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Smart management of emergencies in the agricultural, forestry, and animal production domain: Tackling evolving risks in the climate change era

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A B S T R A C T

The agricultural, forestry, and animal production domain (AFA domain) plays an essential role in meeting global needs and supporting livelihoods while facing escalating challenges from climate change-induced impacts and extreme natural events. This perspective advocates for urgent strategies to enhance resilience through effective emergency management and prevention measures tailored to this critical domain. The analysis here exposed, which includes elements of ontology and the conceptual approach of an emergency management system encompassing both restoration and prevention aspects, entails three case studies across the AFA domain. Each case study, described by location, timing, nature, and consequences, critically evaluates the implemented risk prevention measures, details the emergency and recovery actions, and highlights shortcomings in response efforts. The analysis, incorporating a retrospective comparative component based on the proposed conceptual model, highlights the importance of identifying

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lessons learned and potential future applications. It emphasizes the urgent need for a well-structured emergency management strategy that integrates risk mapping and advanced technology to ensure timely and effective responses. The active engagement of domain professionals (agronomists, foresters, animal production doctors) and scholars of AFA domain sciences, as either farm owners or technical advisors, is crucial to optimize intervention strategies. This engagement is especially important for enhancing resilience during recovery phases, aligning with the best international practices such as making use of local knowledge and citizen engagement strategies. Comprehensive training initiatives, also adopting innovative formats and tools including micro-credentials, e-learning platforms, and the applications of generative Artificial Intelligence for learning assistance, as well as new research insights are strategic for coordinated and effective emergency responses across all stakeholders. Collaboration between the different production systems and areas of expertise, raising awareness of the distinction between *Civil Protection* and *Production Protection* and fostering their close interconnection, is essential for effective emergency response and long-term resilience.

1. Introduction

It is widely acknowledged that the domain related to animal production, agricultural and forestry sectors (hereafter AFA domain) is vital for *i*) addressing the global food, fiber and wood demand of a continuously growing population [1,2], *ii*) supporting rural and mountain livelihoods [3] and *iii*) ensuring essential ecosystem services [4]. These aspects are in line with the United Nations' Sustainable Development Goals [5] and the One Health approach [6].

However, over the last few years significant climate change has taken place making these challenges even more difficult to face since both natural and anthropic environments are highly sensitive to climate and weather patterns. Therefore, phenomena such as changing precipitation and temperature regimes and extremes can significantly disrupt traditional human practices, not only affecting the performance of agricultural, forestry, and animal production activities, but also jeopardizing farmers' incomes throughout the agricultural sector [7]. Accordingly, climatic phenomena are generally included among the most relevant key drivers of food insecurity [8,9]. In addition, climate change alters ecological relationships between animals, plant and microbial species and their interactions with their own ecosystems [10].

Temperature extremes, heavy precipitation and pluvial floods, soil erosion, river floods, landslides, droughts, wildfires, storms including tropical cyclones, as well as compound events, are extreme phenomena directly linked to climate change which pose additional threats [11]. Their intensity, severity, and unpredictability [12] often make prevention and mitigation of risks challenging and they can easily lead to disastrous consequences, at least in delimited areas, with significant short and long-term effects. Historic examples such as wildfires in Australia, floods in Germany, heatwaves across Europe [13] and *Vaia* storms in the Italian north-eastern Alps [14–16] highlight the urgency of a rapid restoration of the involved areas, to recover their functionality. Delayed and inappropriate emergency management can easily lead to cascading effects, that, for their socio-economic consequences and the fragility of the AFA domain [17,18], may, over a long period, promote the further depopulation of rural and mountain areas, exacerbating social costs to safeguard and protect these territories and the populated urban areas present in the underlying plains [19].

Regarding the Italian territory, the agricultural, forestry, and animal production sectors are vital to the country's economy, contributing approximately 2.1 % to its Gross Domestic Product and providing employment for around 1.3 million people [20]. In addition to the high-quality food products (including fruits, vegetables, wine, and olive oil) for which Italy's agricultural sector is renowned, the forestry sector covers about 35 % of Italy's land area, providing essential ecosystem services and biodiversity conservation. Animal production, including dairy and meat, also plays a considerable role in Italy's food industry and exports. Within the EU context, Italy holds a significant position in agriculture, with farms below the EU average size but with an above-average output per farm, indicating the efficiency and productivity of the sector [21]. However, Italy is particularly exposed to climate change and extreme weather events, which threaten agricultural production and the Mediterranean region, including Italy, is identified as a climate change hotspot [22], necessitating adaptation and mitigation strategies tailored to the characteristics of agriculture, forestry, and animal production sectors for their sustainability [23]. While these sectors all belong to the primary production domain and share certain resource dependencies, each one also faces distinct operational challenges and requires specialized professional expertise to address them effectively. This diversity within the AFA domain justifies a unified approach that at the same time recognizes the specific skills needed for the particular challenges of each sector. Notably, between 2021 and 2023, a state of emergency was declared in the Italian territory over 130 times owing to extreme water and meteorological events [24,25].

Based on these premises, this work specifically focuses on the AFA domain in Italy, in relation to the impacts of extreme natural events and related calamities. It aims at establishing intervention strategies and methodologies for emergency events within the AFA domain, diversified for immediate and short to medium-term critical time horizons. The manuscript includes, in addition to elements of ontology, an examination of the conceptual approach of an emergency management system, encompassing both restoration and prevention aspects. The analysis entails case studies addressing the three sectors of agriculture, forestry, and animal husbandry. A comparative analysis of these case studies, including a retrospective application of the conceptual model to understand past responses and guide future strategies, is presented. The main challenges and urgent actions needed to bolster AFA domain resilience through appropriate and timely emergency management, are then discussed.

2. Conceptual framework of emergency in agriculture, forestry, and animal production

2.1. Ontology elements

The terminology describing the various aspects of emergencies encompasses a broad range of concepts and definitions that are crucial for the understanding and management of these events effectively. Here, the focus is first placed on the relationships between the three terms of the phases: 1) *Prevention*, 2) *Emergency Response*, 3) *Restoration*. Although they are listed in sequential order, conventionally starting with *prevention*, their links are actually circular in nature. The use of these phases has faced criticism for oversimplifying complex realities and not accurately reflecting the interconnected nature of disaster events [26]. Despite this, they remain useful as a conceptual framework for analyzing interventions in the context of Disaster Risk Reduction (DRR). These restoration actions, once the acute emergency phase has passed, can be planned and implemented to create opportunities for future preventive actions and these relationships are analyzed in relation to their applications in the agricultural, forestry and animal production sector. The objectives are: a) to emphasize the peculiarities of emergency, restoration and prevention interventions in the AFA domain; b) to identify new professional specializations, directing them towards the problems of the domain that are expected to intensify owing to known dynamics mainly linked to climate change; c) to raise awareness of the skills of the professionals involved (including agronomists, foresters, and animal production doctors) towards new profiles that can go beyond the already known productive functions, environmental sustainability and landscape protection. Our model aims at integrating the various phases of disaster management with specific interventions tailored to the agricultural, forestry and animal production sectors, thereby addressing gaps in current practices in the AFA domain. By emphasizing a more articulated understanding of the relationships between *prevention*, *emergency response*, and *restoration*, this model provides a comprehensive framework that can better inform stakeholders when making decisions during emergencies. Therefore, the overall context of managing emergency situations includes **a)** a general part that determines the relationships between emergencies and relative preventive and restorative actions, and **b)** a special part connected to the different sectors of the AFA domain. The ontological approach outlining the conceptual model of these issues is proposed in Fig. 1, where the various graphic symbols are inspired by Universal Modeling Language approaches. More specifically, the entities of the system are highlighted in boxes with a green background, while the relationships between entities are represented in boxes with a light blue background. The names of the main relations are also indicated, using terms that explicitly describe the nature of the relations themselves.

Critical issues, although urgent and, at least in some cases, of increasing intensity, resulting from events with chronically critical effects (*e.g.*, heat waves, ergonomic aspects of work environments also in relation to extreme weather episodes and/or to the type of

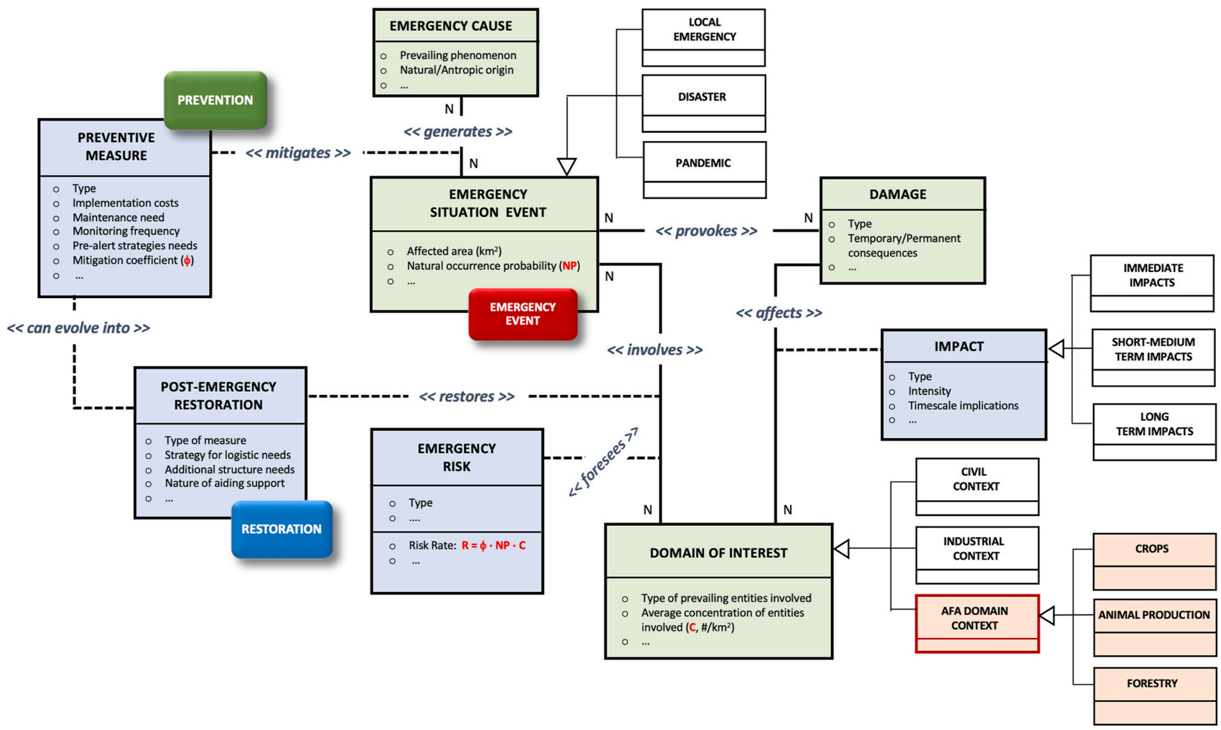

Fig. 1. Conceptual model of emergency management problems. UML graphical syntax is used here with entities and relationships represented in boxes with light green and light blue background. The symbol Δ implies inheritance (=specialization) from a mother-entity to a child-entity. The agricultural, forestry and animal production domain (AFA domain) is represented by the box *AFA DOMAIN CONTEXT*, including all the related child sectors.

agronomical practice such as exposure to pesticides, smoke, excess of humidity) are already routinely addressed by specific disciplines of the AFA domain with specific scientific research [27–29] and therefore are not taken into consideration as high priority in the present work.

2.2. General conceptual approach of emergency management in the AFA domain in relation to their causes

In this work, the focus is on the various sectors of the AFA domain, highlighted with red frames and pink backgrounds in the conceptual scheme of Fig. 1. It is useful to start a deep analysis of the related expected emergencies, mapping the impact levels of the various causes on the specific sectors within the AFA domain. These emergency causes are largely ascribable to natural phenomena and can be categorized into types such as: a) hydro-pedological (*e.g.*, floods, avalanches, debris flows), b) geological (*e.g.*, earthquakes, slope stability, rock falls and landslides), c) climatic phenomena (*e.g.*, hurricanes, storms, rainstorms/hailstorms, intense snowfall, heat waves, fires, droughts) and (d) health emergencies (*e.g.*, epidemics, alien pathogens/insects) even though they are not directly connected to climatic events.

The sectors within the AFA domain can be classified as follows: 1) arable land, including field crops, horticultural crops, orchards and vineyards, 2) protected crops (including greenhouses and nursery production), 3) forests, plantations, and industrial arboriculture systems, 4) dairy farming (cows, sheep and goats, buffaloes), 5) meat farming relating to medium- and large-sized animals (beef cattle and pigs), 6) meat farms for small-sized animals (especially poultry, rabbits, aquaculture, etc.). This classification not only identifies areas at risk but also promotes the development of targeted strategies for risk mitigation, enhancing the overall resilience of the AFA domain. Fig. 2 proposes an *Emergency Causes* X *Domain of Interest* matrix with a qualitative assessment of the expected impacts in each cause/sector combination and helps identify the qualitative-impact intensities and pinpoint areas needing specific training and research efforts. For example, the matrix illustrates how FLOODS and, especially, FIRES, seriously affect all sectors of the AFA domain, necessitating different intervention approaches between crops and animal production sectors. Particularly in the latter, there could be a need for mass relocation of animals and, in the most severe cases, of the entire production system. Simultaneously, it will be necessary to ensure daily interventions such as feeding, milking, and veterinary controls which cannot be delayed for extended periods, whereas crops exposed to atmospheric events are more affected by climatic events compared to the other forms of farming, for which areas, however, adequate protection must be ensured in any case. Since greenhouses and plant nurseries are intensively managed, resulting in minimal fuel accumulation, and often surrounded by areas where fuel is actively managed, creating a mosaic of non-flammable land uses, classifying the emergency level in these facilities as a relevant alert state rather than an extreme alert one is justified. Similarly, owing to their ability to drain water and the natural resilience of their ecosystems, forests are generally able to withstand flooding without suffering extensive or permanent damage, making an active alert state the most appropriate one.

Despite the interactions between causes, related events, and impacts on specific sectors within the AFA domain, the immediate consequences during the emergency phase require a variety of professional skills. Fig. 3 proposes a partial extension of the conceptual scheme of Fig. 1 with the addition of a new entity called *Domain Expert*, which establishes an < < *aids* >> relationship with the class *Post-Emergency Restoration*. The professional skills required can therefore be seen as specializations of the *Domain Expert* and, certainly, the list in Fig. 3 is not exhaustive. The introduction of the *Domain Expert* concept allows for a more interdisciplinary approach to

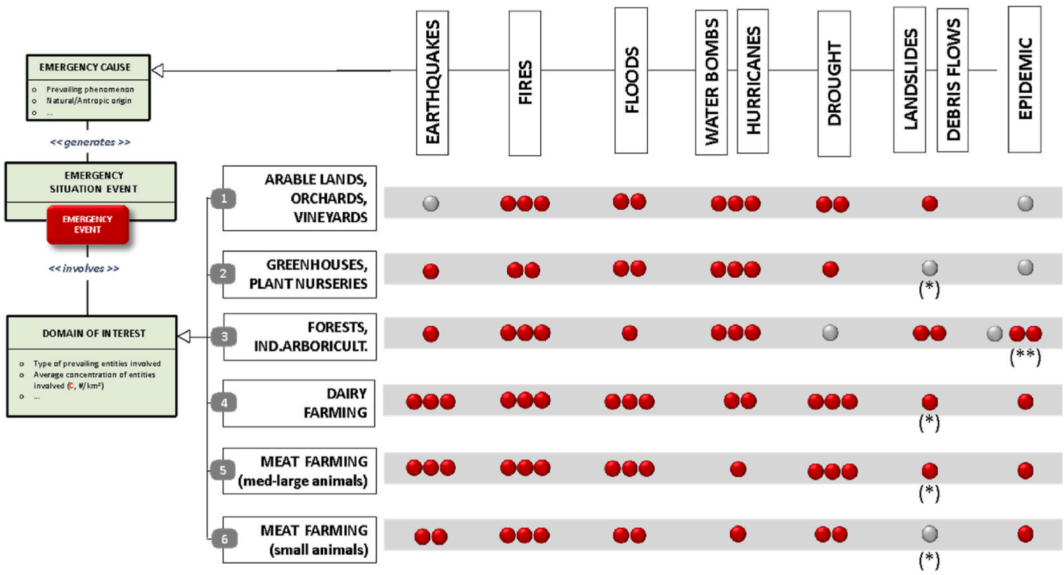

Fig. 2. Emergency levels for the *Cause X Domain of Interest* Matrix Legend: ○ = No or low alert; ● = active alert state; ●● = relevant alert state, with urgent action planning; ●●● = extreme alert state, with need for immediate action. Notes: (*) only when present in an area at risk, owing to the need for moving animals elsewhere. (**) only for trees not subjected to plant defense preventive programs.

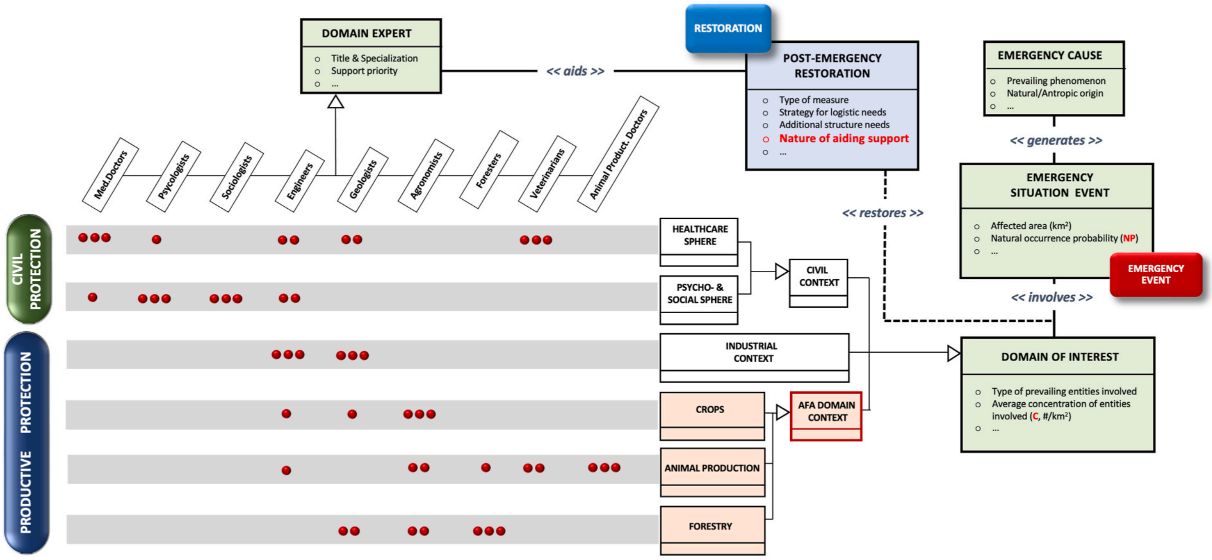

Fig. 3. Relations between professional figures and emergencies involving different types of domains of interest. Legend: OOO = essential role, necessary competence; OO = relevant role, highly recommended competence; O = supporting role on marginal aspects, competence on punctal problems.

emergency management, promoting collaboration among various professionals such as agronomists, foresters, animal production doctors, veterinarians, and engineers. This fosters a comprehensive response to emergencies that takes into account not only immediate recovery but also long-term sustainability and resilience in the AFA domain. The figure also proposes a *Domain Expert* X *Domain of Interest* matrix that clarifies the prioritization of professional roles within different *Domain of Interest* areas, enabling more effective deployment of specialized expertise in the restoration phase.

Two main intervention priorities emerge within the model:

- ***Civil protection***, covering interventions in the civil sphere, including health and psychological support, structural restorations, and the guarantee of sustainable living conditions. Given the high density of population involved in these situations, civil protection efforts often require the highest priority, both ethically and socially;
- ***Productive protection***, focused on restoring primary production sectors in affected areas. Here, interventions prioritize safeguarding primary and secondary sector structures, while interventions in the tertiary service sector often overlap with civil protection efforts.

Some professional roles are critical in only one priority area (*e.g.*, medical doctors, psychologists, sociologists, agronomists, foresters, animal production doctors), while others, such as engineers, geologists, and veterinarians, have cross-sector roles. Specializations within the agricultural, forestry, and animal production contexts are often marginalized in traditional emergency management, despite the fact that these sectors face distinct impacts. Moreover, it should be emphasized that emergency management encompasses not only immediate response but also recovery actions, which should be oriented towards risk prevention.

The model addresses this problem by emphasizing the need for agricultural, forestry and animal production expertise in emergency contexts, a need which is often overshadowed by civil protection procedures. Currently, the competences required by these sectors are often substituted by external actors (*e.g.*, agronomists by engineers, foresters by geologists or naturalists, animal production specialists by veterinarians), highlighting the model's importance in advocating for sector-specific competencies in an emergency response. Additionally, biologists and architects are frequently involved in decision making processes which underscores the inadequate recognition of emergency impacts in the agricultural, forestry, and animal production sectors compared to others and reinforces the need for a model that prioritizes sector-specific skills for recovery and risk prevention. This is especially pertinent as many of these professionals/scholars/experts of the AFA domain are either owners of the agro-silvo-animal production farms/enterprises affected by these disasters or serve as technical advisors, suggesting that, if involved, they could bring valuable expertise to emergency management and recovery efforts improving resilience in the AFA domain [30], as also emphasized by Food and Agriculture Organization (FAO) and the United Nations Office for Disaster Risk Reduction (UNDRR).

3. Specific case studies

In the following chapter, three case studies are described, focusing on the type of agent underlying the emergency. For each case, details are briefly provided, including the location, timing, nature of the event, and main consequences and each paragraph critically examines the risk prevention actions that were implemented. Emergency and recovery actions taken in response to the events are also outlined, highlighting critical elements such as the type and timeliness of these actions. Finally, each paragraph identifies what was missing in the response efforts.

3.1. Rainstorms in 2023

The first case study considered is related to the rainstorms that occurred in the Emilia-Romagna region (Italy) on May 2–3, May 9–10, and May 15–18, 2023. In the province of Forlì (44° 13′ 21.863″ N 12° 2′ 26.632″ E, 44.2227398–12.0407312), rainfall of 300 mm fell over three days, which was eight times higher than the reference climatological monthly value. Particularly in the days 16–18 May 2023, 350×10^6 m^3 of water, equivalent to six months' rain, fell within 36 h across Emilia-Romagna, one of Italy's most important agricultural regions [31]. This resulted in severe flooding and landslides. When the damage was assessed, it was found that 23 rivers had overflowed, and about 700 roads had been closed [32]. Moreover, more than 2000 rainfall-triggered mudslides had cut off villages and destroyed homes, infrastructures, vineyards, orchards and anything else in their wake [33]. Consequently, the impact of these disastrous events on the agricultural and livestock industry was enormous, as reported below specifically for each one.

With respect to the crop production sector, it has been estimated that tens of thousands of hectares of agricultural soil were affected by floods caused by these rainstorms [34]. Initial estimates indicated a risk to around 15×10^6 fruit trees and a grain production loss of at least 400×10^6 kg of wheat, with extensive crop damage expected to total about €1.5 billion [35]. The problem was owing to root asphyxiation caused by prolonged waterlogging and large amounts of suspended sediment eroded from slopes that settled on the valley floor. These sediments, mostly composed of silt and very fine sand, accumulated to a thickness of 40–80 cm, posing major challenges for crops (both herbaceous crops and fruit trees) and soil restoration efforts. Another problem of frequent flooding events is related to the heavy impact on microbial community composition and functionality, with significant (and prolonged) consequences on the health of flooded soils and crop productivity [36–38]. The solution often adopted was to remove the sediments, which, besides being costly, created problems for their disposal, concerning environmental impact and proper management of the extracted materials. The restoration level of the initial biotic and abiotic parameters of soil, which contribute to its fertility and are profoundly affected by landslides [39], depends greatly on both the efficiency of sediment removal and the time elapsed before the removal operation begins.

Some preventive actions were taken, but they only partially mitigated the impacts owing to critical omissions. The Emilia Romagna region had implemented measures to reduce agricultural land risk through organic practices favoring soil health and resilience [40]. However, these measures were insufficient to fully protect agricultural lands during extreme flooding. Additionally, some approved preventive projects either never came to fruition or were only partially completed by the time of the event [40]. Furthermore, the flooding exposed critical inadequacies in prevention, such as *i*) inadequate and poorly maintained drainage and land setting systems in agricultural areas, *ii*) limited water infiltration and water holding capacity of agricultural soils (*e.g.*, as described for recently reclassified *Vertisols*, characterized by deep soil drying, high density, and poor gas exchange), *iii*) poor river maintenance and land management for efficient water harvesting systems, *iv*) lack of early warning systems and emergency preparedness tailored to farming communities, *v*) insufficient implementation of resilient practices such as mountain reforestation, and *vi*) limited coordination between the parties involved, including agricultural agencies and farmers [32,41].

On May 4, 2023, a 12-month state of emergency was declared, and the civil protection service was activated to support rescue efforts, particularly towards the displaced population. This also included *i*) damage assessments to quantify losses to crops, livestock, farm equipment, and infrastructure, *ii*) restoration of damaged agricultural infrastructure (such as irrigation canals, roads, bridges and fences), *iii*) distribution of emergency supplies to affected farms, *iv*) implementation of soil remediation measures to remove debris and contaminants, *v*) offering mental health support and counseling to the farming community, and *vi*) reconstruction of adequate land setting and drainage systems. However, the recovery process was hampered by the scale of damage, delays in aid reaching farmers owing to unavailability and bureaucratic hurdles, lack of coordination between different recovery programs and agencies, and farmers having to navigate complex application processes for assistance.

Based on what happened, it can be argued that a thorough review of inadequate prevention exposed by the 2023 flooding is crucial for improving agricultural land emergency and risk management plans. To this purpose, mapping agricultural areas/farms at risk of emergency events [42] appears crucial for effective resilient agricultural management. Moreover, investing in upgrading flood control infrastructure in key agricultural areas, developing emergency plans tailored to farming communities and early warning systems are of paramount importance. In this event, early weather alerts were issued starting on April 20, 2023, allowing some preparation time [32]. From a technological standpoint, several key actions can enhance disaster resilience: *i*) integrating the hazard maps previously described into planning and operational simulation tools, such as digital twins, to simulate impacts, *ii*) applying intelligent assets and tools to build flood resilient systems, enabling real-time or preventive decisions concerning diversion tactics, *iii*) utilizing real-time data from weather forecasting models, integrated with data from dam and river sensors, to detect anomalies and to automatically raise emergency alerts, *iv*) adopting digital twins for evidence-based infrastructure planning decisions and monitoring the progress of investments aimed at rebuilding infrastructure, and *v*) elaborating current and future scenarios of climate change events and impacts. Implementing these measures can improve decision-making throughout the disaster resilience life cycle - from response to recovery, from mitigation to preparedness - by collecting more data and transforming them into intelligent insights for smart river and water management [43]. Additionally, providing incentives and support for farmers to adopt resilient practices such as cover crops, agro-forestry, and precision irrigation is beneficial. Streamlining emergency aid and recovery programs to get assistance to farmers faster and improving coordination between agricultural agencies, disaster authorities, and farmers is indispensable. Enforcing regulations to limit development in high-risk areas and maintain permeable surfaces, along with initiative-taking maintenance and upgrades to ageing flood control infrastructure, is also necessary. In these actions the proactive involvement of agronomists and scholars of agricultural sciences is fundamental, especially considering their wide knowledge of the agricultural context and its vulnerabilities. It is also crucial to restore soil health and biological functionality in its biotic and abiotic parameters, which are seriously compromised by mudslides [44], as soon and completely as possible [39,45,46]. Considering the ecosystem services provided by soil and how they can be threatened by mudslides [47] restoration is even more vital.

With respect to the animal production sector, from a general perspective, the management of livestock during emergency events not only affects animal welfare, health, and survival but also has an impact on food availability, food safety, and public health. A recent survey published in the Disaster Medicine and Public Health Preparedness Journal [48] by 53 members of the World Organization for Animal Health, revealed that floods and forest fires have been the most commonly encountered natural disasters over the past decade. Specifically concerning the rainstorms of May 2023, it is noteworthy that in the provinces of the Emilia-Romagna region involved in flooding (Forlì-Cesena, Ravenna, Bologna, Rimini), approximately 250,000 cattle, sheep, goats, and pigs, along with about 400 poultry farms and nearly 45,000 beehives were affected [49]. Critical issues during the emergency phase included difficulties for breeders to access livestock farms owing to impassable roads, challenges in recovering and disposing of drowned animals, water shortages from broken pipes, and supply shortages of forage and concentrates. Direct damage to the livestock sector was estimated at around €300–400 million, not accounting for implications on the entire food chain, from crop losses in flooded areas to disruptions in the supply of milk, meat, and eggs to the food industry.

Although multiple international guidelines for risk prevention exist, they primarily focus on population safety and environmental security, often mentioning animals and farms only as potential vectors of infectious diseases [32], as was evident when on May 4, 2023, a state of emergency was declared and such health and safety related measures were implemented. In this regard, it is important to note that risk reduction plans should involve the entire food chain (farmers, feed companies, breeders, dairies, slaughterhouses, animal production professionals, etc.) and be validated using models and disaster simulations with a machine learning approach. During the emergency phase, the Breeders' Association of the Emilia-Romagna Region (ARAER) was one of the first organizations to intervene with post-flood support to farmers. Additional support came from Civil Protection, Fire and Rescue services, Local Police, Alpine Rescue teams and volunteers. ARAER set up various initiatives, mainly on a voluntary basis, including direct feed collections, donations, and the establishment of collection centers to aid livestock farms which were at risk of running out of feed. Within two months of the flood, 18 tons of concentrates and 2000 large bales of forage had been distributed to affected farms. However, relief efforts were hindered by the lack of a specific plan which should have ensured: *i*) location traceability of the livestock farms involved; *ii*) rapid intervention for the feeding and milking of dairy animals and water availability; *iii*) access to emergency recovery for animals of different species and categories; *iv*) availability of vehicles capable of reaching farms and transporting animals; *v*) emergency feeding for displaced animals; *vi*) restoration of farm equipment (tractors, mixer wagons, milking systems, etc.). Therefore, to effectively manage emergency situations on farms like the ones in this case study a collaborative approach is essential, requiring coordinated effort from various stakeholders including authorities, organizations such as Civil Protection, breeders' associations and private companies. Central to this effort are experts in farm animal care, with knowledge of animal feeding and nutrition, and animal management and husbandry. Furthermore, integrating principles of precision livestock farming and precision feeding, alongside the employment of cutting-edge technologies such as robotics and sensors in the livestock sector, can prove invaluable not only in mitigating risks, but also in effectively managing emergencies and facilitating recovery. Additionally, risk reduction plans involving the entire food chain and the involvement of professionals in the animal production sector with expertise extended also to emergency management are of paramount importance. The high risk of livestock waste spillage and/or alteration of large quantities of livestock feed with events like those mentioned not only represents a serious threat to animal, public and environmental health but also requires the involvement of specific chemical, biochemical, microbiological and engineering skills of the AFA domain for the valorization of these biomasses in a circular economy context or, when too late, their safe disposal.

3.2. The Vaia storm in 2018

The second case study taken into consideration is the *Vaia* storm, which occurred in North-Eastern Italy between October 27 and 30, 2018 [15]. Meteorologically, the storm was associated with a mid-tropospheric trough over Western Europe, featuring a pronounced large-scale trough typical of intense Alpine precipitation events. The storm was exceptional in terms of wind, accumulated rainfall (up to 850 mm in three days), and integrated water vapor transported over the Mediterranean [50]. The storm resulted in heavy rain, floods, landslides, storm surges, and extensive forest damage [51], causing significant societal and environmental damage, including 16 casualties, interruptions to traffic and the electricity supply, infrastructural damage, and disruptions to daily life. The storm's effects were far-reaching, affecting various parts of Italy with extreme weather conditions [50,52]. The growing stock volume of fallen trees was 8.5×10^6 m^3 over a forest area of 42,500 ha in the northeastern Alpine region [53], making the worst incident of wood destruction in Italy's history. Such large-scale tree mortality has had significant impacts on forest ecosystem services, including soil protection from erosion, infrastructure protection from rock falls and avalanches, as well as loss of timber value in productive forests. A further problem related to soil erosion is the impact on resident microbial communities and on soil multi-functionality since eroded soils exhibit significant changes in the structure of microbial communities, with implications on microbial network complexity and nutrient cycling [54]. Finally, there has also been a loss of identity and aesthetic value for iconic Italian landscapes, which has important socio-economic implications, particularly for tourism and recreational activities.

Preventive measures against *Vaia* windthrows included silvicultural treatments in spruce forests to increase their mechanical stability by reducing the height-to-diameter ratio of the trees. Nevertheless, these measures only partially succeeded in mitigating the effects of the storm owing to its extreme intensity and tree mechanical stability was overcome. Moreover, the homogeneous and largely monospecific structure of many spruce forests in Northeast Italy, a result of centuries-old forest management practices, further limited the effectiveness of these preventive actions. In the immediate aftermath of the *Vaia* event, emergency and recovery actions were necessary to recover the vast volumes of deadwood in the affected area as quickly and as completely as possible to prevent its technological degradation and to reduce the dangerous accumulation of easily ignitable deadwood in the forest [55]. Such deadwood can also be easily colonized by fungal taxa exhibiting both saprophytic and pathogenic lifestyles [56,57]. Despite timely intervention some difficulties remained, such as the lack of companies capable of cutting and transporting dead trees over large areas and market sluggishness in absorbing large quantities of wood which led to speculation and depreciation of wood value [58].

What was missing in the circumstances of the *Vaia* storm was integrated land planning capable of mitigating the severity of extreme events and flexible administrative protocols (*e.g.*, de-bureaucratization) for the timely implementation of strategic restoration programs [59]. This would include measures such as training enterprises in the management of windthrow areas, the creation of storage areas for deadwood, and emergency planning of economic supply chains. Recovering the wood production chain, starting from sawmills and logging infrastructure, can be deemed mandatory. Furthermore, if the technological degradation of dead wood should occur, it would be crucial to have strategies for these biomasses that would still allow their valorization in a context of a circular economy of the forest environment. In this respect, providing expertise and knowledge to enterprises and employing professionals to plan, design, and implement prevention, emergency, and restoration measures appeared to be crucial. Moreover, from a recovery point of view, large-scale restoration plans could be financed by multiple funding sources, including emergency civil protection resources, EU funds (*e.g.*, Rural Development Program funds, Next Generation EU), and private capital. They should include restoration measures such as deadwood management, seeding, tree planting and hydraulic and naturalistic engineering works, for which the involvement of forestry professionals and scholars is essential.

The case study of the *Vaia* storm is also interesting because it provides an opportunity to address the topic of secondary critical events emerging from the first. These are generally triggered by specific consequences of the initial event and can emerge within a short to medium time lapse, and may present an impact intensity comparable to, or even greater than the original one. A typical example is the infestation of the European spruce bark beetle (*Ips typographus* L.) in the forests of north-eastern Italy, where in the Bolzano province alone a forest surface of about 17,000 ha has been affected over the last 3 years. The impact of this infestation, exacerbated by the enormous volume of deadwood resulting from the *Vaia* storm, adds to the initial damage caused by the original emergency. The beetles, mainly attacking Norwegian spruce trees, burrow under the bark, creating tunnels that block the flow of sap, ultimately leading to the death of the host trees [60]. Without the *Vaia* storm the criticality linked to the bark beetle would have been treated, despite its gravity, as a chronic issue manageable with ordinary approaches by specific disciplines. However, the enormous volume of deadwood caused by the *Vaia* created conditions for the uncontrolled development of the beetle, which led to such a significant long-term risk that the issue has been transformed into an emergency, necessitating the specific approaches involved in this case study. In this context, preventive actions for beetle attacks would involve salvage logging to reduce the amount of deadwood acting as an inoculum for the insect. Up to now, these measures have only partially succeeded owing to the large scale of the infestation and the high reproduction rate of the beetles under warming temperatures. Moreover, the critical issues in emergency management for the beetle infestation overlap with those found for the *Vaia* storm, highlighting the need for comprehensive and integrated approaches to disaster resilience where the knowledge and experience of forestry professionals and scholars is of vital importance. In all this, timely action is a crucial aspect for which emergency management planning and training are essential.

3.3. Wildfire events in 2017

The third case study concerns two severe wildfire events that were part of a series of large wildfires which hit Italy in 2017, resulting in significant environmental and economic damage [61]. The first event occurred at the Vesuvius National Park in July 2017, where approximately 60 % of the national park was affected by high-severity fires [62]. The second event took place in the Western Alps in October 2017, where simultaneous large wildfires burned around 10,000 ha of land over a period of two weeks causing stand-replacing effects in the protection of forests from rock fall and avalanches [63]. These wildfires were notable for their intensity, extension and severity, leading to a marked socio-economic impact with loss of forest functionality [64], threats to safety and health, and damage to iconic landscapes [65]. These large and severe wildfires are becoming more and more frequent in Italy as a consequence of land use changes interacting with extreme fire-inducing weather conditions [66]. During these emergencies, the capacity for extinguishing the fires collapses under multiple synchronous large wildfires over extensive areas [61]. Furthermore, fuel management and silvicultural treatments are too limited and insufficient to influence the behavior and severity of these fires [62,63]. And the large amount of canopy and understory fuels accumulated owing to the lack of forest management has been increasing the vulnerability of these forests in certain climatic conditions [67].

One year after the events an emergency plan provided guidelines to reduce the vast volumes of decaying and dead trees that posed a danger to road safety and represented a hazardous accumulation of deadwood over extended areas [68]. The plan detailed how to design restoration measures as a function of forest type, functionality and fire severity and suggested measures such as hydraulic infrastructures, post-fire silvicultural treatments, seeding, afforestation and natural engineering measures [68]. However, in the same way as had already been observed for the *Vaia* event and the consequent European spruce bark beetle infestation, timely intervention faced difficulties owing to the lack of appropriate systems for cutting and extracting dead trees over large areas. Consequently, the low efficiency of restoration actions contributed to deadwood accumulation with high flammability, increasing the probability of future wildfires. As described previously, strategic infrastructural planning for firefighting security and forest resistance (*e.g.*, pyro-silviculture techniques to increase the stand structure diversity and species composition) and deadwood management are of great importance in mitigating the severity of wildfires [66]. In this sense, the involvement of forestry professionals and scholars in defining fuel management and restoration plans is indispensable along with flexible administrative protocols and training programs for timely and effective prevention, especially considering the increasing risk posed by climate change and heat waves [69]. This takes on particular relevance if we consider the set of ecosystem services provided by forests and the need to guarantee them to future generations, as also underlined by the European Union in *Forest Ecosystem Condition, Services, and Biodiversity* (https://forest.jrc.ec.europa.eu/en/activities/forest-ecosystem-services/).

4. Comparative analysis of emergency management strategies in the three case studies

This chapter compares the responses to three emergency situations: the 2023 rainstorms in Emilia-Romagna, the 2018 *Vaia* storm, and the 2017 wildfires. The analysis focuses on three key aspects: 1) the government's response to emergency situations across the three case studies, exploring how evolving strategies and technologies were employed to mitigate impacts; 2) the role of AFA domain professionals/scholars in the emergency response phases, highlighting their contributions and the need for collaboration in enhancing AFA domain resilience; and 3) the retrospective analysis using the proposed conceptual model, which identifies lessons learned and future applications for improving emergency management practices. By adopting this analytical framework, the chapter aims to provide insights into effective emergency management and the integration of various stakeholders, including domain professionals/scholars, by addressing vulnerabilities across diverse emergency events.

4.1. Government response to emergency situations across the three case studies

The analysis of the Italian government's emergency responses across the three emergencies reveals evolving strategies in their management. These approaches demonstrate a commitment to enhance emergency response through the integration of risk maps, real-time monitoring technologies, and targeted financial support. This evolving strategy effectively mitigates the immediate and long-term impacts of natural disasters, highlighting the importance of collaboration between government agencies, regional authorities, and scientific and professional organizations to ensure timely and efficient responses. Regarding the 2023 Emilia-Romagna rainstorms, the declaration of a state of emergency on May 23 enabled the mobilization of resources and the allocation of a dedicated budget for recovery efforts. Risk maps for flood-prone areas were updated, while satellite-based monitoring systems from the European Space Agency and Copernicus provided real-time data to enhance flood risk management and preparedness for future events. For the 2018 *Vaia* storm, following the state of emergency declaration on November 8, government efforts focused on clearing large volumes of deadwood and reforestation, supported by a specific fund managed by the Agricultural Grants Agency (AGEA). The Italian Institute for Environmental Protection and Research (ISPRA) developed updated forest risk maps, while satellite imagery and drones from National Research Council (CNR) and European Space Agency (ESA) were used to monitor forest recovery and address secondary risks, such as soil erosion and bark beetle infestations. Affected parties received partial financial compensation for the damage incurred. In response to the 2017 wildfires, regional forestry and civil protection agencies, supported by land managers, professionals, and research institutes, collaborated to design post-fire restoration plans. Their goal was to request that the State (National Department of Civil Protection) temporarily waive the National Law on wildfires, which prohibits public funding for post-fire restoration within four years of a fire. This waiver allowed them to obtain emergency funds for implementing restoration efforts. Following the 2017 wildfires, the regional government also strengthened wildfire risk assessments for the landscape and adopted strategic fuel management, engaging significant professional and research expertise in the forestry sector. At national level, the Ministry of Agriculture provided financial compensation to farmers and landowners affected by the fires.

4.2. Role of professionals in the emergency Response phases

The comparative analysis also reveals varying degrees of engagement from AFA domain professionals. The 2017 wildfire events showcased significant involvement from forestry professionals in implementing preventive measures such as selective thinning of forest areas. However, the extreme fire behavior underscored the need for comprehensive land management strategies beyond immediate suppression efforts. On the other hand, the *Vaia* Storm of 2018 exemplified effective engagement from domain professionals, especially during the recovery phase. Forestry experts played a crucial role in managing the vast volumes of deadwood resulting from the storm, significantly enhancing disaster resilience despite logistical challenges. This case illustrates how proactive engagement and timely intervention can lead to successful emergency recovery. Moreover, the subsequent bark beetle infestation highlighted the importance of collaboration among domain experts in addressing emerging secondary crises. For these reasons, the *Vaia* Storm case serves as a powerful example of the effective involvement of professionals and scholars in the emergency recovery and protection of vulnerable agro-forestry communities and related ecosystems. In contrast, the response to the 2023 rainstorms exhibited less effective collaboration among professionals, resulting in delays in recovery strategies. This situation emphasizes the necessity for interdisciplinary preemptive planning and the integration of expert knowledge of the domain with emergency management practices of the AFA domain itself. This is especially pertinent as many of these professionals/scholars are either owners of the agro-silvo-animal production farms/enterprises affected by these disasters or serve as technical advisors to these owners, suggesting that, if involved, they could bring valuable expertise to disaster management and recovery efforts improving resilience in the domain. Greater integration of these professionals/scholars into disaster planning and response, as a part of the citizen engagement strategy [70], aligns with international best practices. Organizations such as the Food and Agriculture Organization (FAO) and the United Nations Office for Disaster Risk Reduction (UNDRR) emphasize the importance of involving local professionals/experts in disaster risk reduction and recovery strategies [71]. Their inclusion remains essential for building a more resilient disaster management approach that safeguards the environment and the livelihoods within the agro-silvo-animal production sectors.

4.3. Retrospective analysis using the conceptual model and future applications

The conceptual emergency management model presented here (Figs. 1, and Figs. 2 and 3), offers a structured approach to analyze, manage, and mitigate the impacts of adverse climatic phenomena.

First, to understand how the three case studies fit in this model, it is crucial to categorize each event according to its specific vulnerabilities and impacts. The first case study, focusing on the rainstorms in Emilia-Romagna in 2023, highlights significant vulnerabilities within both the agricultural and livestock sectors. The extreme rainfall, classified under the model's *climatic phenomena* category, resulted in severe soil erosion, sediment deposition, and root asphyxiation. Critical vulnerabilities identified include inadequate drainage systems that failed to manage the excessive water and limit soil water infiltration. Additionally, the livestock sector faced substantial challenges, with restricted access to farms and disrupted supply chains caused by damaged infrastructure. Moreover, the risk of environmental contamination with potential health consequences owing to livestock waste spillage and the alteration of large biomass quantities of livestock feed during floods affecting livestock facilities is notably high. Such events can lead to significant ecological impacts, necessitating careful management and preventive measures that extend beyond the AFA domain itself (*e.g.*, addressing contamination risks to drinking water supplies and other public health concerns). These systemic weaknesses underline the importance of utilizing the model to guide recovery efforts and enhance resilience in both the short and long term. The second case study, focusing on the *Vaia* storm of 2018, is categorized under both *climatic phenomena* and *geological emergencies*. This storm brought extreme winds and rainfall that devastated forested areas in northern Italy, leading to soil erosion and landslides. The vulnerabilities highlighted in this case include the accumulation of deadwood, which increased the risks of fire and infestation. By applying the model, timely interventions could have been implemented, such as deadwood removal and the restoration of affected ecosystems, ensuring a more effective response to the storm's aftermath. Lastly, the third case study examines the wildfires in Campania and Piedmont in 2017, which were driven by extreme heat and drought. These wildfires come within the *climatic phenomena* category and emphasize the vulnerabilities present in forest management practices. Key issues included the presence of deadwood and inadequate strategies for managing forest ecosystems, which heightened fire risks. The model could have guided a more structured approach to wildfire management, prioritizing interventions such as forest thinning and the adoption of pyro-silvicultural techniques to promote resilience against future wildfires.

With this framework, we explored the retrospective application of the model to each of these remarkable events and this gave us valuable insights for improving future emergency management strategies. Firstly, it is essential to identify and mitigate vulnerabilities within the affected systems, whether they involve agricultural infrastructure, livestock management, or forest ecosystems. The model's matrix of emergency causes and impacts (Fig. 3) would have facilitated the identification of critical points, such as inadequate drainage systems during the Emilia-Romagna floods or the accumulation of deadwood that heightened fire risks in Campania and Piedmont. Proactively assessing these vulnerabilities is vital for informing effective interventions. Another crucial aspect is the involvement of AFA domain professionals/scholars (Fig. 3). The model emphasizes the importance of specialists in agronomy, forestry management, and animal production throughout the emergency management process. Engaging these professionals/scholars in both the response and recovery phases ensures that actions are grounded on the best available knowledge. For instance, agronomists could contribute to restoring soil health after the floods in Emilia-Romagna, while forestry professionals could guide strategies for the timely removal of fallen trees following the *Vaia* storm. Moreover, the integration of technology and precision management emerges as essential for improving decision-making and optimizing responses during emergencies. The implementation of advanced technologies, such as precision agricultural tools and real-time monitoring systems, would allow for rapid assessments of conditions and efficient resource distribution, as evidenced in the livestock sector during the Emilia-Romagna floods. The necessity for a coordinated emergency response is a recurring theme. Collaboration among various stakeholders (government agencies, local organizations, and domain professionals) can significantly enhance emergency responses, ensuring that resources are allocated where they are most needed and that recovery efforts are comprehensive and inclusive. In Emilia-Romagna, the involvement of civil protection services and breeders' associations was crucial in managing the immediate aftermath of the flooding. Finally, each case study underscores the importance of building long-term resilience. This means not only addressing immediate impacts but also promoting sustainable land management practices, improving infrastructure to withstand future climatic events, and developing risk reduction plans that encompass the entire food chain.

The retrospective application of this model illustrates the potential for an integrated, resilient approach to managing emergencies, ensuring that emergency responses are not only reactive but also proactive, addressing vulnerabilities and promoting sustainable practices for long-term health and safety of both human and environmental systems. The model highlights three essential elements for an effective and resilient emergency management approach: *i*) a planning phase in emergency management to guarantee timeliness and effectiveness, including risk maps and extensive use of technology; *ii*) the involvement of professionals and scholars of the AFA domain to appropriately identify intervention forms and methods that expedite the emergency management phases, including recovery, with particular attention to improving the resilience of the affected area; *iii*) training and capacity-building activities extended to the various actors. Lastly, ongoing training and capacity-building programs are indispensable to equip all stakeholders with the necessary skills and to foster interdisciplinary collaboration, ensuring that scientific and technical knowledge are integrated into emergency planning and decision-making processes. Through this integrated approach, the conceptual model not only enhances immediate emergency response but also sets a foundation for a more robust and sustainable framework capable of safeguarding both the environment and the livelihoods of those within the agricultural, forestry and animal-production sectors.

5. Discussion

The development of agricultural, forestry, and animal production systems worldwide has historically relied on technological advancements and new scientific knowledge. It is interesting to note that currently the AFA domain is undergoing further transformation driven by emerging (bio)technologies [72–74]. This evolution promises greater productivity and profitability within a framework of enhanced sustainability. However, the success of this transition hinges on the widespread adoption of these innovations in the AFA domain, which significantly depends on the roles played by domain professionals. In this respect, scholars in agricultural, forestry, and animal sciences serve as crucial links between innovation and practical application, applying their comprehensive knowledge to facilitate this transformation. Moreover, the interconnected roles of these professionals emphasize the shared reliance of the AFA domain itself on natural resources (such as soil health, water, biodiversity, etc.) and highlight the necessity for coordinated management across the three sectors. While agriculture, forestry, and animal production sectors all belong to the primary production domain and share certain resource dependencies, each sector also faces distinct operational challenges and requires specialized professional expertise to address them effectively. This diversity within the AFA domain justifies an approach that is unified yet recognizes the specific skills needed for each sector's particular challenges. By maintaining ecological stability and optimizing resource use, each sector of the domain can benefit the others; for instance, sustainable forestry practices enhance water cycles and soil health, and restore agricultural and grazing lands, while agronomic methods improve soil quality and sustain ecosystems that support both forests and livestock. As either owners or technical advisors, the domain professionals/scholars are pivotal in fostering synergies that sustain productivity and environmental health, underscoring the need for a unified approach to managing the agricultural, forestry, and animal production domain. Thus, not only research and innovation but also higher education is crucial in facilitating the above-mentioned transition [73,75,76].

However, the impact of climate change, particularly in extreme events, poses significant challenges to achieving this transition, as evidenced by past occurrences. The direct and indirect consequences of these events are evident in the case studies described in the present paper (i.e., rainstorms and floods, windstorms, wildfire), highlighting their potential impact on productivity and socio-economic context. Once again these challenges demonstrate how climate-related events necessitate the involvement of specialized professionals in both preparedness and recovery efforts. Agriculture, forestry, and animal production sectors, as part of the primary production domain, depend on natural and semi-natural resources, where extreme events can significantly disrupt soil, land, and ecosystems that are essential to production. Therefore, the need to integrate the three sectors into a cohesive emergency management framework is quite evident, especially when considering their shared environmental challenges and interdependent resource reliance. The proposed *Emergency Causes X Domain of Interest* matrix (Fig. 3) introduces a novel approach that clarifies the roles of various professionals in emergency management, ensuring that their unique expertise is effectively utilized in addressing specific challenges. In this respect, it is worth mentioning that currently, while risk prevention, prediction, and monitoring, as well as mitigation actions are operational in the domain [77], emergency management receives inadequate attention despite the increasing frequency and severity of extreme climate events. Regarding this aspect, the integration of advanced technologies, such as precision agriculture and real-time monitoring, can improve emergency response and decision-making processes, ensuring that vulnerable areas are prioritized for interventions. Although there are systems of income support and protection (public, private, or mixed) and restoration contribution systems (including insurance), they are often implemented with significant delays, only partially addressing the damage, and affected by considerable bureaucratic constraints. Moreover, the limited emergency activities in place are mostly managed by professionals with marginal knowledge, skills, and competencies relevant to the peculiarities of the domain, resulting in inconsistent and often delayed actions. For instance, the common strategy for forest fires prioritizes containment (primarily protecting, as might be expected, people and buildings) over extinguishing, leading to significant forest area loss [78,79]. Similarly, during extensive flooding events like those in Emilia-Romagna Region in May 2023 [32], the isolation of livestock farms, which in an emergency rely on help from individual and voluntary actions of other farmers, poses risks to animal health and survival, especially in prolonged events.

To address these challenges effectively, it is essential to recognize that involving professionals/scholars from the agricultural, forestry, and animal production sectors is not a return to outdated approaches, but rather an essential evolution to meet current demands. The matrix enhances the operational capabilities of professionals by providing a clear framework for collaboration, ensuring that their combined expertise can lead to more timely and effective responses to emergencies. Furthermore, an evaluation of the effectiveness of the conceptual model presented here is necessary, along with potential adjustments based on feedback from case studies and stakeholder experiences. Currently, experts from these sectors are rarely formally engaged in emergency management efforts and integrating farm/enterprise owners or their technical advisors would represent a substantial advancement over existing approaches. These professionals bring valuable expertise and local knowledge to emergency management within these interconnected sectors of the AFA domain. Since they are either direct stakeholders or advisors in the domain, involving them is not merely common sense but a logical and necessary step towards engaging a wider base of citizens and stakeholders in emergency actions. In this respect, it is relevant to note that timely and appropriate recovery actions are crucial to restoring farm operations and minimizing economic repercussions that could compromise the survival of the farm itself. Indeed, other domains such as health care, buildings and services, and social services (see also Fig. 1), already possess effective emergency management systems (*e.g.*, for pandemics, earthquakes, floods, landslides), involving professionals perfectly aligned with their respective domains (such as medical doctors, veterinarians, engineers, geologists, psychologists, etc.). To address the lack of emergency management in the AFA domain a prompt planning action is urgently needed that also capitalizes on the emergency systems already operational in other domains. This planning should actively involve professionals who possess both domain-specific knowledge and emergency management expertise, with academia playing a crucial role in producing new knowledge and extending educational programs to include emergency management. By making use of the knowledge and skills of those who are directly involved in agricultural/forestry/animal production practices, it is possible to create a more effective and responsive emergency management system. This engagement fosters a sense of ownership and responsibility within the community, enhancing resilience.

Education should be developed by taking advantage of the basic knowledge and technological advancement already acquired or in the process of being acquired in the AFA domain. This knowledge should be tailored to the specific nature of the different types of emergencies (see also Fig. 1: events *vs.* domain sectors) incorporating insights from historical case studies and new emergency scenarios. To achieve this, an investment in both new research and training of researchers focusing on these topics will be fundamental elements. With respect to education, investments in training courses, including tailored courses for domain professionals (such as executive Masters, lifelong learning activities, etc.) and professional re-training, are essential. In this regard, the ever-increasing availability of distance learning and e-learning tools, including e-learning platforms [80], new non-curricular training formats (*e.g.*, microcredentials), and promising applications of generative Artificial Intelligence (AI) for learning assistance with Open Artificial Intelligence technology, could prove particularly useful, especially in the context of lifelong professional learning. These tools can enhance the capabilities of domain professionals, allowing them to respond more effectively to emergencies. In fact, AI-driven simulations and real-time scenario generation, mimicking emergency situations, can immerse learners in controlled yet dynamic virtual reality environments, significantly improving their emergency response capabilities and decision-making under pressure [81,82]. Moreover, by generating plausible responses, offering strategic options, and analyzing potential consequences, AI can equip learners with the skills necessary to navigate complex emergencies effectively (as shown by Refs. [83,84], and [85], among others, for emergency medicine). This, along with the possibility of tailoring (life-long) education to individual needs [86], fosters critical thinking and enhances decision-making capabilities, ultimately leading to more effective emergency management professionals. Additionally, in the context of emergency management, AI can provide predictive insights through data analysis, assisting in both risk assessment and mitigation strategies [87,88]. Legislative and working context recognition and valorization of these professional qualifications are crucial for their wider adoption and courses should combine scientific and technical knowledge of the domain with emergency and risk management skills to ensure timely and coherent actions. Fostering collaboration among domain professionals and those managing emergencies in other domains (health care, buildings, social services) is most important if coordinated interventions across specific geographical areas are to be achieved. Additionally, within the AFA domain, engaging farms (on a voluntary basis) in emergency response efforts, including the provision of material resources (machinery fleet) and operational expertise, could yield significant benefits. This is especially true for maintaining control over a territory, especially in remote and marginal areas. In fact, understanding the intricacies of a landscape, including its natural features, layout, and potential vulnerabilities, is essential for devising effective intervention strategies. Moreover, given that society's ability to adapt and thrive in the face of disasters relies on collective action, as highlighted by the findings of the ENGAGE project (https://www.project-engage.eu/), it is imperative to develop a new participatory preventive strategy that encompasses farms and farmers (including their technical advisors), particularly within the AFA domain for its greater resilience. In this case, central coordination, farmer training, and a review of civil protection systems and professional teams are essential for comprehensive and effective interventions.

6. Conclusions

This analysis underscores the urgent need for a collaborative emergency management system tailored to the AFA domain to mitigate the impact of extreme climatic events and ensure its resilience. Engaging local professionals and domain scholars in this process is essential, as they bring valuable insights and skills that can significantly enhance response strategies. In this regard, the inclusion of recovery and risk management actions will also be fundamental. During the planning phase applying knowledge from the experience gained in other domains where such management is already operational is essential. Additionally, the involvement of Domain Professionals (agronomists, foresters, animal production doctors, scholar of agricultural science in their role as either farm owners or their technical advisors) is necessary thanks to their knowledge of the specific peculiarities of the domain. This does not imply a return to past practices but rather a necessary evolution towards a more integrated approach that values local knowledge and fosters community engagement. The proposed *Emergency Causes X Domain of Interest* matrix offers a novel framework to clearly delineate the roles and responsibilities of various professionals, facilitating coordinated responses to emergencies. Its utility lies in promoting a systematic understanding of interdependencies within the agricultural, forestry, and animal production sectors, thereby enhancing resilience. In this regard, particular attention must be paid not only to increasing the knowledge, competences and skills of professionals with new profiles/specializations but also to the new insights that focused and tailored research can provide. Moreover, raising awareness of the difference between *Civil Protection* and *Production Protection* is strategic in a vision of close interconnection between the two for the greater resilience of the system, including rural and forestry areas. In fact, during the operational phase, collaboration within the AFA domain (among professionals, academia, and stakeholders such as farm and farmers, public institutions) and among domains is essential to effectively and comprehensively address these challenges.

CRediT authorship contribution statement

Stefano Cesco: Conceptualization, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition, Supervision. **Davide Ascoli:** Writing – original draft, Writing – review & editing, Funding acquisition, Supervision. **Lucia Bailoni:** Writing – original draft, Writing – review & editing. **Gian Battista Bischetti:** Writing – original draft. **Pietro Buzzini:** Writing – original draft. **Monica Cairoli:** Writing – original draft. **Luisella Celi:** Writing – original draft. **Giuseppe Corti:** Writing – original draft, Writing – review & editing. **Marco Marchetti:** Writing – original draft, Writing – review & editing. **Giacomo Scarascia Mugnozza:** Writing – original draft, Writing – review & editing. **Simone Orlandini:** Writing – original draft, Writing – review &

editing. **Andrea Porceddu:** Writing – original draft. **Giovanni Gigliotti:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision. **Fabrizio Mazzetto:** Conceptualization, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition, Formal analysis, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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