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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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28

29 **Abstract**

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

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

63

64 **Keywords**

65 Health, welfare, animal, livestock farming systems, production chain, value chain,
66 territory, society

67

68 **Implications**

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

74 sustainability of animal farming in the coming years. An interdisciplinary research
75 programme was launched and funded by INRAE on the basis of this work.

76

77 **Introduction**

78

79 Livestock farming is currently the subject of increasing concern by society and citizens.
80 Questions are being raised about the environmental footprint of livestock production
81 as well as about our stewardship of the animals under our care and their resulting well-
82 being. These questions are given urgency by the twin challenges of ensuring global
83 food security and dealing with the climate change. FAO (Food and Agriculture
84 Organization of the United Nations, 2006) drew attention on the land used for livestock
85 and the competition with crops to feed humans, on the contribution of livestock to global
86 warming, water depletion and pollution, and its impact on biodiversity. In France,
87 according to Delanoue and Roguet (2015), the primary societal concerns regarding
88 livestock farming relate to the so-called intensive and industrial farming (i.e. high
89 productivity, high animal density, high drug use and indoor breeding). The main worries
90 with these systems are about the welfare of animals, their health and the sanitary
91 crises. Underpinning the concerns related to animal health and welfare, there is a
92 societal demand for a healthy diet that will not lead to adverse effects on human health
93 and even provide some benefits. Animal safety is directly related to the livestock
94 farming systems, as illustrated by sanitary crises such as those related to influenza
95 (Sidik, 2023). Animal health management such as the large use of antimicrobials also
96 contributes to antimicrobial resistance dissemination, which is a major threat for the
97 coming decades. In a systematic review on public perceptions regarding production
98 diseases associated with farm animal welfare, Clark et al (2016) mention that citizens

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

117

118 Given the societal loss of trust towards livestock farming, it must change quite strongly
119 in the coming years to regain respect for its stewardship of the animals involved. Now
120 more than ever, it seems urgent and important to consider animal health and animal
121 welfare in the design of future livestock farming systems. In this transformation
122 process, we consider that livestock farming systems must be completely redesigned
123 by all stakeholders in the sector to position health and welfare at the heart of their

124 objectives, as well as the well-being of breeders. Some authors even call for a real
125 paradigm shift, and propose a new conceptual framework called "circular welfare
126 economy" involving a complete overhaul of the agricultural system, the economy and
127 even society as a whole (Bracke et al., 2023). More concretely, synergies and tensions
128 with the other dimensions of performance must be determined in order to guide choices
129 towards the most multi-performing systems. Health and welfare need to be taken into
130 account simultaneously, because they are tightly linked and interact with each other,
131 not always in a positive way, and because they are critical points in the acceptability of
132 livestock farming systems by the citizens and consumers. This raises the question of
133 knowing under what conditions it will be possible to jointly improve the health and
134 welfare of the animals, and to consider them as fully-fledged components of the
135 sustainability of production systems. The purpose of the present paper is to address
136 this question and to propose a conceptual framework in which the corresponding
137 research questions are situated.

138

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

149 some time (Broom, 2007). However, simultaneously taking into account health and
150 welfare as the main objective in designing new livestock farming systems requires
151 multiple expertises. In this paper, we propose a research strategy centered on this
152 goal. We first define animal health and animal welfare, and the research questions
153 raised to evaluate them on farms. Then we address the questions linked to the
154 interactions between health and welfare of animals, both positive and negative. Finally,
155 we consider how the transformation of livestock farming activities toward health and
156 welfare scales up to research questions at the farm level, at the industry and territory
157 levels, and ultimately on the society's view of livestock farming and its evolution.

158

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

160

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

162

163 *Historical perspective from Human medicine*

164

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

174 of modern microbiology and infectiology (L. Pasteur, R. Koch, etc.) brought scientific
175 evidence to support this conception.

176

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

193

194 In human medicine, in addition to the biological components of health, the "holistic
195 theory" of health gives a preponderant part to a "subjective" component; without
196 denying the biological aspects, this approach considers that health depends essentially
197 on the perception of the subject, and therefore on socio-cultural values and references
198 that vary in space, time, and according to individuals. The definition of health

199 established in 1946 by the World Health Organization goes beyond the absence of
200 disease and traditional, strictly physical and biological criteria, and displays a positive
201 and plural dimension in nature (physical and mental integrity, well-being) and scale
202 (individual and population): "*Health is a state of complete physical, mental and social*
203 *well-being, and not merely the absence of disease or infirmity*" (World Health
204 Organization, 2017).

205

206 *Health and disease of farm animals*

207

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

222

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

238

239 Based on the World Health Organisation (WHO) definition of health, and also placing
240 animal health in the perspective of the supply of animal products that are safe for
241 human health, it seems important to consider an integrated ("holistic") approach to
242 farm animal health, to consider the two components of health (risk of exposure to
243 pathogens and physiological balance) and to focus on the best balance to be found in
244 livestock farming practices. Furthermore, it is important to consider both the individual
245 dimension of animal health and the herd level. Mental state of the animals has not until
246 now been considered for farm animals, apart from abnormal behaviours generally
247 observed under intensive farming conditions (for example feather pecking, bites,

248 stereotypies, self-mutilation). In connection with the animal welfare approach, it would
249 also seem useful to take an interest in the concept of “mental states” of production
250 animals.

251

252 Given the variety of livestock farming systems and species raised, and the diversity of
253 points of view (breeder, veterinarian, citizens), it seems illusory to search for a generic
254 and universal definition of animal health. In agreement with van der Linden and
255 Schermer (2022), a pragmatic vision seems appropriate to make progress on the issue
256 of the health of farmed animals. This vision must nevertheless be clearly explained by
257 indicating which points of view are considered (breeder, veterinarian, citizen), which
258 dimensions are taken into account (for example risk with respect to major regulated
259 diseases, impact on the career of the animal (i.e. longevity)). Further, any definition
260 should also be clearly framed in terms of the operational context in which it is to be
261 used, such as research, health monitoring, etc.

262

263 *Practical assessment of animal health*

264

265 The integrated conception of animal health presented above is important if we are to
266 move beyond a narrow focus on the presence or absence of specific diseases.
267 However, this raises research questions with respect to measuring the health of an
268 animal and of a herd in farming conditions. The choice of parameters and their
269 combinations needs to be considered and evaluated, for the different animal species
270 and for different periods of life of the animals. The relationships and boundaries
271 between health and disease should be explored, with the concept that healthy and sick
272 are (opposed) points on a continuum. Accepting that health status is a continuum offers

273 the prospect of defining objective, nuanced and operational criteria on which to build
274 improved diagnostic and intervention tools, tuned according to the domains and
275 biological functions considered (metabolism, reproduction, robustness, longevity, etc).
276 Significant opportunities to achieve this are offered by the advent of on-farm monitoring
277 technologies, and more recently the “Internet of Things” (Tuytens et al., 2022). These
278 provide high-frequency repeated measures allowing health status of animals to be
279 monitored and quantified on a continuous scale (Højsgaard and Friggens, 2010).

280

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

286

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

294

295

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

297

298 *Historical perspective*

299

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

313

314 Philosophical thought has particularly focused on the goal of limiting suffering (where
315 suffering is defined as experiencing pain, affliction or distress: Anonymous, 1971) but
316 beyond it, tended more widely to relate this concern to the presence of sentience in
317 animals in common with humans. During the 18th century, Rousseau (1754) was
318 particularly important in putting very clearly in light this ethical basis: *"It appears, in*
319 *fact, that if I am bound to do no injury to my fellow-creatures, this is less because they*
320 *are rational than because they are sentient beings: and this quality, being common to*
321 *men and beasts, ought to entitle the latter at least to the privilege of not being wantonly*
322 *ill-treated by the former."* Along these lines but more restrictively, Bentham (1789)

323 claimed about animals in a very famous sentence: "*The question is not: Can they*
324 *reason? Or: Can they talk? but: Can they suffer?*" More recently, the scientific results
325 of investigations into animal skills in terms of sentience and awareness or
326 consciousness (see below) confirm the validity of this ethical concern and increase its
327 scope by extending it from the negative aspect (minimizing pain / suffering) to the
328 inclusion of a positive aspect (maximization of pleasures) of mental states. For
329 example, Larrère (2007) states: "*Sentience, this capacity to feel (and express) mental*
330 *states like pain and pleasure, suffering and satisfaction, common to men and animals,*
331 *precedes in the first what distinguishes them from the second (speech, reason,*
332 *symbolization, etc.)."*

333

334 At the European level, the principle of sentient beings was enshrined in 2009 in Article
335 13 of the Treaty on the Functioning of the European Union (2016): "*the Union and the*
336 *Member States shall, since animals are sentient beings, pay full regard to the welfare*
337 *requirements of animals".* Animal welfare has become a political issue, with both the
338 development of animal protection associations and the appropriation of this issue by
339 legislators in the Member States." The sentient nature of animals was already
340 recognized in French law by the addition of positive and preventive obligations of
341 animal suffering to the texts already in force, being the fruit of the law of 10 July 1976
342 on the protection of nature which recognized in its article 9 that: "... *every animal being*
343 *a sentient being must be placed by its owner in conditions compatible with the*
344 *biological imperatives of his species."* It was finally introduced in the Civil Code:
345 "*Animals are living beings endowed with sentience."* (Law of 16 February 2015, Article
346 515-14), opening the way towards an evolution of the legal status of animals.

347

348 Today, animal welfare has become one of the objectives of the European Union: “*In*
349 *formulating and implementing the Union's agriculture, fisheries, transport, internal*
350 *market, research and technological development and space policies, the Union and*
351 *the Member States shall, since animals are sentient beings, pay full regard to the*
352 *welfare requirements of animals, while respecting the legislative or administrative*
353 *provisions and customs of the Member States relating in particular to religious rites,*
354 *cultural traditions and regional heritage.” (Article 13 of the Treaty on the Functioning of*
355 *the European Union, which has consolidated in one single text all the founding*
356 *Treaties; the Treaty of Lisbon: European Union, 2007). Indeed, all the current*
357 *legislation on animal protection and welfare was elaborated at the level of the*
358 *European Union and then implemented into national legislation in the Member States.*

359

360 Concern for welfare can however take several forms: either reducing itself to
361 minimizing as much as possible the supposed causes of suffering or discomfort, or
362 seeking to promote the expression of behaviours specific to the species, by providing
363 in their environment the means for this purpose. Nevertheless, some authors still argue
364 that the actual benefit of animals' ability to exercise “natural behaviour” on its welfare
365 needs to be evidenced (Dawkins, 2023). The latter perspective is one of ethics of
366 integrity (Bovenkerk et al., 2002) that can go so far as to recommend the return - within
367 the limits of what is possible after the impact of the domestication process - to the
368 conditions of a natural/outdoor environment. This even extends to the point of
369 reintroducing the risks associated with it (for example the health risk and the presence
370 of predators in semi-open flocks). Thus, the possibility of contradictions between the
371 concern for animal welfare and provision of a natural environment have to be
372 addressed. In the search for improved welfare, a more moderate vision consists of

373 respecting certain environmental conditions allowing the expression of the behaviours
374 specific to the species.

375

376 In the field of animal farming, the highlighting by Harrison (1964) of the prevailing
377 conditions of intensive livestock production in Great Britain followed by the
378 establishment of the Brambell Committee (1965) marked a turning point in way that
379 citizens considered the animals they share or use for their own purposes. The mission
380 of this committee was to make recommendations and propose minimum welfare
381 standards that meet the basic needs of animals under intensive livestock farming
382 conditions. In 1965, the committee produced a report rightly considered to be the
383 foundation of reflections and approaches relating to the welfare of farmed animals in
384 Europe (1965). The first contribution of this report is an often-overlooked definition
385 (Chapter 4, paragraph 25): *“Welfare is a wide term that embraces both the physical
386 and mental well-being of the animal. Any attempt to evaluate welfare therefore must
387 take into account the scientific evidence available concerning the feelings of animals
388 that can be derived from their structure and functions and also from their behaviour.”*

389 This definition already referred to the existence of mental states in animals, a recurring
390 point of controversy between stakeholders (Fernandes et al., 2019). It can also be
391 noted that this definition considers the animal as a sensitive and conscious individual.
392 Animal sentience includes the ability to perceive sensations through sight, hearing,
393 smell, taste and touch, as well as the ability to feel emotions, bearing in mind that an
394 animal's emotional capacities depend above all on its sensory world (Boissy et al,
395 2007). Consciousness (Le Neindre et al, 2017) relates to the ability of the animal to
396 reflect on its actions, to have a subjective or phenomenal experience of its
397 environment, its own body and/or its own knowledge; it enables it to adapt to a

398 changing and often unpredictable environment. The definition distinguishes 'welfare'
399 as a concept from 'well-being' that describes the state of the individual animal. Further
400 scientific advances in the knowledge about sentience (Le Neindre, 2009) and
401 consciousness (Le Neindre et al., 2017) of animals have reinforced these concepts,
402 now widely accepted, both by national (Agence nationale de sécurité sanitaire de
403 l'alimentation de l'environnement et du travail, 2018; Mormede et al., 2018) and
404 international agencies (World Organisation for Animal Health, 2022).

405

406 *Current definition of welfare*

407

408 Thus, the latest definition of 'animal welfare' by the World Organisation for Animal
409 Health (WOAH) thus states "*Animal welfare means the physical and mental state of an*
410 *animal in relation to the conditions in which it lives and dies*" (World Organisation for
411 Animal Health, 2022). This definition is completed by the statement that "*While animal*
412 *welfare refers to the state of the animal, the treatment that an animal receives is*
413 *covered by other terms such as animal care, animal husbandry, and humane*
414 *treatment.*" In France, according to the opinion of the French Agency for Food,
415 Environmental and Occupational Health & Safety (Agence nationale de sécurité
416 sanitaire de l'alimentation de l'environnement et du travail, 2018), "*an animal's well-*
417 *being is the positive mental and physical state linked to the satisfaction of its*
418 *physiological and behavioural needs, as well as its expectations. This state varies*
419 *according to the perception of the situation by the animal.*" This definition reinforces
420 the importance of the mental dimension of the feeling of the animal considered in its
421 environment. Thus, good health, a satisfactory level of production and an absence of
422 stress are not enough to ensure the well-being of the animal. We must also worry about

423 what the animal feels, namely its unpleasant subjective perceptions (fear, pain and
424 suffering) but also its positive emotions (satisfaction, pleasure, etc.). This means that
425 improving the welfare of animals should no longer be limited to reducing their suffering
426 and stress, but also to developing living conditions that give them positive emotional
427 experiences.

428

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

430

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

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

445

446 The current definitions of welfare reported above are suitable for the animal as an
447 individual, but the practical assessment is often in the context of groups of animals

448 both at the farm and at the slaughterhouse for production animals. The first step is to
449 assess the state of welfare at the level of the individual in its environment. A second
450 step is the integration of individual data at the group level (e.g. the context of the farm).

451
452 The assessment of welfare at the individual level is based on the assessments of the
453 physiological and health status of the animal, as well as its behaviour and its reactivity
454 to humans (animal-based measures). Assessing welfare also implies to take into
455 account the characteristics of the environment as risk factors to animal welfare and
456 levers to improve it (Whay, 2007). An important question is how to move from acquired
457 understanding by studying the welfare of individuals to assessing the overall welfare
458 of a group. Several farm animal welfare assurance schemes have been developed and
459 used on a large scale. The approach adopted in the EU-funded Welfare Quality®
460 project illustrates the degree of complexity of an evaluation tool and the question of an
461 overall evaluation (Veissier et al., 2010). The initial protocols were built for a limited
462 number of production species (pork, laying hens and broilers for fattening, cattle other
463 than calves) as the beginning of a complete evaluation process of the livestock farming
464 systems shared at the European scale and with a decision-making objective in actions
465 to improve welfare. At the European level, these first protocols (Welfare Quality®,
466 2009a, 2009b and 2009c) constitute a reference system, from which new protocols
467 have been developed, with improvements in procedures and adjustments to other
468 species (goats, horses, sheep, turkeys), which have for example also been developed
469 in the AWIN project (AWIN, 2015a, 2015b, 2015c and 2015d). Numerous simplified
470 tools have been derived from these protocols to make evaluations of welfare easier
471 and available to all actors, including the breeders (e.g. BEEP for pigs, EBENE for

472 poultry and rabbits, BOVIWEL for cattle, '*cheval bien-être*' for horses), and the advent
473 of on-farm monitoring technologies opens new perspectives.

474

475 **To which extent are animal health and animal welfare connected?**

476

477 There are conceptual links between animal health and animal welfare, based on the
478 definitions seen previously. The concept of "mental well-being" in connection with
479 positive mental states, is an integral part of the WHO definition of health that includes
480 the mental and social well-being (World Health Organization, 2017). At the same time,
481 the most recent definitions of welfare by Agence nationale de sécurité sanitaire de
482 l'alimentation de l'environnement et du travail (Anses) (2018) or the WOAAH (2022), are
483 based, among other things, on a need to achieve a positive physical state (thus a good
484 health). Apart from these links, there are other connections between health and
485 welfare.

486

487 ***Causal Links between health and welfare***

488

489 A causal link is observed mostly, and described first, in one direction, i.e., the adverse
490 effects of altered animal welfare on disease susceptibility, in particular via a
491 deterioration in immune function, to the point that disease susceptibility and immune
492 function are used as indicators of welfare (Broom and Kirkden, 2004). Advances in the
493 field of psychoneuroimmunology shed light at a functional level on the link between the
494 hypothalamus, the reticular formation and the immune response, suggesting that the
495 immune response is partially under the control of psychological processes (Zachariae,

496 2009). Conversely, the immune system exerts control over the central nervous system,
497 primarily through the cytokine pathway (Dantzer, 2018).

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

512

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

521 relationships between welfare, immunity and disease resistance are more complex
522 than they appear (Berghman, 2016).

523

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

530

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

532

533 Changes in husbandry practices associated with a change in environmental living
534 conditions, like access to outdoors, have profound, but complex and ambiguous,
535 effects on animal health and welfare, and on their interactions. Typically, animals can
536 be given access to outdoors to increase their welfare, but it may have many detrimental
537 effects on their health state. For instance, giving access to an outdoor area and pasture
538 to growing pigs increases the incidence of osteochondrosis as compared to confined
539 indoor housed pigs (for a review, see Etterlin et al., 2016). More generally, access to
540 outdoors increases the risk of exposure to pathogens (parasites, pathogens external
541 to the farm). Moving to outdoor systems in chickens, allows the expression of positive
542 behaviours (Lay Jr et al., 2011) but increases the incidence of parasites like coccidiosis
543 (Sossidou et al., 2015) and red lice (Knierim, 2006). These complex relationships
544 between health and welfare, and production systems have been recently reviewed in
545 the case of alternative pig (Delsart et al., 2020) and organic chicken farming (Holt,

546 2021), where outdoors access increased the risk of injury from predators and from
547 flock mates, the risk and severity of diseases, and the mortality rate. There is therefore
548 a possible level of negative interaction with welfare if biosecurity measures constrain
549 farming practices (e.g. African swine fever, avian influenza, diseases affecting wildlife).
550 The transformation of breeding conditions, to better meet the animals' need for access
551 to external and therefore more complex environments, must be designed in
552 conjunction with a genetic approach to improve the animals' physiological adaptation
553 to less controlled external living conditions (see below).

554

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

562

563 **Improving animal health and animal welfare in the transformation of farming** 564 **activities**

565

566 There is already a considerable body of knowledge that can be mobilized to improve
567 conjointly animal health and welfare of livestock. However, various questions arise at
568 the scientific level. It will be necessary to not only deepen our knowledge of the
569 interactions between health and welfare at the animal level but also to consider
570 different levels of organization. Health and welfare interactions need to also be
571 considered and quantified at the group, herd, farm, value chain and regional levels.

572 This includes going as far as considering impacts and questions involving the citizen
573 and consumer. This is the overall framework of the research agenda that we propose
574 below with the following themes:

575

- 576 - Interactions between animal health and animal welfare at the animal level.
- 577 - Interactions between animal health and animal welfare at the herd level
- 578 - Consideration of the expertise and well-being at work of breeders
- 579 - Interactions at the territory and production and value chain levels
- 580 - Research regarding the link between farming activities and society

581

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

583

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

593

594 Another important issue is to explore the trade-off between the physiological functions
595 of production, reproduction and immunity, as well as to find the best possible
596 equilibrium between efficiency of production, welfare and resilience of the animal (for

597 a review, see Rauw, 2008). Working on the physiological and genetic bases for these
598 trade-offs could help identifying means of action. There are a few examples of such
599 studies investigating trade-offs between production traits and immune function (e.g.,
600 Zerjal et al., 2021), but very few studies that include welfare as well. These questions
601 concern both the short and longer stages over the entire animal's life, and a specific
602 focus should be made in exploring the roles of the prenatal and juvenile periods, and
603 transition phases in sub-adults or adults (weaning, gestation). Another dimension is to
604 analyze the sensitivity of the animals to environmental conditions, such as their
605 average harshness and variability.

606

607 ***Interaction between animal health and animal welfare at the herd level***

608

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

622

623 If we consider the perspective of developing livestock farming systems that place
624 animal health and welfare at the heart of the objectives, it will be necessary to do so
625 whilst guaranteeing performance on all the pillars of sustainability (i.e. social,
626 environmental and economic). This implies not only characterizing the synergies and
627 tensions between health and welfare but also between these two components and the
628 other performance parameters of the livestock farming system that contribute to its
629 sustainability. The compromises that will have to be made in the choice of innovations
630 in rearing practices can only be made in consultation with all the stakeholders. Given
631 the ambition is to design systems that prioritize health and welfare, it will be necessary
632 to know what is the cost of this choice on the other dimensions of performance and,
633 thus, on the acceptability of these innovative systems. It will therefore be necessary to
634 rely on open innovation methods such as living labs, which allow the co-conception of
635 livestock farming systems taking into account the points of view and motivations of all
636 stakeholders (including breeders, upstream and downstream industries, but also
637 citizens' associations and consumers) considered as key players in the research and
638 innovation process (e.g., Leminen, 2015) for general considerations on the living lab
639 concept, and Chiron et al. (2022) for an example of participatory research project in
640 rabbit production).

641

642 As highlighted in the 1.1 and 1.2 sections, a potentially powerful tool for measuring
643 health status and welfare status is the on-farm technology that is being increasingly
644 deployed as part of the general move towards precision livestock farming. These
645 technologies can provide high-frequency objective measures on large numbers of
646 animals (Højsgaard and Friggens, 2010). They already include measuring systems to

647 detect specific health events (e.g. onset of mastitis) and also use behavioural changes
648 to detect events such as onset of oestrus. For these tools to realise their full potential
649 for quantifying the interactions between health status and behavioural status the
650 following research developments are needed. These technologies are currently used
651 to detect specific events rather than to assess in a continuous way how health and
652 behavioural status evolve in response to different farm environments. Achieving the
653 latter requires that the algorithms used to process these data are 're-tuned' to give a
654 more nuanced evaluation of health and behavioural status. Another scientific challenge
655 lies in the interpretation of technology-based behaviour data and animals' emotions.
656 These technologies have been best developed in indoors housing systems (with easy
657 access to power supply and data transmission). Although there has been significant
658 progress, there remains a need to further develop these technologies for use in
659 outdoors, extensive, situations (Bocquier et al., 2014). Further research is also needed
660 to better make the link between measures made on individual animals and those made
661 on groups of animals. For example, camera-based measurements of groups can
662 reveal behaviours like dispersion of the group and average speed of movements (e.g.,
663 Sadoul et al., 2015) but it is not clear how to best combine group and individual
664 measures, or indeed when it is beneficial to do so. Advances on this would improve
665 the tools that could help breeders identify behavioural disorders that can be indicators
666 of disease or poor welfare conditions within the group.

667 The final area for development is not to do with these technologies *per se* but rather to
668 do with their interest and acceptance by breeders; the way they impact their work and
669 their mental workload with these new multiple data and the complexity of the
670 information to analyze, if they are adapted to the needs and skills of breeders and
671 reinforce their ability to observe the animals, or imply new learning and skills (Hostiou

672 et al., 2014). At present, there still remains an unwillingness to accept the measures
673 coming from automated technologies amongst some experts in both fields. In our view,
674 there is a need to provide the proofs that allow these researchers to accept that the
675 benefits of having objective measures available on large-scale can often outweigh any
676 perceived lack of specificity of said measures.

677

678 ***Consideration of the expertise and the well-being at work of breeders***

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

692 Consideration for animal health and rearing conditions vary according to a diversity
693 and heterogeneity of farm types, productions and sizes. These range from mainstream
694 agriculture to alternative-small-holding farms. Small-holders are considered by
695 commercial farming as threats to the biosecurity because of a lack of disease-risk

696 awareness and bioinsecure practices. Going beyond those simplistic representations,
697 Holloway (2019) insisted on the hybrid knowledge that small-holders acquire in the
698 relationships with veterinarians and described how health management is bound up
699 with practices of care. Opposing small-scale farming to commercial farming in terms of
700 biosecurity is reductive as health and care practices are complex and heterogenous in
701 farms (Holloway, 2019). It depends also on the way each farmer is considering how to
702 be a “good farmer”, and a large diversity of farming styles have been identified in some
703 studies (Commandeur, 2006). Moreover, breeders treat the health and welfare of
704 different species, types and groupings of livestock in different ways, with differences
705 between species, between animals of the same species, and between different life-
706 stages or ages (Mahon et al., 2021). A large range of breeders, animal species,
707 geographic situations, and local conditions create infinite combinations of animal-
708 human relationships and ways of rearing. In that context, the challenge is to shift from
709 an advisor-to-breeder knowledge transfer to a recognition and consideration of peer-
710 to-peer systems and to encourage breeders’ exchanges. We make a plea here for
711 setting up research projects on improving conjointly health and welfare of animals at
712 the farm level that are co-constructed with breeders in order to benefit from their skills
713 and expertise. One way to achieve this is to investigate farm situations and results with
714 breeders that have already tested and made strong innovations in health and welfare
715 on their farm, *i.e.* , by tracking breeder’s innovations (Salembier et al., 2021). Another
716 way to achieve this is to use the living labs conception process (see above).

717

718 If animal welfare is a component of sustainability (Buller et al., 2018), the breeders’
719 well-being should be a legitimately associated goal, with a focus on the capability of
720 breeders to create knowledge and competences and to innovate in the field of animal

721 welfare. This is an important aspect to be integrated under the banner of “One Welfare”
722 (Buller et al., 2018). A key question is to what extent does an improvement in the health
723 and welfare of their animals contribute to improving the well-being of breeders, their
724 representation of work, personal and societal beliefs and satisfactions, and comfort at
725 work. However, the contrary may also apply, that innovating on animal health and
726 welfare can introduce new constraints for the breeders such as increased time or
727 arduousness of the work. In parallel, it would be important to analyze what are the
728 obstacles and drivers underlying changes to practices by breeders and transitions
729 towards practices that are sustainable in terms of animal health and welfare; and what
730 kind and extent of innovation are accomplished on the real farms. Porcher (2017)
731 proposed to look in a new way at the relationships between farmers and animals, with
732 the assumption that farm animals such as milking cows work. In this perspective,
733 working conditions of both farmers and animals are considered, animals are respected
734 as workers and the farmers rely on the intelligence of animals without exploiting them.

735

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

737

738 With the emergence of societal concerns on animal health and welfare, breeders have
739 appeared to initially be quite isolated with respect to providing answers and producing
740 change in their farming practices (Quéméré and Le Neindre, 2013). Indeed, changes
741 in regulations have often been the main driver for change in favour of animal welfare
742 (Mounaix et al., 2013). Initially not involved in the debate (ethics, welfare), breeders
743 and their organizations are fully engaged with it (Quéméré and Le Neindre, 2013).
744 Indeed, co-operative organizations, as well as Standards Formulating Organizations
745 (SFO), but also breeder groups initiatives, have been playing an important role in the

746 standards negotiations between breeders and retailers and in the implementation of
747 welfare assessment tools like the Welfare Quality references (Aramyan et al., 2013;
748 Bertrandias et al., 2021). Acknowledging that multi-stakeholder approaches are key to
749 improve animal health and welfare, we then identify three main research topics at the
750 regional and production sector levels that underlie the expected transition process
751 towards livestock farming systems that promote both animal health and welfare.

752

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

754

755 Changes in farming practices toward better health and welfare of animals must take
756 account of all the diversity of farms in terms of their technical and economic
757 orientations, the networks to which they belong (trading, strategic, technical, etc.) and
758 any product differentiations that result with respect to their marketing. For the breeders,
759 improving animal health and welfare should not penalize business returns. It could
760 bring benefits, e.g. better animal productivity, reduction of drug use, and would thus
761 allow breeders to gain the initiative in the animal welfare debate (Lawrence and Stott,
762 2009). However, improving animal health and welfare in livestock farms requires
763 practices and/or system adaptations, new investments (Johan Lagerkvist et al., 2011),
764 and maybe more workforce. These costs must usually be economically compensated
765 by supports, as suggested for the European Common Agricultural Policy (Guyomard
766 et al., 2023), or premiums and state product labelling. The health and welfare
767 differentiation of the products, managed by the downstream part of the supply chain
768 may affect consumer prices. There is a gap between the consumers' stated willingness
769 to pay more for animal health and welfare products and their real purchasing acts that
770 remain price-oriented (Deblitz et al., 2021). Animal welfare labelling will inform

771 consumers and give the opportunity to make conscious consumer choices. This can
772 have the consequence of them consuming fewer animal products (Deblitz et al., 2021).
773 This raises the question of the best productive and industrial strategies, the best public
774 policies to set up to improve animal health and welfare while preserving the economy
775 of the sectors, such as using market-led approaches or relying on supply-side
776 solutions. The issues and questions raised here all relate to how to translate the
777 challenges of emerging new paradigms such as the Eco-Health concept (“human-
778 animal-ecosystem” interface) – for example by focusing on the example of
779 antimicrobial resistance – into organizational processes for livestock rearing in different
780 sectors and regions.

781

782 *Technical, organizational innovations and coordination mechanisms*

783

784 Various approaches can exist to push changes on animal health and welfare in the
785 industry and in different regions. Research may be useful to analyze their efficacy or
786 to support the process, among others different types of coordination (integration, “spot”
787 markets, networks, etc.), the internationalization of agricultural and food markets, and
788 different types of local cooperation between a variety of actors (agricultural or not). It
789 can also be hypothesized that the multiplication of initiatives can potentially blur
790 breeders and consumers perceptions, especially given the poor knowledge of citizens
791 about farming methods (Cornish et al., 2016).

792 Changes to organisational systems will need to take into account: the diversity of
793 systems co-existing in a same rural area (e.g. co-existence of indoor and outdoor
794 systems); actor strategies (e.g. living with pathogens or eradicating them); the
795 knowledge generated on health data (e.g. interactions with wild fauna); and technical

796 innovations (e.g. precision livestock farming) or organisational innovations (e.g. fab lab
797 or networks of breeders). They must also be designed in the context of knowing what
798 options can be developed for documenting or certifying the animal products, i.e. the
799 monitoring and management of infectious diseases and welfare in the different sectors
800 and regions. Likewise they will need to take into account what is the acceptability, by
801 the downstream elements of the supply-chain including consumers, of “new” animal
802 products from adapted livestock farming systems. Indeed, innovative, ground-
803 breaking, systems that focus on health and welfare can be based on non-standard
804 genetic types, produce animals that are heavier or lighter, fatter, older, altered
805 seasonal production patterns. The consequences of these non-standardized animals
806 on the processing of animal products need to be addressed. Finally, the feasibility and
807 acceptability by field actors of new animal management philosophies, such as
808 providing “retirement opportunities” for old animals, should be investigated.

809

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

811

812 The spatial distribution of livestock farming, the evolution of the herds' size and the
813 emissions from the livestock industry, or, more globally, the question of the safe
814 operating space for livestock production (Buckwell and Nadeu, 2018), must also be
815 included in the debate (Deblitz et al., 2021), otherwise new disputes will arise again
816 soon afterwards. These concern all the risks linked to the concentration of animals and
817 industry: excessive effluents, impossibility of closing cycles in a circular economy,
818 epizootics and other health risks. This evaluation can be carried out through stimulating
819 the involvement of actors in different regions and sectors. It may involve developing
820 the joint construction of organisational changes within certain sectors or regions so that

821 account can be taken of the health and welfare of animals throughout their lives. This
822 includes issues such as the euthanizing animals of little economic value (male chicks,
823 female ducklings, male kids, etc.) or alternatives to slaughtering animals for health
824 reasons should also be considered. The potential interest of some practices that are
825 almost non-existent today, such as “smallholders slaughters” managed by the
826 breeders themselves, needs to be evaluated and this requires an environmental as
827 well as an economic and social assessment. In a more holistic way, the structuring and
828 functioning of our global food systems (from farm to fork) should be reexamined and
829 democratically discussed (within the framework of citizens' conferences, for instance).
830 Topics such as the place, size and structure of livestock farming activities, the place of
831 animal products in our diet, for instance, should be discussed. Various prospective
832 studies could be mobilized to enlighten these reflections (Aubert et al., 2019).

833

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

835

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

837 There is a growing societal concern for human health on the one hand, and animal
838 welfare including farm animals in the other hand. They both gradually appear on policy
839 agendas but these two trends, interrelated in this paper, are quite separated in society,
840 science and political debates. Animal welfare concerns the way animals are farmed,
841 transported, slaughtered and finally consumed (Buller and Roe, 2018). These topics
842 are of increasing interest to many people in most parts of the world. Following non-
843 governmental Organizations (NGOs) campaigns, the European Commission intends
844 to propose to phase out and finally prohibit the use of cage systems, for all the species
845 and categories mentioned in the End the Cage Age European Citizens' Initiative

846 (European Commission, 2021). In parallel, dedicated structures and new regulations
847 assigning to animals a status “as subjects”, and commercial standards promoting
848 ethical market segmentation are emerging. These are collectively driving towards a
849 movement of standardization and institutionalization of animal health and welfare.

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

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

869 health issues, the panel of stakeholders should be further expanded to include
870 scientists, veterinarians, civil society and NGOs, farm advisors, etc.

871 *Dialogue between the various stakeholders and society*

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

891 These challenges for the animal health and welfare sciences and for the humanities
892 and social sciences are so vast that they cannot be met by individual disciplines, nor

893 by single or small groups of actors and stakeholders. We believe that, for specific
894 research projects on cutting-edge farming-societal issues, transdisciplinarity research
895 is required. Transdisciplinarity research addresses a complex, socially relevant issue,
896 considers diverse perspectives and disciplinary approaches, links abstract and case-
897 specific knowledge, and develops a common-good-oriented descriptive knowledge to
898 address the issue (Pohl, 2011). A key point is recognizing the limits of science (and its
899 experts) and respecting the expert knowledge of 'lay people' (i.e. citizens).

900

901 **Perspectives and conclusion**

902

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

908

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

917

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

925

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

933

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

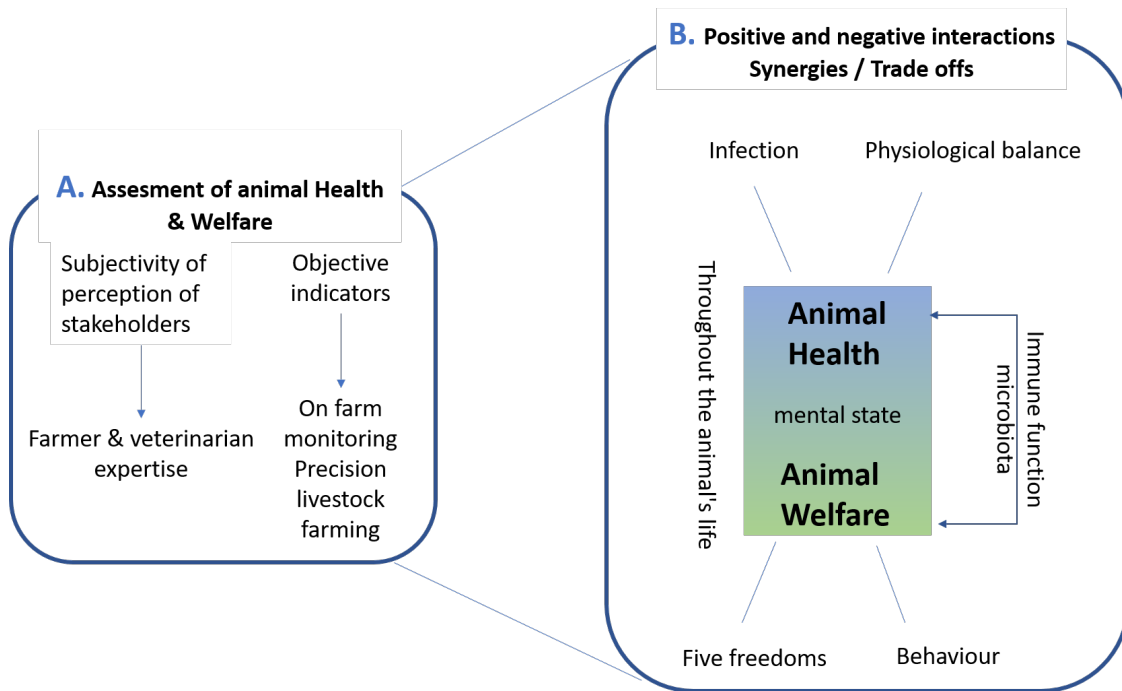
943 **Figure 1.** Challenges to address in moving livestock farming towards greater consideration of
 944 animal health and welfare.

945 A. Better assessment of animal health and welfare

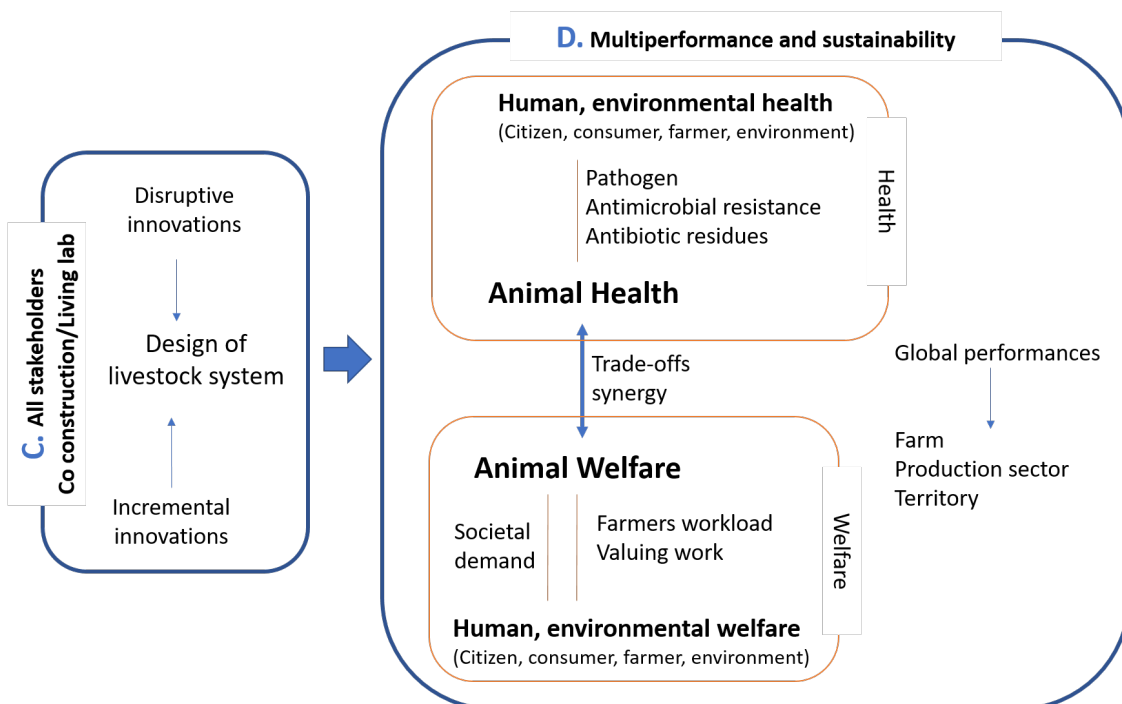
946 B. Understanding the positive and negative interactions between animal health and welfare
 947 (synergies and trade-off)

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

949 D. Multiperformance and sustainability of livestock farming systems improving animal health
 950 and welfare



951



952

953 **Ethics approval**

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

955 **Data and model availability statement**

956 This work was not grounded on data and model.

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960

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962 J.-L.P., M.V., X.F. and C.D. wrote the initial project for the INRAE interdisciplinary
963 programme on animal health and welfare (SANBA), basis of this article. A.B. and P.M.
964 wrote the chapter on the history and definition of animal welfare. F.S. and C.D. wrote
965 the chapter on the history and definition of animal health. M.-B.B., F.Ch., S.P., M.-H.P.,
966 P.V., X.F. and C.D. wrote the initial version of the other chapters. F.Ca., A.D., S.E.,
967 G.F., N.C.F., R.G., and I.M. contributed to the improvement of the text and figure.
968 N.C.F. edited the English writing.

969 **Declaration of interest**

970 The authors declare that they have no competing interests.

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