of European wildfire risk identified from the literature and their relevance along the dimensions of wildfire risk. (Haz. = hazard, Exp. = exposure, Vul. = vulnerability).

Risk driver	*Relevance in the context of European wildfire risk*	*Affected wildfire risk dimension*		
		Haz.	*Exp.*	*Vul.*
Demographics	**Rural land abandonment to increase fuel-intensive and flammable landscapes** (Ascoli et al., 2021; Ganteaume et al., 2013; Nunes & Lourenço, 2017; Rodrigues et al., 2020; Sil et al., 2019; Spadoni et al., 2023; Viedma et al., 2015)	x		
	Loss of social cohesion among rural communities (Nunes & Lourenço, 2017; Rodrigues et al., 2022; Uyttewaal et al., 2023)			x
	Settlement expansion in areas covered by natural vegetation (Beltrán-Marcos et al., 2023; Blandford, 2019; Colantoni et al., 2020; Ganteaume et al., 2021; OECD, 2023; Triantis, 2023; Vacca et al., 2020)		x	
Socioeconomic development including inequalities	**Socioeconomic inequality among communities** (De Diego et al., 2023; Ferrara et al., 2019; Preston et al., 2009; Rodrigues et al., 2022)	x		x
	Insufficient institutional support for rural areas (Lambrou et al., 2023; Skulska et al., 2020)			x
	Economic dependence on agriculture & forestry (Alcasena et al., 2016; Rodrigues et al., 2023; Stougiannidou & Zafeiriou, 2021)		x	x
Ecosystem degradation	**Replacement of native species with monocultures of flammable species** (Anderegg et al., 2020; Barquín et al., 2022; Duane et al., 2021; Gómez-González et al., 2020; Hermoso et al., 2021; OECD, 2023; Rego et al., 2013)	x		

for each SSP, relative to SSP2 are indicated by means of arrows. SSP2 refers to a continuation of current trends, and thus, a proportional increase in each risk dimension relative to the status quo.

5.2. Narratives for future wildfire risk in Europe

SSP1: Sustainable development.

High rates of agricultural intensification and productivity improvements (Popp et al., 2017) raise wealth in the agricultural sector. Alongside public support for the provision of ecosystem services and an increasing demand for bio-based materials (Mitter et al., 2020), this creates profitable value chains in agriculture and forestry, and reduces unmanaged abandoned land with its concomitant fuel load. With strict land use regulation (Kok et al., 2019; Popp et al., 2017) and effective environmental policies (Mitter et al., 2020), development in the agricultural and forestry sectors remains within environmental limits, preventing ecosystem degradation and the spread of invasive species, thereby reducing landscape flammability. Sustainable development boosts human capital in rural areas and reduces within-country inequality (Kok et al., 2019), mitigating ignitions related to socioeconomic disparities. Overall, this reduces socioeconomic pressure on hazard in *SSP1*.

Effective institutions maintain high environmental standards (Mitter et al., 2020) and the sustainable governance of land use (Popp et al., 2017). This ensures high but well-managed urbanization rates (O'Neill et al., 2017), alleviating the pressure on increasing wildfire exposure from uncontrolled expansion of human settlements. Due to agricultural productivity increases, and thus an increase in value-added per unit of land, as well as increasing demand for bio-based materials (Mitter et al., 2020), exposure increases, albeit on well-managed land.

Sustainable economic development (Kok et al., 2019) and institutional support (Mitter et al., 2020) enhance the capacity of rural communities to reduce risks and vulnerability. High social cohesion, low tension and conflict (Mitter et al., 2020), alongside significant human capital investment (Kok et al., 2019) further facilitate this. Rising education levels of the farming population (Mitter et al., 2020) increase their resilience to economic disruptions caused by fires.

SSP3: Rivalry.

Increased concerns for self-sufficiency and public payments to maintain production potentials (Mitter et al., 2020), reduce pressure on land abandonment, despite low agricultural production standards and technology diffusion (Mitter et al., 2020). With minimal land use regulation (Popp et al., 2017), economic exploitation of agricultural land with relaxed environmental standards comes at the expense of land and ecosystem degradation (Kok et al., 2019), compromising landscape resilience. Inequalities also within some countries (Kok et al., 2019) increase ignition pressure, elevating wildfire hazard in a future characterized by *SSP3*.

Ineffective land-use management and planning (Popp et al., 2017) in *SSP3* lead to the expansion of settlements into natural vegetation areas (O'Neill et al., 2017), increasing exposure of assets and people in fuel intensive and poorly-managed landscapes. Also, regional rivalries and a decline in the trade of agricultural commodities raise the importance of self-sufficiency, resulting in increased market concentration (Mitter et al., 2020), and higher exposure in agriculture and forestry of large firms with significant market shares.

The EU experiences regional rivalry (Kok et al., 2019), with increasing tension and conflict (Mitter et al., 2020) reducing community cohesion. Low economic growth and ineffective governance leads to many countries struggling to maintain living standards (Kok et al., 2019), leading to poor risk literacy. Decreasing infrastructure investments (Mitter et al., 2020) and conflicts within the EU (Kok et al., 2019), limit response aid and risk sharing mechanisms, exacerbating the vulnerability of rural communities to wildfires. Poor urban–rural linkages, little diversification of agricultural supply chains and low technological standards further increase vulnerabilities especially among the farming population (Mitter et al., 2020).

SSP4: Inequality.

Pressures on hazard are comparable to *SSP3*, but further exacerbated by agricultural policies designed for elites and largely ignoring the interests of the low- to medium-income majority (Mitter et al., 2020). Demand for agricultural commodities stagnates, while structural change in agriculture occurs rapidly for large, industrialized farms (Mitter et al., 2020), in contrast to low productivity small scale farmers (Popp et al., 2017). Poor environmental standards and the overuse of natural resources (Mitter et al., 2020) increases pressure on smallholder farmers' livelihoods, causing land abandonment and an increase of unmanaged vegetation. Simultaneously, the spread of invasive species and low environmental standards (Mitter et al., 2020), increase landscape flammability, exacerbating wildfire hazard. Moreover, socioeconomic disparities between elites and a low- to medium-income majority (Kok et al., 2019) heighten ignition pressure.

Low infrastructure development and poor environmental standards prevail in rural and less favored areas (Mitter et al., 2020). In

Table 2
Drivers of wildfire hazard and corresponding indicators and qualitative directions provided by the SSPs. Arrows indicate the trend relative to SSP2, where ↓ implies a decrease, ↑ implies an increase and → implies that no distinct trend could be identified.

Driver	Corresponding indicator in the SSPs	SSP1	SSP3	SSP4	SSP5
Rural land abandonment to increase fuel-intensive and flammable landscapes	Institutional support for rural areas and technology development & diffusion (Mitter et al., 2020; Popp et al., 2017)	↓	→	↑	→
Replacement of native species with monocultures of flammable species	Level of environmental standards (Kok et al., 2019) & management of natural resource use (Mitter et al., 2020).	↓	↑	↑	↑
Socioeconomic inequality among communities	Within-country inequalities (Kok et al., 2019)	↓	↑	↑	↓

Table 3
Drivers of wildfire exposure and corresponding indicators and qualitative directions provided by the SSPs. Arrows indicate the trend relative to SSP2, where ↓ implies a decrease, ↑ implies an increase and → implies that no distinct trend could be identified.

Driver	Corresponding indicator in the SSPs	SSP1	SSP3	SSP4	SSP5
Settlement expansion in areas covered by natural vegetation	Indicators on land use (Popp et al., 2017) and environmental regulation (Mitter et al., 2020) and urbanization (O'Neill et al., 2017),	→	↑	→	↑
Economic dependence on agriculture & forestry	Indicators on market concentration & demand of agriculture & forestry (Mitter et al., 2020).	↑	↑	↑	↑

Table 4
Drivers of wildfire vulnerability and corresponding indicators and qualitative directions provided by the SSPs. Arrows indicate the trend relative to SSP2, where ↓ implies a decrease, ↑ implies an increase and → implies that no distinct trend could be identified.

Driver	Corresponding indicator in the SSPs	SSP1	SSP3	SSP4	SSP5
Loss of social cohesion among rural communities	Social cohesion (Kok et al., 2019), tension & conflict (Mitter et al., 2020).	↓	↑	↑	↓
Socioeconomic inequality among communities	Descriptions of socioeconomic inequality and human capital development (Kok et al., 2019)	↓	↑	↑	→
Insufficient institutional support for rural areas	Quality of governance (Kok et al., 2019) and institutional support in rural areas (Mitter et al., 2020)	↓	↑	↑	→
Economic dependence on agriculture & forestry	Human capital development among farming population (Mitter et al., 2020)	↓	↑	↑	↓

addition to economic constraints, highly regulated land-use change (Popp et al., 2017) and high rates of urbanization (O'Neill et al., 2017), slow the expansion of human settlements in areas covered by natural vegetation. Exposure of agricultural assets is characterized by large, industrialized, and capital-intensive farms on the one hand and poor smallholder farms on the other, whose needs are largely ignored (Mitter et al., 2020).

Disparities in economic opportunity, low social cohesion (Kok et al., 2019) and increasing tensions and conflict (Mitter et al., 2020) reduce communities' capacities for dealing with wildfire risk. Disparities in economic opportunity leave low-income communities working in a labor intensive, low-tech economy (Kok et al., 2019) with particularly low levels of resilience, especially among smallholder farms. While elites benefit from high investments in human capital and institutional support (Kok et al., 2019), communities of lower socioeconomic status are poorly represented in institutions and their interests in agricultural policies largely ignored (Mitter et al., 2020), leaving them especially vulnerable.

SSP 5: Fossil-fueled development.

High demand for bio-based materials promotes rapid technology uptake and structural change in agriculture (Mitter et al., 2020). Alongside rapid increases in land productivity (Popp et al., 2017), competitive agricultural value chains result in low pressure on wildfire hazard from land abandonment. Yet, perceived trade-offs between the environment and economic development result in low environmental standards and degradation (Kok et al., 2019), increasing landscape flammability. Consequently, ecosystem degradation and invasive species spread (Mitter et al., 2020) drives wildfire hazard in *SSP5*. At the same time, enhanced human and social capital and a push for economic development (Kok et al., 2019), reduce ignition pressure from inequalities.

Incomplete regulation of land use change (Popp et al., 2017) including urban sprawl (O'Neill et al., 2017) into the WUI, expands human settlements in flammable natural landscapes with lower environmental standards and a limited focus on rural development (Mitter et al., 2020). Simultaneously, the high demand for European bio-based raw materials and innovative agricultural products drives technological advancement and growth in agriculture (Mitter et al., 2020), resulting in a high level of exposure of socioeconomic assets.

A focus on economic and human capital development promotes social cohesion (Kok et al., 2019), and reduces tensions and conflict (Mitter et al., 2020), enhancing communities' resilience to wildfires. High investment in social and human capital (Kok et al., 2019) improve risk literacy in society. Additionally, rapid technology adoption in agriculture and increased education levels of the farming population (Mitter et al., 2020) boost their coping capacities. However, a business-oriented governance approach (Kok et al., 2019) prioritizes the reduction of business interruptions, potentially overlooking other aspects of wildfire related vulnerability.

5.3. The European wildfire risk scenario space

The wildfire risk narratives developed above differentiate the dynamics of hazard, exposure and vulnerability. Fig. 3 illustrates a wildfire risk scenario space, capturing plausible changes in these dimensions based on different socioeconomic trajectories. While the continuation of current trends in land degradation, settlement expansion and social and economic development would lead to a proportional increase of wildfire risk across all dimensions compared to the status quo (represented by SSP2), changes in hazard, exposure and vulnerability differ across the trajectories represented by SSP1, 3, 4 and 5.

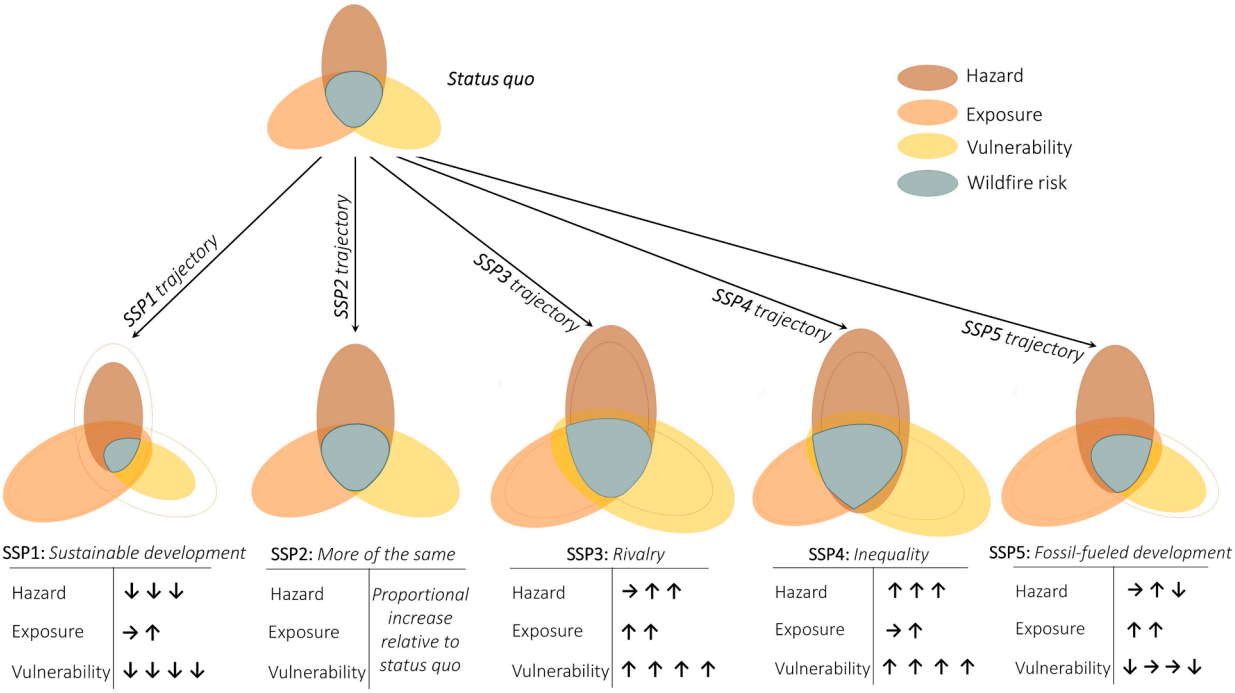


Fig. 3. Scenarios by dimensions of risk. This shows how different dimensions of risk are affected by the SSPs; and shows that future wildfire risk in Europe is subject to a high degree of uncertainty associated with socioeconomic development. Scenarios narratives are in line with the SSPs interpreted in the context of wildfire risk. Arrows are carried over from Tables 2-4 and indicate the trend relative to SSP2, where ↓ implies a decrease, ↑ implies an increase and → implies that no distinct trend could be identified, each representing a driver following the order they are introduced in Tables 2-4. (Color should be used in print.).

5.4. Implications for future wildfire risk management

Fig. 3 shows that depending on the socioeconomic trajectory, future wildfire risk may not only differ in size, but also with respect to the dimensions determining it. This uncertainty has important implications for the design of future wildfire risk management, highlighting that managing risk may not follow a one-size-fits-all approach.

As SSPs are designed without explicit assumptions about climate policies or climate change (O'Neill et al., 2014), they can serve as counterfactuals for evaluating the effectiveness of possible wildfire risk management strategies. As a result of socioeconomic dynamics shaping wildfire risk, the scenarios not only represent different levels of wildfire risk, as shown in Fig. 3, but also embody a spectrum of challenges related to wildfire management and adaptation introduced in section 2.2.

Hazard-focused approaches for reducing wildfire risk are facilitated by environmental regulation and technological advances. In *SSP1*, high environmental awareness and effective institutions support sustainable land use and investments in rural development (Kok et al., 2019; Mitter et al., 2020), reducing landscape flammability through sustainable practices. Conversely, in *SSP5*, poor environmental regulation exacerbates landscape flammability, limiting the effectiveness of technological suppression, despite rapid technological progress and strong faith in technology (Kok et al., 2019). Poor environmental standards and regional rivalries hinder cooperation and transnational fire suppression efforts in *SSP3*, while the exploitation of natural resources by a business-oriented elite in *SSP4* further increases environmental challenges to reducing wildfire hazard (Kok et al., 2019).

Exposure-focused wildfire risk management is dependent on the quality of governance and land-use management. In *SSP1*, effective institutions and governance foster sustainable land use (Kok et al., 2019), creating opportunities to reduce pressure from settlement expansion into the wildland urban interface, contrasted by *SSP3,* where poor land-use management creates little prospects for exposure-focused wildfire risk reduction. Similarly, in *SSP4*, a wealthy upper class dominates institutions and policies, focusing on protecting elite assets, largely disregarding lower-income populations (Kok et al., 2019; Mitter et al., 2020). *SSP5*'s focus on business interests (Mitter et al., 2020) facilitates the protection of high-end assets yet neglects the exposure of rural communities and smallholder farms.

Low social and economic challenges and strong social cohesion (Kok et al., 2019) alongside effective institutions and successful cooperation between public, private and civil actors (Mitter et al., 2020) facilitate risk management and increase prospects for effective vulnerability-focused approaches in *SSP1*. *SSP3* faces significant obstacles, with high socioeconomic inequalities and ineffective institutions (Kok et al., 2019) likely to impede efforts to reduce vulnerability. Social disparities in *SSP4* (Kok et al., 2019) make risk financing and compensation difficult to implement, particularly for vulnerable, low- to medium-income populations.

The narratives developed in 5.2 highlight the three-dimensionality of wildfire risk, setting boundary conditions for assessing

management approaches over the 21st century. Addressing hazard, exposure and vulnerability remains critical across all scenarios, with varying levels of feasibility and effectiveness, depending on the underlying socioeconomic dynamics.

6. Discussion and conclusion

Applying the SSP framework, this paper examines how socioeconomic dynamics shape future European wildfire risk. Sustainable land use and profitable agricultural value chains reduce hazard in a future characterized by sustainable development (*SSP1*). In contrast, poor environmental regulation and concomitant degradation (*SSP3* and *SSP4*), alongside increasing pressure on land abandonment as competitive value chains disappear (*SSP4*) increase wildfire hazard. Exposure remains high across scenarios, especially when ineffective land use planning increases the expansion of human settlements in areas with unmanaged flammable vegetation (*SSP3* and *SSP5*), with further exposure of livelihoods in areas with low agricultural productivity (*SSP4*). Vulnerability significantly drives wildfire risk where low economic development and poor investment in human capital leave communities with low capacities to manage wildfire risk (*SSP3)*. Similarly, societal disparities leave low to medium income majorities highly vulnerable to wildfires (*SSP4*). High coping capacities from increasing socioeconomic welfare (*SSP1* and *SSP5*), enhance resilience and reduce vulnerability, compared to current trends (*SSP2*). However, the prioritization of business-related objectives in institutional risk management (*SSP5*) runs into the risk of disregarding other aspects of wildfire related vulnerability.

The interplay of social, economic and ecological changes, and the role of governance as an enabler and barrier of effective wildfire risk management is widely acknowledged (AGIF, 2023; OECD, 2023). Scenario analysis highlights challenges in adapting current wildfire risk management, resulting in potential paradoxes. In scenarios where risk is driven significantly by increased vulnerability (*SSP3* and *SSP4*), social and economic conditions, such as the ineffectiveness of governance, reduce the feasibility of the very measures attempting to address this driver of risk (e.g. through a risk sharing mechanism). With significant socioecological challenges across scenarios, except for *SSP1*, poor environmental regulation not only drives wildfire risk, but also hampers the feasibility and effectiveness of hazard-and exposure- focused wildfire risk management.

Wildfires transition from a climate hazard to a potential disaster at the intersection with exposure and differential vulnerabilities, underscoring the need for holistic risk management addressing all risk dimensions. While suppression efforts and landscape resilience mitigate risk from routine fires, prioritizing hazard reduction reaches limits under extreme conditions (Fernandes et al., 2016). By prioritizing suppression, prevailing wildfire risk management in Europe is even claimed to trade-off short term effectiveness with long-term risk, by increasing fuel loads and thereby future wildfire hazards (Arévalo & Naranjo-Cigala, 2018; Silva et al., 2010). Flexible, risk-based approaches are frequently recommended in the scientific discourses (see e.g. Clarke et al., 2023), but political action still predominantly favors hazard reduction over addressing exposure, vulnerability, and governance issues (see review by Bacciu et al., 2022).

With wildfire risk assessments largely neglecting the complexity of wildfires in a world undergoing socioeconomic change (Essen et al., 2022; OECD, 2023), this paper contributes towards a more nuanced understanding of the determinants of wildfire risk and the implications of socioeconomic dynamics on the success of management approaches. By contextualizing the SSP narratives to European wildfire risk, this analysis illustrates possible requirements for and challenges of implementing effective management strategies. This underscores that wildfire risk management is interconnected with broader societal dynamics and embedded in the overall policy landscape, requiring a whole-of-society approach, beyond fire and emergency management agencies.

While socioeconomic scenarios are well established in the research community and are useful in policy design, they cannot serve as predictions or attempts at reality. Scenarios are based on perceived dynamics and trends and can provide a narrow view of possible outcomes given the inability to account for unexpected change. Also, scenarios may oversimplify socioeconomic processes. Societies might not follow a single trajectory but could shift between or combine different paths. Moreover, the scenarios developed in this study do not account for the effect of multiple hazards. Wildfires are often preceded by droughts and heat (Sutanto et al., 2020) and followed by erosion or debris flows (Cheung & Giardino, 2023), exacerbating wildfire impacts.

The reliance on evidence from Southern Europe, where most research on damaging fires is concentrated, means that relevant drivers in other socioeconomic contexts may be overlooked due to incomplete understanding and insufficient evidence to date. However, as shown in Terres et al. (2015), the risk of farmland abandonment - a major driver of fuel loads and landscape connectivity – is particularly high not only in the Mediterranean, but also in Baltic and Scandinavian countries. Also, Modugno et al. (2016) show that the urban–rural interface – a key factor in exposure to fires – is far larger in Central and Northern Europe than the Mediterranean region. Thus, we believe that our findings are broadly applicable across Europe, capturing general patterns and trends that are relevant for the geographical context, without explicitly including or excluding any specific countries.

Our findings emphasize the role of socioeconomic dynamics in shaping future wildfire risk and the need for adaptable management strategies in response to evolving conditions. Considering multiple plausible futures enhances wildfire risk management effectiveness, ensuring the robustness of a strategy despite future uncertainties (Maier et al., 2016). This is relevant within the current EU policy landscape, where the success of the EU Green Deal's nature restoration law[11], will significantly influence European wildfire risk and the management thereof. Aimed at restoring ecosystems across the EU, this law not only reduces wildfire hazard by addressing the driver of ecosystem degradation, but also promotes sustainable land use practices as an important component of effective risk management. Also, the effectiveness of supranational hazard-focused management approaches, such as the *rescEU* firefighting fleet[12],

[11] https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en (last access: 19.06.2024).
[12] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2943 (last access: 10/06/2024).

integrating firefighting resources from 10 Member States and 450 firefighters in 2023, hinges on continued European cooperation and coordination. Increasing tensions and regional rivalry, could compromise this mechanism. The approach presented in this study can also inform the transition to new paradigms in managing fires, as understanding societal and political dynamics is crucial for adopting transformative strategies to mitigate wildfire risk, like managed retreat (McConnell & Koslov 2024).

The explorative scenarios of wildfire risk (*what could happen*), developed in this study offer a starting point for future co-production of normative wildfire risk management scenarios *(what should happen*) (Nalau & Cobb, 2022). By laying the qualitative groundwork for further scenario analysis in the context of wildfire risk, this paper helps identify novel areas for empirical and model-based research to support the consideration of socioeconomic change in risk assessments.

CRediT authorship contribution statement

Eva Preinfalk: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **John Handmer:** Writing – review & editing, Writing – original draft, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Eva Preinfalk reports financial support was provided by European Commission. John Handmer reports financial support was provided by European Commission. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

This research has received funding from the European Union's Horizon 2020 Coordination and support programme under grant agreement No.101036534. We thank Thomas Schinko and three anonymous reviewers for constructive feedback on earlier versions of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crm.2024.100638.

References

Agif, 2023. Landcape Fire Governance Framework. 8th International Wildland Fire Conference.

Alcamo, J., 2001. Scenarios as tools for international environmental assessments. Environmental issue report 24. European Environment Agency, Copenhagen 60, 2000–2050.

Alcasena, F.J., Salis, M., Nauslar, N.J., Aguinaga, A.E., Vega-García, C., 2016. Quantifying economic losses from wildfires in black pine afforestations of northern Spain. Forest Policy Econ. 73, 153–167. https://doi.org/10.1016/j.forpol.2016.09.005.

Anderegg, W.R.L., Trugman, A.T., Badgley, G., Anderson, C.M., Bartuska, A., Ciais, P., Cullenward, D., Field, C.B., Freeman, J., Goetz, S.J., Hicke, J.A., Huntzinger, D., Jackson, R.B., Nickerson, J., Pacala, S., Randerson, J.T., 2020. Climate-driven risks to the climate mitigation potential of forests. Science 368 (6497), eaaz7005. https://doi.org/10.1126/science.aaz7005.

Ara Begum, R., Lempert, R., Ali, E., Benjaminsen, T. A., Bernauer, T., Cramer, W., Cui, X., Mach, K., Nagy, G., Stenseth, N. C., Sukumar, R., & Wester, P. (2022). *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844.

Arévalo, J., Naranjo-Cigala, A., 2018. Wildfire Impact and the "Fire Paradox" in a Natural and Endemic Pine Forest Stand and Shrubland. Fire 1 (3), 44. https://doi.org/10.3390/fire1030044.

Arnell, N.W., Freeman, A., Gazzard, R., 2021. The effect of climate change on indicators of fire danger in the UK. Environ. Res. Lett. 16 (4), 044027 https://doi.org/10.1088/1748-9326/abd9f2.

Ascoli, D., Moris, J., Marchetti, M., Sallustio, L., 2021. Land use change towards forests and wooded land correlates with large and frequent wildfires in Italy. Annals of Silvicultural Research 46 (2). https://doi.org/10.12899/asr-2264.

Ascoli, D., Plana, E., Oggioni, S.D., Tomao, A., Colonico, M., Corona, P., Giannino, F., Moreno, M., Xanthopoulos, G., Kaoukis, K., Athanasiou, M., Colaço, M.C., Rego, F., Sequeira, A.C., Acácio, V., Serra, M., Barbati, A., 2023. Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal. Int. J. Disaster Risk Reduct. 92, 103715 https://doi.org/10.1016/j.ijdrr.2023.103715.

Bacciu, V., Sirca, C., Spano, D., 2022. Towards a systemic approach to fire risk management. Environ Sci Policy 129, 37–44. https://doi.org/10.1016/j.envsci.2021.12.015.

Barquín, J., Concostrina-Zubiri, L., Pérez-Silos, I., Hernández-Romero, G., Vélez-Martín, A., Álvarez-Martínez, J.M., 2022. Monoculture plantations fuel fires amid heat waves. Science 377 (6614), 1498. https://doi.org/10.1126/science.ade5923.

Bednar-Friedl, B., Biesbroek, R., Schmidt, D., Alexander, P., Børsheim, K. Y., Carnicer, J., Georgopoulou, E., Haasnoot, M., & et al. (2023). *Europe (Chapter 13). In: Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate*

Change. Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K, Alegría, A., Craig, M., Langsdorf, S., et al. (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844.

Beltrán-Marcos, D., Calvo, L., Fernández-Guisuraga, J.M., Fernández-García, V., Suárez-Seoane, S., 2023. Wildland-urban interface typologies prone to high severity fires in Spain. Sci. Total Environ. 894, 165000 https://doi.org/10.1016/j.scitotenv.2023.165000.

Blandford, D. (2019). *Burn Baby Burn- Controlling the Risk of Wildfires in Greece* [Discussion paper prepared for the annual meetings of the Agricultural Economics Society at Warwick University, U.K., April 15-17 2019]. https://www.researchgate.net/publication/332472616_Burn_Baby_Burn_-Controlling_the_Risk_of_Wildfires_in_Greece.

Bloemen, P., Reeder, T., Zevenbergen, C., Rijke, J., Kingsborough, A., 2018. Lessons learned from applying adaptation pathways in flood risk management and challenges for the further development of this approach. Mitig. Adapt. Strat. Glob. Chang. 23 (7), 1083–1108. https://doi.org/10.1007/s11027-017-9773-9.

Bryant, B.P., Westerling, A.L., 2014. Scenarios for future wildfire risk in California: Links between changing demography, land use, climate, and wildfire. Environmetrics 25 (6), 454–471. https://doi.org/10.1002/env.2280.

Caldecott, B., Clark, A., Koskelo, K., Mulholland, E., Hickey, C., 2021. Stranded Assets: Environmental Drivers, Societal Challenges, and Supervisory Responses. Annu. Rev. Env. Resour. 46 (1), 417–447. https://doi.org/10.1146/annurev-environ-012220-101430.

Chan, E., Huang, Z., Lam, H., Wong, C., Zou, Q., 2019. Health Vulnerability Index for Disaster Risk Reduction: Application in Belt and Road Initiative (BRI) Region. Int. J. Environ. Res. Public Health 16 (3), 380. https://doi.org/10.3390/ijerph16030380.

Cheung, D.J., Giardino, J.R., 2023. Debris flow occurrence under changing climate and wildfire regimes: A southern California perspective. Geomorphology 422, 108538. https://doi.org/10.1016/j.geomorph.2022.108538.

Clarke, H., Cirulis, B., Borchers-Arriagada, N., Storey, M., Ooi, M., Haynes, K., Bradstock, R., Price, O., Penman, T., 2023. A flexible framework for cost-effective fire management. Glob. Environ. Chang. 82, 102722 https://doi.org/10.1016/j.gloenvcha.2023.102722.

Colantoni, A., Egidi, G., Quaranta, G., D'Alessandro, R., Vinci, S., Turco, R., Salvati, L., 2020. Sustainable Land Management, Wildfire Risk and the Role of Grazing in Mediterranean Urban-Rural Interfaces: A Regional Approach from Greece. Land 9 (1), 21. https://doi.org/10.3390/land9010021.

Crenshaw, K. (1989). Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of Antidisrimination Doctrine, Feminist Theory and Antiracist Politics (University of Chicago Legal Forum Volume 1989 , Issue 1; pp. 139–168).

Cronin, M.A., George, E., 2023. The Why and How of the Integrative Review. Organizational Research Methods 26 (1), 168–192. https://doi.org/10.1177/1094428120935507.

Cutter, S.L., Boruff, B.J., Shirley, W.L., 2003. Social Vulnerability to Environmental Hazards *: Social Vulnerability to Environmental Hazards. Social Science Quarterly 84 (2), 242–261. https://doi.org/10.1111/1540-6237.8402002.

Daigneault, A., Johnston, C., Korosuo, A., Baker, J.S., Forsell, N., Prestemon, J.P., Abt, R.C., 2019. Developing Detailed SharedSocioeconomic Pathway (SSP) Narratives for the Global Forest Sector. J. for. Econ. 34 (1–2), 7–45. https://doi.org/10.1561/112.00000441.

De Diego, J., Fernández, M., Rúa, A., Kline, J.D., 2023. Examining socioeconomic factors associated with wildfire occurrence and burned area in Galicia (Spain) using spatial and temporal data. Fire Ecology 19 (1), 18. https://doi.org/10.1186/s42408-023-00173-8.

de Rigo, D., Libertà, G., Durrant, T., Vivancos, T., San-Miguel-Ayanz, J., 2017. *Forest fire danger extremes in Europe under climate change: Variability and uncertainty* (Research Report hal-02906196). Publications Office of the European Union.

Dellink, R., Chateau, J., Lanzi, E., Magné, B., 2017. Long-term economic growth projections in the Shared Socioeconomic Pathways. Glob. Environ. Chang. 42, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004.

Duane, A., Castellnou, M., Brotons, L., 2021. Towards a comprehensive look at global drivers of novel extreme wildfire events. Clim. Change 165 (3–4), 43. https://doi.org/10.1007/s10584-021-03066-4.

Dupuy, J., Fargeon, H., Martin-StPaul, N., Pimont, F., Ruffault, J., Guijarro, M., Hernando, C., Madrigal, J., Fernandes, P., 2020. Climate change impact on future wildfire danger and activity in southern Europe: A review. Ann. for. Sci. 77 (2), 35. https://doi.org/10.1007/s13595-020-00933-5.

Ebi, K.L., Kram, T., Van Vuuren, D.P., O'Neill, B.C., Kriegler, E., 2014. A New Toolkit for Developing Scenarios for Climate Change Research and Policy Analysis. Environment: Science and Policy for Sustainable Development 56 (2), 6–16. https://doi.org/10.1080/00139157.2014.881692.

EC DG Env. (2021). Land-based wildfire prevention: Principles and experiences on managing landscapes, forests and woodlands for safety and resilience in Europe. Publications Office. https://data.europa.eu/doi/10.2779/695867.

EEA. (2021). *Forest fires in Europe*. https://www.eea.europa.eu/en/analysis/indicators/forest-fires-in-europe?activeAccordion=546a7c35-9188-4d23-94ee-005d97c26f2b.

Eriksen, S., Schipper, E.L.F., Scoville-Simonds, M., Vincent, K., Adam, H.N., Brooks, N., Harding, B., Khatri, D., Lenaerts, L., Liverman, D., Mills-Novoa, M., Mosberg, M., Movik, S., Muok, B., Nightingale, A., Ojha, H., Sygna, L., Taylor, M., Vogel, C., West, J.J., 2021. Adaptation interventions and their effect on vulnerability in developing countries: Help, hindrance or irrelevance? World Dev. 141, 105383 https://doi.org/10.1016/j.worlddev.2020.105383.

Essen, M., McCaffrey, S., Abrams, J., Paveglio, T., 2022. Improving wildfire management outcomes: Shifting the paradigm of wildfire from simple to complex risk. J. Environ. Plan. Manag. 1–19 https://doi.org/10.1080/09640568.2021.2007861.

European Commission. (2023). *Wildfires: EU doubles rescEU firefighting fleet for summer 2023*. file:///C:/Users/preinfalk/Downloads/Wildfires_EU_doubles_rescEU_firefighting_fleet_for_summer_2023.pdf.

Faiola, A., & Labropoulou, E. (2023). *How wildfires are threatening the Mediterranean way of life*. https://www.washingtonpost.com/world/2023/09/02/greece-fires-2023-rhodes/.

Fernandes, P.M., Pacheco, A.P., Almeida, R., Claro, J., 2016. The role of fire-suppression force in limiting the spread of extremely large forest fires in Portugal. Eur. J. for. Res. 135 (2), 253–262. https://doi.org/10.1007/s10342-015-0933-8.

Ferrara, C., Salvati, L., Corona, P., Romano, R., Marchi, M., 2019. The background context matters: Local-scale socioeconomic conditions and the spatial distribution of wildfires in Italy. Sci. Total Environ. 654, 43–52. https://doi.org/10.1016/j.scitotenv.2018.11.049.

Forzieri, G., Girardello, M., Ceccherini, G., Spinoni, J., Feyen, L., Hartmann, H., Beck, P.S.A., Camps-Valls, G., Chirici, G., Mauri, A., Cescatti, A., 2021. Emergent vulnerability to climate-driven disturbances in European forests. Nat. Commun. 12 (1), 1081. https://doi.org/10.1038/s41467-021-21399-7.

Ganteaume, A., Camia, A., Jappiot, M., San-Miguel-Ayanz, J., Long-Fournel, M., Lampin, C., 2013. A Review of the Main Driving Factors of Forest Fire Ignition Over Europe. Environ. Manag. 51 (3), 651–662. https://doi.org/10.1007/s00267-012-9961-z.

Ganteaume, A., Barbero, R., Jappiot, M., Maillé, E., 2021. Understanding future changes to fires in southern Europe and their impacts on the wildland-urban interface. Journal of Safety Science and Resilience 2 (1), 20–29. https://doi.org/10.1016/j.jnlssr.2021.01.001.

Gómez-González, S., Ochoa-Hueso, R., Pausas, J.G., 2020. Afforestation falls short as a biodiversity strategy. Science 368 (6498), 1439. https://doi.org/10.1126/science.abd3064.

Gould, C.F., Heft-Neal, S., Johnson, M., Aguilera, J., Burke, M., Nadeau, K., 2024. Health Effects of Wildfire Smoke Exposure. Annu. Rev. Med. 75 (1), 277–292. https://doi.org/10.1146/annurev-med-052422-020909.

Haasnoot, M., Middelkoop, H., Offermans, A., van Beek, E., van Deursen, W.P.A., 2012. Exploring pathways for sustainable water management in river deltas in a changing environment. Clim. Change 115 (3–4), 795–819. https://doi.org/10.1007/s10584-012-0444-2.

Hallegatte, S., Vogt-Schilb, A., Rozenberg, J., Bangalore, M., Beaudet, C., 2020. From Poverty to Disaster and Back: A Review of the Literature. Economics of Disasters and Climate Change 4 (1), 223–247. https://doi.org/10.1007/s41885-020-00060-5.

Hermoso, V., Regos, A., Morán-Ordóñez, A., Duane, A., Brotons, L., 2021. Tree planting: A double-edged sword to fight climate change in an era of megafires. Glob. Chang. Biol. 27 (13), 3001–3003. https://doi.org/10.1111/gcb.15625.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, Möller, A. Okem, & B. Rama, Eds.; p. 3056 pp).

Jiang, L., O'Neill, B.C., 2017. Global urbanization projections for the Shared Socioeconomic Pathways. Glob. Environ. Chang. 42, 193–199. https://doi.org/10.1016/j.gloenvcha.2015.03.008.

JRC. (2022). *Advance report on wildfires in Europe, Middle East and North Africa 2021*. Publications Office. https://data.europa.eu/doi/10.2760/039729.
Jurgilevich, A., Räsänen, A., Groundstroem, F., Juhola, S., 2017. A systematic review of dynamics in climate risk and vulnerability assessments. Environ. Res. Lett. 12 (1), 013002 https://doi.org/10.1088/1748-9326/aa5508.
Kaijser, A., Kronsell, A., 2014. Climate change through the lens of intersectionality. Environmental Politics 23 (3), 417–433. https://doi.org/10.1080/09644016.2013.835203.
Kienberger, S., Blaschke, T., Zaidi, R.Z., 2013. A framework for spatio-temporal scales and concepts from different disciplines: The 'vulnerability cube'. Nat. Hazards 68 (3), 1343–1369. https://doi.org/10.1007/s11069-012-0513-x.
Kocher, S., Butsic, V., 2017. Governance of Land Use Planning to Reduce Fire Risk to Homes Mediterranean France and California. Land 6 (2), 24. https://doi.org/10.3390/land6020024.
Kok, K., Biggs, R., Zurek, M., 2007. Methods for developing multiscale participatory scenarios: Insights from southern Africa and Europe. Ecol. Soc. 12 (1).
Kok, K., Pedde, S., Gramberger, M., Harrison, P.A., Holman, I.P., 2019. New European socio-economic scenarios for climate change research: Operationalising concepts to extend the shared socio-economic pathways. Reg. Environ. Chang. 19 (3), 643–654. https://doi.org/10.1007/s10113-018-1400-0.
Kuran, C.H.A., Morsut, C., Kruke, B.I., Krüger, M., Segnestam, L., Orru, K., Nævestad, T.O., Airola, M., Keränen, J., Gabel, F., Hansson, S., Torpan, S., 2020. Vulnerability and vulnerable groups from an intersectionality perspective. Int. J. Disaster Risk Reduct. 50, 101826 https://doi.org/10.1016/j.ijdrr.2020.101826.
Kwakkel, J.H., Walker, W.E., Marchau, V.A., 2010. Classifying and communicating uncertainties in model-based policy analysis. Int. J. Technol. Policy Manage. 10 (4), 299–315.
Lambrou, N., Kolden, C., Loukaitou-Sideris, A., Anjum, E., Acey, C., 2023. Social drivers of vulnerability to wildfire disasters: A review of the literature. Landsc. Urban Plan. 237, 104797 https://doi.org/10.1016/j.landurbplan.2023.104797.
Lehtonen, H.S., Aakkula, J., Fronzek, S., Helin, J., Hildén, M., Huttunen, S., Kaljonen, M., Niemi, J., Palosuo, T., Pirttioja, N., Rikkonen, P., Varho, V., Carter, T.R., 2021. Shared socioeconomic pathways for climate change research in Finland: Co-developing extended SSP narratives for agriculture. Reg. Environ. Chang. 21 (1), 7. https://doi.org/10.1007/s10113-020-01734-2.
Maier, H.R., Guillaume, J.H.A., Van Delden, H., Riddell, G.A., Haasnoot, M., Kwakkel, J.H., 2016. An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? Environ. Model. Softw. 81, 154–164. https://doi.org/10.1016/j.envsoft.2016.03.014.
McConnell, K., Koslov, L., 2024. Critically assessing the idea of wildfire managed retreat. Environmental Research Letters 19 (4), 041005. https://doi.org/10.1088/1748-9326/ad31d9.
McWethy, D.B., Schoennagel, T., Higuera, P.E., Krawchuk, M., Harvey, B.J., Metcalf, E.C., Schultz, C., Miller, C., Metcalf, A.L., Buma, B., Virapongse, A., Kulig, J.C., Stedman, R.C., Ratajczak, Z., Nelson, C.R., Kolden, C., 2019. Rethinking resilience to wildfire. Nat. Sustainability 2 (9), 797–804. https://doi.org/10.1038/s41893-019-0353-8.
Mitter, H., Techen, A.-K., Sinabell, F., Helming, K., Schmid, E., Bodirsky, B.L., Holman, I., Kok, K., Lehtonen, H., Leip, A., Le Mouël, C., Mathijs, E., Mehdi, B., Mittenzwei, K., Mora, O., Østad, K., Øygarden, L., Priess, J.A., Reidsma, P., Schönhart, M., 2020. Shared Socio-economic Pathways for European agriculture and food systems: The Eur-Agri-SSPs. Glob. Environ. Chang. 65, 102159 https://doi.org/10.1016/j.gloenvcha.2020.102159.
Modugno, S., Balzter, H., Cole, B., Borrelli, P., 2016. Mapping regional patterns of large forest fires in Wildland-Urban Interface areas in Europe. J. Environ. Manage. 172, 112–126. https://doi.org/10.1016/j.jenvman.2016.02.013.
Montiel Molina, C., Galiana-Martín, L., 2016. Fire Scenarios in Spain: A Territorial Approach to Proactive Fire Management in the Context of Global Change. Forests 7 (12), 273. https://doi.org/10.3390/f7110273.
Moritz, M.A., Batllori, E., Bradstock, R.A., Gill, A.M., Handmer, J., Hessburg, P.F., Leonard, J., McCaffrey, S., Odion, D.C., Schoennagel, T., Syphard, A.D., 2014. Learning to coexist with wildfire. Nature 515 (7525), 58–66. https://doi.org/10.1038/nature13946.
Muttarak, R., Lutz, W., 2014. Is Education a Key to Reducing Vulnerability to Natural Disasters and hence Unavoidable Climate Change? Ecol. Soc. 19 (1), art42. https://doi.org/10.5751/ES-06476-190142.
Nalau, J., Cobb, G., 2022. The strengths and weaknesses of future visioning approaches for climate change adaptation: A review. Glob. Environ. Chang. 74, 102527 https://doi.org/10.1016/j.gloenvcha.2022.102527.
Nunes, A.N., Lourenço, L., 2017. Increased vulnerability to wildfires and post fire hydro-geomorphic processes in Portuguese mountain regions: What has changed? Open Agriculture 2 (1), 70–82. https://doi.org/10.1515/opag-2017-0008.
O'Neill, B., van Aalst, M., Zaiton Ibrahim, Z., Berrang Ford, L., Bhadwal, S., Buhaug, H., Diaz, D., Frieler, K., Garschagen, M., Magnan, A., Midgley, G., Mirzabaev, A., Thomas, A., & Warren, R. (2022). *Key Risks Across Sectors and Regions. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]* (pp. 2411–2538). Cambridge University Press, Cambridge, UK and New York, NY, USA.
O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K.L., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P., 2014. A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Clim. Change 122 (3), 387–400. https://doi.org/10.1007/s10584-013-0905-2.
O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., van Ruijven, B.J., van Vuuren, D.P., Birkmann, J., Kok, K., Levy, M., Solecki, W., 2017. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob. Environ. Chang. 42, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004.
Oecd, 2023. Taming Wildfires in the Context of Climate Change. OECD. https://doi.org/10.1787/dd00c367-en.
Palazzo, A., Vervoort, J.M., Mason-D'Croz, D., Rutting, L., Havlík, P., Islam, S., Bayala, J., Valin, H., Kadi Kadi, H.A., Thornton, P., Zougmore, R., 2017. Linking regional stakeholder scenarios and shared socioeconomic pathways: Quantified West African food and climate futures in a global context. Glob. Environ. Chang. 45, 227–242. https://doi.org/10.1016/j.gloenvcha.2016.12.002.
Pausas, J.G., Vallejo, V.R., 1999. The role of fire in European Mediterranean ecosystems. In: Chuvieco, E. (Ed.), Remote Sensing of Large Wildfires. Springer, Berlin Heidelberg, pp. 3–16. https://doi.org/10.1007/978-3-642-60164-4_2.
Popp, A., Calvin, K., Fujimori, S., Havlik, P., Humpenöder, F., Stehfest, E., Bodirsky, B.L., Dietrich, J.P., Doelmann, J.C., Gusti, M., Hasegawa, T., Kyle, P., Obersteiner, M., Tabeau, A., Takahashi, K., Valin, H., Waldhoff, S., Weindl, I., Wise, M., van Vuuren, D.P., 2017. Land-use futures in the shared socio-economic pathways. Glob. Environ. Chang. 42, 331–345. https://doi.org/10.1016/j.gloenvcha.2016.10.002.
Preston, B.L., Brooke, C., Measham, T.G., Smith, T.F., Gorddard, R., 2009. Igniting change in local government: Lessons learned from a bushfire vulnerability assessment. Mitig. Adapt. Strat. Glob. Chang. 14 (3), 251–283. https://doi.org/10.1007/s11027-008-9163-4.
Quintas-Soriano, C., Buerkert, A., Plieninger, T., 2022. Effects of land abandonment on nature contributions to people and good quality of life components in the Mediterranean region: A review. Land Use Policy 116, 106053. https://doi.org/10.1016/j.landusepol.2022.106053.
Radeloff, V.C., Hammer, R.B., Stewart, S.I., Fried, J.S., Holcomb, S.S., McKeefry, J.F., 2005. THE WILDLAND–URBAN INTERFACE IN THE UNITED STATES. Ecol. Appl. 15 (3), 799–805. https://doi.org/10.1890/04-1413.
Rahman, M.S., 2013. Climate Change, Disaster and Gender Vulnerability: A Study on Two Divisions of Bangladesh. American Journal of Human Ecology 2 (2), 72–82. https://doi.org/10.11634/216796221302315.
Rego, F., Moreno, J. M., Vallejo, R., & Xanthopoulos, G. (2018). *Forest fires: Sparking firesmart policies in the EU [Research & innovation projects for policy]*. Publications Office. https://data.europa.eu/doi/10.2777/248004.
Rego, F., Louro, G., Constantino, L., 2013. The impact of changing wildfire regimes on wood availability from Portuguese forests. Forest Policy Econ. 29, 56–61. https://doi.org/10.1016/j.forpol.2012.11.010.
Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., Kc, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Tavoni, M., 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob. Environ. Chang. 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
Rodrigues, M., Jiménez-Ruano, A., De La Riva, J., 2020. Fire regime dynamics in mainland Spain. Part 1: Drivers of change. Sci. Total Environ. 721, 135841 https://doi.org/10.1016/j.scitotenv.2019.135841.

Rodrigues, M., Cunill Camprubí, À., Balaguer-Romano, R., Coco Megía, C.J., Castañares, F., Ruffault, J., Fernandes, P.M., Resco de Dios, V., 2023. Drivers and implications of the extreme 2022 wildfire season in Southwest Europe. Sci. Total Environ. 859, 160320 https://doi.org/10.1016/j.scitotenv.2022.160320.
Rodrigues, A., Santiago, A., Laím, L., Viegas, D.X., Zêzere, J.L., 2022. Rural Fires—Causes of Human Losses in the 2017 Fires in Portugal. Appl. Sci. 12 (24), 12561. https://doi.org/10.3390/app122412561.
Rounsevell, M.D.A., Metzger, M.J., 2010. Developing qualitative scenario storylines for environmental change assessment. Wires Clim. Change 1 (4), 606–619. https://doi.org/10.1002/wcc.63.
San-Miguel-Ayanz, J., Moreno, J.M., Camia, A., 2013. Analysis of large fires in European Mediterranean landscapes: Lessons learned and perspectives. For. Ecol. Manage. 294, 11–22. https://doi.org/10.1016/j.foreco.2012.10.050.
Schinko, T., Berchtold, C., Handmer, J., Deubelli-Hwang, T., Preinfalk, E., Linnerooth-Bayer, J., Scolobig, A., Serra, M., Plana, E., 2023. A framework for considering justice aspects in integrated wildfire risk management. Nat. Clim. Chang. 13 (8), 788–795. https://doi.org/10.1038/s41558-023-01726-0.
Schumann, R.L., Mockrin, M., Syphard, A.D., Whittaker, J., Price, O., Gaither, C.J., Emrich, C.T., Butsic, V., 2020. Wildfire recovery as a "hot moment" for creating fire-adapted communities. Int. J. Disaster Risk Reduct. 42, 101354 https://doi.org/10.1016/j.ijdrr.2019.101354.
Sil, Â., Fernandes, P.M., Rodrigues, A.P., Alonso, J.M., Honrado, J.P., Perera, A., Azevedo, J.C., 2019. Farmland abandonment decreases the fire regulation capacity and the fire protection ecosystem service in mountain landscapes. Ecosyst. Serv. 36, 100908 https://doi.org/10.1016/j.ecoser.2019.100908.
Silva, J.S., Rego, F., Fernandes, P., Rigolot, E., 2010. Towards Integrated Fire Management—Outcomes of the European Project Fire Paradox. European Forest Institute. Research Report 15 (Research Report 23).
Skulska, I., Duarte, I., Rego, F.C., Montiel-Molina, C., 2020. Relationships Between Wildfires, Management Modalities of Community Areas, and Ownership Types in Pine Forests of Mainland Portugal. Small-Scale Forestry 19 (2), 231–251. https://doi.org/10.1007/s11842-020-09445-6.
Spadoni, G.L., Moris, J.V., Vacchiano, G., Elia, M., Garbarino, M., Sibona, E., Tomao, A., Barbati, A., Sallustio, L., Salvati, L., Ferrara, C., Francini, S., Bonis, E., Dalla Vecchia, I., Strollo, A., Di Leginio, M., Munafò, M., Chirici, G., Romano, R., Ascoli, D., 2023. Active governance of agro-pastoral, forest and protected areas mitigates wildfire impacts in Italy. Sci. Total Environ. 890, 164281 https://doi.org/10.1016/j.scitotenv.2023.164281.
Stoof, C.R., Kok, E., Cardil Forradellas, A., Van Marle, M.J.E., 2024. In temperate Europe, fire is already here: The case of The Netherlands. Ambio 53 (4), 604–623. https://doi.org/10.1007/s13280-023-01960-y.
Stougiannidou, D., Zafeiriou, E., 2021. Wildfire economic impact assessment: An empirical model-based investigation for Greek agriculture. Modeling Earth Systems and Environment. https://doi.org/10.1007/s40808-021-01306-1.
Sullivan, A.L., 2017. Inside the Inferno: Fundamental Processes of Wildland Fire Behaviour: Part 2: Heat Transfer and Interactions. Current Forestry Reports 3 (2), 150–171. https://doi.org/10.1007/s40725-017-0058-z.
Sutanto, S.J., Vitolo, C., Di Napoli, C., D'Andrea, M., Van Lanen, H.A.J., 2020. Heatwaves, droughts, and fires: Exploring compound and cascading dry hazards at the pan-European scale. Environ. Int. 134, 105276 https://doi.org/10.1016/j.envint.2019.105276.
Tasri, E.S., Karimi, K., Muslim, I., 2022. The effect of economic variables on natural disasters and the impact of disasters on economic variables. Heliyon 8 (1), e08678.
Tedim, F., Leone, V., Amraoui, M., Bouillon, C., Coughlan, M., Delogu, G., Fernandes, P., Ferreira, C., McCaffrey, S., McGee, T., Parente, J., Paton, D., Pereira, M., Ribeiro, L., Viegas, D., Xanthopoulos, G., 2018. Defining Extreme Wildfire Events: Difficulties, Challenges, and Impacts. Fire 1 (1), 9. https://doi.org/10.3390/fire1010009.
Terres, J.-M., Scacchiafichi, L.N., Wania, A., Ambar, M., Anguiano, E., Buckwell, A., Coppola, A., Gocht, A., Källström, H.N., Pointereau, P., Strijker, D., Visek, L., Vranken, L., Zobena, A., 2015. Farmland abandonment in Europe: Identification of drivers and indicators, and development of a composite indicator of risk. Land Use Policy 49, 20–34. https://doi.org/10.1016/j.landusepol.2015.06.009.
Thomas, K., Hardy, R.D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J.T., Rockman, M., Warner, B.P., Winthrop, R., 2019. Explaining differential vulnerability to climate change: A social science review. Wires Clim. Change 10 (2), e565.
Torraco, R.J., 2005. Writing Integrative Literature Reviews: Guidelines and Examples. Hum. Resour. Dev. Rev. 4 (3), 356–367. https://doi.org/10.1177/1534484305278283.
Triantis, L., 2023. Normalising spatial vulnerability in the era of climate crisis? Private property, informality, and post-disaster planning in peri-urban east Attica/Greece. Plan. Theory 22 (1), 27–57. https://doi.org/10.1177/14730952221098260.
Uyttewaal, K., Prat-Guitart, N., Ludwig, F., Kroeze, C., Langer, E.R., 2023. Territories in Transition: How social contexts influence wildland fire adaptive capacity in rural Northwestern European Mediterranean areas. Fire Ecology 19 (1), 13. https://doi.org/10.1186/s42408-023-00168-5.
Vacca, P., Caballero, D., Pastor, E., Planas, E., 2020. WUI fire risk mitigation in Europe: A performance-based design approach at home-owner level. Journal of Safety Science and Resilience 1 (2), 97–105. https://doi.org/10.1016/j.jnlssr.2020.08.001.
Vázquez-Varela, C., Martínez-Navarro, J.M., Abad-González, L., 2022. Traditional Fire Knowledge: A Thematic Synthesis Approach. Fire 5 (2), 47. https://doi.org/10.3390/fire5020047.
Versey, H.S., 2021. Missing Pieces in the Discussion on Climate Change and Risk: Intersectionality and Compounded Vulnerability. Policy Insights Behav. Brain Sci. 8 (1), 67–75. https://doi.org/10.1177/2372732220982628.
Viedma, O., Moity, N., Moreno, J.M., 2015. Changes in landscape fire-hazard during the second half of the 20th century: Agriculture abandonment and the changing role of driving factors. Agr Ecosyst Environ 207, 126–140. https://doi.org/10.1016/j.agee.2015.04.011.
Wunder, S., Fraccaroli, C., Górriz-Mifsud, E., & Varela, E. (2023). *Can economic incentives help reducing wildfire risk? FIRE-RES project* [CTFC Policy brief series 2]. 10.5281/zenodo.7994139.