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## Improving animal health and welfare in the transition of livestock farming systems: towards social acceptability and sustainability

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### ► To cite this version:

Christian Ducrot, François Charrier, Alain Boissy, Maria Belén Barrio, Sergine Even, et al.. Improving animal health and welfare in the transition of livestock farming systems: towards social acceptability and sustainability. 2023. hal-04198999v2

**HAL Id: hal-04198999**

**<https://hal.inrae.fr/hal-04198999v2>**

Preprint submitted on 24 Jan 2024

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1 **Improving animal health and welfare in the transition of livestock farming**  
2 **systems: towards social acceptability and sustainability**

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8 January 2024 - Article in press in the journal **Animal**

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30

### 31 **Abstract**

32 The need to integrate more clearly societal expectations on livestock farming has led  
33 the authors of this article to consider that livestock farming systems must be  
34 redesigned to position health and welfare at the heart of their objectives. This article  
35 proposes a vision of the advances in knowledge required at different scales to  
36 contribute to this transformation. After defining health and welfare of animals, the article  
37 emphasizes the need to consider health in a broader perspective, to deepen the  
38 question of positive emotional experiences regarding welfare, and raises the question  
39 of how to assess these two elements on farms. The positive interactions between  
40 health and welfare are presented. Some possible tensions between them are also  
41 discussed, in particular when improving welfare by providing a more stimulating and  
42 richer environment such as access to outdoor increases the risk of infectious diseases.  
43 Jointly improving health and welfare of animals poses a number of questions at various  
44 scales, from the animal level to the production chain. At the animal level, the authors  
45 highlight the need to explore: the long-term links between better welfare and  
46 physiological balance, the role of microbiota, the psycho-neuro-endocrine mechanisms  
47 linking positive mental state and health, and the trade-off between the physiological  
48 functions of production, reproduction and immunity. At the farm level, in addition to  
49 studying the relationships at the group level between welfare, health and production,

50 the paper supports the idea of co-constructing innovative systems with livestock  
51 farmers, as well as analyzing the cost, acceptability and impact of improved systems  
52 on their working conditions and well-being. At the production chain or territory levels,  
53 various questions are raised. These include: studying the best strategies to improve  
54 animal health and welfare while preserving economic viability, the labelling of products  
55 and the consumers' willingness to pay, the consequences of heterogeneity in animal  
56 traits on the processing of animal products, and the spatial distribution of livestock  
57 farming and the organization of the production and value chain. At the level of the  
58 citizen and consumer, one of the challenges is to better inter-relate sanitary and health  
59 perspectives on the one hand, and welfare concerns on the other hand. There is also  
60 a need to improve citizens' knowledge on livestock farming, and to develop more  
61 intense and constructive exchanges between livestock farmers, the livestock industry  
62 and citizens. These difficult issues plead for interdisciplinary and transdisciplinary  
63 research involving various scientific disciplines and the different stakeholders,  
64 including public policy makers through participatory research.

65

## 66 **Keywords**

67 interaction, value chain, territory, society

68

## 69 **Implications**

70 This collective reflection was performed to push interdisciplinary research in order to  
71 improve both the health and welfare of farm animals. The goal is to place health and  
72 welfare of the animals at the core of the livestock farming systems, and to favour  
73 transitions in the livestock farming systems and sectors. These goals are key elements  
74 in the acceptability of animal farming for the citizen and important aspects for the

75 sustainability of animal farming in the coming years. Different research areas of interest  
76 are highlighted, various of them requiring interdisciplinary or transdisciplinary  
77 approaches.

78

## 79 **Introduction**

80

81 Livestock farming is currently the subject of increasing concern by society and citizens.  
82 Questions are being raised about the environmental footprint of livestock production  
83 as well as about our stewardship of the animals under our care and their resulting well-  
84 being. These questions are given urgency by the twin challenges of ensuring global  
85 food security and dealing with the climate change. FAO (Food and Agriculture  
86 Organization of the United Nations, 2006) drew attention on the land used for livestock  
87 and the competition with crops to feed humans, on the contribution of livestock to global  
88 warming, water depletion and pollution, and its impact on biodiversity. In France,  
89 according to Delanoue and Roguet (2015), the primary societal concerns regarding  
90 livestock farming relate to the so-called intensive and industrial farming (i.e. high  
91 productivity, high animal density, high drug use and indoor breeding). The main worries  
92 with these systems are about the welfare of animals, their health and the sanitary  
93 crises. Underpinning the concerns related to animal health and welfare, there is a  
94 societal demand for a healthy diet that will not lead to adverse effects on human health  
95 and even provide some benefits. Animal safety is directly related to the livestock  
96 farming systems, as illustrated by sanitary crises such as those related to influenza  
97 (Sidik, 2023). Animal health management such as the large use of antimicrobials also  
98 contributes to antimicrobial resistance dissemination, which is a major threat for the  
99 coming decades. In a systematic review on public perceptions regarding production

100 diseases associated with farm animal welfare, Clark et al (2016) mention that citizens  
101 have a holistic view of welfare and health of animals, and they consider that what is  
102 bad for animals is also bad for consumers. Furthermore, efforts to protect the health of  
103 animals at the expense of more open livestock farming systems (e.g. closed systems  
104 to limit disease exposure of the animals) is not supported by citizens. Clark et al (2016)  
105 indicate that more welfare friendly systems are associated with additional benefits for  
106 the consumer (quality, safety). However, at the same time, welfare is not a priority  
107 when shopping, with barriers to consumption such as price, availability and perceived  
108 personal influence remaining. The expectations of the society concerning the health  
109 and welfare of animals are shared by livestock farmers. The latter are concerned by  
110 the welfare of their animals and try to give them the best life from their point of view  
111 (Buddle et al., 2021). Indeed, without any constraints and regulations, farmers may  
112 innovate in this field, as in the case of dam-rearing systems (Vaarst et al., 2020) or by  
113 the use of alternative practices in health management (Hellec et al., 2021). This invites  
114 us to consider animal health through a global “one health” approach. Also, under the  
115 treaty on the functioning of the European Union (Article 13 of Lisbon Treaty), animals  
116 are recognized as sentient beings and consequently the EU and the Member States  
117 must pay due regard to the welfare requirements of animals when preparing and  
118 implementing EU policies in agriculture or internal markets, for examples.

119

120 Given the societal loss of trust towards livestock farming in the European context, it  
121 must change quite strongly in the coming years to regain respect for its stewardship of  
122 the animals involved. Today more than ever, it seems urgent and important to consider  
123 animal health and animal welfare together in the design of future livestock farming  
124 systems. The recognition of animals as sentient beings leads us to reconsider human-

125 animal relationships on a global scale. However, the capacity to transform livestock  
126 farming activities is highly context dependent. This ambition is part of a context in which  
127 we can consider, at least in the European countries, that food security is assured, even  
128 if the increasing number of climatic accidents may lead us to reconsider this state of  
129 affairs. Another important factor is the dual urgency of climate change and human  
130 dietary transition, which will probably lead to a reduction in the consumption of animal  
131 products in developed countries. In this transformation process, we consider that  
132 livestock farming systems must be completely redesigned by all stakeholders in the  
133 sector to position health and welfare at the heart of their objectives, as well as the well-  
134 being of livestock farmers. Some authors even call for a real paradigm shift, and  
135 propose a new conceptual framework called "circular welfare economy" involving a  
136 complete overhaul of the agricultural system, the economy and even society as a whole  
137 (Bracke et al., 2023). More concretely, synergies and tensions with the other  
138 dimensions of performance must be determined in order to guide choices towards the  
139 most multi-performing systems. Health and welfare need to be taken into account  
140 simultaneously, because they are tightly linked and interact with each other, not always  
141 in a positive way, and because they are critical points in the acceptability of livestock  
142 farming systems by the citizens and consumers. This raises the question of knowing  
143 under what conditions it will be possible to jointly improve the health and welfare of the  
144 animals, and to consider them as fully-fledged components of the sustainability of  
145 production systems. The purpose of the present paper is to address this question in  
146 the European context of livestock farming and to propose a conceptual framework in  
147 which the corresponding research questions are situated.

148

149 The process of innovation to achieve improved health and welfare of the animals within  
150 sustainable systems can take an incremental and progressive path, made of small  
151 steps, to optimize the system without making it deviate from its trend, with possible  
152 forms of substitution of one element by another. Alternatively, it can make a break and  
153 fundamentally modify the livestock farming system in a more disruptive way, even  
154 through a progressive path. Both paths can be useful, though some voices claim that  
155 no significant improvement can be expected from small steps changes to intensive  
156 livestock farming systems (Leterrier et al., 2022 ; Bracke et al., 2023). There is already  
157 knowledge and experience in the domains of health and welfare of farmed animals,  
158 and the interactions between health and welfare at animal level have been studied for  
159 some time (Broom, 2007). However, simultaneously taking into account health and  
160 welfare as the main objective in designing new livestock farming systems requires  
161 multiple expertises. In this paper, we propose a research strategy centered on this  
162 goal. We first define animal health and animal welfare, and the research questions  
163 raised to evaluate them on farms. Then we address the questions linked to the  
164 interactions between health and welfare of animals, both positive and negative. Finally,  
165 we consider how the transformation of livestock farming activities toward health and  
166 welfare scales up to research questions at the farm level, at the industry and territory  
167 levels, and ultimately on the society's view of livestock farming and its evolution.  
168 Thinking about the transformation of livestock farming practices strongly depends on  
169 the territory in which livestock farming activities take place, in terms of farming systems  
170 and organization of the sector. In this paper, we focus on the European context of  
171 livestock farming where average farm sizes are considerably smaller than in America  
172 and China. However, if we foresee the future of livestock farming including health and



173 welfare improvements, the question of farm size would be one of the major factors to  
174 consider.

175

176 **What do we mean by animal health and animal welfare?**

177

178 ***What does animal health refer to?***

179

180 *Historical perspective from Human medicine*

181

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

193

194 In the physiological or dynamic conception, the disease reflects an imbalance of the  
195 organism, a disturbance of its "internal environment", of its anatomical and functional  
196 integrity. This conception is therefore centered on the “sick person”, and not on the  
197 “disease, external and distinct element”. Illness and health are a continuum and not

198 strictly independent (Conti, 2018). The treatment (and therefore the restoration of  
199 health) aims to return to harmony, the balance of “humors” which explains the  
200 systematic use of purgatives, emetics, bloodletting in ancient times. Identified since  
201 Greco-Roman antiquity (Hippocrates, Galen, etc.), this conception, transmitted by Arab  
202 medicine from the Middle Ages, has been enriched over the centuries. At the end of  
203 the 19th century, the advent of experimental physiology (C. Bernard, R. Virchow, etc.)  
204 brought scientific and explanatory elements to support this conception. In Oriental or  
205 Asian medicine (traditional Chinese; Indian called Ayurvedic - from âyur = longevity  
206 and veda = knowledge -) the notions of illness and health can be compared to the  
207 physiological conception (Mazars, 1994; Saylor, 2004). These two complementary  
208 conceptions (ontological and physiological) have largely contributed and continue to  
209 contribute to nourishing biomedical research.

210

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

222

223 *Health and disease of farm animals*

224

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

239

240 The philosophical approaches developed for human health emphasize the importance  
241 of well-being, subjectivity, socio-cultural values and contexts to characterize the health  
242 status or the presence of disease, particularly for benign or chronic diseases. Perhaps  
243 because these values and contexts were not readily accessible in animals – one  
244 cannot ask an animal how it feels – they have not traditionally featured in the  
245 characterization of animal health status. The perception of health of farm animals can  
246 be quite different depending on whether it is made by the breeder, the veterinarian, or  
247 the citizen/consumer (Mahon et al., 2021). Taking the health of the udder of dairy cows

248 as an example, different livestock farmers do not necessarily consider the same criteria  
249 to determine that a cow has a sub-clinical infection, the veterinarian will tend to retain  
250 objective indicators (somatic cell count) based on a consensus standard of the  
251 profession, and the consumer will have the expectation that the cow has not undergone  
252 any treatment that could alter the quality of the milk. In broiler flocks as another  
253 example, different farmers may consider different levels of mortality to be normal, and  
254 the level of productivity achieved is an indicator of health for some of them.

255

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

263

264 Given the variety of livestock farming systems and species raised, and the diversity of  
265 points of view (breeder, veterinarian, citizens), it seems illusory to search for a generic  
266 and universal definition of animal health. In agreement with van der Linden and  
267 Schermer (2022), a pragmatic vision seems appropriate to make progress on the issue  
268 of the health of farmed animals. This vision must nevertheless be clearly explained by  
269 indicating which points of view are considered (breeder, veterinarian, citizen), which  
270 dimensions are taken into account (for example risk with respect to major regulated  
271 diseases, impact on the career of the animal (i.e. longevity)). Further, any definition

272 should also be clearly framed in terms of the operational context in which it is to be  
273 used, such as research, health monitoring, etc.

274

275 *Practical assessment of animal health*

276

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

292

293 It would also be useful to consider how to define health at the level of the lifespan of  
294 the animal (or key stages of its career). Studies are emerging that make use of the  
295 repeated measures that are increasingly available, including the monitoring of the

296 maintenance of good health or the capacity of the animals to recover quickly after a  
297 disease (Vaarst and Alrøe, 2012).

298

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

307

308 ***What does animal welfare refer to?***

309

310 *Historical perspective*

311

312 The relationship between humans and animals, both domestic and wild, is multi-  
313 millennial. In fact, the mutual dependence between human societies and certain animal  
314 populations have been such that animals have gradually changed in their physiology  
315 and behaviour through the process of domestication (e.g., Price, 1984; Mignon-  
316 Grasteau et al., 2005 ; Larson and Burger, 2013; Ahmad et al., 2020). In the same  
317 way, the presence of animals has been intimately involved in the development of  
318 human cultures to the point of shaping them (Patou-Mathis, 2009). The process of  
319 domestication is far from being reduced to its purely economic aspects, even in current  
320 livestock farming systems, but also includes symbolic and affective dimensions. This

321 tension at the heart of the human-animal relationship between a utilitarian perspective  
322 of exploitation and a more affective feeling has long exercised philosophers. Their most  
323 significant concerns about the human-animal relationship led to efforts to elucidate the  
324 ethical dimension of farming animals.

325

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

345

346 At the European level, the principle of sentient beings was enshrined in 2009 in Article  
347 13 of the Treaty on the Functioning of the European Union (2016): "*the Union and the*  
348 *Member States shall, since animals are sentient beings, pay full regard to the welfare*  
349 *requirements of animals*". Animal welfare has become a political issue, with both the  
350 development of animal protection associations and the appropriation of this issue by  
351 legislators in the Member States." The sentient nature of animals was already  
352 recognized in French law by the addition of positive and preventive obligations of  
353 animal suffering to the texts already in force, being the fruit of the law of 10 July 1976  
354 on the protection of nature which recognized in its article 9 that: "... *every animal being*  
355 *a sentient being must be placed by its owner in conditions compatible with the*  
356 *biological imperatives of his species*." It was finally introduced in the Civil Code:  
357 "*Animals are living beings endowed with sentience*." (Law of 16 February 2015, Article  
358 515-14)(République Française, 2015), opening the way towards an evolution of the  
359 legal status of animals.

360

361 Today, animal welfare has become one of the objectives of the European Union: "*In*  
362 *formulating and implementing the Union's agriculture, fisheries, transport, internal*  
363 *market, research and technological development and space policies, the Union and*  
364 *the Member States shall, since animals are sentient beings, pay full regard to the*  
365 *welfare requirements of animals, while respecting the legislative or administrative*  
366 *provisions and customs of the Member States relating in particular to religious rites,*  
367 *cultural traditions and regional heritage*." (Article 13 of the Treaty on the Functioning of  
368 the European Union, which has consolidated in one single text all the founding  
369 Treaties; the Treaty of Lisbon: European Union, 2007). Indeed, all the current



370 legislation on animal protection and welfare was elaborated at the level of the  
371 European Union and then implemented into national legislation in the Member States.

372

373 Concern for welfare can however take several forms: either reducing itself to  
374 minimizing as much as possible the supposed causes of suffering or discomfort, or  
375 seeking to promote the expression of behaviours specific to the species, by providing  
376 in their environment the means for this purpose. The latter perspective is one of ethics  
377 of integrity (Bovenkerk et al., 2002) that can go so far as to recommend the return -  
378 within the limits of what is possible after the impact of the domestication process - to  
379 the conditions of a natural/outdoor environment. Therefore, some authors argue that  
380 the actual benefit of animals' ability to exercise "natural behaviour" on its welfare needs  
381 to be evidenced (Dawkins, 2023). In the search for improved welfare, a more moderate  
382 vision consists of respecting certain environmental conditions allowing the expression  
383 of the behaviours specific to the species.

384

385 In the field of animal farming, the highlighting by Harrison (1964) of the prevailing  
386 conditions of intensive livestock production in Great Britain followed by the  
387 establishment of the Brambell Committee (1965) marked a turning point in way that  
388 citizens considered the animals they share or use for their own purposes. The mission  
389 of this committee was to make recommendations and propose minimum welfare  
390 standards that meet the basic needs of animals under intensive livestock farming  
391 conditions. In 1965, the committee produced a report rightly considered to be the  
392 foundation of reflections and approaches relating to the welfare of farmed animals in  
393 Europe (1965). The first contribution of this report is an often-overlooked definition  
394 (Chapter 4, paragraph 25): "*Welfare is a wide term that embraces both the physical*

395 *and mental well-being of the animal. Any attempt to evaluate welfare therefore must*  
396 *take into account the scientific evidence available concerning the feelings of animals*  
397 *that can be derived from their structure and functions and also from their behaviour.”*

398 This definition already referred to the existence of mental states in animals, a recurring  
399 point of controversy between stakeholders (Fernandes et al., 2019). It can also be  
400 noted that this definition considers the animal as a sensitive and conscious individual.  
401 Animal sentience includes the ability to perceive sensations through sight, hearing,  
402 smell, taste and touch, as well as the ability to feel emotions, bearing in mind that an  
403 animal's emotional capacities depend above all on its sensory world (Boissy et al,  
404 2007). Consciousness (Le Neindre et al, 2017) relates to the ability of the animal to  
405 reflect on its actions, to have a subjective or phenomenal experience of its  
406 environment, its own body and/or its own knowledge; it enables it to adapt to a  
407 changing and often unpredictable environment. The definition distinguishes ‘welfare’  
408 as a concept from ‘well-being’ that describes the state of the individual animal. Further  
409 scientific advances in the knowledge about sentience (Le Neindre, 2009) and  
410 consciousness (Le Neindre et al., 2017) of animals have reinforced these concepts,  
411 now widely accepted, both by national (Agence nationale de sécurité sanitaire de  
412 l'alimentation de l'environnement et du travail, 2018; Mormede et al., 2018) and  
413 international agencies (World Organisation for Animal Health, 2022).

414

415 *Current definition of welfare*

416

417 Thus, the latest definition of ‘animal welfare’ by the World Organisation for Animal  
418 Health (**WOAH**) thus states “*Animal welfare means the physical and mental state of*  
419 *an animal in relation to the conditions in which it lives and dies”* (World Organisation

420 for Animal Health, 2022). This definition is completed by the statement that *“While*  
421 *animal welfare refers to the state of the animal, the treatment that an animal receives*  
422 *is covered by other terms such as animal care, animal husbandry, and humane*  
423 *treatment.”* In France, according to the opinion of the French Agency for Food,  
424 Environmental and Occupational Health & Safety (Agence nationale de sécurité  
425 sanitaire de l’alimentation de l’environnement et du travail, 2018), *“an animal’s well-*  
426 *being is the positive mental and physical state linked to the satisfaction of its*  
427 *physiological and behavioural needs, as well as its expectations. This state varies*  
428 *according to the perception of the situation by the animal.”* This definition reinforces  
429 the importance of the mental dimension of the feeling of the animal considered in its  
430 environment. Thus, good health, a satisfactory level of production and an absence of  
431 stress are not enough to ensure the well-being of the animal. We must also worry about  
432 what the animal feels, namely its unpleasant subjective perceptions (fear, pain and  
433 suffering) but also its positive emotions (satisfaction, pleasure, etc.). This means that  
434 improving the welfare of animals should no longer be limited to reducing their suffering  
435 and stress, but also to developing living conditions that give them positive emotional  
436 experiences.

437

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

439

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

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

454

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

460

461 The assessment of welfare at the individual level is based on the assessments of the  
462 physiological and health status of the animal, as well as its behaviour and its reactivity  
463 to humans (animal-based measures). Assessing welfare also implies to take into  
464 account the characteristics of the environment as risk factors to animal welfare and  
465 levers to improve it (Whay, 2007). An important question is how to move from acquired  
466 understanding by studying the welfare of individuals to assessing the overall welfare  
467 of a group. Several farm animal welfare assurance schemes have been developed and  
468 used on a large scale. The approach adopted in the EU-funded Welfare Quality®

469 project illustrates the degree of complexity of an evaluation tool and the question of an  
470 overall evaluation (Veissier et al., 2010). The initial protocols were built for a limited  
471 number of production species (pork, laying hens and broilers for fattening, cattle other  
472 than calves) as the beginning of a complete evaluation process of the livestock farming  
473 systems shared at the European scale and with a decision-making objective in actions  
474 to improve welfare. At the European level, these first protocols (Welfare Quality®,  
475 2009a, 2009b and 2009c) constitute a reference system, from which new protocols  
476 have been developed, with improvements in procedures and adjustments to other  
477 species (goats, horses, sheep, turkeys), which have for example also been developed  
478 in the AWIN project (AWIN, 2015a, 2015b, 2015c and 2015d). Numerous simplified  
479 tools have been derived from these protocols to make evaluations of welfare easier  
480 and available to all actors, including the livestock farmers (e.g. BEEP for pigs, EBENE  
481 for poultry and rabbits, BOVIWEL for cattle, '*cheval bien-être*' for horses), and the  
482 advent of on-farm monitoring technologies opens new perspectives.

483

#### 484 **To which extent are animal health and animal welfare connected?**

485

486 There are conceptual links between animal health and animal welfare, based on the  
487 definitions seen previously. The concept of "mental well-being" in connection with  
488 positive mental states, is an integral part of the WHO definition of health that includes  
489 the mental and social well-being (World Health Organization, 2017). At the same time,  
490 the most recent definitions of welfare by Agence nationale de sécurité sanitaire de  
491 l'alimentation de l'environnement et du travail (Anses) (2018) or the WOA (2022), are  
492 based, among other things, on a need to achieve a positive physical state (thus a good

493 health). Apart from these links, there are other connections between health and  
494 welfare.

495

### 496 ***Causal Links between health and welfare***

497

498 A causal link is observed mostly, and described first, in one direction, i.e., the adverse  
499 effects of altered animal welfare on disease susceptibility, in particular via a  
500 deterioration in immune function, to the point that disease susceptibility and immune  
501 function are used as indicators of welfare (Broom and Kirkden, 2004). Advances in the  
502 field of psychoneuroimmunology shed light at a functional level on the link between the  
503 hypothalamus, the reticular formation and the immune response, suggesting that the  
504 immune response is partially under the control of psychological processes (Zachariae,  
505 2009). Conversely, the immune system exerts control over the central nervous system,  
506 primarily through the cytokine pathway (Dantzer, 2018).

507 Andrew Fraser and Donald Broom, two pioneers in the field of farm animal welfare,  
508 were among the first to address this link between welfare, animal behaviour and health,  
509 particularly in their book *Farm Animal Behaviour and Welfare* (first published in 1974;  
510 (Fraser and Broom, 1997). They rely on some observations suggesting that certain  
511 animal husbandry practices affect both animal welfare and disease incidence. For  
512 example, they cite a 1974 study that reported an increase in chronic infections in  
513 poultry, as livestock farming systems were intensified. And intensification of production  
514 systems is very often associated with higher antimicrobial use. A recent review by  
515 Rodrigues da Costa and Diana (2022) suggests that, in farm animals, better welfare  
516 often leads to lower antimicrobial use, as was hypothesized, and that, generally, poor  
517 welfare is associated with higher antimicrobial use. Diseases linked to physiological

518 imbalances, with or without an infectious component, are very dependent on  
519 husbandry practices and, in this sense, are possibly in strong interaction with the state  
520 of animal welfare.

521

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

532

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

539

540 ***Health and welfare may respond differently to livestock farming practices***

541

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

562 The climate change also should affect differently the effect of outdoor access on the  
563 health and welfare of farm animals, with the increase of vector borne diseases risk and  
564 periods of heat stress in the European area. Even if intensive farming systems are also  
565 concerned, those that are more extensive will increase the exposure of animals to  
566 these weather extremes. Potential challenges have thus to be considered to anticipate



567 negative health and welfare effects of giving outdoor access. The transformation of  
568 breeding conditions, to better meet the animals' need for access to external and  
569 therefore more complex environments, must be designed in conjunction with a genetic  
570 approach to improve the animals' physiological adaptation to less controlled external  
571 living conditions (see below).

572

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

580

## 581 **Improving animal health and animal welfare in the transformation of farming** 582 **activities**

583

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

593

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

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

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

597 - Interactions at the territory and production and value chain levels

598 - Research regarding the link between farming activities and society

599

600 ***Interactions between animal health and animal welfare at the animal level***

601

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

611

612 Another important issue is to explore the trade-off between the physiological functions  
613 of production, reproduction and immunity, as well as to find the best possible  
614 equilibrium between efficiency of production, welfare and resilience of the animal (for  
615 a review, see Rauw, 2008). Working on the physiological and genetic bases for these  
616 trade-offs could help identifying means of action. There are a few examples of such  
617 studies investigating trade-offs between production traits and immune function (e.g.,

618 Zerjal et al., 2021), but very few studies that include welfare as well. These questions  
619 concern both the short and longer stages over the entire animal's life, and a specific  
620 focus should be made in exploring the roles of the prenatal and juvenile periods, and  
621 transition phases in sub-adults or adults (weaning, gestation).

622

### 623 ***Interaction between animal health and animal welfare at the herd level***

624

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

639

640 If we consider the perspective of developing livestock farming systems that place  
641 animal health and welfare at the heart of the objectives, it will be necessary to do so  
642 whilst guaranteeing performance on all the pillars of sustainability (i.e. social,

643 environmental and economic). This implies not only characterizing the synergies and  
644 tensions between health and welfare but also between these two components and the  
645 other performance parameters of the livestock farming system that contribute to its  
646 sustainability. Systems that improve health and welfare should reduce production  
647 losses due to disease and mortality rate, avoiding the wastage of animal products that  
648 takes place at the production stage (Redlingshöfer et al., 2017), while considering that  
649 in European conditions food losses and waste mainly take place at the consumption  
650 stage (FAO, 2011). Farming systems that reduce the production of very fragile animals  
651 would decrease the mortality rate of animals, particularly young ones, as well as those  
652 avoiding the birth of animals with little or no economic value (male chicks, female  
653 ducklings or male kids, for example). Another issue is the mass slaughter of livestock  
654 to prevent the spread of infectious diseases, with concerns about welfare and waste.  
655 It would be important to work on alternative means of controlling infectious diseases to  
656 improve the current situation, such as the options using vaccination tested in France  
657 for avian influenza (Ministère de l'agriculture et de la souveraineté alimentaire, 2023).  
658 For example, 21 million poultry had to be euthanized in France in 2022 because of the  
659 influenza epidemic, resulting in very high compensation costs for the public authorities.

660

661 The compromises that will have to be made in the choice of innovations in rearing  
662 practices can only be made in consultation with all the stakeholders. Given the ambition  
663 is to design systems that prioritize health and welfare, it will be necessary to know what  
664 is the cost of this choice on the other dimensions of performance and, thus, on the  
665 acceptability of these innovative systems. It will therefore be necessary to rely on open  
666 innovation methods such as living labs, which allow the co-conception of livestock  
667 farming systems taking into account the points of view and motivations of all

668 stakeholders (including livestock farmers, upstream and downstream industries, but  
669 also citizens' associations and consumers) considered as key players in the research  
670 and innovation process (e.g., Leminen, 2015) for general considerations on the living  
671 lab concept, and Chiron et al. (2022) for an example of participatory research project  
672 in rabbit production).

673

674 As highlighted in the 1.1 and 1.2 sections, a potentially powerful tool for measuring  
675 health status and welfare status is the on-farm technology that is being increasingly  
676 deployed as part of the general move towards precision livestock farming. These  
677 technologies can provide high-frequency objective measures on large numbers of  
678 animals (Højsgaard and Friggens, 2010). They already include measuring systems to  
679 detect specific health events (e.g. onset of mastitis) and also use behavioural changes  
680 to detect events such as onset of oestrus. For these tools to realise their full potential  
681 for quantifying the interactions between health status and behavioural status the  
682 following research developments are needed. These technologies are currently used  
683 to detect specific events rather than to assess in a continuous way how health and  
684 behavioural status evolve in response to different farm environments. Achieving the  
685 latter requires that the algorithms used to process these data are 're-tuned' to give a  
686 more nuanced evaluation of health and behavioural status. Another scientific challenge  
687 lies in the interpretation of technology-based behaviour data and animals' emotions.  
688 These technologies have been best developed in indoors housing systems (with easy  
689 access to power supply and data transmission). Although there has been significant  
690 progress, there remains a need to further develop these technologies for use in  
691 outdoors, extensive, situations (Bocquier et al., 2014). Further research is also needed  
692 to better make the link between measures made on individual animals and those made

693 on groups of animals. For example, camera-based measurements of groups can  
694 reveal behaviours like dispersion of the group and average speed of movements (e.g.,  
695 Sadoul et al., 2015) but it is not clear how to best combine group and individual  
696 measures, or indeed when it is beneficial to do so. Advances on this would improve  
697 the tools that could help livestock farmers identify behavioural disorders that can be  
698 indicators of disease or poor welfare conditions within the group.

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

705

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

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

718 behaviour, but their own interpretations of animal welfare and health are often poorly  
719 considered.

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

743 on their farm, *i.e.* , by tracking breeder's innovations (Salembier et al., 2021). Another  
744 way to achieve this is to use the living labs conception process (see above).

745

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

764

765 ***Interactions at the territory and production and value chain levels***

766



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

782

783 *Social, legal, economic and institutional processes involved*

784

785 Changes in farming practices toward better health and welfare of animals must take  
786 account of all the diversity of farms in terms of their technical and economic  
787 orientations, the networks to which they belong (trading, strategic, technical, etc.) and  
788 any product differentiations that result with respect to their marketing. For the livestock  
789 farmers, improving animal health and welfare should not penalize business returns. It  
790 could bring benefits, e.g. better animal productivity, reduction of drug use, and would  
791 thus allow farmers to gain the initiative in the animal welfare debate (Lawrence and

792 Stott, 2009). However, improving animal health and welfare in livestock farms requires  
793 practices and/or system adaptations, new investments (Johan Lagerkvist et al., 2011),  
794 and maybe more workforce. These costs must usually be economically compensated  
795 by supports, as suggested for the European Common Agricultural Policy (Guyomard  
796 et al., 2023), or premiums and state product labelling. The health and welfare  
797 differentiation of the products, managed by the downstream part of the supply chain  
798 may affect consumer prices. There is a gap between the consumers' stated willingness  
799 to pay more for animal health and welfare products and their real purchasing acts that  
800 remain price-oriented (Deblitz et al., 2021). Animal welfare labelling will inform  
801 consumers and give the opportunity to make conscious consumer choices. This can  
802 have the consequence of them consuming fewer animal products (Deblitz et al., 2021).  
803 This raises the question of the best productive and industrial strategies, the best public  
804 policies to set up to improve animal health and welfare while preserving the economy  
805 of the sectors, such as using market-led approaches or relying on supply-side  
806 solutions. The issues and questions raised here all relate to how to translate the  
807 challenges of emerging new paradigms such as the Eco-Health concept ("human-  
808 animal-ecosystem" interface) – for example by focusing on the example of  
809 antimicrobial resistance – into organizational processes for livestock rearing in different  
810 sectors and regions.

811

812 *Technical, organizational innovations and coordination mechanisms*

813

814 Various approaches can exist to push changes on animal health and welfare in the  
815 industry and in different regions. Research may be useful to analyze their efficacy or  
816 to support the process, among others different types of coordination (integration, "spot"

817 markets, networks, etc.), the internationalization of agricultural and food markets, and  
818 different types of local cooperation between a variety of actors (agricultural or not). It  
819 can also be hypothesized that the multiplication of initiatives can potentially blur  
820 livestock farmers and consumers perceptions, especially given the poor knowledge of  
821 citizens about farming methods (Cornish et al., 2016).

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

839

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

841

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

863

864 ***Research regarding the link between farming activities and society***

865

866 *Combined consideration for societal concerns of health and welfare of animals*

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

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

887 In our view, both challenges, animal health and welfare, could be better inter-related  
888 in an integrative perspective of improving farming sustainability (Buller et al., 2018),  
889 taking into account societal challenges, and providing better conditions for animal  
890 health and farming. However, this is no easy task as animal welfare and health also

891 involve the entirety of the food chain, transcending the traditional divisions between  
892 production and consumption (Buller and Roe, 2018), with concern on ethical food and  
893 consumption. For instance, in 2016, the United Nations Committee on World Food  
894 Security Draft Recommendation has included an animal health and welfare article  
895 (Buller et al., 2018). This is in line with Haraway (2008) who proposed the statement  
896 of 'response-ability' both on farm and beyond into the supply chain. Here we propose  
897 to adopt an enlarged view that would include all stakeholders: livestock farmers,  
898 processors, retailers, public institutions, consumers. In addition, to integrate animal  
899 welfare and health issues, the panel of stakeholders should be further expanded to  
900 include scientists, veterinarians, civil society and NGOs, farm advisors, etc.

901 *Dialogue between the various stakeholders and society*

902 As seen previously, a discordance exists between citizens and livestock farmers'  
903 perceptions of animal health and welfare due to an increasing dissociation of citizens  
904 living in urban contexts far removed from farming practices reality (Vanhonacker et al.,  
905 2008). Physical health, an adequate and sufficient food and drinking water to meet  
906 animal needs are included in animal welfare, both by citizens and farmers. Citizens  
907 tend to include additional values: freedom to move and freedom to fulfil natural desires  
908 (Vanhonacker et al., 2008), that are integrated in the current definition of welfare. Also,  
909 citizens do not have a clear vision of animal health, apart from the fact that poor  
910 husbandry conditions and intensive farming increase the risk of disease and overuse  
911 of antimicrobials (Clark et al., 2016). Coming back to the idea of improving the  
912 knowledge of society and citizens on farming activities, as well as their image of  
913 livestock farming, there is a strong need for more intense and constructive exchanges  
914 between livestock farmers, livestock industry and citizens. These different parties need

915 to better know each other, to exchange their points of view, maybe to reconcile their  
916 midterm vision of what livestock farming could be ideally, and to work together to break  
917 up conflicts. Only a concerted path of this type will improve the vision of citizens about  
918 farming. In this respect, and as previously mentioned, the organization of citizens'  
919 conventions (on livestock farming, and/or agricultural/food systems), including  
920 substantial training periods for participants, could be useful.

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

930

### 931 *Acceptability of options to transform the livestock farming activities*

932 The production chain is a complex system with many stakeholders who depend on  
933 each other, so that change is a difficult task, with various log-jams to break down  
934 (Vermunt et al., 2021) and a general path dependency (Cowan and Gundy, 1996).  
935 Disruptive transformations of the system might be more difficult to accomplish from the  
936 industry and farmer points of view, but could achieve a sufficient level of change for  
937 the citizens and consumers in terms of the acceptability of livestock farming. On the  
938 other hand, more incremental and gradual improvements in the farming system could  
939 be more accessible to farmers, but not sufficient from the citizens' point of view. Even

940 if socio-technical system lock-in theory teaches us that removing barriers implies a  
941 multi-level approach of the production chain (then rising questions on food chain  
942 governance), it seems difficult to determine what type of change will ultimately occur  
943 and when, or which combinations of incremental and disruptive transitions. Different  
944 trends are at work, among others the societal loss of confidence in livestock farming  
945 but also the younger generation's disaffection with the current livestock farming  
946 profession at a time when the farming population is ageing. They might precipitate  
947 changes in farming practices and go beyond the locks, for example with a new  
948 generation of farmers with different values and skills.

949

## 950 **Perspectives and conclusion**

951

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

957

958 Instead of correcting health and well-being damages, the approach is first to define  
959 what is considered good health and good welfare by stakeholders, and then to find  
960 practical and objective means of assessing these two components (Figure 1A). Health  
961 and welfare are partly linked given their definitions but also because they have positive  
962 effects on each other. The mechanisms involved need further investigation. In addition,  
963 the desire to improve both raises specific questions because they sometimes interact



964 negatively and considering them together may lead to trade-offs that need to be  
965 explored throughout the animal's life (Figure 1B).

966

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

974

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

982

983 Dealing with these questions is far beyond the scope of any single discipline in the  
984 animal and veterinary sciences. Furthermore, it requires a broader view of the  
985 agricultural system, and at a higher level of the value-chain, in its ecological and social  
986 environments. Concerning research, another aspect that is not obvious is that  
987 improving efficiency at a lower level of the system does not always improve the  
988 efficiency at a higher level of the system (Nguyen-Ba et al., 2023). These points argue

989 in favor of new skills and competences of the different stakeholders which can be  
990 provided through education and training. As far as researchers are concerned, this  
991 reinforces the need to develop interdisciplinary approaches and to train researchers in  
992 the plurality of knowledge and the systemic approaches of complexity.

993

994 Some of the research questions raised in this paper refer to biology, for example  
995 psycho-neuro-endocrinal mechanisms linking positive mental state and health, and  
996 many others relate to animal sciences. However, some of them undeniably involve  
997 cultural aspects that can differ from place to place. These include options available in  
998 some countries that might not be applicable in others. Part of the questioning presented  
999 here calls for regionally-focused research, that can take place in different cultural  
1000 contexts. It also pleads for an interdisciplinary approach involving Human sciences and  
1001 economics in close collaboration with animal and veterinary sciences, and for  
1002 transdisciplinary research involving all stakeholders.

1003

1004 **Figure's caption**

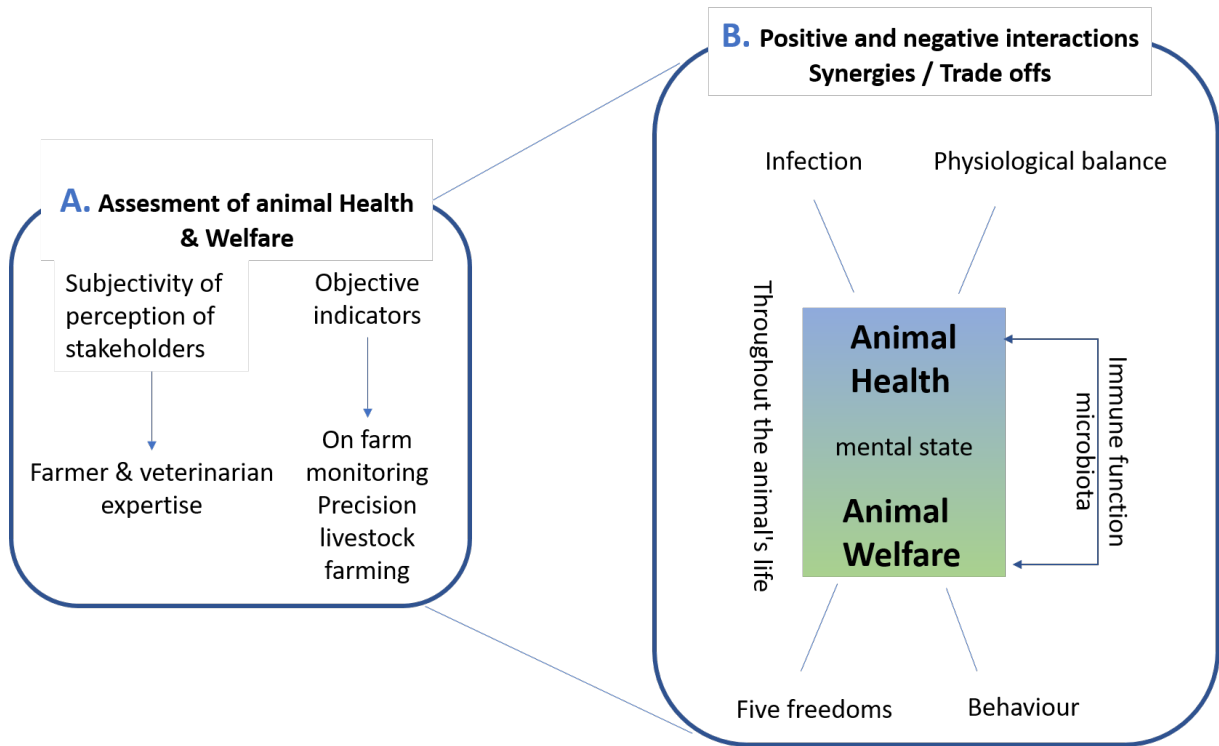
1005 Figure 1. Challenges to address in moving livestock farming towards greater consideration of  
1006 animal health and welfare.

1007 A. Better assessment of animal health and welfare

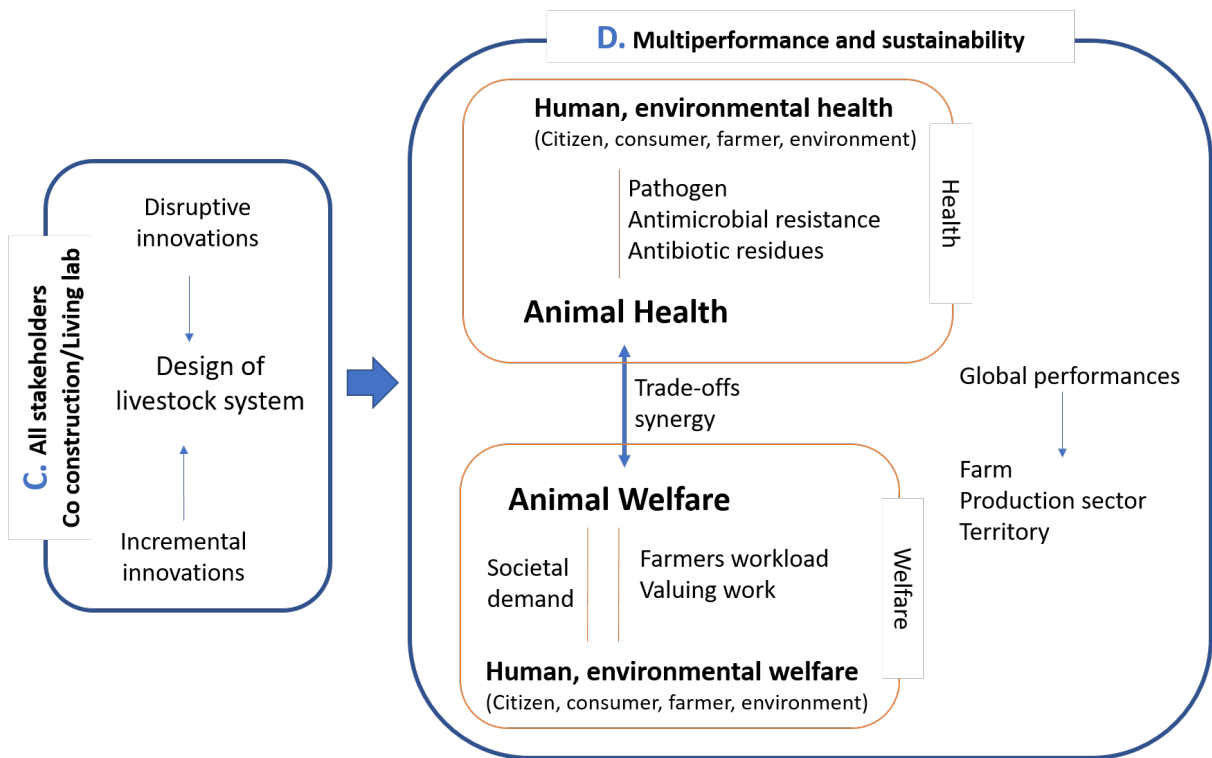
1008 B. Understanding the positive and negative interactions between animal health and welfare  
1009 (synergies and trade-off)

1010 C. Co-design of innovative livestock farming systems improving animal health and welfare

1011 D. Multiperformance and sustainability of livestock farming systems improving animal health  
1012 and welfare



1013



1014

1015 **Ethics approval**

1016 This work was conducted without carrying any experiment on animals.

1017 **Data and model availability statement**

1018 This work was not grounded on data and model.

1019

1020 **Declaration of Generative AI and AI-assisted technologies in the writing**  
1021 **process**

1022 The authors did not use any artificial intelligence assisted technologies in the writing  
1023 process

1024

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1032

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1034 J.-L.P., M.V., X.F. and C.D. wrote the initial project for the INRAE interdisciplinary  
1035 programme on animal health and welfare (SANBA), basis of this article. A.B. and P.M.  
1036 wrote the chapter on the history and definition of animal welfare. F.S. and C.D. wrote  
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1040 N.C.F. edited the English writing.

#### 1041 **Declaration of interest**

1042 The authors declare that they have no competing interests.

#### 1043 **Acknowledgements**

1044 The publication was deposited as a pre-print in a HAL pre-print  
1045 repository: <https://hal.inrae.fr/hal-04198999>

#### 1046 **Financial support statement**

1047 This research received no specific grant from any funding agency, commercial or not-  
1048 for-profit section. It was carried out as part of the metaprogramme “SANté et Bien-être  
1049 des Animaux en élevage” (SANBA) of the French National Research Institute for  
1050 Agriculture, Food and Environment (INRAE).

1051

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