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Systematising experts' understanding of traditional burning in Portugal: a mental model approach

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ABSTRACT

Background. Traditional burning is a practice with social and ecological value used worldwide. However, given the often improper and negligent use of fire, this practice is often associated with rural fire ignitions. **Aims.** Systematise experts' understanding of traditional burning and identify its challenges in the Portuguese context. **Methods.** Twenty-eight Portuguese experts from industry, academia, NGOs and public entities with in-depth involvement in fire and forest management were interviewed to create a mental model of traditional burning in Portugal. **Key results.** Eight dimensions were identified: motivations behind traditional burning, alternative solutions, risks before a traditional burn, risks during a traditional burn, underlying causes of risk, exogenous elements and factors, potential impacts, and activities leading to a successful traditional burn. **Conclusions.** This study provides a comprehensive understanding of traditional burn practice in the Portuguese context and offers a baseline to support stakeholders and policymakers in managing traditional burning's social and environmental impacts in the future. **Implications.** This research offers several implications across the eight dimensions identified, including the need to improve regulations on the use of fire and fuel reduction policies, promote fire use education and feasible and affordable alternatives to traditional burning, and increase communities' commitment to mitigation actions.

Keywords: expert elicitation, fire-prone countries, Gioia methodology, mental model approach, risk communication, risk perception, rural fires, traditional burning.

Introduction

Fire is used as a land management tool worldwide, including in Canada (Lewis *et al.* 2018), China (Feng *et al.* 2019), New Zealand (Bayne *et al.* 2019), Thailand (Adeleke *et al.* 2017), India (Sharma *et al.* 2022), Ireland (Carroll *et al.* 2021), Australia (Morgan *et al.* 2020) and the United States (Han *et al.* 2020). Traditional burning, also known as cultural burning, is defined as the 'purposeful use of fire by a cultural group (e.g. family unit, tribe, clan/moiety, or society) for a variety of purposes and outcomes' (Clark *et al.* 2021, p. 3). This traditional method is used to eliminate residual materials from agricultural and forestry activities and as a cleaning method to eliminate excess biomass, control invasive species and reduce wildfire hazard (Nunes *et al.* 2021).

In Portugal, traditional burning has a recognised value when associated with agricultural and forestry practices. In particular, it is used to dispose of residues resulting from forestry or farming operations (e.g. pruning vines and olive trees, cuttings and piled-up waste) and thus control exotics species and reduce rural fire hazard (Nunes *et al.* 2021). However, the negligent use of fire and a lack of careful monitoring and control can cause spread beyond the designated area and result in major fires with severe ecological and socio-economic consequences, such as human casualties and significant property damages (Ganteaume *et al.* 2021), including in agricultural and industrial areas. Furthermore, Pacheco and Claro (2018) identified indirect societal costs such as decreased real estate value, post-fire restoration efforts and resource losses.

In the Portuguese context, negligence as one of the classifications of causes of rural fires has been described as 'the misguided use of fire in activities such as burning trash,

mass burning of agricultural and forest fuels, fun and leisure activities; failure to properly extinguish cigarettes by smokers; the dispersal and transport of incandescent particles from chimneys; etc.' (Castro *et al.* 2020, p. 4). In fact, one of the main causes of wildfires in Portugal (Nunes *et al.* 2021) is the negligent use of fire, which is responsible for 47% of rural fires, 21% of which are linked to burning piles of forest and agricultural residues (DGPFR 2021). The national database of rural fire records indicates that in 2021 (January–October), of a total of 27 118 ha of burned area, 2370 ha was linked to burning piled waste. Furthermore, between 2014 and 2017, rural fires linked to burning piled waste burned on average 9786 ha (ICNF 2023). Because of its association with rural fires, traditional burning is a controversial topic that has been attracting increasing public attention and concern (Bayne *et al.* 2019; Carroll *et al.* 2021; McGee and Cabling 2022).

The controlled use of fire is a critical livelihood support practice with social and ecological value that can be used to decrease fuel loads in a smaller, less intense and less severe manner compared with an uncontrolled wildfire (McKemey *et al.* 2021). However, some studies also show that the use of fire can have negative effects, such as the modification of soil function in physical (e.g. pore size, distribution and water repellence), chemical (e.g. nutrient availability, mineralogy and pH ratios) and biological aspects (e.g. microbial composition and carbon sequestration) (Doerr and Cerdà 2005). Fires are also a source of atmospheric emissions (Akagi *et al.* 2011).

As such, traditional burning management must balance two considerations: fire as a necessary natural and traditional tool and the risks that such fires can pose. According to the International Risk Governance Council (IRGC), risk 'refers to uncertainty about and the severity of the consequences of an activity or event with respect to something that humans value', where 'uncertainty can pertain to the type of consequences, the likelihood of these occurring (often expressed in probabilities), the severity of the consequences or the time or location where and when these consequences may occur' (IRGC 2017, p. 5). In the present study, which focuses on traditional burning, undesirable consequences include situations where the fire escapes (and eventually later rekindles) owing to human activities or behaviours, resulting in negative ecological and socio-economic impacts. In contrast, undertaking traditional burns under low-risk conditions may result in desirable practical outcomes, including fuel load reduction.

Many countries strive to regulate traditional burning and improve fire management by enforcing the need for fire permits and disseminating safe burning practices. However, one study found that, although most rural residents were aware of the local wildfire risk and acted to prevent a fire from escaping, few recognised that using fire for agricultural purposes contributed to wildfires in the area, leading to the use of fire without obtaining a permit (McGee and Cabling 2022). Thus, government efforts to reduce wildfire risk are not enough on their own, and effective risk mitigation strategies require a joint effort between public agencies and private landowners (Doerr *et al.* 2013). A key challenge in such work may be attributed to the diversity of people inhabiting fire-prone rural areas and the widely varying experiences, beliefs, attitudes and values related to fire. These can influence the understanding and interpretation of risk messages by people who act according to the constraints of their contexts (Eriksen and Prior 2011).

A mental model approach

One way to explore how perspectives on risk may vary is through the lens of mental models. According to Zaksek and Arvai (2004), how risk management information and topics are seen can vary between experts, actors from different stakeholder groups and laypeople. As such, Morgan *et al.* (2002) proposed the use of mental models to translate the nature and magnitude of risk, allowing a deeper understanding of how to mitigate social and environmental impacts in the future.

According to its original definition, a mental model is a 'small-scale model' of reality that people carry in their minds and that allows them to interpret how the world works. Mental models are used to anticipate events, reasons and underlying explanations (Craik 1943). The application of mental models in studies of communication and risk perception aims to identify specific information needs (e.g. gaps in knowledge, misunderstandings, questions, concerns about terminologies and beliefs of the population) by contrasting the mental models of specialists and laypeople concerning a specific risk (Morgan *et al.* 2002). Therefore, this method is applicable to different contexts and fields of study, such as: to plan potential policy changes in restoration activities (Walpole *et al.* 2020); to investigate the perceptions of risk and mitigation actions of employees (Stege *et al.* 2019); to compare the perspectives of government agencies, academic experts and suppliers on providing risk information (Aliperti *et al.* 2020); and to integrate different perspectives to improve the overall understanding of a system (Özesmi and Özesmi 2004). This approach has already been advocated for managing wildfire risk (Steelman and McCaffrey 2013) and employed to improve wildfire risk communication (Zaksek and Arvai 2004). However, this approach has yet to be applied to understand the challenges surrounding traditional burning.

Traditional burning in the Portuguese context

Portugal is one of the countries with the highest absolute fire danger in western-central Europe (European Environment Agency 2021) owing to the dry and warm Mediterranean summers, the prevalence of flammable vegetation types in

rugged terrain, contemporary land use changes and a widespread wildland–urban interface (WUI) (Davim *et al.* 2021). Northern Portugal, in particular, is classified as a highly fire-prone region, first because of its vegetation and then because of anthropogenic factors (Oliveira *et al.* 2012; Galizia *et al.* 2021), including negligence.

Traditional burning involves creating a small pile of cut weeds and or any other agricultural and forest exploitation leftovers or debris, lighting it (Lewis *et al.* 2018), and carefully monitoring and controlling it to prevent spreading. Although traditional burning is an ancestral practice, the risks associated with this practice have grown exponentially owing to climate change (Nunes *et al.* 2019). Beyond the environmental component, multiple elements may drive the risks from fire use and traditional burning in the country, such as: monocultures that are highly combustible and have high economic value (e.g. pine and eucalyptus) (Canaveira 2020); rural desertification due to migratory movement to the main cities, leading to an increase in land occupation by bushes and dense forest; failure to comply with the current Portuguese legislation about mandatory phytosanitary requirements; inadequate forest management practices due to a lack of bush and forest residue collection; insufficient resources (human and material) to prevent, control and fight fires; impunity for negligence and arson; territorial fragmentation; ineffective management practices; and out-of-date landowner registries (Gomes 2006). Furthermore, while Portuguese legislation mandates that traditional burns must be communicated to municipalities, rekindles and waste of firefighting resources due to false alarms are two phenomena with a significant presence in the Portuguese forest fire management system that impact suppression resources (Pacheco *et al.* 2014).

The high number of rural fires caused by the negligent use of fire (DGPFR 2021) led to the creation of a formal process for traditional burning that requires farmers and landowners to follow strict guidelines set by the government, including obtaining a permit and complying with regulations regarding weather conditions, time of the year and the area in question.

Nonetheless, despite human activity and behaviour being the cause of most Portuguese rural fire ignitions in the last three decades, whether by deliberate actions, negligence, accident or carelessness, knowledge of the human causes in rural fires is still limited (Parente *et al.* 2018; Castro *et al.* 2020).

As such, the objective of the present study is to understand traditional burning and its challenges in the Portuguese context and systematise the aggregated knowledge of experts about this practice. Following a mental model approach, this study identified eight dimensions that allow a comprehensive understanding of the perspective of these experts on how traditional burning may or may not mitigate risk and manage social and environmental impacts.

Methods

The present research involved two stages: (i) the creation of an expert mental model that started with an initial model supported by a literature review that was then iteratively developed with experts through interviews, which included interacting with an online collaboration platform (Mural); and (ii) the qualitative analysis of the previous semi-structured interviews (using the NVivo software) to help to refine and systematise the expert mental model and ultimately arrive at the final version described in the results.

The first stage, following the mental model methodology (Morgan *et al.* 2002), started by reviewing and systematising the current scientific knowledge about rural fire risks, with a focus on traditional burning, and formally representing this knowledge in an initial influence diagram (Morgan *et al.* 2002). Regarding this process, Morgan *et al.* (2002) stated that 'there is no simple recipe for converting the scientific information on risk into an influence diagram; the process is iterative, as specialists from the relevant disciplines review one another's work and reflect on their own'. Thus, in the present study, data collection involved semi-structured interviews that encompassed gathering a rich understanding of the context, practices and challenges of traditional burning in Portugal and systematising the mental model on an online collaborative platform called Mural.

Overall, the semi-structured interviews with experts explored topics such as: why they thought people undertake traditional burns, what is burned and what risks are involved in this practice; whether they thought traditional burning practitioners know about these risks, about the factors that may contribute to increasing these risks, and how to mitigate them; and finally, what they thought would make people adopt the necessary precautions when undertaking traditional burns. This promoted some discussion and sensitised the experts for the interaction with the mental model. Then, each expert was asked to interact with the mental model on Mural. This dynamic improved the engagement of the experts and empowered them to contribute to the model by adding or repositioning topics and verbalising agreements and disagreements. Every two or three interviews, the mental model was updated as the research team discussed and consolidated the additions and changes proposed by the experts. The next batch of experts would then interact with the reviewed mental model. There were nine of these iterations. The semi-structured interviews were recorded to support further analysis in the next stage.

The second stage, following Gioia *et al.* (2013), involved the qualitative analysis of the semi-structured interviews in the NVivo software. Building on the mental model developed in the first stage, which was structured as a set of first-order concepts, second-order themes and aggregate dimensions, the second stage evolved the mental model through a qualitative analysis that offered a more refined

and nuanced contribution. All the interviews were coded by the first co-author and then changes to the mental model were discussed among the research team. This qualitative analysis process enabled the creation of a data structure that provides a graphic representation of how the research team progressed from raw data to each theme. Eight aggregate dimensions emerged from this process and act as the 'building blocks' of the mental model. This qualitative analysis allowed a more comprehensive and refined mental model to emerge, compared with what would have been achieved through the interaction with the experts during the first stage. The final version of the mental model resulting from this second stage is described in the next section.

Sampling and data collection

The present study involved a sample that included experts from academia (seven), industry (five), public entities (nine), and NGOs (seven), accounting for 28 interviews, as shown in Table 1.

The expert's selection started with identifying the types of stakeholders (academia, industry, public entities and NGOs) that could provide and contribute to a thorough understanding of the context and risks related to traditional burning. Next, using a purposive sampling approach, the research team identified individuals and organisations with recognised involvement and experience in fire and forest management, considering their impact in the field (for stakeholders representing academia), the relevance of their industry or association in the national context, or their role in policy making or fire management (for stakeholders representing public entities). Individuals and organisations were then directly contacted by the research team and invited to participate in the study.

In accordance with ethical standards, the participants agreed to have their interviews recorded for further analysis. The interviews were conducted remotely (via Zoom) between June and September of 2021, and each interview took, on average, 1 h 30 min, totalling almost 39 h of recorded data. The data collected were transcribed, coded, analysed and structured following a qualitative analysis approach (Gioia *et al.* 2013). The NVivo software was used to support this data analysis process.

Results

Overall, the experts' mental model encompasses eight main aggregate dimensions (Fig. 1), organised around the traditional burning process (from start to finish): motivations behind traditional burning, alternative solutions, risks before a traditional burn and risks during a traditional burn, underlying causes of risk, exogenous elements and factors, potential impacts, and activities leading to a successful traditional burn.

These eight aggregate dimensions highlight the common underlying assumptions related to traditional burning. They help to holistically explain traditional burning in the Portuguese context from the experts' perspective. The aggregate dimensions, second-order themes, first-order concepts and illustrative quotes are shown in Table 2. The mental model is described in the following subsections.

Motivations behind traditional burning

The mental model shows different *motivations behind traditional burning*, such as land clearing and management, property protection, and waste and residue disposal. Traditional

Table 1. Sample description, showing the number of participants from the different fields and sectors segments and their roles.

Experts	Role	Entities
Industry sector ($n = 5$)	Executive director; head of department; directors; manager	Forestry companies (The Navigator Company and Sonae Arauco); energy company (REN)
Academia ($n = 7$)	Faculty members	Universities (University of Porto, School of Agriculture of the University of Lisbon, University of Coimbra, and University of Trás-os-Montes and Alto Douro); a firefighter school (ENB – Escola Nacional de Bombeiros)
NGOs ($n = 7$)	Executive director; chairman of the board; engineers; technical consultant	Forest owners associations (FORESTIS, Centro Pinus, MONTIS, MaisFloresta)
Public sector ($n = 9$)	Cavalry colonel; commanders; operations deputy; engineers; landscape architect	Agency for the Integrated Management of Rural Fires (AGIF – Agência para a Gestão Integrada de Fogos Rurais); National Emergency and Civil Protection Authority (ANEPC – Autoridade Nacional de Emergência e Proteção Civil); professional firefighters (UEPS – Unidade de Emergência de Proteção e Socorro, CNFSBF, Comando Nacional da Força de Sapadores Bombeiros Florestais, and AFOCELCA); the Institute for Nature Conservation and Forests (ICNF – Instituto da Conservação da Natureza e das Florestas); the National Republican Guard (GNR – Guarda Nacional Republicana)

A total of 28 experts were interviewed. Industry actors represent 18% of the sample and consist of executive directors, heads of department, directors and managers. Academic actors, including PhD and associate professors, correspond to 25% of the sample. Actors from NGOs represent another 25% and consist of executive directors, a chairman of the board, engineers and a technical consultant. The remaining 32% correspond to actors from public entities: a cavalry colonel, commanders, an operations deputy, engineers, and a landscape architect.

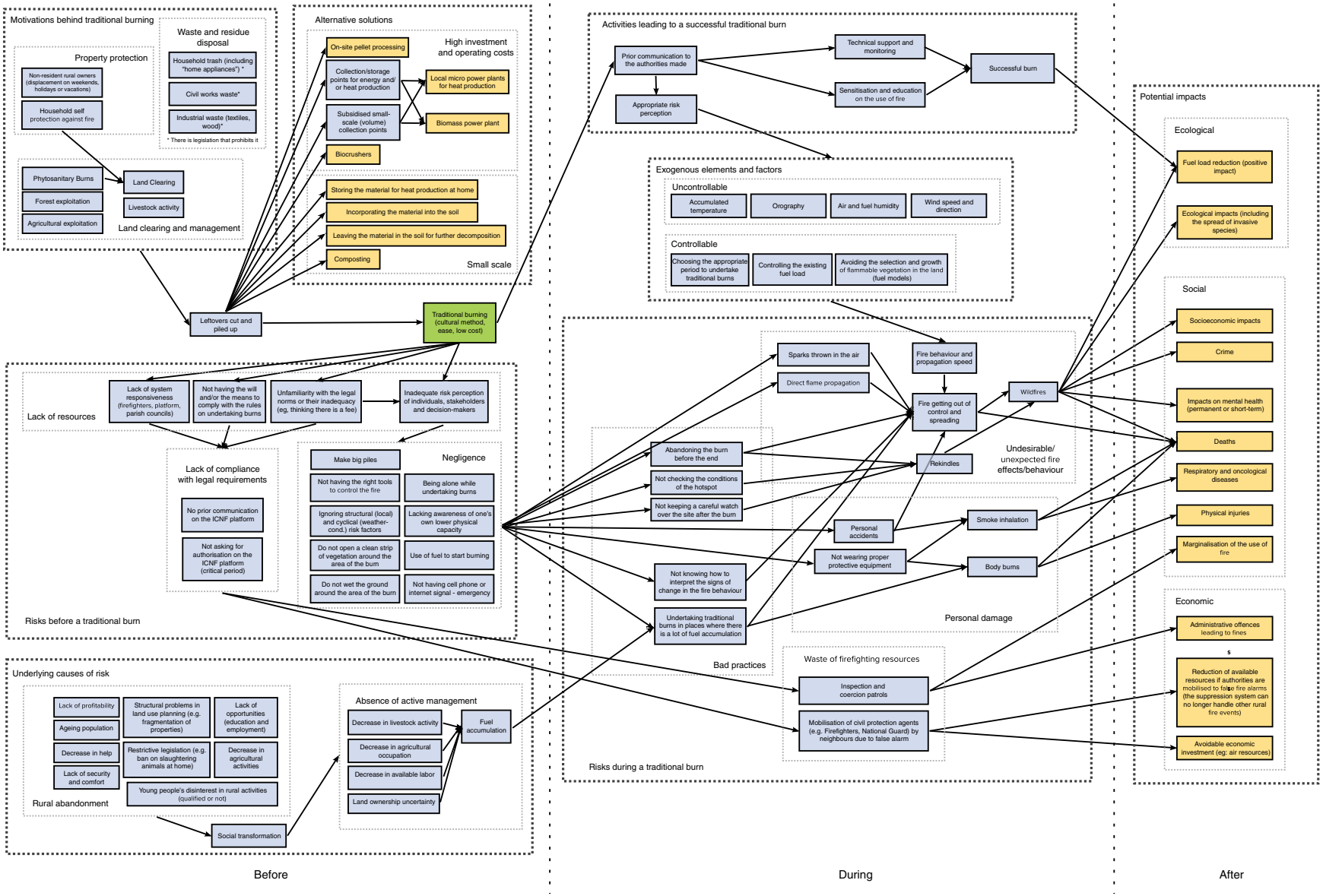

Fig. 1. The experts' mental model. This encompasses eight aggregate dimensions: motivations behind traditional burning, alternative solutions, risks before a traditional burn, risks during a traditional burn, underlying causes of risk, exogenous elements and factors, potential impacts and activities leading to a successful traditional burn.

Table 2. Data analysis structure.

Aggregate dimension	Second-order themes	First-order concepts	Illustrative quotes
Motivations behind traditional burning	Land clearing and management *n* = 27	Agricultural and forest exploitation Land cleaning Phytosanitary burns Non-resident rural owners	Traditional burning is the most economical method for people to get rid of those leftovers that have no use. (Industry sector – Head of sustainable networks and easements) When the issue of cleaning the forests was raised and this by-product ceased to be a benefit and became a cost, people began to treat it in an economical way. There were no uses, no one to look for it; what people did was they gathered it and burned it. (Industry sector – Head of sustainable networks and right of way)
	Property protection *n* = 8	Self-protection against fire Protecting homes from wildfire	Burning in the sense of fuel reduction is another motivation. But this is a very technical fire, which I would say, was never used much in Portugal. It is recent. (Industry sector – Head of forestry innovation and development)
	Waste and residue disposal *n* = 18	Waste burning Industrial waste Construction waste	I have some difficulty in accepting that people still use this practice of fire to destroy some household waste or industrial waste, but it is indeed a reality. It is the reality that we face. (Public sector – Commander of volunteer firefighters)
Alternative solutions	Solutions with high investment and operating costs *n* = 22	Biomass power plant On-site pellet processing	Not all hypotheses are viable, not all are admissible. (…) For a given situation, for a given location, it may be impossible to collect biomass and transport it to a plant, or to do bio-shredding, or to compost. Not all of these situations are possible in all places, at all times. (Industry sector – Head of forestry innovation and development)
	Small-scale solutions *n* = 16	Storage for heat production at home Incorporating the material into the soil	There are initiatives to centralise sites of containers for collecting agroforestry residues, but I believe it would not be enough to motivate people to go there to allocate or leave residues. (Academia – Associate professor with a PhD in economics)
Risks before a traditional burn	Negligence *n* = 26	Making big piles Lacking awareness of one's own limited physical capacity (elderly population)	We see this very often, burns in less suitable spaces, with people very poorly informed and prepared for the purpose. People who are already very old and who maintain this habit of burning without being properly prepared. (Public sector – Commander of volunteer firefighters)
	Lack of compliance with legal requirements *n* = 7	No prior communication on the ICNF platform Not asking for authorisation (critical period)	People do not have the will to communicate the traditional burns in advance because they do not realise the importance of this communication. (NGO – Executive director)
	Lack of resources *n* = 14	Unfamiliarity with the legal norms regarding traditional burning or their inadequacy Not having the will or the means to comply with the rules on undertaking traditional burns	There are normative circumstances that also increase the risks, namely, the illegalisation of burning and a legal framework that is very restrictive, very enforced and very repressive. It leads some people to marginality and to hide the burning practice. (Public sector – Landscape architect)
Underlying causes of risk	Rural abandonment *n* = 27	Lack of profitability Lack of opportunities (education and employment)	In the past, burns were carried out daily, because people lived off the land. Currently, with climate change and the rural exodus (…), the favourable opportunity window for traditional burning is shorter, which increases the risks and the complexity of situations. (NGO – Engineer and specialist in forest management and forest defence)
	Absence of active management *n* = 25	Lack of land cleaning Lack of landowner identification	Therefore, there is no coherent territorial planning and people abandon the land, and then we have fuel there, with continuity over several plots, from different owners. (Public sector – Deputy commander of operations)

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Table 2. (*Continued*)

Aggregate dimension	Second-order themes	First-order concepts	Illustrative quotes
Exogenous elements and factors	Controllable *n* = 13	Existing fuel load Fuel models (type)	A substantial percentage of traditional burns get out of control because people devalue the risks. They only look at the temperature and humidity. There is no analysis of the other factors that increase fire risk. (Public sector – Regional commander of the volunteer firefighters)
	Uncontrollable *n* = 25	High accumulated temperature Orography	In the context of climate change that we are experiencing, these situations can elude our normal perception of risk. And sometimes we think that a cloudy day is enough to safely undertake controlled burns, but this is false. (NGO – Engineer and specialist in forest management and forest defense)
Risks during a traditional burn	Undesirable/ unexpected fire effects or behaviour *n* = 27	Sparks thrown in the air Reignition	Now, there is another risk, which is more important, which is basically that a burn gets out of control, and a fire occurs. (Industry sector – Executive director)
	Bad practices *n* = 20	Undertaking traditional burns in places where there is high fuel accumulation Abandoning a traditional burn before the end	Many times, a traditional burn is started and abandoned for fear of law enforcement repression, which can lead to situations getting out of control. (Academia – Ex-president of the National School of Firefighters)
	Personal damage *n* = 22	Smoke inhalation Not wearing proper protective equipment	Burning is always a threat to people and the threat starts with smoke inhalation, particularly when we [elderly people] have reduced physical capacity. We [elderly] already have some age-limited mobility. (Public sector – National commander of the forest sapper force)
	Waste of firefighting resources *n* = 22	Inspection and coercion patrols Mobilisation of civil protection agents by neighbours due to false alarms	A known problem, which is catastrophic in Portugal (…): if you see a column of smoke, you don't know if it's a controlled burn or a wildfire. So there is an alert and the suppression resources are mobilised. Therefore, it's common to have means mobilised to try to fight a 'fire' that may not even be a fire or give rise to one. (Public sector – Independent Technical Commission Engineer)
Activities leading to a successful traditional burn	Technical support and monitoring *n* = 18	Guidelines and inspections should facilitate and support traditional burns Neighbourhood watch practice	During the spring and summer holidays, when people move from urban centres to rural areas, the risk of burning issues is greatest. Therefore, you either work first in terms of communication, or you increase inspection during these periods. (Industry sector – Head of sustainable networks and easements)
	Sensitisation and education on the use of fire *n* = 21	Attempt to convey good practice related to traditional burning Engagement of stakeholders in risk mitigation campaigns	There is no technical sensitisation action or any technical follow-up; there are not enough resources to do this. That would happen in the perfect world, which does not exist. (Public sector – Deputy commander of operations)
	Adequate risk perception *n* = 22	Communication of traditional burns to authorities Knowledge of good practice related to the use of fire	(…) in terms of risk communication, it is particularly important to communicate and inform, given that not everyone has access to the same level of information. (NGO – Executive director)
Potential impacts	Ecological *n* = 14	Ecological impacts (including the spread of invasive species) Fuel load reduction (positive impact)	One of the impacts is the reduction of the fuel load; whether we like it or not (…), the ecological impacts are regrettable, but the fuel load ceases to exist. There won't be another fire there that year. (NGO – Engineer at the civil protection municipal service) I just do not really agree with the reduction of fuel being a positive impact (…); because I did not manage the fuel (…) I lost all the biodiversity of that space. (Public sector – Deputy commander of operations)

(*Continued on next page*)

Table 2. (*Continued*)

Aggregate dimension	Second-order themes	First-order concepts	Illustrative quotes
	Social *n* = 24	Physical injuries Deaths	And throughout our research activity, we studied several situations that started with traditional burns and the people involved ended up losing their lives because the fire got out of control. They didn't have the resources or the capacity to limit the spread of the fire and ended up being surprised by the smoke or the fire itself. (Academic – Associate professor and researcher in fire behaviour and fire safety)
	Economic *n* = 21	Administrative offenses – fines Avoidable economic investment (e.g. air resources)	From an economic and financial perspective, it also ends up being a risk, because I can cause damage that leads to loss of value in terms of agriculture, forestry and even infrastructure. (Public sector – Regional commander of volunteer firefighters)

Data from the qualitative analyses employed in the present study encompasses aggregate dimensions, second-order themes, first-order concepts and illustrative quotes

burning is commonly used for phytosanitary purposes and as a clearing method for self-protection against rural fires. The use of traditional burns as a means to reduce fuel load is indicated by the experts as a recent motivation in the country.

Despite legislation prohibiting the burning of waste from industrial and domestic sectors in Portugal, according to the interviewed experts, the burning of civil works waste, industrial waste (e.g. textiles and wood), household trash and home appliances still occurs in some areas.

Motivations for traditional burning in rural areas include the disposal of waste from forestry operations and livestock and agricultural activity. Additionally, the experts suggested that the use of fire may also be motivated by the needs of non-resident rural property owners and emigrants who periodically visit rural areas on weekends, holidays, or vacations. During their visits, these individuals may do maintenance on their land and gardens, which can involve burning residues that have accumulated on their properties.

Overall, this burning was described as a traditional, easy and low-cost method of managing useless residues. In terms of characteristics, the experts described traditional burning as a rooted culture, a part of the routine/habit of the Portuguese population, a convenient and necessary method, and a means to keep the aesthetic look of the land that is both cheap and effective.

Risks before a traditional burn

According to the interviewed experts, the dimension of *risks before a traditional burn* encompasses several risk factors that were clustered into three categories in the mental model: lack of resources, negligence and lack of compliance with legal requirements. The lack of resources includes situations such as: a lack of responsiveness from fire brigades and fire management systems; inadequate risk perception and unfamiliarity with the legal norms (e.g. thinking there is a fee to request authorisation to undertake a traditional burn) or their inadequacy; or lack of willingness and/or the means to comply with the rules. The lack of one of these resources may lead to negligence or non-compliance with the legal requirements for undertaking traditional burns.

Negligence was seen as being motivated by an inadequate perception of risk on the part of traditional burning practitioners and includes examples such as: making piles that are too big; being alone while undertaking traditional burns; ignoring structural (local) and cyclical (weather conditions) risk factors; not clearing a strip of vegetation or not wetting the ground around the area of the traditional burn; not having a cell phone or internet signal for emergency communication; not having the right tools to control the fire; and lacking awareness of one's own limited physical capacity, especially in the case of the elderly population.

In addition, the interviewees also described how inadequate risk perception by stakeholders and decision-makers can lead to the formulation of inefficient and overly restrictive public policies, which in turn can contribute to the marginalisation of fire use. Non-compliance with the legal requirements was thought to occur owing to unfamiliarity with these requirements or their inadequacy, lack of responsiveness, or lack of will. Therefore, to prevent non-compliance with legal requirements due to misunderstandings, the interviewees thought it essential to clarify and inform people about the importance of communicating traditional burns pre-emptively to prevent potential deployment of firefighting resources, which is described in the subsection on risks during a traditional burn.

Risks during a traditional burn

The experts' descriptions related to the dimension of *risks during a traditional burn* encompassed four categories: bad practices, personal damage, waste of firefighting resources and undesirable/unexpected fire effects/behaviour.

The bad practices category can be seen as an extension of the negligence category that focuses on actions that take place during a traditional burn. Bad practices could refer to abandoning a traditional burn before the end, not checking

the conditions of a hotspot, undertaking traditional burns in places where there is a lot of fuel accumulation, not keeping a careful watch over the site after a traditional burn, or not knowing how to interpret the signs of change in fire behaviour.

According to the interviewees, these bad practices generally increase the risks associated with the 'undesirable/unexpected fire effects/behaviour' category, which included: sparks thrown into the air, direct flame propagation, rekindles, uncontrolled burning and wildfires. Rural fire incidents may occur depending on a fire's behaviour and propagation speed and some of the possible causes include small spot fires that get out of control or fires that have been successfully suppressed but not completely extinguished and rekindle.

In the traditional burning context, waste of firefighting resources stems from a lack of compliance with legal requirements, namely the use of fire without obtaining a permit. This lack of compliance leads to more inspection patrols and can cause civil protection agents (e.g. firefighters and the National Guard) to be mobilised to answer false fire alarms from neighbours. Law enforcement actions such as restrictive policies determining when landowners and farmers can legally undertake traditional burns can unintentionally drive some individuals (particularly those who do not comply with legal requirements) to abandon a traditional burn before its end.

The personal damage category includes the risks during a traditional burn that may compromise individual safety, such as personal accidents and not wearing proper protective equipment, which can cause smoke inhalation and body burns.

From the experts' perspective, the *risks before a traditional burn* differ from those *during a traditional burn* because the former are related to the conditions that influence the decision-making process of whether to undertake a traditional burn or not.

Underlying causes of risks

The *underlying causes of risks* describe the indirect factors that contribute to increased rural fire risks and include rural abandonment and the absence of active management, which are both drivers of fuel accumulation. The rural population was seen to be sensitive to the possible effects of climate change on the security of their homes and dependence on resources for subsistence agriculture. Rural communities' challenges were seen as intensified by poor access to markets and public services, lack of economic diversification and reduced labour opportunities, and insufficient access to information and knowledge. A lack of profitability, security and comfort can lead to migration and decreased agricultural activities, leaving only the aging population behind. Furthermore, structural problems in land use planning (e.g. fragmentation of properties) and a lack of opportunities for educated youth to productively employ their skills evoke their disinterest in rural activities (qualified or not).

In parallel, the experts believe that the absence of active land management is the result of the decrease in livestock activity, agricultural occupation and available labour, increased labour costs, and land ownership uncertainty due to the lack of clarity in defining land boundaries and property rights. A practical example cited by one of the interviewees, which concerns the socio-environmental transformation and increased risks of traditional burning, is the increasingly small window of opportunity for this practice. Despite the underlying causes of risk focusing on social transformation, the environmental challenges are addressed in the *exogenous elements and factors* subsection.

Alternative solutions

The *alternative solutions* dimension describes less risky alternatives to traditional burning such as crushing waste, processing it into pellets on site, leaving it in the soil for further decomposition or incorporating it into the soil to improve its structure and quality, collecting/storing it to use as biomass, composting it to produce organic fertiliser, and using it for energy production at small or large scales.

Micro biomass power plants are a relevant solution to reduce fuel load and fire risk in small rural communities, as the biomass available can be used for heating public spaces (e.g. schools, health centres and swimming pools) and private homes. However, according to the experts, the widespread use of biomass would potentially require incentives from public policies (e.g. encouraging renewable energy sources, the active management of fuels and the use of biomass for home heating).

Alternatives like crushing, on-site pellet processing, local micro power plants for heat production, or biomass plants are dependent on a large investment and entail high machine operating costs. Additionally, the logistics surrounding the collection/storage of the material to use for biomass and energy production make these alternatives inconvenient and inefficient. For example, transporting the material to feed the combustors is a challenging task. Thus, residues could be made more compact through densification processes, such as transforming them into solid fuels like pellets or briquettes. Still, once again, these solutions require large investments that may make them financially and economically unfeasible.

According to an interviewee, some municipalities provide a service of centralised sites with containers for collecting agroforestry residues. Still, he believes the mere existence of centralised sites would not be enough to motivate and engage citizens to use the service offered, owing the additional effort of transport and disposal into the containers.

On the opposite side, solutions like leaving the material in the soil for further decomposition or incorporating it into the soil to improve its structure and quality, storing it for

heat production at home, and composting it to produce organic fertiliser are usually oriented at small-scale operations. In order to turn these solutions into large-scale operations that are commercially feasible, local authorities could incentivise the establishment of cooperatives.

Exogenous elements and factors

Some *exogenous elements and factors* can lead to an increase in the risks related to fire behaviour and propagation speed. On one hand, some exogenous factors depend on human decisions and activity, such as controlling the existing fuel load, avoiding the selection and growth of flammable vegetation on the land (fuel models), and choosing the appropriate period to undertake traditional burns according to the last rain. On the other hand, exogenous factors such as cumulative temperature, air and fuel humidity, orography, and wind speed and direction cannot be controlled by humans and can impact fire behaviour and propagation speed.

According to the experts, evaluating the risks of a traditional burn should involve an analysis of not only temperature and humidity, but also of other exogenous factors like orography, wind speed and direction, existing fuel load and flammability. As such, the loss of know-how related to traditional burning in consequence of the disinterest of young people in rural activities has been a matter of concern for experts.

Climate change and landscape transformation are critical environmental factors that must be considered and used to shape new patterns of risk. In other words, the exogenous conditions that guided someone's decision to undertake a traditional burn in the past (e.g. a cloudy day) may not ensure safety nowadays. Thus, the demand for updated risk assessment owing to climate change is a challenging issue for future land management and rural fire risk prevention. As the climate continues to change, traditional approaches to risk assessment and management may no longer be adequate. It is imperative to adapt and update risk assessment frameworks including the evolving environmental conditions, impacts of climate change on fire behaviour, land management practices and societal vulnerabilities.

Activities leading to a successful traditional burn

The *activities leading to a successful traditional burn* dimension focuses on determinant actions in the risk mitigation process, such as adequate risk perception, technical support and monitoring, sensitisation and education on the use of fire, including appropriate risk communication strategies. Communicating the risks associated with traditional burning is essential, considering that people were seen to have different levels of information and experience with the use of fire.

The experts highlighted that risk mitigation actions (e.g. monitoring and sensitisation) must be intensified during the summer and spring seasons, when the population increases in rural areas. During this period, urban citizens visit rural areas for tourism and recreational purposes, and non-resident rural owners and emigrants return to their rural properties on weekends, holidays, or vacations, using the opportunity to tidy their land and gardens. Furthermore, more technical support and monitoring are needed to better support traditional burning practitioners.

According to the expert community, sensitisation efforts and technical support actions must be aimed at supporting traditional burning and incentivising alternative solutions. In other words, the experts argued that guidelines and inspections should facilitate and support the traditional burning process, offering useful information so that it can be performed safely. They also advocated raising awareness and providing education on the use of alternative solutions as a way to decrease the number of ignitions. The experts believe that, with more support, it is possible to incorporate a mindset that includes alternative solutions into the behaviour of future generations.

Potential impacts

Many of the aforementioned risks before and during a traditional burn may lead to fire getting out of control and escaping, resulting in rural fires and, consequently, varied impacts. Therefore, the expert mental model included 12 impact variables distributed across social, environmental and economic categories.

The impacts pointed out by the experts were mostly negative, except for fuel load reduction. For some experts, traditional burning contributes to fuel load reduction, thus mitigating rural fire risk. In contrast, other experts did not identify any positive impacts brought by traditional burning.

In terms of ecological impacts, the mental models mentioned the spread of invasive species as an example. Regarding social impacts, some of the examples mentioned were mental health problems (permanent or short-term), physical injuries, respiratory, cardiac and oncological diseases, and death. Crime and the marginalisation of the use of fire were cited as unintended consequences of the implementation of more rigorous inspections and coercion/enforcement actions. Indeed, although the implementation of stricter penalties and sanctions for violating fire regulations may deter some individuals from using fire, these measures can lead to behaviours such as concealing the use of fire, selecting unsafe burning conditions, or failing to properly manage fires until completion.

Lastly, examples of economic impacts include administrative offences leading to fines and the reduction of available resources if authorities are mobilised to false fire alarms. For example, the latter would mean that firefighters and other authorities are not able to handle other rural fire events, and there has to be an investment in air resources that could otherwise be avoided.

Discussion

Systematising the experts' understanding of traditional burnings in Portugal, this study identified eight aggregate dimensions: motivations behind traditional burning, alternative solutions, risks before a traditional burn, risks during a traditional burn, underlying causes of risk, exogenous elements and factors, potential impacts, and activities leading to a successful traditional burn. These eight dimensions offer a comprehensive view of the traditional burning practice from an expert's perspective and help to organise literature that was previously scattered. A number of implications can be drawn from these dimensions. As such, Table 3 connects supporting literature with theoretical and practical implications.

The *motivations behind traditional burning* identified in the mental model – land clearing and management, property protection, and waste and residue disposal – are in line with existing literature on this topic (Bayne *et al.* 2019; Castro *et al.* 2020; Nunes *et al.* 2021; Sharma *et al.* 2022). Lewis *et al.* (2018) reported debris control and hazard abatement as the predominant motivators of fire use, and despite Portuguese law having made fuel load management mandatory, the experts mentioned that reducing fuel load is a recent motivation for traditional burning. Except for burning waste, this dimension shows how traditional burning can contribute to sustaining a healthy landscape and thus produce benefits for local residents (Huffman 2013; Lewis *et al.* 2018). Despite the importance of preserving this historical practice (Carroll *et al.* 2021), some experts support a decrease in the number of ignitions through the promotion of alternative solutions.

The findings regarding *alternative solutions* are in line with studies that indicate the existing solutions require high investments and operating costs or are small-scale oriented (Kumar *et al.* 2015; Shyamsundar *et al.* 2019; Nunes 2021). Whereas some authors claim stringent regulations and shifts in public opinion threaten traditional burning (Carroll *et al.* 2021), others support enforcing burning bans and promoting alternative solutions to traditional burning (Shyamsundar *et al.* 2019; Nunes 2021). Biomass energy recovery, for instance, has been suggested as an alternative solution to reduce the risk of rural fires (Nunes 2021), and the interviewed experts agreed with that. However, according to them, making the biomass recovery market economically sustainable may be challenging, depending on the volume of material and how far the plants are for biomass supply. The Portuguese government has been encouraging the use of alternative solutions (Decreto-Lei No 14/2019), but there is still a need to promote a feasible, affordable and capable scaling alternative (Shyamsundar *et al.* 2019). In this sense, policymakers could provide appropriate financial and management plans so landowners can access the required machinery, or local municipalities could establish and provide a community service for machinery allocation.

The dimension of *underlying causes of risk* is in line with studies that connect rural depopulation and the abandonment of traditional agriculture with vegetation build-up and thus increased fire risk (Doerr *et al.* 2013; Castro *et al.* 2020). In Portugal, fuel load management is a problem for private owners, owing to the difficulty in dealing with the costs (Nunes 2021). In addition, some studies link the risks of fire use to monocultures that are highly combustible and have greater economic value (e.g. pine and eucalyptus) (Canaveira 2020), territorial fragmentation (Gomes 2006) and the lack or non-enforcement of regulations in some countries (Gomes 2006; Ganteaume *et al.* 2021). These findings express the need to encourage people to settle in rural areas, implement and enforce fuel reduction policies (Ganteaume *et al.* 2021), and overcome the structural issue of small land parcels through cross-tenure collaborations and coordinated actions (Wysong *et al.* 2021).

The several *risks before and during a traditional burn* and their connections as reported by the experts demonstrate that the traditional burning practice requires an understanding of how multiple elements interact and influence one another (e.g. fire effects on vegetation, weather conditions, legal requirements and fire intensity) (Huffman 2013). Negligent traditional burning practices may be tied to the inability to identify an appropriate window for undertaking traditional burns securely (Carroll *et al.* 2021) or impunity for negligent fires (Gomes 2006). However, the latter was not specified in the mental model. Governments tend to further constrain traditional fire management during times of fire increase (Huffman 2013), but increasingly restrictive policies that determine when landowners and farmers can legally undertake traditional burns raise concerns (Carroll *et al.* 2021). As such, using fire without obtaining a permit (McGee and Cabling 2022) was mentioned in the experts' mental model, showing that governmental efforts to reduce wildfire risk sometimes influence risk management decisions, but not necessarily in the 'correct' way (Doerr *et al.* 2013). This scenario supports the idea that the use of fire permits needs to be articulated with the day-to-day routines of the rural population, preventing conflicts between temporal restrictions on traditional burning and traditional patterns (Carroll *et al.* 2021).

The dimension of *risks during a traditional burn* highlights that fire use can cause wildfires if prevention activities are unsuccessful (McGee and Cabling 2022) and that rekindling incidents have a significant presence in the Portuguese forest fire management system and an important impact on suppression resources (Pacheco *et al.* 2014). Indeed, some works report the increasing number of residents calling local fire brigades when smoke from traditional burns is sighted (Carroll *et al.* 2021) and the waste of resources due to false alarms (Pacheco *et al.* 2014). These findings imply the necessity of emphasising the importance of (1) communicating traditional burns in advance, especially considering the potential deployment and waste of firefighting resources;

Table 3. Connection of the aggregate dimensions with the supporting literature and implications.

Aggregate dimension	Supporting literature	Implications
Motivations behind traditional burning	Land clearing and management • elimination of residual materials from agricultural and forestry activities (Nunes *et al.* 2021) • land use management (Castro *et al.* 2020) • cleaning method – traditional burning of leftovers from cleaning operations (Nunes *et al.* 2021) • remove pests, diseases, and unwanted vegetation build-up (Bayne *et al.* 2019) Property protection • cultural burning protects threatened species and reduces wildfire risk, but there is limited empirical evidence to support these claims (McKemey *et al.* 2021) • debris control and hazard abatement are now the predominant motivators for the use of fire (Lewis *et al.* 2018) Waste and residue disposal • prohibition of abandonment, disposal and open burning of waste. (Decreto-Lei No 102-D/2020).	• sustain a healthy landscape, producing benefits for local residents through fire use (Huffman 2013; Lewis *et al.* 2018) • stress the beneficial ecological and social role of traditional burning (Carroll *et al.* 2021) • preserve this historical practice, giving it a wider modern purpose (Carroll *et al.* 2021) • stringent regulations and shifts in public opinion threaten traditional burning (Carroll *et al.* 2021)

Alternative solutions	High investment and operating costs
	• bioenergy production from biomass requires a large investment and high operating costs, which may make it financially and economically unfeasible (Wangwongwatana 2020)
	  • viable source of power for rural electrification in India (Kumar *et al.* 2015)
	  • viable solution, mainly if processed on an industrial scale (Nunes 2021)
	• on-site pellet processing faces logistical issues as the material has a low density, even when baled (Nunes 2021)
	• cost of biological residue crushers and supply chain and rental market constraints (Shyamsundar *et al.* 2019)
	
	Small scale
	• the decomposition process is time-consuming (Wangwongwatana 2020)
	• lack of bush and forest residue collection points results in inadequate forest management practices (Gomes 2006)
	• incorporate residues into the soil – increases the nutrient value and fertility of the soil, but sometimes machinery is needed and no incentives are provided (Kumar *et al.* 2015)
	• most alternatives are oriented to small-scale operations and not economically feasible except for one's own use (Wangwongwatana 2020)
	• belief that there are no profitable alternatives to burning crop residues (Shyamsundar *et al.* 2019)
		• encourage the use of alternative solutions (Decreto-Lei No 14/2019)
		• reduce the risk of rural fires through biomass energy recovery (Nunes 2021)
		• make the biomass market economically sustainable – experts agree that this is viable in some regions with market logic, the right volume of material and a nearby supply of plant material
		• promote better biomass management for the future (e.g. the use of renewable biomass resources and waste to design and produce insulation materials for buildings) (Rabbat *et al.* 2022)
		• support the establishment of landowner/producer cooperatives for large-scale operations to make some alternative solutions more economically and commercially feasible
		• promote a feasible, affordable and capable scaling alternative to traditional burning (Shyamsundar *et al.* 2019)

Risks before a traditional burn	Lack of resources • the risk of rural fires stems in part from the absence of effective management policies aimed at rural areas (Coelho *et al.* 2020) • the government can influence risk management decisions but not necessarily in the 'correct' way (Doerr *et al.* 2013) • governmental efforts to reduce wildfire risk are not enough on their own (Doerr *et al.* 2013) • concerns linked to increasingly restrictive policies that determine when farmers can legally undertake traditional burns (Carroll *et al.* 2021) • governments tend to further constrain traditional fire management during times of fire increase (Huffman 2013) Lack of compliance with legal requirements • use of fire without obtaining a permit (McGee and Cabling 2022) Negligence • the negligent use of fire is one of the main causes of wildfires in Portugal (Nunes *et al.* 2021)	• promote the education of residents and land planners about fire risk (Ganteaume *et al.* 2021) • joint effort between public agencies and private landowners in risk mitigation strategies (Doerr *et al.* 2013) • articulate the use of fire permits with the day-to-day routines of the rural population • avoid the marginalisation of traditional burning practices by revising the imposition of law enforcement and traditional burning reproof • prevent conflicts between temporal restrictions on traditional burning and traditional patterns, such as limiting farmers' ability to account for annual weather variations when planning and undertaking traditional burns (Carroll *et al.* 2021)

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Table 3. (*Continued*)

Aggregate dimension	Supporting literature	Implications
	• 47% of rural fires in Portugal are caused by the negligent use of fire • negligent (intentional) fires in Portugal burn mostly forest and agricultural areas (Davim *et al.* 2021) • impunity for negligent fires and arson (Gomes 2006) • inability to identify an appropriate window for secure traditional burning (Carroll *et al.* 2021) • in rural areas, most fires are due to negligence during agricultural work (Ganteaume *et al.* 2021)	
Underlying causes of risk	Rural abandonment • the rural depopulation and abandonment of traditional agriculture in Mediterranean Europe has led to vegetation build-up, increasing the risk of severe fires (Doerr *et al.* 2013) • monocultures that are highly combustible and have a greater economic value (e.g. pine and eucalyptus) (Canaveira 2020) • rural desertification leads to an increase in land occupation by bushes and dense forests (Gomes 2006) • the progressive abandonment of agricultural land and reductions in the size of livestock herds, in the amount of forest fuel consumed by grazing, and in the collection of firewood (Castro *et al.* 2020) • poor rural land planning increases the vulnerability of populations (Ganteaume *et al.* 2021) Absence of active management • vegetation is not always properly managed, facilitating fire propagation (Ganteaume *et al.* 2021) • lack or non-enforcement of regulations in some countries (Ganteaume *et al.* 2021) • existing regulations and policies may complicate the ability of farmers to manage land effectively and to achieve long-term landscape health goals • failure to comply with the current Portuguese legislation about mandatory phytosanitary requirements (Gomes 2006) • territorial fragmentation (Gomes 2006)	• overcome structural issues (e.g. small land parcels) through cross-tenure collaboration efforts such as: shared vision, coordinated actions, accountability, communication, and project coordination and resourcing (Wysong *et al.* 2021) • implement and enforce fuel reduction policies (Ganteaume *et al.* 2021) • revise rural development policies, whose lack of continuity and soundness was responsible for signficant damage in Portugal (Ganteaume *et al.* 2021) • encourage the population to settle in rural areas by offering incentives • encourage land consolidation/reparcelling by offering incentives
Exogenous elements and factors	Uncontrollable exogenous elements and factors • high absolute fire danger in Portugal (European Environment Agency 2021) as a result of the dry and warm Mediterranean summer (Davim *et al.* 2021) • fires typically associated with dense live and dead fuels, prior prolonged dryness, high temperatures and strong winds (Doerr *et al.* 2013) • increased fire risk due to changes in fuel land cover, demographic shifts and climate change (Carroll *et al.* 2021) Controllable exogenous elements and factors • prevalence of flammable vegetation types in rugged terrain (Davim *et al.* 2021) • contemporary land use is changing and WUI is spreading (Davim *et al.* 2021) • the current 'critical period of rural fires' does not cover the entire period where climatic anomalies occur and where large-scale rural fires can potentially happen (Nunes *et al.* 2019) • changes in land use, land cover and fuel management (Ganteaume *et al.* 2021) • increased risks in some areas due to the expansion of forests and changes in fuel conditions (Carroll *et al.* 2021)	• better prepare and inform the population about fire preparedness and fire response procedures (Ganteaume *et al.* 2021) • inform people about the mutable and uncontrollable exogenous elements and factors and translate this information into risk mitigation actions directed at traditional burning practitioners • limit the extent of plantations of very flammable exotic species (such as *Eucalyptus globulus* in Portugal) (Ganteaume *et al.* 2021) • policymakers' decisions (e.g. regulations on the critical period of rural fires) should take into account the challenges of climate change (Nunes *et al.* 2019)
Risks during a traditional burn	Bad practices • knowledge of human causes (deliberate actions, negligence, accidents, or carelessness) in rural fires is still limited (Parente *et al.* 2018; Castro *et al.* 2020) • increasing number of tourists or 'new' residents without any awareness of the 'culture of risk' in fire-prone areas (Ganteaume *et al.* 2021)	• improve safety through better training with an emphasis on safety issues (Molina-Terrén *et al.* 2019) • intensify awareness and information campaigns through different channels including social networks (Ganteaume *et al.* 2021)

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Table 3. (*Continued*)

Aggregate dimension	Supporting literature	Implications
	Personal damage • concerns about respiratory health and human safety (Carroll *et al.* 2021) • health problems like eye irritations, bronchitis and asthma, which can lead to an increase in disease mitigation expenses and a reduction in work capacity (Kumar *et al.* 2015) Undesirable/unexpected fire effects/behaviour • rekindles have a significant presence in the Portuguese forest fire management system and an important impact on suppression resources (Pacheco *et al.* 2014) • fire use can cause wildfires if prevention activities are unsuccessful (McGee and Cabling 2022) Waste of firefighting resources • insufficient resources (human and material) to prevent, control and fight fire (Gomes 2006) • waste of resources due to false alarms (Pacheco *et al.* 2014) • increasing number of residents calling local fire brigades when they see smoke from traditional burns (Carroll *et al.* 2021)	• inform people about undesirable/unexpected fire effects/behaviour and traditional burning good practices in order to mitigate rekindles and incidents • disseminate the role of fire prevention policies, such as mandatory brush-clearing (Ganteaume *et al.* 2021) • revise policies and practices to mitigate the number of fatalities (Molina-Terrén *et al.* 2019) • focus on prevention planning at the structural, risk awareness and participation of the population levels (Molina-Terrén *et al.* 2019) • keep a systematic record of the lessons learned from incidents (Molina-Terrén *et al.* 2019)
Activities leading to a successful traditional burn	Appropriate risk perception • poor translation of risk information into mitigation actions owing to the diversity of people in fire-prone areas (Eriksen and Prior 2011) • the widely varying experiences, beliefs, attitudes and values related to fire can influence people's understanding and interpretation of risk messages (Eriksen and Prior 2011) • rural residents are aware of local wildfire risks and act to prevent fires from escaping (McGee and Cabling 2022) Prior communication to the authorities • efforts to regulate traditional burns and improve fire management, such as applying the use of fire permits and safe burning practices (McGee and Cabling 2022) Technical support and monitoring • a more formal link between fire use professionals, fire services, land managers and regulators is necessary to preserve and promote the appropriate use of traditional burning (Carroll *et al.* 2021) • acknowledge the need for increased supervision of the land being burned, increased coordination with local fire brigades and the use of personal protective equipment (Carroll *et al.* 2021) • preventive fuel management investments are less attractive because the benefits are not immediate (Collins *et al.* 2013) Sensitisation and education on the use of fire • an educational program on the community-led burning regime would serve purposes such as improving forest health and educating young people about traditional burning (Lewis *et al.* 2018) • the longevity of traditional burning knowledge and practice faces serious threats as climate change disrupts fire activity (Huffman 2013) • practicing traditional fire management requires understanding how multiple elements interact and influence one another, e.g. fire effects on vegetation, the season of the year, burning illegal or regulated by the government and fire intensity (Huffman 2013) • risks are overblown in the media and in the minds of the non-farming public (Carroll *et al.* 2021)	• increase private landowners' commitment to rural fire risk mitigation (Doerr *et al.* 2013) • promote risk communication and mitigation actions according to the diversity of people inhabiting fire-prone areas • support knowledge and expertise transfer (from elderly rural populations to new generations) • invest in preventative fuel management and make its short-term benefits visible
Potential impacts	Ecological • change soil function in physical, chemical and biological aspects (Doerr and Cerdà 2005) • source of atmospheric emissions (Akagi *et al.* 2011) • concerns such as air quality, wildlife protection, habitat destruction, water quality and carbon storage (Adeleke *et al.* 2017)	• implement effective risk mitigation strategies and actions at the community and landowner levels in order to reduce human and economic losses with fires (Doerr *et al.* 2013) • consolidate the beneficial ecological role of traditional burning among stakeholders, namely

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Table 3. (*Continued*)

Aggregate dimension	Supporting literature	Implications
	Social • air pollution causes several public health problems and even deaths (Molina-Terrén *et al.* 2019) • the number of fatalities is highest in the most fire-prone regions, during the peak months of the fire season and on days with adverse weather conditions (Molina-Terrén *et al.* 2019) • traditional burning can sometimes cause poor visibility, leading to an increase in the number of road accidents (Ganteaume *et al.* 2021) Economic • fire spread may lead to human casualties and significant property damages (Doerr *et al.* 2013)	in reducing accumulated fuel and mitigating large fires • reduce wildfire risks through a well-managed use of fire (Ganteaume *et al.* 2021) • assess the effectiveness of fire management policies based on the socio-ecological damages they prevent instead of based on the burned area (Ganteaume *et al.* 2021)

The eight dimensions identified in the present study helped to organise the scattered literature and draw some theoretical and practical implications.

(2) making people aware of traditional burning good practice in order to mitigate rekindles and fire spread; (3) revising the imposition of law enforcement and traditional burning reproof in order to avoid marginal and illegal practices of traditional burning; (4) systematically recording the lessons learned from incidents (Molina-Terrén *et al.* 2019); and (5) focusing on prevention planning including structural risk, risk awareness and participation of the population (Molina-Terrén *et al.* 2019).

The dimension of *exogenous elements and factors* shows that traditional burning practitioners need to be aware of the mutable exogenous factors and be conscious of good risk mitigation practices in order to prevent fire from escaping and later rekindling. Fires are typically associated with dense live and dead fuels, prolonged dry conditions, high temperatures and strong winds (Doerr *et al.* 2013). Furthermore, changes in fuel land cover (e.g. the prevalence of flammable vegetation types), demographic shifts and climate change increase fire risk (Carroll *et al.* 2021; Davim *et al.* 2021; Ganteaume *et al.* 2021). According to Nunes *et al.* (2019), the current 'critical period of rural fires' does not cover the period where climatic anomalies occur and large-scale rural fires can potentially happen. In addition, some authors share the same concerns as the interviewed experts regarding the disinterest of young people in rural activities (White 2012), contributing to a loss of know-how related to traditional burning (Huffman 2013; Christianson 2015; Bayne *et al.* 2019). These findings are in line with the mental model and demonstrate that current environmental challenges and changes require promoting education about this new reality, as well as aligning policy-makers' decisions and initiatives with such challenges by, for example, adapting the regulations on the critical period of rural fires (Nunes *et al.* 2019) and limiting the growth of highly flammable species (Ganteaume *et al.* 2021).

The *activities leading to a successful traditional burn* highlighted in the mental model are in line with efforts to regulate traditional burning and improve fire management in order to make burning practices safer (McGee and Cabling 2022). For instance, support and monitoring actions allow a more formal link between fire use professionals, fire services, landowners and regulators in order to promote the appropriate use of traditional burning (Carroll *et al.* 2021). Sensitisation and education regarding the use of fire are also relevant in order to educate young people about traditional burning (Lewis *et al.* 2018) and ensure the longevity of this practice (Huffman 2013). However, as stated by the experts, it is necessary to increase private landowners' commitment to rural fire risk mitigation (Doerr *et al.* 2013). Thus, it becomes clear that there is a need to promote risk communication and mitigation actions according to the diversity of people inhabiting fire-prone areas (Eriksen and Prior 2011) and to support knowledge and expertise transfer (from elderly rural populations to new generations).

Finally, the concerns surrounding the *impacts* dimension are aligned with other studies on this topic, namely in terms of air quality (Akagi *et al.* 2011; Carroll *et al.* 2021), which results in several public health problems and even death (Adeleke *et al.* 2017). Fire spreading may lead to human casualties and significant property damage (Ganteaume *et al.* 2021). Although some researchers state that a well-managed use of fire can reduce rather than increase wildfire risk (Carroll *et al.* 2021), the beneficial role of fire is a topic that raised contrasting perspectives among the interviewed experts. Nonetheless, this dimension emphasises the need for effective risk mitigation actions and for communities and public agencies to join efforts in order to reduce human and economic losses due to fires (Doerr *et al.* 2013).

Conclusions

The present study followed a mental model approach to provide a clear understanding of traditional burning in the Portuguese context. Building on a rich sample of experts from several fields linked to fire and forest management in Portugal, the present research further develops the existing literature and sought to understand the practice of

traditional burning from the perspective of experts through focus groups (Carroll *et al.* 2021) and survey methods (McGee and Cabling 2022). Based on the aggregated knowledge from the expert community, a mental model was built comprising eight main dimensions.

Despite the present study focusing on the Portuguese context, it represents a fire-prone country (Oliveira *et al.* 2012; Galizia *et al.* 2021) that can be 'the canary in the mine' for other countries (Elbein 2019). In other words, the findings, contributions and aggregated knowledge from the Portuguese experts may be applied to other regions. Still, it would be interesting for future research to compare the mental models of experts from different countries, explore the similarities and differences, and use this information to identify potential crosscutting risk communication strategies oriented to traditional burning. In addition, the present study may inspire researchers to follow a mental model approach for other relevant topics regarding the use of fire, such as the protection of homes and homeowners from wildland fires and the risks of leisure activities in forested areas.

Moreover, future research should seek to extend the mental model approach to other stakeholders (e.g. laypeople) and understand their perspectives on traditional burning. The combination of experts' and laypeople's mental models could allow researchers to fill current knowledge gaps and identify misunderstandings concerning traditional burning, and ultimately use this information to design improved risk communication and mitigation strategies.

Finally, the present research provides a baseline to help policymakers and stakeholders identify the most relevant aspects of how experts perceive traditional burning. These contributions may motivate the planning and design of more effective risk communication strategies and thus mitigate social and environmental impacts in the future.

References

Adeleke A, Apidechkul T, Kanthawee P, Suma Y, Wongnuch P (2017) Contributing Factors and Impacts of Open Burning in Thailand: Perspectives from Farmers in Chiang Rai Province, Thailand. *Journal of Health Research* **31**, 159–167. doi:10.14456/jhr.2017.20

Akagi SK, Yokelson RJ, Wiedinmyer C, Alvarado MJ, Reid JS, Karl T, Crounse JD, Wennberg PO (2011) Emission factors for open and domestic biomass burning for use in atmospheric models. *Atmospheric Chemistry and Physics* **11**, 4039–4072. doi:10.5194/acp-11-4039-2011

Aliperti G, Nagai H, Cruz AM (2020) Communicating risk to tourists: A mental models approach to identifying gaps and misperceptions. *Tourism Management Perspectives* **33**, 100615. doi:10.1016/j.tmp.2019.100615

Bayne KM, Clifford VR, Baillie BR, Pearce HG (2019) Fire as a Land Management Tool: Rural Sector Perceptions of Burn-off Practice in New Zealand. *Rangeland Ecology & Management* **72**, 523–532. doi:10.1016/j.rama.2018.12.001

Canaveira P (2020) Portugal's National Forestry Accounting Plan 2021-2025. *Agência Portuguesa Do Ambiente* **80**.

Carroll MS, Edgeley CM, Nugent C (2021) Traditional Use of Field Burning in Ireland: History, Culture and Contemporary Practice in the Uplands. *International Journal of Wildland Fire* **30**(6), 399–409. doi:10.1071/WF20127

Castro ACM, Nunes A, Sousa A, Lourenço L (2020) Mapping the Causes of Forest Fires in Portugal by Clustering Analysis. *Geosciences* **10**(2), 53. doi:10.3390/geosciences10020053

Christianson A (2015) Social science research on Indigenous wildfire management in the 21st century and future research needs. *International Journal of Wildland Fire* **24**, 190–200. doi:10.1071/WF13048

Clark SA, Miller A, Hankings D (2021) Good Fire: Current Barriers to the Expansion of Cultural Burning and Prescribed Fire in California and Recommended Solutions. The Karuk Tribe. 17 February. Updated June 17, 2022. Available at https://fusee.org/fusee/good-fire-current-barriers-to-the-expansion-of-cultural-burning-and-prescribed-fire-in-california-and-recommended-solutions

Coelho S, Rafael S, Coutinho M, Monteiro A, Medina J, Figueiredo S, Cunha S, Lopes M, Miranda AI, Borrego C (2020) Climate-Change Adaptation Framework for Multiple Urban Areas in Northern Portugal. *Environmental Management* **66**, 395–406. doi:10.1007/s00267-020-01313-5

Collins RD, de Neufville R, Claro J, Oliveira T, Pacheco AP (2013) Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics. *Journal of Environmental Management* **130**, 1–9. doi:10.1016/j.jenvman.2013.08.033

Craik KJW (1943) 'The Nature of Explanation.' (CUP Archive)

Davim DA, Rosa CG, Fernandes PM (2021) Survival of Prescribed Burning Treatments to Wildfire in Portugal. *Forest Ecology and Management* **493**(August), 119250. doi:10.1016/j.foreco.2021.119250

Decreto-Lei No 102-D/2020, de 10 de dezembro da Presidência do Conselho de Ministros - Ambiente e Ação Climática. Diário da República: Série I, No 239 (2020). Available at https://diariodarepublica.pt/dr/detalhe/decreto-lei/102-d-2020-150908012 [In Portuguese]

Decreto-Lei No 14/2019, de 21 de janeiro da Presidência do Conselho de Ministros - Adjunto e Economia. Diário da República: Série I, No 14 (2019). Available at https://diariodarepublica.pt/dr/detalhe/decreto-lei/14-2019-118051707 [In Portuguese]

DGPFR/Divisão de Gestão do Programa de Fogos Rurais (2021) 8.° Relatório Provisório De Incêndios Rurais De 2021. ICNF – SGIF/Sistema de Gestão de Informação de Incêndios Florestais. Available at https://www.icnf.pt/api/file/doc/504914cdd1a211bb [In Portuguese]

Doerr SH, Cerdà A (2005) Fire effects on soil system functioning: New insights and future challenges. *International Journal of Wildland Fire* **14**, 339–342. doi:10.1071/WF05094

Doerr SH, Santín C, Maynard T, Smith N, Gonzalez S (2013) 'Wildfire: A burning issue for insurers?' (Lloyds: London, UK) doi:10.13140/2.1.2551.9681

Elbein S (2019) What Portugal's hellish wildfires can tell us about forest futures. Science. (National Geographic Society) Available at https://www.nationalgeographic.com/science/article/how-to-live-with-mega-fires-portugal-forests-may-hold-secret

Eriksen C, Prior T (2011) The art of learning: wildfire, amenity migration and local environmental knowledge. *International Journal of Wildland Fire* **20**, 612–624. doi:10.1071/WF10018

European Environment Agency (2021) Forest fires in Europe. Available at https://www.eea.europa.eu/ims/forest-fires-in-europe

Feng X, Fu T-M, Cao H, Tian H, Fan Q, Chen X (2019) Neural network predictions of pollutant emissions from open burning of crop residues: Application to air quality forecasts in southern China. *Atmospheric Environment* **204**, 22–31. doi:10.1016/j.atmosenv.2019.02.002

Galizia LF, Curt T, Barbero R, Rodrigues M (2021) Understanding fire regimes in Europe. *International Journal of Wildland Fire* **31**, 56–66. doi:10.1071/WF21081

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**, 20–29. doi:10.1016/j.jnlssr.2021.01.001

Gioia DA, Corley KG, Hamilton AL (2013) Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods* **16**(1), 15–31. doi:10.1177/1094428112452151

Gomes JFP (2006) Forest fires in Portugal: how they happen and why they happen. *International Journal of Environmental Studies* **63**, 109–119. doi:10.1080/00207230500435304

Han X, Frey GE, Sun C (2020) Regulation and Practice of Forest-Management Fires on Private Lands in the Southeast United States: Legal Open Burns versus Certified Prescribed Burns. *Journal of Forestry* **118**, 385–402. doi:10.1093/jofore/fvaa017

Huffman MR (2013) The Many Elements of Traditional Fire Knowledge: Synthesis, Classification, and Aids to Cross-cultural Problem Solving in Fire-dependent Systems Around the World. *Ecology and Society* **18**, 3. doi:10.5751/ES-05843-180403

ICNF (2023) Informação estatística oficial do Sistema de Gestão de Informação de Incêndios Florestais (SGIF). Available at https://www.icnf.pt/florestas/gfr/gfrgestaoinformacao/estatisticas [In Portuguese]

IRGC (2017) Introduction to the IRGC Risk Governance Framework, revised version. (Eds M-V Florin, MT Bürkler) (EPFL International Risk Governance Center: Lausane) doi:10.5075/epfl-irgc-233739

Kumar P, Kumar S, Joshi L (2015) 'Socioeconomic and Environmental Implications of Agricultural Residue Burning.' (Springer India: New Delhi) doi:10.1007/978-81-322-2014-5

Lewis M, Christianson A, Spinks M (2018) Return to Flame: Reasons for Burning in Lytton First Nation, British Columbia *Journal of Forestry* **116**(2), 143–150. doi:10.1093/jofore/fvx007

McGee TK, Cabling LPB (2022) Preventing wildfires with fire permits in rural Edson, Alberta. *International Journal of Wildland Fire* **31**, 599–606. doi:10.1071/WF20177

McKemey M, The Banbai Rangers, Patterson M (Lesley), Hunter J, Ridges M, Ens E, Miller C, Costello O, Reid N (2021) Indigenous cultural burning had less impact than wildfire on the threatened Backwater grevillea (*Grevillea scortechinii* subsp. sarmentosa) while effectively decreasing fuel loads. *International Journal of Wildland Fire* **30**, 745–756. doi:10.1071/WF20135

Molina-Terrén DM, Xanthopoulos G, Diakakis M, Ribeiro L, Caballero D, Delogu GM, Viegas DX, Silva CA, Cardil A (2019) Analysis of forest fire fatalities in Southern Europe: Spain, Portugal, Greece and Sardinia (Italy). *International Journal of Wildland Fire* **28**, 85–98. doi:10.1071/WF18004

Midmore P, Sherwood A-M, Roughley G (2001) Policy reform and the sustainability of farming in the uplands of the United Kingdom: conflicts between environment and social support *Journal of Environmental Policy and Planning* **3**(1), 43–63. doi:10.1002/jepp.69

Morgan G, Fischhoff B, Bostrom A, Atman CJ (2002) 'Risk Communication: A Mental Models Approach'. p. 367. (Cambridge University Press)

Morgan GW, Tolhurst KG, Poynter MW, Cooper N, McGuffog T, Ryan R, Wouters MA, Stephens N, Black P, Sheehan D, Leeson P, Whight S, Davey SM (2020) Prescribed Burning in South-Eastern Australia: History and Future Directions. *Australian Forestry* **83**(1), 4–28. doi:10.1080/00049158.2020.1739883

Nunes LJR (2021) Characterization of Cytisus striatus (Hill) Rothm.: Waste Biomass Energy Recovery as a Measure to Reduce the Risk of Rural Fires. *Recycling* **6**, 36. doi:10.3390/recycling6020036

Nunes LJR, Meireles CIR, Pinto Gomes CJ, Almeida Ribeiro NMC (2019) The Evolution of Climate Changes in Portugal: Determination of Trend Series and Its Impact on Forest Development. *Climate* **7**(6), 78. doi:10.3390/cli7060078

Nunes LJR, Raposo MAM, Pinto Gomes CJ (2021) A Historical Perspective of Landscape and Human Population Dynamics in Guimarães (Northern Portugal): Possible Implications of Rural Fire Risk in a Changing Environment. *Fire* **4**(3), 49. doi:10.3390/fire4030049

Oliveira SLJ, Pereira JMC, Carreiras JMB (2012) Fire frequency analysis in Portugal (1975–2005), using Landsat-based burnt area maps. *International Journal of Wildland Fire* **21**, 48–60. doi:10.1071/WF10131

Özesmi U, Özesmi SL (2004) Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling* **176**, 43–64. doi:10.1016/j.ecolmodel.2003.10.027

Pacheco AP, Claro J (2018) Operational flexibility in forest fire prevention and suppression: a spatially explicit intra-annual optimization analysis, considering prevention, (pre)suppression, and escape costs. *European Journal of Forest Research* **137**, 895–916. doi:10.1007/s10342-018-1147-7

Pacheco AP, Claro J, Oliveira T (2014) Simulation analysis of the impact of ignitions, rekindles, and false alarms on forest fire suppression. *Canadian Journal of Forest Research* **44**, 45–55. doi:10.1139/cjfr-2013-0257

Parente J, Pereira MG, Amraoui M, Tedim F (2018) Negligent and intentional fires in Portugal: Spatial distribution characterization. *Science of The Total Environment* **624**, 424–437. doi:10.1016/j.scitotenv.2017.12.013

Rabbat C, Awad S, Villot A, Rollet D, Andrès Y (2022) Sustainability of biomass-based insulation materials in buildings: Current status in France, end-of-life projections and energy recovery potentials. *Renewable and Sustainable Energy Reviews* **156**, 111962. doi:10.1016/j.rser.2021.111962

Sharma G, Annadate S, Sinha B (2022) Will open waste burning become India's largest air pollution source? *Environmental Pollution* **292**, 118310. doi:10.1016/j.envpol.2021.118310

Shyamsundar P, Springer NP, Tallis H, Polasky S, Jat ML, Sidhu HS, Krishnapriya PP, Skiba N, Ginn W, Ahuja V, Cummins J, Datta I, Dholakia HH, Dixon J, Gerard B, Gupta R, Hellmann J, Jadhav A, Jat HS, Keil A, Ladha JK, Lopez-Ridaura S, Nandrajog SP, Paul S, Ritter A, Sharma PC, Singh R, Singh D, Somanathan R (2019) Fields on fire: Alternatives to crop residue burning in India. *Science* **365**, 536–538. doi:10.1126/science.aaw4085

Steelman TA, McCaffrey S (2013) Best practices in risk and crisis communication: Implications for natural hazards management. *Natural Hazards* **65**, 683–705. doi:10.1007/s11069-012-0386-z

Stege TAM, Bolte JFB, Claassen L, Timmermans DRM (2019) Particulate matter exposure in roadwork companies: A mental models study on work safety. *Safety Science* **120**, 137–145. doi:10.1016/j.ssci.2019.06.043

Walpole EH, Toman E, Stidham M, Wilson R (2020) The science and practice of ecological restoration: a mental models analysis of restoration practitioners. *Environment Systems and Decisions* **40**, 588–604. doi:10.1007/s10669-020-09768-x

Wangwongwatana S (2020) 'Review of Existing Good Practices to Address Open Burning of Agricultural Residues.' (United Nations Environment Programme (UNEP))

White B (2012) Agriculture and the Generation Problem: Rural Youth, Employment and the Future of Farming. *IDS Bulletin* **43**, 9–19. doi:10.1111/j.1759-5436.2012.00375.x

Wysong M, Legge S, Clark A, Maier S, Cowell S, Mackay G Bardi Jawi Rangers, Nyul Nyul Rangers, Yawuru Country Managers, (2021) The sum of small parts: changing landscape fire regimes across multiple small landholdings in north-western Australia with collaborative fire management. *International Journal of Wildland Fire* **31**, 97–111. doi:10.1071/WF21118

Zaksek M, Arvai JL (2004) Toward Improved Communication about Wildland Fire: Mental Models Research to Identify Information Needs for Natural Resource Management. *Risk Analysis* **24**, 1503–1514. doi:10.1111/j.0272-4332.2004.00545.x

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