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Evaluating the flood damage on dairy farms: a methodological proposal

The debate on climate change arose several concerns on the impacts of floods on agriculture and, consequently, on food security. At the same time, the European Floods Directive asks Members States to implement suitable measures to mitigate flood damage on economic activities, including farms. Still, while several analyses were developed to estimate potential flood damages on crops, a gap exists for livestock productions. The purpose of this study is to develop a conceptual model for the assessment of flood economic damages on dairy farms. Results propose a static and a dynamic model of farms recovery actions to re-establish the farming activity, which takes into account all farm components, as well as their interaction. Facing the destruction caused by floods, a first reaction of farmers could be closing the activity, with repercussion on this well-being as well as on farm workers', and on the economy of rural areas. From this perspective, this study wants to provide a first methodological pathway to support farmers in restoring their activity.

1. Introduction

Worldwide, floods are among the most frequent and damaging natural disasters. According to international reports (CRED and UNISDR, 2016), in the last decade, they accounted for 47% of all whether related disasters. with an average number of floods per year raising to 171, equal to 50 events/year more than the value recorded in the previous decade Such events caused around 25% of the total economic damages due to natural disasters (CRED and UNISDR, 2016). Nevertheless, the true economic cost of weather-related disasters could be worse than the official figures, since only 35% of records include information about economic losses (CRED and UNISDR, 2016). The nature of disastrous floods also changed in recent years, with flash floods and acute riverine floods becoming increasingly frequent. In these cases, the speed of the water and the transport of solid material may seriously aggravate the impact of the flood (CRED and UNISDR, 2016). Nonetheless, while the overall exposure to floods has declined in most European countries, especially those in central and northern Europe, relative exposure has increased in several western and southern European states including France, Germany, Italy and the Netherlands (Paprotny et al., 2018).

In Italy, flood risk is particularly relevant: at least 28 flood events were registered just from 2010 to 2016 (Paprotny et al., 2017). ISPRA (2015) estimated that almost 23% of the national surface is under hydraulic hazard, especially in the Northern regions: Emilia-Romagna (45.7% of the surface), Tuscany (11.1%), Vene-

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to (9.7%), Lombardy (8.5%) and Piedmont (7.8%). In these areas, the presence of rivers and a dense network of artificial drainage canals for agriculture irrigation further aggravates the exposure to floods. Guzzetti et al. (2013) estimated that between 1944 and 2012 the overall damage caused by earthquakes, landslides and floods in Italy exceeded 240 billion euros, of which about 25% caused by hydrogeological events, corresponding to 61.5 billion euros, with an average of 0.9 billion a year.

The debate on climate change arose several concerns on the impacts that natural disasters and especially flood can have on the development of the human society (WHO, 2018). In particular, the effect on agriculture is relevant since it directly affects the food security and safety of people around the world (FAO, 2011). Several studies have proposed methods to estimate the economic damages of floods on agriculture. Still, the focus of such studies is limited on damage to crops, neglecting the other damageable components of a farm (see Bremond, 2013 and section 3), like livestock, machineries, buildings, equipment, food stock, etc... In this framework, the purpose of this study is to develop a conceptual model for the assessment of the economic damages of floods on dairy farming systems. The study wants thus to contribute to the debate by filling a gap in the literature, since up to now no scientific studies have been carried out on this issue. This theme is particularly relevant in Europe, where since 2007 the European Flood Directive asks Member States to adopt concrete actions to prevent and mitigate flood damages on economic activities. A proper estimation of the economic damages on agriculture and livestock production is thus essential to estimate the compensation as well as to develop policies to mitigate flood damages and make farmers able to continue their economic activity in case of flood. The paper is organized as follow: in the next paragraphs, the theoretical background will be deepened, by first explaining what the Floods Directive asks Member States, and then the state of art of the studies about the estimation of flood damages on agriculture. Then, the proposed methodology for the assessment of damages on the dairy production will be presented. Finally, we will discuss the methodology pathway and we will propose future developments of the study.

1.1. The Floods Directive

The European Directive 2007/60/EC, also known as "Floods Directive" (FD), aims to establish a reference framework for the assessment and management of flood risk in the European Union (Official Journal of the European Union, 2007). The main purpose is to reduce the negative consequences of floods on human health, economic activities, environment and cultural heritage. To do so, the FD outlines an implementation path through which each Member State shall draft appropriate Flood Risk Management Plan (FRMPs). Such plans have the objective to define the measures that need to be applied to mitigate the potential damage of floods on the areas at risk. The FD organizes the programming of the FRMPs in cycles that last 6 years. At the moment, the European Commission has released the evaluation of the first cycle which lasted from 2010 to 2015.

Before the FD, several regulations were already dealing with water and flood events at the European scale. The FD, however, introduces several innovative elements. First, the previous directive 2000/60/CE - also known as "Water Directive (WD)" - was focused on the management of river basins, to assure their ecological and chemical sustainability, but there was no mention of direct measures to reduce flood risk, as well as of the possible consequences on flood risk from the climate change. On the opposite, by explicitly asking for integration with the WD and climate change policies, the FD created a comprehensive framework for the management of river basins. Second, following the European Union Solidarity Fund, it was already possible to deliver an immediate financial help for the regions affected by natural disasters but under this policy, no action was foreseen about possible preventions measures. The measures included in FRMPs must be instead of different kinds, covering the whole cycle of flood risk management: (i) prevention actions: by preventing damage caused by floods by avoiding construction of houses and industries in present and future flood-prone areas; by adapting future developments to the risk of flooding; and by promoting appropriate land-use, agricultural and forestry practices; (ii) protection actions: by taking measures, both structural and non-structural, to reduce the likelihood of floods and/or the impact of floods in a specific location; (iii) preparedness actions: by informing the population about flood risks and what to do in the event of a flood; by developing emergency plans; and (iv) recovery actions: by returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population (European Commission, 2014). Third, while before the reduction and the management of flood risk was in the hands of each Member State, the FD provides a common European framework for all the European countries, based on the principle of cooperation between the European countries and the third parties. The cooperation base should go beyond national borders and be at the river basin scale. At the same time, the FD recognizes that the impact of floods may be different for the European countries, and for each regions and sub-regions and, for this reason, the purposes of prevention and management measures should consider the specific local characteristics of the area under potential risk.

According to the FD, the path towards the development of FRMPs must follow three steps. In the first stage, each Member State should develop a Preliminary Flood Risk Assessment (PFRA). Using maps, figures and analytical description of past flood events, they should be able to delineate the areas which may suffer from future potential negative consequences of floods on human health, environment, cultural heritage and economic activity.

In the second stage, for the areas identified in the PFRA, Member States should elaborate Flood Hazard Maps (FHMs) and Flood Risk Maps (FRMs). These maps are conceived as the knowledge base of the potential flood hazard and associated damage in the areas, to be used in the definition of the purposes of local policies and actions about the management of flood risk. FHMs shall cover the geographical areas that could be flooded, following scenarios of (i) low probability, (ii) medium probability, and (iii) high probability of flood. FRMs have the purpose to describe the potential negative consequences associated with the previous flood scenarios. These negative consequences should be described in terms of: (i) the indicative number of inhabitants potentially affected, (ii) the type of economic activity of the area potentially affected, (iii) the potential accidental pollution in case of flooding, (iv) other information, such as the potential content of transported sediments and others.

Finally, in the third stage, on the base of FHMs and FRMs, Member States shall elaborate the FRMPs, for each river basin and region. Considering the specific characters of the areas under potential flood risk, they should propose specific solutions at the scale of river basin and in coordination with the European regulations. According to the FD, each Member State shall ensure that one or more FRMPs can be elaborated for a unique river basin, depending on the local characteristics. The FRMPs shall consider several elements of the flood and of the area it covers, such as: the flood extent and flood conveyance routes; the areas that have the potential to retain flood water, such as natural floodplains; the environmental objectives; the soil and water management; the spatial planning and the land use; the nature conservation; and finally, an analysis of the costs and benefits of the adopted measures.

In Italy, the FD was implemented by the D.Lgs. 23/02/2010, n. 49 (Gazzetta Ufficiale della Repubblica Italiana, 2010). In the following years, eight FRMPs were approved, one for each River District (ISPRA, 2019). In general, FRMPs contain a general description of the area and the sub-regions included in the river basin, as well as a description of the FRMPs elaboration, including the participation of all the relevant stakeholders. This point is important since the Italian River Districts contain different administrative Regions and at the same time, the Regions may participate in different River Districts. The opinions of the Regions are thus included. Moreover, the Regions are responsible to activate the specific local stakeholders for the specific local areas. FRMPs also contain the FHMs and the FRMs. Finally, they contain a list of measures to be applied at the scale of the basin, as well as at the scale of sub-regions. The elaboration and the implementation of FRMPs is thus done through a cooperation between the supra-regional River Districts, the Regions and the local authorities responsible for each sub-regions.

According to the analysis included in the evaluation of the first FD programming cycle (2010-2015), within the European countries, 50% of measures included in FRMPs were focused on prevention and preparedness, 40% on protection, while only 10% on recovery actions (European Commission, 2019a). Moreover, according to the European Commission (2019a), the estimate of costs and benefits of these measures is not precise, as well as the supporting funds. In Italy, for example, there is a lack of precise cost-benefits analyses (ISPRA, 2018; European Commission, 2019b), which are expected to be done for the next programming cycle (Autorità di Bacino del Po, 2016) of the FD. Accordingly, more should be done for the estimation of recovery actions and related costs, in order to prioritize measures and make them more applicable.

1.2. The analysis of flood damages in agriculture

As previously discussed, FRMPs should contain an estimation of the potential negative consequences deriving from flood events on the various exposed elements; therefore, the need arises for competent authorities to have adequate models for the quantitative assessment of potential flood damage. At the same time, FRMPs shall contain a cost-benefit analysis of the measures that have been planned to mitigate flood risk. Again, methods for the correct estimation of flood damages are needed in order to assess the applicability and the effectiveness of the risk reduction measures (i.e. in terms of avoided damage) and establish an order of priority among them. The FD considers agriculture as one of the economic sectors that can be subject to flood risk, and that needs to be protected and restored. As for other economic sectors, a detailed estimate of the possible losses linked to physical damage caused by flood needs to be done. In fact, several studies have proposed methods and models to estimates flood damage on agriculture.

"Flood" is defined as the temporary covering by water of land not normally covered by water. This includes floods from rivers, mountain torrents, Mediterranean ephemeral watercourses, and floods from the sea in coastal areas. In this context, "flood risk" means the combination of the probability of a flood event to happen and of the potential negative consequences associated with a flood event for the human health, the environment, the cultural heritage and the economic activity (Official Journal of the European Union, 2007). The estimate of the expected damage on a given area is thus essential in defining the potential or effective risk on that area. Such negative impact may be influenced not only by the intensity of the event, but also by the morphological and land use characteristics of the territory itself, which affect the dynamics of the event and the type, number and value of the elements exposed to potential damage. In literature, different methods elaborate different pathways where these elements are organized.

Flood impacts can be economic, human and ecological. According to Merz et al., (2010) flood damage can be of two kinds: direct and indirect. Direct Damages are the damages caused directly from the physical contact of floodwater with humans or any other objects. Indirect Damages are instead caused by the links that the elements not directly exposed to the water have with other elements that have suffered direct damages and, for this reason, they may occur outside the flood event (Merz et al., 2010). In agriculture, a direct damage can be the destruction of the crop or the flooding of the buildings, while an indirect damage can be the disruption of the economic activity due to the missing production. Nevertheless, the interpretation may vary from scholar to scholar, depending on the purpose of the study (Castellini and Ragazzoni, 2017). For some scholars, the direct damage is the economic loss (i.e. Forster et al., 2008), while for others, the direct damage is just the loss of the yield to which the economic consequence is associated (i.e. Hussain, 1995).

Direct and indirect damages can be further classified into tangible and intangible damages, depending on whether or not they can be assessed in monetary values. Tangible damages are those that can be easily expressed in monetary terms, while intangible damages are difficult to be translated into monetary values, since they are not marketable (Merz et al. 2010). Literature recognizes also the presence of macroeconomic damages, as the short- or the long-term impacts on the economy (i.e. Parker, 2004). Merz et al. (2010) distinguish also between micro-, meso- and macro- spatial scales in the analysis of flood damage. In micro-scale analyses, the assessment is done for every single exposed element, e.g. buildings or infrastructure objects. In meso-scale studies, the assessment is based on spatial aggregations of exposed elements, like at census scale. Finally, in macro-scale damage assessments, the analysis is based on large-scale spatial units, such as municipalities, regions, countries. The temporal dimension of the assessment is another crucial element since it defines how many effects should be taken into account in the model, thus the magnitude of the flood damage (Merz et al., 2010; Castellini and Ragazzoni, 2017).

A final element in the characterisation of flood damage models is the source of the information: "empirical approaches" use damage data collected after flood events, while "synthetic approaches" use damage data collected via what-if-questions, and are thus based on experts' opinions.

On the base of all these elements – the estimate of direct/indirect and tangible/intangible damages, the spatial scale, the temporal dimension and the source of information – damage functions are built. The latter provide an estimate of the expected damage as a function of the parameters representing the hazard and the vulnerability characteristics of the exposure (Merz et al., 2010).

In the literature, flood damages in the agricultural sector usually include negative impact on crops and other intermediate and final products (Bremond et al., 2013), in terms of lost yield, damage to the farm buildings and infrastructures, including the costs of cleaning and evacuation (Dutta et al., 2003; Thieken et al., 2008; Merz et al., 2010), and damage to farms' machineries and other technologies (Dutta et al., 2003). Still, it must be stressed that, up to now, agriculture has receive less attention than other sectors and a limited number of (simplified) models is available (Bremond et al., 2013, Author 3 et al., 2019), probably because the economic damage in this sector is considered lower than damages in urban areas (Merz et al., 2010). For example, damage on farms' buildings are usually estimated using methods coming from residential and industrial sector. Moreover, the estimation of flood damage on farms has been carried out only on the cropping systems, and not on livestock farms.

The approaches in developing available damage functions usually define damages on crops as the reduction of the crop's yield (Hussain, 1995), the worsening of the product's quality, the damages to soil due to pollution or soil erosion, which is usually connected to increasing costs of production (USACE, 1985), and the economic damage due to the loss of sale (Kok et al., 2004; Forster et al, 2008; Agenais et al, 2013, Author et al., 2019).

Usually, in the construction of the damage functions, the input parameters are the water height, the event duration (Hussain, 1995; Citeau et al, 2003; Dutta et al, 2003; Klaus et al, 2016), the water speed (Citeau et al, 2003), the presence of solid material, pollution or salinity (Hussain, 1995), and the season of occurrence, which affects the probability of having the flood (Forster et al, 2008; Author 3 et al., 2019).

The input vulnerability parameters are instead connected to the specific crops cultivated, which yield and quality can be more or less affected by the flood (Dutta et al, 2003; Agenais et al, 2013; USACE, 1985), and the amount of it in terms of cultivated surface (Dutta et al, 2003; USACE, 1985), its cost of harvest as well as its market price (USACE, 1985), which determine the loss of gain (Forster et al, 2008; Author 3 et al., 2019). A specific element of the damage models for the agricultural sector is the inclusion of the time – the month or even the week – of occurrence of the flood with respect to the crops growth stages (Hussain, 1995; Penning-Roswell, 2003; Citeau et al, 2003; Forster et al, 2008; Agenais et al, 2013; Klaus et al, 2016; Author 3 et al., 2019), among the input variables. Models also combine the different damages of different crops (USACE, 1985; Dutta et al., 2003; Citeau, 2005; Agenais et al, 2013) in order to have a territorial exposure to flood damage.

In case of livestock farms, up to now and to the best our knowledge, no models have been developed. This is probably due to a difficulty in estimating all the different components of a farm as well as their interactions. Indeed, the total economic damage to a livestock farm is not simply linked to the physical damage on the herd, but also to the damage on all the other productive factors characterising the farm, to which the wellbeing of the herd is connected.

Moreover, the time of recovery in the case of livestock farms may complicate the modelling of damage. In fact, the studies proposed up to now were based on farms with annual crops, where the recovery time can be thought as the recovery time of the field, just equal to approximately one year (i.e. Forster et al., 2008). In the case of dairy farms, the recovery time should at least follow the growth of the animal from the birth to its productive time, usually included between the second and the third year (Balsani, 2002).

Finally, in the literature, there is a lack of data about the effective flood impacts on livestock farms, which hampers understanding and modelling of damage. Few studies report such impacts (i.e. Posthumus et al., 2009; Inchaisri et al., 2013). For example, by directly questioning the English farmers who suffered flooding in 2007, Posthumus et al. (2009) reported that, in that specific case, livestock farmers experienced additional damages than crop farms. Beyond the loss of gain due to the loss of milk, livestock farmers incurred many costs such as the extra purchase of feed to replace lost summer grazing, and also for subsequent winter feeding because conserved grass was lower in both quantity and quality. In case of farms with pasture, farmers had to face the increasing cost of additional slurry disposal, since livestock was kept indoors due to loss of grazing. In some cases, farmers experienced temporary disruption of potable water supplies and incurred in additional costs to secure water for their livestock. Few farmers reported losses of livestock due to flooding, but there was an increase of treatment costs of common diseases such as dairy mastitis and lameness. Livestock farmers incurred relatively high repair costs for fences, gates and hedges, as field boundaries are more prevalent and essential on livestock farms than arable farms. Despite this contribution is important to have a first clue of the potential damages, such information is not organized to produce a model applicable in different contexts.

2. Methodological approach of this study

To fill the gap in the literature, this study wants to develop a conceptual model for the estimation of economic damages from a flood event on a dairy farm. The model has been developed within Flood-IMPAT+ (an Integrated Meso & micro scale Procedure to Assess Territorial flood risk, www.floodimpatproject.polimi.it), an Italian research project which aimed at developing new damage estimation tools in support of the implementation of the FD. In fact, few damage estimation models are presently available for the Italian context while transferability of models developed in other countries is challenging because of lack of empirical data (i.e. damage data on past flood events) for their validation. Specifically, no models exist In Italy for the estimation of flood damage on agriculture. The model presented in this study can be considered as an integration of the AGRIDE-c model for the estimation of flood damage to crops (see Molinari et al., 2019), towards the development a comprehensive tool for the estimation of damage on all the damageable components of a farm, within a systemic approach. In detail, in this study, the productive factors of the dairy farm are considered as damageable components. A dairy farm is usually described on the base of its productive factors: (i) the land capital, (ii) the operative capital, and (iii) the labour (De Benedictis and Cosentino, 1979). The land capital includes the land and all the operations done on it, such as the annual or multiannual crops, the land settlements and hydraulic system, the buildings and the internal roads. The operative capital includes the stock capital, such as the livestock and the dead stock with simple (seeds, fertilizers, feed, etc…) or repeated (machineries) utility. The labour includes the manual and operative labour-force. In the model, we included only those productive factors/components that may imply changes in the farm profit because of direct and indirect damage on the herd. Thus, among the land capital, the model considers the building and the internal roads; among the operative capital, the model includes the herd, the food stock and the machineries. The model does not consider instead the labour since there is not a direct connection with the damage on the herd. Still, indirect damages can occur when workers must work to restore the activity, without having a gross saleable product to compensate. Moreover, the model does not include the direct damage to the land, the annual crops, the land settlements and hydraulic systems, because these damages are already included in AGRIDE-c or do not have direct impact on the herd (Molinari et al., 2019). In continuity with the conceptual model of AGRIDE-c, the damage is first estimated in physical terms and then translated into monetary values, as both decreasing gross saleable product and increasing costs. To cover the gap in damage data about past flood events, a synthetic approach has been implemented for the development of the model, based on the investigation of damage mechanisms (i.e. of the interaction between damage-influencing factors and characteristics of exposed elements leading to a damage/loss), by means of an expert what-if analysis and the comparison with farmers who were affected by floods in the past. In detail, economist, experts in flood damage, veterinaries, farmers associations and public institutions were involved in the modelling process by means of focus groups. This allowed to identify not only the main involved damage mechanisms but also the parameters of interest (see Section 3). The temporal scale of the model considers not only the immediate economic damages, but also the time of recovery. In fact, the hypothesis at the base of the analysis is that the flooded dairy farm decide to cope with immediate damages and continue the same farming activity. Results are thus organised in two parts: a static model of the immediate damages and a dynamic model of the damages that occur during time and the recovery time that it is necessary. The model includes only the recovery actions that are at farmer's responsibility. Several damages occur at territorial level and are thus responsibility of the local or national authorities, and are beyond the scope of this study.

It must be stressed that the model presented in the next paragraph only shows conceptually the different mechanisms leading to flood damage in dairy farms, their main control parameters as well as the links between the different possible damages. Further studies shall deepen the estimate and accounting the situations of a farm pre- and post- flood, to precisely define the costs of the flood event on a livestock farm.

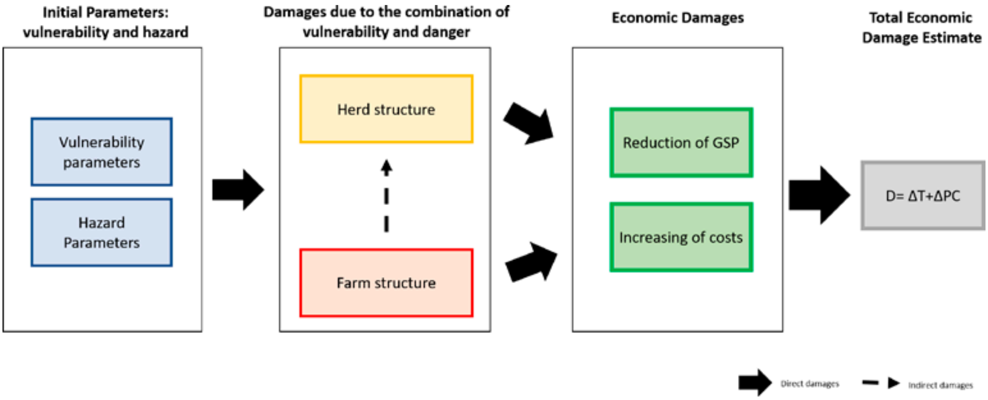
3. Results

Results are organised as follow: the static analysis captures the interactions between the flood and the different components of the farms, as well as among the same components, in order to estimate the immediate, physical and economic, damage on the farm. The temporal analysis considers the effect of the damages during the time and the time needed to recover from such damages.

3.1. Static analysis

Figure 1 shows the general scheme of the model's impact of flood on dairy farms. The static model is composed by four parts. (i) To start, the hazard and vulnerability parameters are considered, thus the external elements not controlled by the farms. The intensity of the damages depends on their magnitude. In particular, vulnerability parameters relate to the internal characteristics of the farm, while hazard parameters refer to the characteristics of the flood. (ii) Once the vulnerability and hazard parameters are set, a second step consists in analysing the consequences of the flood on the farm, especially on the herd and on the farm structure. These damages can be directly due tothe values assumed by the vulnerability and hazard parameters on the herd but it is also possible that the damages on the herd depend on the damages on the other farm components (i.e. on the farm structure). In this case, we refer to indirect damages. (iii) All these damages have economic consequences, entailing increasing costs and reduced gross saleable product (GSP). (iv) Finally, considering these economic consequences, it is possible to compute the effective economic damage the farm face when flood occurs.

Figure 1. Scheme of the possible damages.

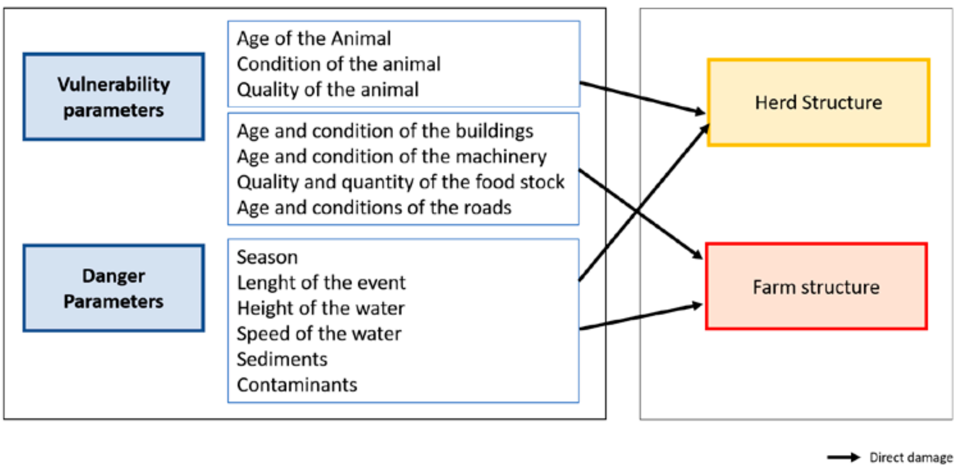


In the next sections, the different parts will be deepened.

Part I. Vulnerability and hazard parameters

Figure 2 shows in the detail the possible hazard and vulnerability parameters of the model and their direct impact on the herd and the farm structure. Their real inclusion in the estimation of the damage depends on the local characteristics of the hazard and of the farm at stake. First, damages depend on external and internal characters of the farm. The internal characteristics, here called "Vulnerability parameters", include the herd and the structures of the farm, which define the farm. To characterize the herd we considered three indicators: (i) the age of the ani-

Figure 2. detail of the initial parameters.



mal – calf, stirk, grown dairy cow; (ii) the condition of the cow – pregnant, primigravida, not pregnant, and the sanitary of the animal before the flooding; (iii) the quality of the animal, in terms of pool genetic. To characterize the farm's structure, we consider the age and the condition of the different buildings, the machineries that constitutes the farm, the food stock and the roads. It is important to take into account not just the presence of them, but their age and conditions, e.g. the buildings materials, the level of maintenance of buildings and machinery, the storage conditions, the type of road. In this way, it is possible to consider both their depreciation in the calculus of the damages, the loss of the farmer's investments, and their susceptibility to be damaged in case of flood (i.e. their vulnerability).

Beyond depending on the internal characteristics and the production organization of the farm, damages also depend on how the flood takes place. In the schema, the "Hazard parameters" cover the different features that characterize each single flood event. Among the parameters, we included: (i) the period of the year where the flood occurs; (ii) the duration of the event; (iii) the water velocity; (iii) the possibility that water carries sediments; and (iv) the possibility that water deposits contaminants.

Part 2. The damages on the farm

By considering how hazard and vulnerability parameters interact, i.e. by considering possible damage mechanisms, we are able to design which are the possible consequences on the farm. We divided the possible damages in two categories: the damages on the herd and the damages on the farm structure. Figure 3 shows the model of the flood consequences on the farm. The possible direct damages, which are defined by the direct exposure of the element to the water, are both on the herd, as direct damages on the animals, in terms of deaths, injuries, etc., and on the farm structure, especially on the buildings, machineries, and roads. These direct damages may cause indirect damages on the herd. Another source of indi-

Figure 3. Detail of the damages on the farm structure and herd.

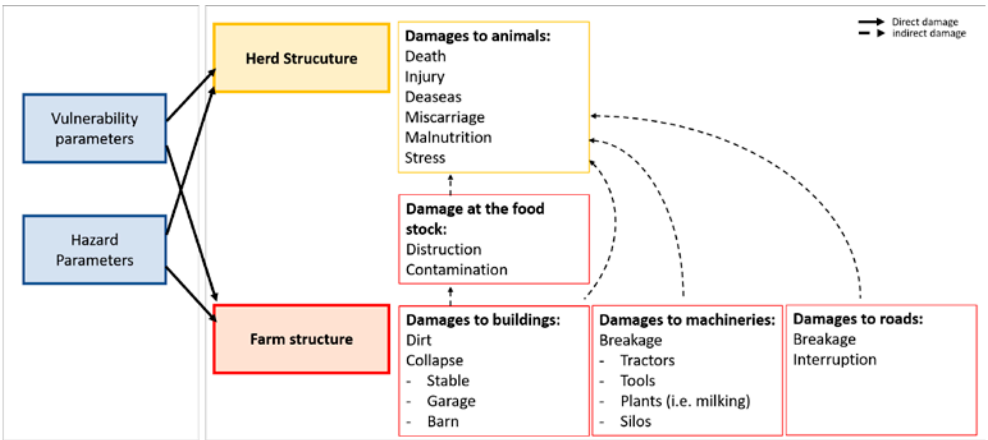


Table 1. Main consequences on the animal of flood event and the recovery actions.

Flood damages on the herd	Recovery actions
Death of the animal	Carcass disposal
Injury	Killing
	Treatment
Diseases	Killing
	Treatment
Miscarriage	Killing
	Insemination
Malnutrition	/
Stress	/

rect damages on the herd is damages on the food stock because of damages to the buildings. Table 1 deepens the consequences.

ince this study is based on the hypothesis that the farmer decides to continue the farming activity despite the suffered damage, Table 1 is divided in two columns: the type of damage and the actions farmers need to take to fix the damage and to restore the activity. The first direct damage on the herd is the death of the animal. In this case, the only possible action for farmers is the disposal of the carcass. Despite this case is possible, it is also true that the death of the animals because of drowning is usually considered a rare event, since when announced flood warning is issued, farmers immediately act to rescue the animals, which are their main source of profit.

The flood and the consequent displacement of the animals may cause injuries and diseases. The decision between killing and treating the animals that are injured or sick mainly depends on the gravity of the problem. Among the injuries, the foot and the leg injuries are the more crucial in determining if it is worth to treat the animal. In case of flood, it is also possible that epidemic diseases occur as the animals may live in unhealthy spaces. Moreover, in case of displacement, cows may be moved in places where other herds are located. The proximity of different herds may alter their immunity system and thus increase the probability of occurrence of the typical diseases, such as mastitis or dermatitis. Another source of sickness consists in the limitation of potable water to the cows, because of the disruption of the water supply system or because of physical damage to farm's buildings (and the pipes). This would also results in additional costs for the farmer (to guarantee the water for the animals), which depends on the magnitude of the flood event and the presence of contaminants.

Miscarriages can happen as direct consequences of the flood on the animal, but also because of the damages on the different farms components. Depending on the age of pregnancy, the farmer can decide to kill the animal or to maintain

Table 2. Damages on the farm's structure and the recovery actions.

	Flood damages on the farm structure	**Recovery actions**
Machinery: Tractors, Silos, Other tools, Milking plant	Total or partial breakage of the machinery	Restoration
		Replacement
	Breakage of the electrical system	Restoration
		Replacement
Buildings: Stable, Garage, Barn	Dirt	Cleaning
	Collapse	Reconstruction
Food stock	Destruction	Elimination of the food stock and further replacement
	Contamination	
Roads	Breaking of part of the street	Reconstruction
	Road interruption	Reconstruction

the animal for a future insemination. Usually, when the cow is at least 7-8 months pregnant the preferred solution is to kill the animal. The reason is the potential lack in the dairy production, which depends on the cow maternity. Finally, possible consequences are connected to the malnutrition and the stress that the animal may suffer because of the flood event.

Table 2 shows the damages to the farm structure. As it is possible to observe, they depend on the farm structure itself (i.e. on the vulnerability parameters).

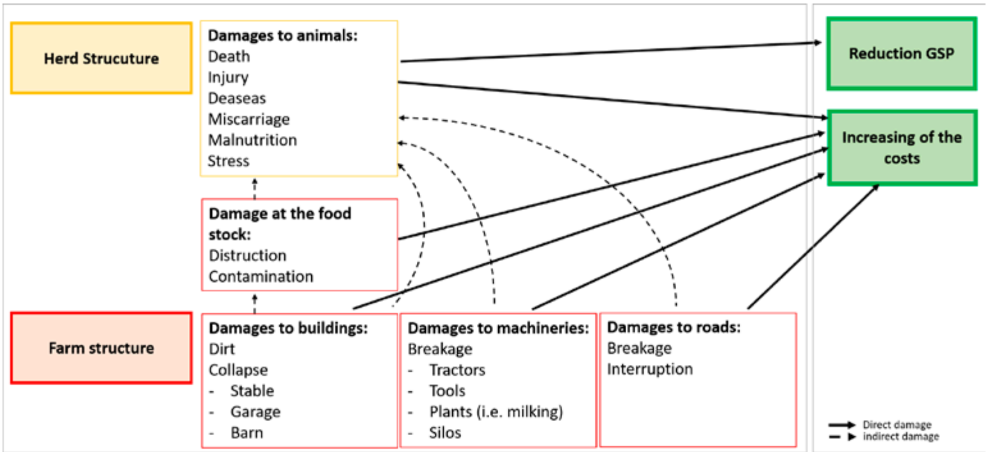
The collapse of buildings is not frequent in case of flood. More frequently, the water flowing in and out of the farm may deposit sediments, leaving mud in the buildings and in the machineries. The most frequent actions that farmers may implement are the cleaning, the reconstruction and the fixing of broken machinery and tools. Milky plants and silos are recognized as the most critical instruments, because of their function in the economic process. In fact, the breakage of the milking plants impedes the dairy production, thus it is one of the first thing to be repaired. The silos contain the food stock. Their damage cause the loss of the collected food, but also the worsening of its quality. Farmers can decide either to replace all the food or part of it, depending on its conditions and the costs of replacement.

Finally, damage on the roads considers both the damage to the internal infrastructure of the farm, and the external one. In the first case, the farmer must restore the connections inside the farm. In the second case, the infrastructure maintenance is responsibility of public authorities.

Part 3. Economic damages

The damages and the actions required to restore the farming activity have an economic impact on the profit of the farm, in terms of increased costs and re-

Figure 4. Detail of the economic consequences.



duced revenues. In tables 3 and 4 the damages described in tables 1 and 2 are associated with the variation of costs and revenues.

Being the animals the first source of profit, the economic direct damages on the herd are described as both increasing costs for restoring the herd and reduced revenues, since the animals are not producing at the best of their potential (Table 3).

When the animal dies or has to be killed, there is the cost connected to the disposal of the carcass. To this cost is typically associated the missed gain coming from the missed sale of the killed animal's milk, in case of lactating cow. At the same time, the death of a cow or a veal is associated with the missed gain from the sale of the meat. The decision to not kill the animal should be based also on considerations about the maintaining of the internal renovation of the herd, in order to maintain the gross profit of the barn. When animals have to be killed, new productive animals are bought, increasing the total amount of costs.

When the animal does not die and needs to be treated, costs connected to the veterinary treatments occur. In case of miscarriage, when it occurs at the beginning of the pregnancy, the farmer may decide to re-fertilise the cow in order to start a new pregnancy. On the contrary, when the miscarriage happens in an advanced pregnancy, it is more convenient for the farmer to slaughter the animal. Thus, in this case the costs are connected to the disposal of the carcass. At the same time, if the animal is healthy, the meat can be sold, thus having a gain for the farmer.

When malnutrition happens, the cow may produce less milk, thus the farmer may face a reduction of the revenues coming from the sale of the milk. The same effect it is possible in case of stress. However, while it is possible to quantify the level of malnutrition by comparing what the animals are eating before and after the flooding, the impact of stress in decreasing the quantity of the production is more difficult to estimate. Beyond the visible reduced revenue caused by the missing of a part of the production, it could be important to estimate also the costs

Table 3. Economic direct damages on the herd.

Flood damages on the herd	Recovery actions	Economic direct damages	
		Increased costs	Reduced revenues
Death	Carcass disposal	Cost of carcass disposal	Missed sale of the milk and of the meat
		Cost for the replacement of the animal	
Injury	Killing	Cost of carcass disposal	Missed sale of the milk and of the meat
		Cost for the replacement of the animal	
	Treatment	Cost of treatment	Missed sale of the milk for the treatment period
Diseases	Killing	Cost of carcass disposal	Missed sale of the milk and of the meat
		Cost for the replacement of the animal	
	Treatment	Cost of treatment	Missed sale of the milk for the treatment period
Miscarriage	Killing	Cost of carcass disposal	Missed sale of the milk
		Cost for the replacement of the animal	
	Insemination	Cost of the insemination	
Malnutrition	/		Missed production milk in proportion to the malnutrition
			Reduced gain for the low quality of the milk
Stress	/		Missed production of milk in proportion to the stress
			Reduced gain for the low quality of the milk

connected to the reduction of the quality of the milk. In fact, malnutrition and stress – also caused by the medical treatments – may affect not only the quantity of milk produced by the cows, but also its quality. For a lower quality milk, the price payed to the farmer may be lower than in normal conditions, thus causing reduced revenue.

Table 4 shows costs associated to damages on the farm structure. These costs are first linked to the restoration of the stables and the machineries, as well as to their cleaning, in order to provide the animals with a safe and disinfected environment.

Table 4. Economic damages on the farms structures.

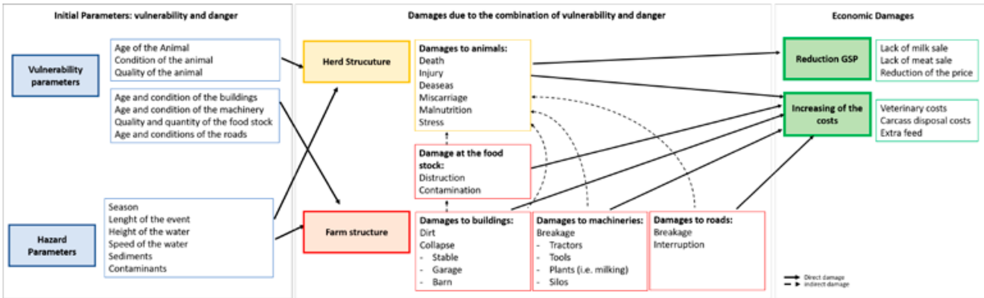
	Direct Flood damages	Recovery actions	Economic direct damages
			Increased costs
Machinery: Tractors, Silos, Other tools Milking plant	Total or partial breakage of the machinery	Restoration	Costs of the restoration
		Replacement	Costs of the replacement
	Breakage of the electrical system	Restoration	Costs of the restoration
		Replacement	Costs of the replacement
Buildings: Stable, Garage, Barn	Dirt	Cleaning	Costs of the cleaning
	Collapse	Reconstruction	Costs of the restoration
Food stock	Destruction	Elimination of the food stock and further replacement	Cost of extra feed
	Contamination		Cost of extra feed
Roads	Breaking of part of the street	Reconstruction	Costs of the restoration
	Road interruption	Reconstruction	Costs of the restoration

Damaging of the silos may imply damage of the food stock, which can be destroyed or contaminated. In this case, farmers must throw away the food stock, and replace it in order to feed the cows. Such damage thus entails costs in purchasing the extra animal food. To properly estimate these costs, several elements need to be taken into account. First, the bargaining of certain crops (e.g. corn silage) usually passes through auctions, which depend on the previous year's market quotation. Thus in extraordinary conditions, such as flood events, we may assume that the complete replacement with the same quality feed is highly difficult. Second, costs of the extra feed must be differently accounted for according to the season the flood happens: if it occurs at the beginning of the harvest year or at the end, the cost may be lower or higher. Third, the competition between farmers t being located in the same-flooded area and looking for the same feed may affect the local crop's market competition, thus the cost and the possibility to find feed at a reasonable price. For all these reasons, farmers may decide to change the cows diet, with possible consequences of malnutrition. In fact, new diets shall provide the same quantity of dry matter, to be able to produce a similar milk quantity and quality.

Finally, costs to fix damage to roads mainly depend on whether the roads are internal the farm, or they are competence of the public body. Damages to roads may cause a partial or complete isolation of the farm, or of parts of it, from the external help, probably increasing the time of recovery.

Figure 5 shows the model of Fig. 1 with the details explained in the previous paragraphs. As it is possible to notice, damage evaluation needs to follow a precise path, which has to consider all the interconnections between the components of a

Figure 5. Detail of the model.



farm, i.e. not only the direct damages of the flood on the herd, but also the direct damages on the farm structure and how they affect the composition of the herd.

3.2 .*Temporal analysis*

After considering the possible and immediate consequences of the flood, and the possible recovery actions with the possible associated costs, this paragraph is focused on the possible timing for the recovery of the initial economic activity.

In a dairy farm, in fact, the temporal horizon of one animal lasts for several years. Farmers invest in one animal that is supposed to provide revenues for several years in the future. In fact, in a closed cycle dairy farm, the veal is fed for two-three years without any revenue. When it is finally productive, a cow may have six or seven pregnancies and consequent lactations. Being the herd the unique source of profit of a dairy farm, the damages on the animals affect the capacity of recovering in the long-term. To describe this, we first explain the possible recovering time of the damages previously explained and then, on the base of that, we trace the recovery timeline.

Table 5 reports the time required to recover the initial conditions of the herd. When farmers opt for replacing the dead animals, by buying new ones, the recovery time is immediate; on the contrary, when farmers do not decide to replace animals who died because of the flood, the timing of recovery depends on the age of the dead animal that should be replaced by a veal in the herd. If the animal that died was at the end of its productive period, the time of recovery is shorter, if it was at the beginning it is necessary to consider at least the three years of the veal's growth before it becomes productive.

In the focus groups, it was also reported that, in previous flood events, deaths were happening in the herd for no apparent reason, for almost one year after the flood. In other words, it seems that healthy and productive animals were still suffering from the stress of the flood (or because of unrecognized diseases) for a long time after the flood and it took at least one year to stabilize the herd.

For the sick animals, recovery time depends on the treatment. Usually when a cow has a mastitis, it is not possible to use the milk it produces for 5-6 days, thus

Table 5. Time of recovering of the herd depending on the economic damages sustained.

Flood damage on the herd	Recovery actions	Increased costs	Reduced revenues	Timing of recovery
Death of the animal	Carcass disposal	Cost of carcass disposal	Missed sale of the milk and of the meat	The time to replace the dead animal + 1 year of possible deaths of animals
Injury	Killing	Cost of carcass disposal	Missed sale of the milk and of the meat	Time to replace the dead animals
	Treatment	Cost of treatment		Time of treatment
Diseases	Killing	Cost of carcass disposal	Missed sale of the milk and of the meat	Time to replace the dead animals
	Treatment	Cost of treatment		Time of treatment
Miscarriage	Killing	Cost of carcass disposal	Missed sale of the milk	Time to replace the dead animals
	Insemination			
Malnutrition	/	Buying of the same feed, but lower quantity	Missed of milk in proportion to the malnutrition	Two months
		Buying of different feed (change of diet)	Missed of milk in proportion to the malnutrition	One year
Stress	/		Missed of milk in proportion to the stress	Two moths + 1 year of possible deaths of animals

it means that there is a lack of revenue, beyond the increasing cost of treatments.

As discussed before, malnutrition and stress mainly depend on the fact that, for the first period, the animals are hosted in other environments than what they are used to live in. Being the cows very susceptible from external factors, changes in their living conditions may affect their productivity. This situation may last for at least the period they are not fed as they are usually fed or that they are located and managed in different environments, or even for more time. In case the farmer needs to change the diet, because he does not find the same feed, the time of recovery from the malnutrition could be the harvest year at maximum. Again in this case, the period of year when the flood happens determines the magnitude of the cost and the recovery time.

As stressed before, damages to the animals also depend on the damages to the farm structures and to the food stock. According to farmers participating in the focus groups, it took one month for them to be able to enter in the farm after past flood events, and at least one month to be able to return the animals.

Table 6. Time of recovering of the farm structure depending on the damages sustained.

Consequence of the flood on the farm structure	Type of damages	Possible actions of the farmers	Increased costs	Timing of recovery
Damage to machinery: Tractors, Silos, Other tools Milking plant	Total or partial breakage of the machinery	Restoration	Costs of the restoration	One month to be able to do something + at least one month for cleaning, repair and restore the farm structures
		Replacement	Costs of the replacement	
	Breakage of the electrical system	Restoration	Costs of the restoration	
		Replacement	Costs of the replacement	
Damage to buildings: Stable, Garage, Barn	Dirt	Cleaning	Costs of the cleaning	
	Collapse	Reconstruction	Costs of the restoration; Cost of rent for other stables	
Damage to the food stock	Destruction	Elimination of the food stock and further replacement	Cost of purchasing of the feed	One year at maximum to have the new harvest
	Contamination		Cost of purchasing of the feed	
Damage to roads	Breaking of part of the street	Reconstruction	Costs of the restoration	
	Road interruption	Reconstruction	Costs of the restoration	

In the meantime, cows were fed and milked outside the farm, and for this reason, they produced less. The time recovery of the damages on the food stock is of one year at maximum (i.e. if the flood happens at the beginning of the harvest year), following the harvest year.

Figure 6 summarizes the timeline for the farm recovery. Considering all the damages previously discussed, the minimum time to restore the same level of pro-

Figure 6. Timeline of the farm's recovery.

After one month	The farmers can enter in the farm to clean and restore it
After two months	The farmer can return the animal
From two months to one year	The farmer treats the sick animals and try to replace the dying animals
After one year	The farmer restore the food ration, following the cropping system
After one year	The herd is stable: the death of the animals stops
After three years	The farmer restore the level of productions pre-flooding, considering: - Replacement of stressed cows - The animals that were calves during the flood arrive in lactation

duction pre-flooding is three years. In three years, the animals that lived the flood and were thus stressed or sick are almost completely replaced by the new generations, and the animals that enter in the lactation stage are the animals born after one year after the flood, thus they do not potentially suffer any consequence, such as stress or healthy weakness, from it. After one year, the herd became stable with no unexpected deaths. From this time to the third year, the herd is producing, while replacing the old and stressed animals.

4. Discussion and conclusion

The purpose of this study was to develop a conceptual model of the potential flood damages on a dairy farm. The increasing number and intensity of flood events in the past has led political authorities to be more prepared to reduce and mitigate flood damages.

To this aim, the availability of reliable flood risk estimates is critically needed, both before and after the flood event. In fact, in the first case, risk assessments may support the local authorities to define the most suitable and economically efficient mitigation measures on the basis of cost-benefit analysis of alternative measures, and help to plan emergency management strategies, identifying different areas of intervention, with different degree of risk and therefore of priority. In the second case, the ex-post assessment of the economic flood damage may provide support to administrations and insurance companies in estimating the monetary losses caused by the flood and therefore the compensation to be paid to the injured parties (Merz et al., 2010).

The analysis of the FRMPs, which were implemented so far at the European scale, reveals that few countries have forecasted recovery measures, and few of them have included forms of insurance (European Court of Auditor, 2019). Private insurances are already in places in several countries, but the compensation is not effective if correct estimates of flood damages are not done. In the Common Agricultural Policy (CAP) 2014-2020, the Income Stabilisation Tool was introduced as a form of insurance in case of natural disasters (European Parliament, 2016). In the case of the agricultural sector, a coordination between the measures included in the Floods Directive and the CAP actions could sustain a more efficient implementation of both. In fact, a correct estimate of the potential flood damages will support the correct application of such instruments.

As reported in literature, in the agricultural sector, flood damage estimates are still simplistic and mainly focused on cropping systems (Merz et al., 2010). Our study wants to fill the gap, by proving a conceptual model for estimating flood damages on dairy farms.

In the model, the significant components of dairy farms are considered as well as their linkages and all the direct and indirect damages to the herd have been included, following what literature asks (Dutta et al., 2003, Bremond et al., 2013, Author 3 et al. 2019). At the same time, the temporal dimension of the model is able to capture damages that manifest during the time passing after the occurrence of the event, i.e. long term/indirect damages, by better identifying the magnitude of the flood impact (Merz et al., 2010). Further studies shall more precisely account the direct and indirect costs and reduced revenues (Author 1 et al., 2016), as well as the correct estimative methods. For instance, by measuring the percentage of somatic cells in the milk, the analysis of the Linear Score could be a useful method to estimate the decreasing quality and quantity of the milk for cows that have suffered a flood event, and thus the flood damage (Samoré and Stella, 1998; Author 1 et al., 2016). One limit of our model is that it considers only the costs coming from direct and indirect damages on the herd (i.e. damages due to the direct damages on the farm machineries, buildings, roads and food stocks because of the presence of systemic links among them and the herd). Our study does not include the potential costs coming from the use of other productive factors such as the labour, or the machinery used for the recovery that the farmer pays potentially in debt, since he has not the full amount of revenue. These costs are are beyond the scope of this analysis. Nonetheless, as observed in literature, the analysis of the costs should also consider the social dimension of the flood event, i.e. the consequences on the well-being of the farmer and the workers (Castellini and Ragazzoni, 2017).

The novelty of this study relies on the fact that this is the first attempt to provide a common framework for the evaluation of flood damages on dairy farms that is generally valid in a variety of contexts. Facing the destructions that flood may cause to the economic activity, a first reaction could be to stop the activity, with repercussion on the well-being of the farmer and the farmworkers, but also on the economy of rural areas. This study wants to contribute to the debate of building tools and scientific analysis to support farmers in restoring the activity in an economically sustainable way.

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