Animal board invited review: Improving animal health and welfare in the transition of livestock farming systems: Towards social acceptability and sustainability

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ABSTRACT

The need to integrate more clearly societal expectations on livestock farming has led the authors of this article to consider that livestock farming systems must be redesigned to position health and welfare at the heart of their objectives. This article proposes a vision of the advances in knowledge required at different scales to contribute to this transformation. After defining health and welfare of animals, the article emphasises the need to consider health in a broader perspective, to deepen the question of positive emotional experiences regarding welfare, and raises the question of how to assess these two elements on farms. The positive interactions between health and welfare are presented. Some possible tensions between them are also discussed, in particular when improving welfare by providing a more stimulating and richer environment such as access to outdoor increases the risk of infectious diseases. Jointly improving health and welfare of animals poses a number of questions at various scales, from the animal level to the production chain. At the animal level, the authors highlight the need to explore: the long-term links between better welfare and physiological balance, the role of microbiota, the psycho-neuro-endocrine mechanisms linking positive mental state and health, and the trade-off between the physiological functions of production, reproduction and immunity. At the farm level, in addition to studying the relationships at the group level between welfare, health and production, the paper supports the idea of co-constructing innovative systems with livestock farmers, as well as analysing the cost, acceptability and impact of improved systems on their working conditions and well-being. At the production chain or territory levels, various questions are raised. These include studying the best strategies to improve animal health and welfare while preserving economic viability, the labelling of products and the consumers' willingness to pay, the consequences of heterogeneity in animal traits on the processing of animal products, and the spatial distribution of livestock farming and the organisation of the production and value chain. At the level of the citizen and consumer, one of the challenges is to better inter-relate sanitary and health perspectives on the one hand, and welfare concerns on the other hand. There is also a need to improve citizens' knowledge on livestock farming, and to develop more intense and constructive

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exchanges between livestock farmers, the livestock industry and citizens. These difficult issues plead for interdisciplinary and transdisciplinary research involving various scientific disciplines and the different stakeholders, including public policy makers through participatory research.

Implications

This collective reflection was performed to push interdisciplinary research in order to improve both the health and welfare of farm animals. The goal is to place health and welfare of the animals at the core of the livestock farming systems, and to favour transitions in the livestock farming systems and sectors. These goals are key elements in the acceptability of animal farming for the citizen and important aspects for the sustainability of animal farming in the coming years. Different research areas of interest are highlighted, various of them requiring interdisciplinary or transdisciplinary approaches.

Introduction

Livestock farming is currently the subject of increasing concern by society and citizens. Questions are being raised about the environmental footprint of livestock production as well as about our stewardship of the animals under our care and their resulting well-being. These questions are given urgency by the twin challenges of ensuring global food security and dealing with the climate change. Food and Agriculture Organization of the United Nations, 2006 (**FAO)** drew attention on the land used for livestock and the competition with crops to feed humans, on the contribution of livestock to global warming, water depletion and pollution, and its impact on biodiversity. In France, according to Delanoue and Roguet (2015), the primary societal concerns regarding livestock farming relate to the so-called intensive and industrial farming (i.e. high productivity, high animal density, high drug use and indoor breeding). The main worries with these systems are about the welfare of animals, their health and the sanitary crises. Underpinning the concerns related to animal health and welfare, there is a societal demand for a healthy diet that will not lead to adverse effects on human health and even provide some benefits. Animal safety is directly related to the livestock farming systems, as illustrated by sanitary crises such as those related to influenza (Sidik, 2023). Animal health management such as the large use of antimicrobials also contributes to antimicrobial resistance dissemination, which is a major threat for the coming decades. In a systematic review on public perceptions regarding production diseases associated with farm animal welfare, Clark et al (2016) mention that citizens have a holistic view of the welfare and health of animals, and they consider that what is bad for animals is also bad for consumers. Furthermore, efforts to protect the health of animals at the expense of more open livestock farming systems (e.g. closed systems to limit disease exposure of the animals) are not supported by citizens. Clark et al (2016) indicate that more welfare-friendly systems are associated with additional benefits for the consumer (quality, safety). However, at the same time, welfare is not a priority when shopping, with barriers to consumption such as price, availability and perceived personal influence remaining. The expectations of the society concerning the health and welfare of animals are shared by livestock farmers. The latter are concerned with the welfare of their animals and try to give them the best life from their point of view (Buddle et al., 2021). Indeed, without any constraints and regulations, farmers may innovate in this field, as in the case of dam-rearing systems (Vaarst et al., 2020) or by the use of alternative practices in health management (Hellec et al., 2021). This invites us to consider animal health through a global "one health" approach. Also, under the treaty on the functioning of the European Union (**EU**) (Article 13 of Lisbon Treaty), animals are recognised as sentient beings and consequently, the EU and the Member States must pay due regard to the welfare requirements of animals when preparing and implementing EU policies in agriculture or internal markets, for examples.

Given the societal loss of trust towards livestock farming in the European context, it must change quite strongly in the coming years to regain respect for its stewardship of the animals involved. Today more than ever, it seems urgent and important to consider animal health and animal welfare together in the design of future livestock farming systems. The recognition of animals as sentient beings leads us to reconsider human-animal relationships on a global scale. However, the capacity to transform livestock farming activities is highly context-dependent. This ambition is part of a context in which we can consider, at least in the European countries that food security is assured, even if the increasing number of climatic accidents may lead us to reconsider this state of affairs. Another important factor is the dual urgency of climate change and human dietary transition, which will probably lead to a reduction in the consumption of animal products in developed countries. In this transformation process, we consider that livestock farming systems must be completely redesigned by all stakeholders in the sector to position health and welfare at the heart of their objectives, as well as the well-being of livestock farmers. Some authors even call for a real paradigm shift, and propose a new conceptual framework called "circular welfare economy" involving a complete overhaul of the agricultural system, the economy and even society as a whole (Bracke et al., 2023). More concretely, synergies and tensions with the other dimensions of performance must be determined in order to guide choices towards the most multiperforming systems. Health and welfare need to be taken into account simultaneously, because they are tightly linked and interact with each other, not always in a positive way, and because they are critical points in the acceptability of livestock farming systems by the citizens and consumers. This raises the question of knowing under what conditions it will be possible to jointly improve the health and welfare of the animals, and to consider them as fully fledged components of the sustainability of production systems. The purpose of the present paper is to address this question in the European context of livestock farming and to propose a conceptual framework in which the corresponding research questions are situated.

The process of innovation to achieve improved health and welfare of the animals within sustainable systems can take an incremental and progressive path, made of small steps, to optimise the system without making it deviate from its trend, with possible forms of substitution of one element by another. Alternatively, it can make a break and fundamentally modify the livestock farming system in a more disruptive way, even though a progressive path. Both paths can be useful, though some voices claim that no significant improvement can be expected from small steps changes to intensive livestock farming systems (Leterrier et al., 2022; Bracke et al., 2023). There is already knowledge and experience in the domains of health and welfare of farmed animals, and the interactions between health and welfare at animal level have been stud-

ied for some time (Broom, 2007). However, simultaneously taking into account health and welfare as the main objective in designing new livestock farming systems requires multiple expertises. In this paper, we propose a research strategy centered on this goal. We first define animal health and animal welfare, and the research questions raised to evaluate them on farms. Then, we address the questions linked to the interactions between health and welfare of animals, both positive and negative. Finally, we consider how the transformation of livestock farming activities towards health and welfare scales up to research questions at the farm level, at the industry and territory levels, and ultimately on the society's view of livestock farming and its evolution. Thinking about the transformation of livestock farming practices strongly depends on the territory in which livestock farming activities take place, in terms of farming systems and organisation of the sector. In this paper, we focus on the European context of livestock farming where average farm sizes are considerably smaller than in America and China. However, if we foresee the future of livestock farming including health and welfare improvements, the question of farm size would be one of the major factors to consider.

What do we mean by animal health and animal welfare?

What does animal health refer to?

Historical perspective from Human medicine

Western medicine has been dominated by two conceptions of disease, termed "ontological" and "physiological", both considering health as the absence of disease. In the ontological conception, disease is seen as a distinct entity, exogenous to the organism, such as a spirit, a parasite, a germ, a poison, which "penetrates" the individual to cause disturbances (symptoms). The treatment and the cure (the return to health) consist in eliminating, expelling this foreign "element". "Disease enters and leaves humans, as if through the door" (Canguilhem, 2005). In primitive and archaic societies, the supernatural, represented by gods, demons, and wizards, was frequently invoked, especially during epidemics. At the end of the 19th century, the emergence of modern microbiology and infectiology (L. Pasteur, R. Koch, etc.) brought scientific evidence to support this conception.

In the physiological or dynamic conception, the disease reflects an imbalance of the organism, a disturbance of its "internal environment", of its anatomical and functional integrity. This conception is therefore centered on the "sick person", and not on the "disease, external and distinct element". Illness and health are a continuum and not strictly independent (Conti, 2018). The treatment (and therefore the restoration of health) aims to return to harmony, the balance of "humors" which explains the systematic use of purgatives, emetics, and bloodletting in ancient times. Identified since Greco-Roman antiquity (Hippocrates, Galen, etc.), this conception, transmitted by Arab medicine from the Middle Ages, has been enriched over the centuries. At the end of the 19th century, the advent of experimental physiology (C. Bernard, R. Virchow, etc.) brought scientific and explanatory elements to support this conception. In Oriental or Asian medicine (traditional Chinese; Indian called Ayurvedic - from âyur = longevity and veda = knowledge -), the notions of illness and health can be compared to the physiological conception (Mazars, 1994; Saylor, 2004). These two complementary conceptions (ontological and physiological) have largely contributed and continue to contribute to nourishing biomedical research.

In human medicine, in addition to the biological components of heath, the "holistic theory" of health gives a preponderant part to a "subjective" component; without denying the biological aspects, this approach considers that health depends essentially on the perception of the subject, and therefore on socio-cultural values and references that vary in space, time, and according to individuals. The definition of health established in 1946 by the World Health Organisation goes beyond the absence of disease and traditional, strictly physical and biological criteria, and displays a positive and plural dimension in nature (physical and mental integrity, well-being) and scale (individual and population): "*Health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity*" (World Health Organization, 2017).

Health and disease of farm animals

The two historical approaches to health mentioned previously echo two important dimensions of the health of farm animals. The first one is the exposure to external, infectious, and toxic agents, which are the main causes of transmissible diseases, some of which are zoonotic and may involve wildlife (for example African swine fever, bovine tuberculosis, avian influenza, brucellosis). This includes the transmission, asymptomatic in animals, of pathogenic agents to humans (eg salmonella, hepatitis E virus, trichina). The second dimension refers to the physiological imbalances that can be increased by deficient rearing conditions of animals highly selected for production potential in highly intensive livestock farming systems. These disorders can result in excess morbidity and mortality (Calavas and Rosner, 1997) thus altering longevity (Rostellato et al., 2022), sudden drops in performance (lack of robustness), and are often linked to physiological imbalance or common metabolic or infectious diseases (for example diarrhea in piglets at weaning, mortality of one-day chicks, mastitis in dairy cows, bronchopneumonia in young cattle).

The philosophical approaches developed for human health emphasise the importance of well-being, subjectivity, socio-cultural values and contexts to characterise the health status or the presence of disease, particularly for benign or chronic diseases. Perhaps because these values and contexts were not readily accessible in animals – one cannot ask an animal how it feels – they have not traditionally featured in the characterisation of animal health status. The perception of health of farm animals can be quite different depending on whether it is made by the breeder, the veterinarian, or the citizen/consumer (Mahon et al., 2021). Taking the health of the udder of dairy cows as an example, different livestock farmers do not necessarily consider the same criteria to determine that a cow has a sub-clinical infection, the veterinarian will tend to retain objective indicators (somatic cell count) based on a consensus standard of the profession, and the consumer will have the expectation that the cow has not undergone any treatment that could alter the quality of the milk. In broiler flocks as another example, different farmers may consider different levels of mortality to be normal, and the level of productivity achieved is an indicator of health for some of them.

Based on the World Health Organisation (**WHO**) definition of health, and also placing animal health in the perspective of the supply of animal products that are safe for human health, it seems important to consider an integrated ("holistic") approach to farm animal health, to consider the two components of health (risk of exposure to pathogens and physiological balance) and to focus on the best balance to be found in livestock farming practices. Furthermore, it is important to consider both the individual dimension of animal health and the herd level.

Given the variety of livestock farming systems and species raised, and the diversity of points of view (breeder, veterinarian, citizens), it seems illusory to search for a generic and universal definition of animal health. In agreement with van der Linden and Schermer (2022), a pragmatic vision seems appropriate to make progress on the issue of the health of farmed animals. This vision must nevertheless be clearly explained by indicating which points of view are considered (breeder, veterinarian, citizen), which

dimensions are taken into account (for example risk with respect to major regulated diseases, impact on the career of the animal (i.e. longevity)). Further, any definition should also be clearly framed in terms of the operational context in which it is to be used, such as research, health monitoring, etc.

Practical assessment of animal health

The integrated conception of animal health presented above is important if we are to move beyond a narrow focus on the presence or absence of specific diseases. However, this raises research questions with respect to measuring the health of an animal and of a herd in farming conditions. The choice of parameters and their combinations needs to be considered and evaluated, for the different animal species and for different periods of life of the animals. The relationships and boundaries between health and disease should be explored, with the concept that healthy and sick are (opposed) points on a continuum. Accepting that health status is a continuum offers the prospect of defining objective, nuanced and operational criteria on which to build improved diagnostic and intervention tools, tuned according to the domains and biological functions considered (metabolism, reproduction, robustness, longevity, etc). Significant opportunities to achieve this are offered by the advent of on-farm monitoring technologies, and more recently the "Internet of Things" (Tuyttens et al., 2022). These provide high-frequency repeated measures allowing the health status of animals to be monitored and quantified on a continuous scale (Højsgaard and Friggens, 2010).

It would also be useful to consider how to define health at the level of the lifespan of the animal (or key stages of its career). Studies are emerging that make use of the repeated measures that are increasingly available, including the monitoring of the maintenance of good health or the capacity of the animals to recover quickly after a disease (Vaarst and Alrøe, 2012).

These research questions focused on evaluating the health status of the animal should go hand-in-hand with research on the different perceptions of what health is for different stakeholders, which can be extremely contrasted depending on who they are: livestock farmers, veterinarians, or citizens. These perceptions can also vary within the same social group, for example between farmers in conventional and organic livestock farming. This implies the need for dialogue between these actors and the co-construction of consensus in order to apply the positive and plural dimension of the WHO definition of animal health and to move towards approaches that suit all actors.

What does animal welfare refer to?

Historical perspective

The relationship between humans and animals, both domestic and wild, is multimillennial. In fact, the mutual dependence between human societies and certain animal populations have been such that animals have gradually changed in their physiology and behaviour through the process of domestication (e.g., Price, 1984; Mignon-Grasteau et al., 2005; Larson and Burger, 2013; Ahmad et al., 2020). In the same way, the presence of animals has been intimately involved in the development of human cultures to the point of shaping them (Patou-Mathis, 2009). The process of domestication is far from being reduced to its purely economic aspects, even in current livestock farming systems, but also includes symbolic and affective dimensions. This tension at the heart of the human-animal relationship between a utilitarian perspective of exploitation and a more affective feeling has long exercised by philosophers. Their most significant concerns about the human-animal relationship led to efforts to elucidate the ethical dimension of farming animals.

Philosophical thought has particularly focused on the goal of limiting suffering (where suffering is defined as experiencing pain, affliction or distress (Oxford English Dictionary, 1971)) but beyond it, tended more widely to relate this concern to the presence of sentience in animals in common with humans. During the 18th century, Rousseau (1754) was particularly important in putting very clearly in light this ethical basis*: "It appears, in fact, that if I am bound to do no injury to my fellow-creatures, this is less because they are rational than because they are sentient beings: and this quality, being common to men and beasts, ought to entitle the latter at least to the privilege of not being wantonly ill-treated by the former.*" Along these lines but more restrictively, Bentham (1789) claimed about animals in a very famous sentence: "*The question is not: Can they reason? Or: Can they talk? but: Can they suffer? "* More recently, the scientific results of investigations into animal skills in terms of sentience and awareness or consciousness (see below) confirm the validity of this ethical concern and increase its scope by extending it from the negative aspect (minimising pain / suffering) to the inclusion of a positive aspect (maximisation of pleasures) of mental states. For example, Larrère (2007) states: *"Sentience, this capacity to feel (and express) mental states like pain and pleasure, suffering and satisfaction, common to men and animals, precedes in the first what distinguishes them from the second (speech, reason, symbolisation, etc.).*"

At the European level, the principle of sentient beings was enshrined in 2009 in Article 13 of the Treaty on the Functioning of the European Union (2016): "*the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals*". Animal welfare has become a political issue, with both the development of animal protection associations and the appropriation of this issue by legislators in the Member States." The sentient nature of animals was already recognised in French law by the addition of positive and preventive obligations of animal suffering to the texts already in force, being the fruit of the law of 10 July 1976 on the protection of nature which recognised in its article 9 that: "*... every animal being a sentient being must be placed by its owner in conditions compatible with the biological imperatives of his species*." It was finally introduced in the Civil Code: "*Animals are living beings endowed with sentience*." (Law of 16 February 2015, Article 515-14; République Française, 2015), opening the way towards an evolution of the legal status of animals.

Today, animal welfare has become one of the objectives of the European Union: "*In formulating and implementing the Union's agriculture, fisheries, transport, internal market, research and technological development and space policies, the Union and the Member States shall, since animals are sentient beings, pay full regard to the welfare requirements of animals, while respecting the legislative or administrative provisions and customs of the Member States relating in particular to religious rites, cultural traditions and regional heritage.*" (Article 13 (European Union, 2016) of the Treaty on the Functioning of the European Union, the Treaty of Lisbon, which has consolidated in one single text all the founding Treaties). Indeed, all the current legislation on animal protection and welfare was elaborated at the level of the European Union and then implemented into national legislation in the Member States.

Concern for welfare can however take several forms: either reducing itself to minimising as much as possible the supposed causes of suffering or discomfort or seeking to promote the expression of behaviours specific to the species, by providing in their environment the means for this purpose. The latter perspective is one of ethics of integrity (Bovenkerk et al., 2002) that can go so far as to recommend the return - within the limits of what is possible after the impact of the domestication process - to the conditions of a natural/outdoor environment. Therefore, some authors argue that the actual benefit of animals' ability to exercise "natural behaviour" on its welfare needs to be evidenced (Dawkins, 2023).

In the search for improved welfare, a more moderate vision consists of respecting certain environmental conditions allowing the expression of the behaviours specific to the species.

In the field of animal farming, the highlighting by Harrison (1964) of the prevailing conditions of intensive livestock production in Great Britain followed by the establishment of the Brambell Committee (1965) marked a turning point in the way that citizens considered the animals they share or use for their own purposes. The mission of this committee was to make recommendations and propose minimum welfare standards that meet the basic needs of animals under intensive livestock farming conditions. In 1965, the committee produced a report rightly considered to be the foundation of reflections and approaches relating to the welfare of farmed animals in Europe (1965). The first contribution of this report is an often-overlooked definition (Chapter 4, paragraph 25): "*Welfare is a wide term that embraces both the physical and mental well-being of the animal. Any attempt to evaluate welfare therefore must take into account the scientific evidence available concerning the feelings of animals that can be derived from their structure and functions and also from their behaviour.*" This definition already referred to the existence of mental states in animals, a recurring point of controversy between stakeholders (Fernandes et al., 2019). It can also be noted that this definition considers the animal as a sensitive and conscious individual. Animal sentience includes the ability to perceive sensations through sight, hearing, smell, taste and touch, as well as the ability to feel emotions, bearing in mind that an animal's emotional capacities depend above all on its sensory world (Boissy et al., 2007). Consciousness (Le Neindre et al., 2017) relates to the ability of the animal to reflect on its actions, to have a subjective or phenomenal experience of its environment, its own body and/or its own knowledge; it enables it to adapt to a changing and often unpredictable environment. The definition distinguishes 'welfare' as a concept from 'well-being' that describes the state of the individual animal. Further scientific advances in the knowledge about sentience (Le Neindre et al., 2009) and consciousness (Le Neindre et al., 2017) of animals have reinforced these concepts, now widely accepted, both by national (Agence nationale de sécurité sanitaire de l'alimentation de l'environnement et du travail, 2018; Mormede et al., 2018) and international agencies (World Organisation for Animal Health, 2022).

Current definition of welfare

Thus, the latest definition of 'animal welfare' by the World Organisation for Animal Health (**WOAH**) thus states "*Animal welfare means the physical and mental state of an animal in relation to the conditions in which it lives and dies*" (World Organisation for Animal Health, 2022). This definition is completed by the statement that *"While animal welfare refers to the state of the animal, the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment.*" In France, according to the opinion of the French Agency for Food, Environmental and Occupational Health & Safety (Agence nationale de sécurité sanitaire de l'alimentation de l'environnement et du travail, 2018), "*an animal's well-being is the positive mental and physical state linked to the satisfaction of its physiological and behavioural needs, as well as its expectations. This state varies according to the perception of the situation by the animal.*" This definition reinforces the importance of the mental dimension of the feeling of the animal considered in its environment. Thus, good health, a satisfactory level of production and an absence of stress are not enough to ensure the well-being of the animal. We must also worry about what the animal feels, namely its unpleasant subjective perceptions (fear, pain and suffering) but also its positive emotions (satisfaction, pleasure, etc.). This means that improving the welfare of animals should no longer be limited to reducing their suffering and stress, but also to developing living conditions that give them positive emotional experiences.

Practical assessment of animal welfare: from the individual to the group

The framework that historically underlies the practical approach to animal welfare, known as the "Five freedoms", was first published by FAWC in 1979, then in 2009 in its current form (Animal Welfare Committee, 2009). This statement includes, in general terms, indications of what human beings must offer animals to ensure their welfare:

- Lack of hunger and thirst by having free access to safe water and food to maintain a good level of health and vigour.
- No discomfort through a proper environment, including a comfortable shelter and rest area.
- Absence of pain, injury and illness through preventive measures or rapid diagnosis, followed by appropriate treatment.
- Freedom of expression of normal behaviour thanks to sufficient space, adapted facilities and the company of other congeners.
- Absence of fear and distress by ensuring living conditions and treatment of animals avoiding mental suffering.

The current definitions of welfare reported above are suitable for the animal as an individual, but the practical assessment is often in the context of groups of animals both at the farm and at the slaughterhouse for production animals. The first step is to assess the state of welfare at the level of the individual in its environment. A second step is the integration of individual data at the group level (e.g. the context of the farm).

The assessment of welfare at the individual level is based on the assessments of the physiological and health status of the animal, as well as its behaviour and its reactivity to humans (animal-based measures). Assessing welfare also implies to take into account the characteristics of the environment as risk factors to animal welfare and levers to improve it (Whay, 2007). An important question is how to move from acquired understanding by studying the welfare of individuals to assessing the overall welfare of a group. Several farm animal welfare assurance schemes have been developed and used on a large scale. The approach adopted in the EU-funded Welfare Quality® project illustrates the degree of complexity of an evaluation tool and the question of an overall evaluation (Veissier et al., 2010). The initial protocols were built for a limited number of production species (pork, laying hens and broilers for fattening, cattle other than calves) as the beginning of a complete evaluation process of the livestock farming systems shared at the European scale and with a decision-making objective in actions to improve welfare. At the European level, these first protocols (Welfare Quality®, 2009a, 2009b and 2009c) constitute a reference system, from which new protocols have been developed, with improvements in procedures and adjustments to other species (goats, horses, sheep, turkeys), which have for example also been developed in the AWIN project (AWIN, 2015a, 2015b, 2015c and 2015d). Numerous simplified tools have been derived from theses protocols to make evaluations of welfare easier and available to all actors, including the livestock farmers (e.g. BEEP for pigs, EBENE for poultry and rabbits, BOVIWEL for cattle, '*cheval bien-être*' for horses), and the advent of on-farm monitoring technologies opens new perspectives.

To which extent are animal health and animal welfare connected?

There are conceptual links between animal health and animal welfare, based on the definitions seen previously. The concept of "mental well-being" in connection with positive mental states, is

an integral part of the WHO definition of health that includes the mental and social well-being (World Health Organization, 2017). At the same time, the most recent definitions of welfare by Agence nationale de sécurité sanitaire de l'alimentation de l'environnement et du travail (Anses) (2018) or the WOAH (2022), are based, among other things, on a need to achieve a positive physical state (thus a good health). Apart from these links, there are other connections between health and welfare.

Causal links between health and welfare

A causal link is observed mostly, and described first, in one direction, i.e., the adverse effects of altered animal welfare on disease susceptibility, in particular via a deterioration in immune function, to the point that disease susceptibility and immune function are used as indicators of welfare (Broom and Kirkden, 2004). Advances in the field of psychoneuroimmunology shed light at a functional level on the link between the hypothalamus, the reticular formation and the immune response, suggesting that the immune response is partially under the control of psychological processes (Zachariae, 2009). Conversely, the immune system exerts control over the central nervous system, primarily through the cytokine pathway (Dantzer, 2018).

Andrew Fraser and Donald Broom, two pioneers in the field of farm animal welfare, were among the first to address this link between welfare, animal behaviour and health, particularly in their book *Farm Animal Behaviour and Welfare* (first published in 1974; (Fraser and Broom, 1997). They rely on some observations suggesting that certain animal husbandry practices affect both animal welfare and disease incidence. For example, they cite a 1974 study that reported an increase in chronic infections in poultry, as livestock farming systems were intensified. And intensification of production systems is very often associated with higher antimicrobial use. A recent review by Rodrigues da Costa and Diana (2022) suggests that, in farm animals, better welfare often leads to lower antimicrobial use, as was hypothesised, and that, generally, poor welfare is associated with higher antimicrobial use. Diseases linked to physiological imbalances, with or without an infectious component, are very dependent on husbandry practices and, in this sense, are possibly in strong interaction with the state of animal welfare.

Data on the effects of improved welfare on disease resistance are less abundant, this is probably at least partly due to the fact that research in the field of positive welfare started late (Boissy et al., 2007). Results from Lutgendorf (2001) and Sachser (2001), as cited by Broom (Dahlem Workshop, 2001) indicate that improved welfare status, aided by social support from conspecifics, reduces the risk of disease. There is indeed some evidence that improved welfare can be a means to improve immune function, without the use of drug inputs, and a means to improve immunocompetence, including response to treatment, when needed, and to vaccines or infection. However, the relationships between welfare, immunity and disease resistance are more complex than they appear (Berghman, 2016).

Consequently, there seems to be no simple relationship between measures of immune activity and welfare (Boissy et al., 2007). As stated by Dawkins (2019): "*Research is urgently needed into the relationship between animal welfare, immunity, gut microbiota and disease and we are not yet in a position to claim that improving welfare will improve resistance to disease. 'Boosting' the immune system is not straightforward and an interdisciplinary approach is needed*".

Health and welfare may respond differently to livestock farming practices

Changes in husbandry practices associated with a change in environmental living conditions, like access to outdoors, have profound, but complex and ambiguous, effects on animal health and welfare, and on their interactions. Typically, animals can be given access to the outdoors to increase their welfare, with some positive impacts (better environmental conditions, the possibility to exercise, less infectious disease transmission due to confinement, lower antimicrobial use (Nielsen et al., 2021), but possible detrimental effects on their health state. For instance, giving access to an outdoor area and pasture to growing pigs increases the incidence of osteochondrosis as compared to confined indoor housed pigs (for a review, see Engelsen Etterlin, 2016). More generally, access to the outdoors increases the risk of exposure to pathogens (parasites, pathogens external to the farm). Moving to outdoor systems in chickens allows the expression of positive behaviours (Lay Jr et al., 2011) but increases the incidence of parasites like coccidiosis (Sossidou et al., 2015) and red lice (Knierim, 2006). These complex relationships between health and welfare, and production systems have been recently reviewed in the case of alternative pig (Delsart et al., 2020) and organic chicken farming (Holt, 2021), where outdoors access increased the risk of injury from predators and from flock mates, the risk and severity of diseases, and the mortality rate. There is therefore a possible level of negative interaction with welfare if biosecurity measures constrain farming practices (e.g. African swine fever, avian influenza, diseases affecting wildlife).

The climate change also should affect differently the effect of outdoor access on the health and welfare of farm animals, with the increase of vector-borne diseases risk and periods of heat stress in the European area. Even if intensive farming systems are also concerned, those that are more extensive will increase the exposure of animals to these weather extremes. Potential challenges have thus to be considered to anticipate the negative health and welfare effects of giving outdoor access. The transformation of breeding conditions, to better meet the animals' need for access to external and therefore more complex environments, must be designed in conjunction with a genetic approach to improve the animals' physiological adaptation to less controlled external living conditions (see below).

Apart from the links discussed above, that all show that welfare and health usually vary in the same direction (bad welfare equal to bad health and probably vice versa), the question of possible tensions between them may be raised when thinking about the likely effects of profound changes in breeding practices. This raises research questions at the different scales at which these interactions, and potential tensions, are studied, from the animal to the livestock farming system in his territory. These research questions are presented below.

Improving animal health and animal welfare in the transformation of farming activities

There is already a considerable body of knowledge that can be mobilised to improve conjointly animal health and welfare of livestock. However, various questions arise at the scientific level. It will be necessary to not only deepen our knowledge of the interactions between health and welfare at the animal level but also to consider different levels of organisation. Health and welfare interactions need to also be considered and quantified at the group, herd, farm, value chain and regional levels. This includes going as far as considering impacts and questions involving the citizen and consumer. This is the overall framework of the research agenda that we propose below with the following themes:

- Interactions between animal health and animal welfare at the animal level.
- Interactions between animal health and animal welfare at the herd level.

- Consideration of the expertise and well-being at work of livestock farmers.
- Interactions at the territory and production and value chain levels.
- Research regarding the link between farming activities and society.

Interactions between animal health and animal welfare at the animal level

As seen previously, different studies already explored positive interactions between health and welfare. However, this field of research remains fully open and among the various questions that can be addressed, we identify two that we consider as pushing at the boundaries of the scientific state-of-the-art. Does improving the state of animal welfare, in particular by facilitating the induction of prolonged or repeated positive emotions, impact their health, in terms of physiological balance and of their resistance to external aggressors, including pathogens? In addition, the role of the microbiota in the psycho-neuro-endocrine mechanisms, through the "gut-brain" axis, that link different aspects of welfare and health, should be further explored.

Another important issue is to explore the trade-off between the physiological functions of production, reproduction and immunity, as well as to find the best possible equilibrium between the efficiency of production, welfare and resilience of the animal (for a review, see Rauw, 2008). Working on the physiological and genetic bases for these trade-offs could help identifying means of action. There are a few examples of such studies investigating trade-offs between production traits and immune function (e.g., Zerjal et al., 2021), but very few studies include welfare as well. These questions concern both the short and longer stages over the entire animal's life, and a specific focus should be made in exploring the roles of the prenatal and juvenile periods, and transition phases in sub-adults or adults (weaning, gestation).

Interaction between animal health and animal welfare at the herd level

Moving from the individual to the group of individuals, or to the farm, changes the scale and raises specific research questions. Research is needed on how do interactions between individuals, and between individuals and their environment, impact the health and welfare of the group. Key areas of focus are on positive emotions, microbiota flows, and exchanges of pathogens between animals and their environment. The context in which group livestock farming systems increasingly favour outdoors access to animals for promoting welfare, and the emergence of mixed species groups in extensive systems clearly pose questions. One paradigm that has gained traction in recent years is that the resilience of the livestock farm may be enhanced by encouraging a broader variability in the adaptive capacities of the individual animals in the group. If shown to be the case, this will be important especially in agro-ecological livestock farming systems where the group of animals will be more confronted by, and need to be able to cope with, environmental fluctuations, especially in the context of climatic change with exposure to weather extremes such as heat stress.

If we consider the perspective of developing livestock farming systems that place animal health and welfare at the heart of the objectives, it will be necessary to do so whilst guaranteeing performance on all the pillars of sustainability (i.e. social, environmental and economic). This implies not only characterising the synergies and tensions between health and welfare but also between these two components and the other performance parameters of the livestock farming system that contribute to its sustainability. Systems that improve health and welfare should reduce production losses due to disease and mortality rate, avoiding the wastage of animal products that takes place at the production stage (Redlingshöfer et al., 2017), while considering that in European conditions food losses and waste mainly take place at the consumption stage (FAO, 2011). Farming systems that reduce the production of very fragile animals would decrease the mortality rate of animals, particularly young ones, as well as those avoiding the birth of animals with little or no economic value (male chicks, female ducklings or male kids, for example). Another issue is the mass slaughter of livestock to prevent the spread of infectious diseases, with concerns about welfare and waste. It would be important to work on alternative means of controlling infectious diseases to improve the current situation, such as the options using vaccination tested in France for avian influenza (Ministère de l'agriculture et de la souveraineté alimentaire, 2023). For example, 21 million poultry had to be euthanised in France in 2022 because of the influenza epidemic, resulting in very high compensation costs for the public authorities.

The compromises that will have to be made in the choice of innovations in rearing practices can only be made in consultation with all the stakeholders. Given the ambition to design systems that prioritise health and welfare, it will be necessary to know what is the cost of this choice on the other dimensions of performance and, thus, on the acceptability of these innovative systems. It will therefore be necessary to rely on open innovation methods such as living labs, which allow the co-conception of livestock farming systems taking into account the points of view and motivations of all stakeholders (including livestock farmers, upstream and downstream industries, but also citizens' associations and consumers) considered as key players in the research and innovation process (e.g., Leminen, 2015) for general considerations on the living lab concept, and Chiron et al. (2022) for an example of participatory research project in rabbit production).

As highlighted previously, a potentially powerful tool for measuring health status and welfare status is the on-farm technology that is being increasingly deployed as part of the general move towards precision livestock farming. These technologies can provide high-frequency objective measures on large numbers of animals (Højsgaard and Friggens, 2010). They already include measuring systems to detect specific health events (e.g. onset of mastitis) and also use behavioural changes to detect events such as the onset of oestrus. For these tools to realise their full potential for quantifying the interactions between health status and behavioural status, the following research developments are needed. These technologies are currently used to detect specific events rather than to assess in a continuous way how health and behavioural status evolve in response to different farm environments. Achieving the latter requires that the algorithms used to process these data are 're-tuned' to give a more nuanced evaluation of health and behavioural status. Another scientific challenge lies in the interpretation of technology-based behaviour data and animals' emotions. These technologies have been best developed in indoors housing systems (with easy access to power supply and data transmission). Although there has been significant progress, there remains a need to further develop these technologies for use in outdoors, extensive, and situations (Bocquier et al., 2014). Further research is also needed to better make the link between measures made on individual animals and those made on groups of animals. For example, camera-based measurements of groups can reveal behaviours like dispersion of the group and average speed of movements (e.g., Sadoul et al., 2015) but it is not clear how to best combine group and individual measures, or indeed when it is beneficial to do so. Advances on this would improve the tools that could help livestock farmers identify behavioural disorders that can be indicators of disease or poor welfare conditions within the group.

The final area for development is not to do with these technologies *per se* but rather to do with their interest and acceptance by farmers; the way they impact their work and their mental workload with these new multiple data and the complexity of the information to analyse, if they are adapted to the needs and skills of farmers and reinforce their ability to observe the animals, or imply new learning and skills (Hostiou et al., 2014).

Consideration of the expertise and the well-being at work of livestock farmers

Because of their daily work with, and dependence on animals, livestock farmers have an expertise, an extended spectrum of skills, emotions, and knowledge that should be considered with a real interest by scientists, farm advisors and veterinarians (O'Kane et al., 2017; Hansen and Østerås, 2019; Mahon et al., 2021) and more generally by society. Salmona (1985) pointed out the key role of farmers' fear of diseases and strong emotional concern about animal pain and health in farming practice. In their job, care and disease with pain management are consubstantial; consequently, farmers must practically and emotionally cope with this reality. New ideas and practices emerge as farmers evolve in the way they define themselves as 'good' livestock rearers. Their insight skills in animal handling and management are also changing. By experimenting with practices, farmers develop new knowledge areas about animal health and behaviour, but their own interpretations of animal welfare and health are often poorly considered.

Consideration for animal health and rearing conditions vary according to the diversity and heterogeneity of farm types, productions and sizes. These range from mainstream agriculture to alternative-small-holding farms. Small-holders are considered by commercial farming as threats to the biosecurity because of a lack of disease-risk awareness and bioinsecure practices. Going beyond those simplistic representations, Holloway (2019) insisted on the hybrid knowledge that small-holders acquire in the relationships with veterinarians and described how health management is bound up with practices of care. Opposing small-scale farming to commercial farming in terms of biosecurity is reductive as health and care practices are complex and heterogenous in farms (Holloway, 2019). It depends also on the way each farmer is considering how to be a "good farmer", and a large diversity of farming styles have been identified in some studies (Commandeur, 2006). Moreover, livestock farmers treat the health and welfare of different species, types and groupings of livestock in different ways, with differences between species, between animals of the same species, and between different life-stages or ages (Mahon et al., 2021). A large range of farmers, animal species, geographic situations, and local conditions create infinite combinations of animal-human relationships and ways of rearing. In that context, the challenge is to shift from an advisor-to-breeder knowledge transfer to a recognition and consideration of peer-to-peer systems and to encourage livestock farmers' exchanges. We make a plea here for setting up research projects on improving conjointly the health and welfare of animals at the farm level that are co-constructed with farmers in order to benefit from their skills and expertise. One way to achieve this is to investigate farm situations and results with farmers that have already tested and made strong innovations in health and welfare on their farm, i.e., by tracking breeder's innovations (Salembier et al., 2021). Another way to achieve this is to use the living labs conception process (see above).

If animal welfare is a component of sustainability (Buller et al., 2018), the livestock farmers' well-being should be a legitimately associated goal, with a focus on the capability of farmers to create knowledge and competences and to innovate in the field of animal welfare. This is an important aspect to be integrated under the banner of "One Welfare" (Buller et al., 2018). A key question is to what extent does an improvement in the health and welfare of their animals contribute to improving the well-being of farmers, their representation of work, personal and societal beliefs and satisfactions, and comfort at work. However, the contrary may also apply, that innovating on animal health and welfare can introduce new constraints for the farmers such as increased time or arduousness of the work. In parallel, it would be important to analyse what are the obstacles and drivers underlying changes to practices by farmers and transitions towards practices that are sustainable in terms of animal health and welfare; and what kind and extent of innovation are accomplished on the real farms. Porcher (2017) proposed to look in a new way at the relationships between farmers and animals, with the assumption that farm animals such as milking cows work. In this perspective, the working conditions of both farmers and animals are considered, animals are respected as workers and the farmers rely on the intelligence of animals without exploiting them.

Interactions at the territory and production and value chain levels

With the emergence of societal concerns on animal health and welfare, livestock farmers have appeared to initially be quite isolated with respect to providing answers and producing a change in their farming practices (Quéméré and Le Neindre, 2013). Indeed, changes in regulations have often been the main driver for change in favour of animal welfare (Mounaix et al., 2013). Initially not involved in the debate (ethics, welfare), livestock farmers and their organisations are fully engaged with it (Quéméré and Le Neindre, 2013). Indeed, co-operative organisations, as well as Standards Formulating Organisations (SFOs), but also breeder groups initiatives, have been playing an important role in the standards negotiations between farmers and retailers and in the implementation of welfare assessment tools like the Welfare Quality references (Aramyan et al., 2013; Bertrandias et al., 2021). Acknowledging that multistakeholder approaches are key to improve animal health and welfare, we then identify three main research topics at the regional and production sector levels that underlie the expected transition process towards livestock farming systems that promote both animal health and welfare.

Social, legal, economic and institutional processes involved

Changes in farming practices towards better health and welfare of animals must take account of all the diversity of farms in terms of their technical and economic orientations, the networks to which they belong (trading, strategic, technical, etc.) and any product differentiations that result with respect to their marketing. For the livestock farmers, improving animal health and welfare should not penalise business returns. It could bring benefits, e.g. better animal productivity, reduction of drug use, and would thus allow farmers to gain the initiative in the animal welfare debate (Lawrence and Stott, 2009). However, improving animal health and welfare in livestock farms requires practices and/or system adaptations, new investments (Johan Lagerkvist et al., 2011), and maybe more workforce. These costs must usually be economically compensated by supports, as suggested for the European Common Agricultural Policy (Guyomard et al., 2023), or premiums and state product labelling. The health and welfare differentiation of the products, managed by the downstream part of the supply chain, may affect consumer prices. There is a gap between the consumers' stated willingness to pay more for animal health and welfare products and their real purchasing acts that remain price-oriented (Deblitz et al., 2021). Animal welfare labelling will inform consumers and give them the opportunity to make conscious consumer choices. This can have the consequence of them consuming fewer animal

products (Deblitz et al., 2021). This raises the question of the best productive and industrial strategies, the best public policies to set up to improve animal health and welfare while preserving the economy of the sectors, such as using market-led approaches or relying on supply-side solutions. The issues and questions raised here all relate to how to translate the challenges of emerging new paradigms such as the Eco-Health concept (''human-animal-ecosystem" interface) – for example by focusing on the example of antimicrobial resistance – into organisational processes for livestock rearing in different sectors and regions.

Technical, organisational innovations and coordination mechanisms

Various approaches can exist to push changes on animal health and welfare in the industry and in different regions. Research may be useful to analyse their efficacy or to support the process, among others different types of coordination (integration, ''spot" markets, networks, etc.), the internationalisation of agricultural and food markets, and different types of local cooperation between a variety of actors (agricultural or not). It can also be hypothesised that the multiplication of initiatives can potentially blur livestock farmers and consumers' perceptions, especially given the poor knowledge of citizens about farming methods (Cornish et al., 2016).

Changes to organisational systems will need to take into account: the diversity of systems co-existing in a same rural area (e.g. co-existence of indoor and outdoor systems); actor strategies (e.g. living with pathogens or eradicating them); the knowledge generated on health data (e.g. interactions with wild fauna); and technical innovations (e.g. precision livestock farming) or organisational innovations (e.g. fab lab or networks of farmers). They must also be designed in the context of knowing what options can be developed for documenting or certifying the animal products, i.e. the monitoring and management of infectious diseases and welfare in the different sectors and regions. Likewise, they will need to take into account what is the acceptability, by the downstream elements of the supply-chain including consumers, of ''new" animal products from adapted livestock farming systems. Indeed, innovative, ground-breaking, systems that focus on health and welfare can be based on non-standard genetic types, produce animals that are heavier or lighter, fatter, older, altered seasonal production patterns. The consequences of these non-standardised animals on the processing of animal products need to be addressed. Finally, the feasibility and acceptability by field actors of new animal management philosophies, such as providing ''retirement opportunities" for old animals, should be investigated.

Spatial distribution of farms, global conception of agricultural/food systems

The spatial distribution of livestock farming, the evolution of the herds' size and the emissions from the livestock industry, or, more globally, the question of the safe operating space for livestock production (Buckwell and Nadeu, 2018), must also be included in the debate (Deblitz et al., 2021), otherwise, new disputes will arise again soon afterwards. These concern all the risks linked to the concentration of animals and industry: excessive effluents, impossibility of closing cycles in a circular economy, epizootics and other health risks. This evaluation can be carried out through stimulating the involvement of actors in different regions and sectors. It may involve developing the joint construction of organisational changes within certain sectors or regions so that account can be taken of the health and welfare of animals throughout their lives. This includes issues such as euthanising animals of little economic value (male chicks, female ducklings, male kids, etc.) or alternatives to slaughtering animals for health reasons should also be considered. The potential interest of some practices that are almost non-existent today, such as ''smallholders slaughters" managed by the livestock farmers themselves, needs to be evaluated and this requires an environmental as well as an economic and social assessment. In a more holistic way, the structuring and functioning of our global food systems (from farm to fork) should be reexamined and democratically discussed (within the framework of citizens' conferences, for instance). Topics such as the place, size and structure of livestock farming activities, the place of animal products in our diet, for instance, should be discussed. Various prospective studies could be mobilised to enlighten these reflections (Aubert et al., 2019).

Research regarding the link between farming activities and society

Combined consideration for societal concerns of health and welfare of animals

There is a growing societal concern for human health on the one hand, and animal welfare including farm animals on the other hand. They both gradually appear on policy agendas but these two trends, interrelated in this paper, are quite separated in society, science and political debates. Animal welfare concerns the way animals are farmed, transported, slaughtered and finally consumed (Buller and Roe, 2018). These topics are of increasing interest to many people in most parts of the world. Following non-governmental Organisations (**NGOs**) campaigns, the European Commission intends to propose to phase out and finally prohibit the use of cage systems, for all the species and categories mentioned in the End the Cage Age European Citizens' Initiative (European Commission, 2021). In parallel, dedicated structures and new regulations assigning to animals a status ''as subjects", and commercial standards promoting ethical market segmentation are emerging. These are collectively driving towards a movement of standardisation and institutionalisation of animal health and welfare.

Regarding health, and from a societal perspective, there are two public health threats. One major concern is the use of antimicrobials on livestock farms, with husbandry challenges associated with a drastic reduction in antimicrobial use in livestock to avoid resistance to antimicrobials used for humans (McEwen and Collignon, 2018). Another important health threat is the fact that emerging infectious diseases are dominated by zoonoses (Jones et al., 2008), which are diseases transmissible between animals and humans, directly or indirectly (e.g. food-borne, vector-borne zoonoses).

In our view, both challenges, animal health and welfare, could be better inter-related in an integrative perspective of improving farming sustainability (Buller et al., 2018), taking into account societal challenges, and providing better conditions for animal health and farming. However, this is no easy task as animal welfare and health also involve the entirety of the food chain, transcending the traditional divisions between production and consumption (Buller and Roe, 2018), with concern on ethical food and consumption. For instance, in 2016, the United Nations Committee on World Food Security Draft Recommendation has included an animal health and welfare article (Buller et al., 2018). This is in line with Haraway (2008) who proposed the statement of 'response-ability' both on farm and beyond into the supply chain. Here, we propose to adopt an enlarged view that would include all stakeholders: livestock farmers, processors, retailers, public institutions, and consumers. In addition, to integrate animal welfare and health issues, the panel of stakeholders should be further expanded to

include scientists, veterinarians, civil society and NGOs, farm advisors, etc.

Dialogue between the various stakeholders and society

As seen previously, a discordance exists between citizens and livestock farmers' perceptions of animal health and welfare due to an increasing dissociation of citizens living in urban contexts far removed from farming practices reality (Vanhonacker et al., 2008). Physical health, an adequate and sufficient food and drinking water to meet animal needs are included in animal welfare, both by citizens and farmers. Citizens tend to include additional values: freedom to move and freedom to fulfil natural desires (Vanhonacker et al., 2008), that are integrated into the current definition of welfare. Also, citizens do not have a clear vision of animal health, apart from the fact that poor husbandry conditions and intensive farming increase the risk of disease and overuse of antimicrobials (Clark et al., 2016). Coming back to the idea of improving the knowledge of society and citizens on farming activities, as well as their image of livestock farming, there is a strong need for more intense and constructive exchanges between livestock farmers, livestock industry and citizens. These different parties need to better know each other, to exchange their points of view, maybe to reconcile their midterm vision of what livestock farming could be ideally, and to work together to break up conflicts. Only a concerted path of this type will improve the vision of citizens about farming. In this respect, and as previously mentioned, the organisation of citizens' conventions (on livestock farming, and/or agricultural/food systems), including substantial training periods for participants, could be useful.

These challenges for the animal health and welfare sciences and for the humanities and social sciences are so vast that they cannot be met by individual disciplines, nor by single or small groups of actors and stakeholders. We believe that, for specific research projects on cutting-edge farming-societal issues, transdisciplinarity research is required. Transdisciplinarity research addresses a complex, socially relevant issue, considers diverse perspectives and disciplinary approaches, links abstract and case-specific knowledge, and develops a common-good-oriented descriptive knowledge to address the issue (Pohl, 2011). A key point is recognising the limits of science (and its experts) and respecting the expert knowledge of 'lay people' (i.e. citizens).

Acceptability of options to transform the livestock farming activities

The production chain is a complex system with many stakeholders who depend on each other, so that change is a difficult task, with various log-jams to break down (Vermunt et al., 2022) and a general path dependency (Cowan and Gunby, 1996). Disruptive transformations of the system might be more difficult to accomplish from the industry and farmer points of view, but could achieve a sufficient level of change for the citizens and consumers in terms of the acceptability of livestock farming. On the other hand, more incremental and gradual improvements in the farming system could be more accessible to farmers, but not sufficient from the citizens' point of view. Even if socio-technical system lock-in theory teaches us that removing barriers implies a multilevel approach of the production chain (then rising questions on food chain governance), it seems difficult to determine what type of change will ultimately occur and when, or which combinations of incremental and disruptive transitions. Different trends are at work, among others the societal loss of confidence in livestock farming but also the younger generation's disaffection with the current livestock farming profession at a time when the farming population is aging. They might precipitate changes in farming practices and go beyond the locks, for example with a new generation of farmers with different values and skills.

Perspectives and conclusion

To date, animal health and welfare have been treated as incidental issues in livestock farming systems. Taking into consideration these two components as a key and central point of the livestock farming systems have various and important implications. It questions the nature of the dominant production systems as well as the organisation of the livestock sectors, through four complementary challenges (Fig. 1).

Instead of correcting health and well-being damages, the approach is first to define what is considered good health and good welfare by stakeholders, and then to find practical and objective means of assessing these two components (Fig. 1A). Health and welfare are partly linked given their definitions but also because they have positive effects on each other. The mechanisms involved need further investigation. In addition, the desire to improve both raises specific questions because they sometimes interact negatively and considering them together may lead to trade-offs that need to be explored throughout the animal's life (Fig. 1B).

Transforming livestock farming systems to improve animal welfare and health also raises a number of questions about: the design of livestock farming systems to ensure good health and welfare, the economic profitability of these improved systems, the well-being of livestock farmers at work, and the adaptation of the livestock sectors to incorporate these innovations (Fig. 1C). Work is needed to study the levers for action and to support these approaches, including the role of public policies in facilitating the transformations.

Finally, the evolution of livestock farming systems to improve animal health and welfare needs to be considered in the context of a broader vision of livestock production, with a view to multiperformance and sustainability (Fig. 1D). This point relates notably to the acceptability of animal farming by the society, and its place in a one health and one welfare perspective. Working with citizens and consumers on the co-construction of a common vision of acceptable and environmentally friendly livestock farming is an important and urgent task.

Dealing with these questions is far beyond the scope of any single discipline in the animal and veterinary sciences. Furthermore, it requires a broader view of the agricultural system, and at a higher level of the value-chain, in its ecological and social environments. Concerning research, another aspect that is not obvious is that improving efficiency at a lower level of the system does not always improve the efficiency at a higher level of the system (Nguyen-Ba et al., 2023). These points argue in favor of new skills and competences of the different stakeholders which can be provided through education and training. As far as researchers are concerned, this reinforces the need to develop interdisciplinary approaches and to train researchers in the plurality of knowledge and the systemic approaches of complexity.

Some of the research questions raised in this paper refer to biology, for example psycho-neuro-endocrinal mechanisms linking positive mental state and health, and many others relate to animal sciences. However, some of them undeniably involve cultural aspects that can differ from place to place. These include options available in some countries that might not be applicable in others. Part of the questioning presented here calls for regionally focused research that can take place in different cultural contexts. It also pleads for an interdisciplinary approach involving Human sciences and economics in close collaboration with animal and veterinary

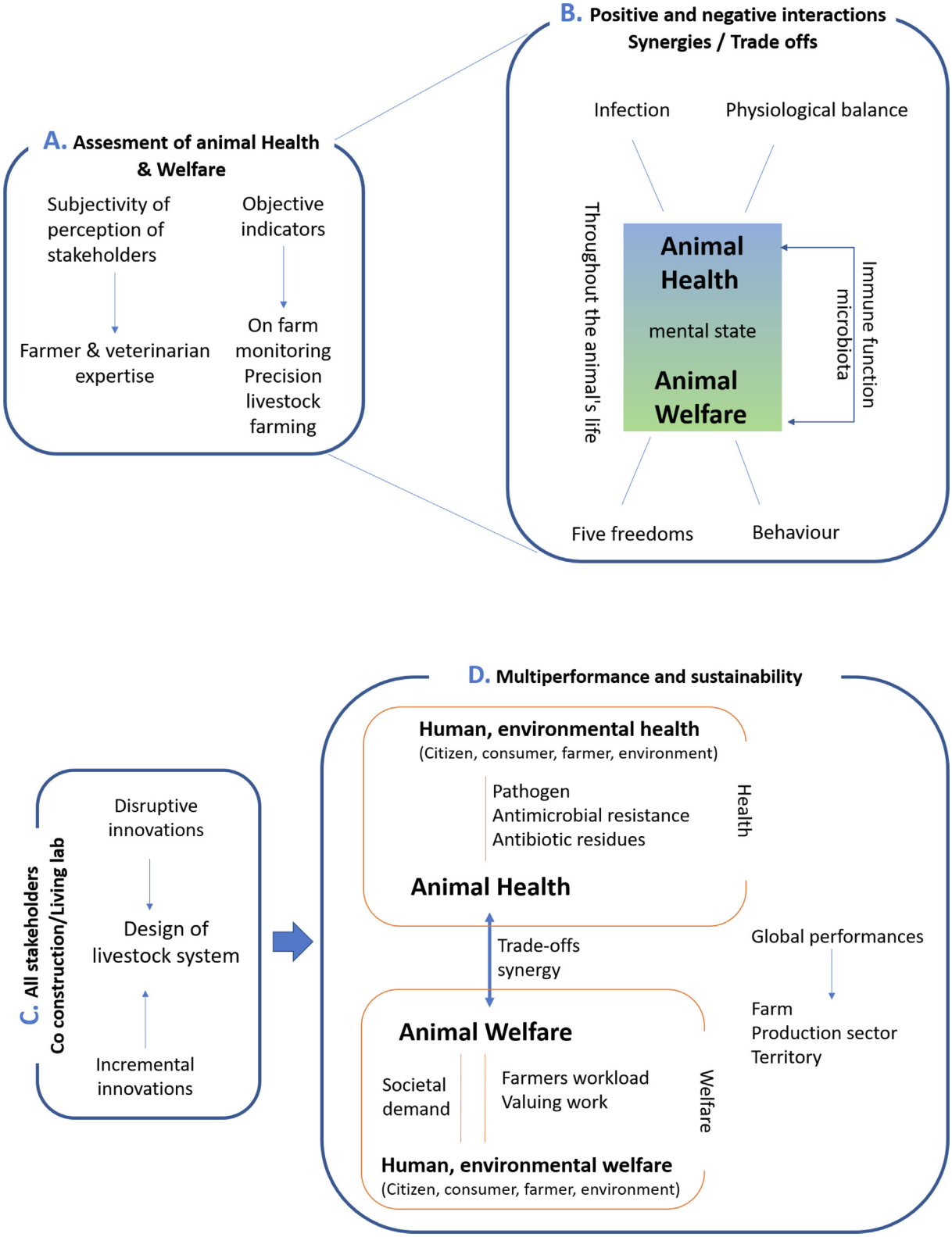

Fig. 1. Challenges to address in moving livestock farming towards greater consideration of animal health and welfare. A. Better assessment of animal health and welfare. B. Understanding the positive and negative interactions between animal health and welfare (synergies and trade-off). C. Co-design of innovative livestock farming systems improving animal health and welfare. D. Multiperformance and sustainability of livestock farming systems improving animal health and welfare.

sciences, and for transdisciplinary research involving all stakeholders.

Ethics approval

This work was conducted without carrying out any experiments on animals.

Data and model availability statement

This work was not grounded on data and models. Information can be made available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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