Animal Health and Welfare for a Sustainable Livestock sector

Ulf Magnusson SLU, Michael Apley KSU, Sofia Boqvist SLU, Rebecca Doyle UNIMELB

(Note that some tables and figures will be added to the final version of this text)

Table of Contents

Introduction

Good animal health and welfare promotes high productivity, efficient use of natural resources, lower greenhouse gas emissions per kg of milk, meat, egg wool and hide, produced, reduction of the need for antimicrobials, protection of farmers and consumers from food borne and other zoonoses, secured livelihood for farmers and food security and increase consumers trust in the livestock sector. Thus, animal health and welfare relate to all the sustainability dimensions of livestock adopted by the Global Agenda (FAO, 2018) and are relevant in capital intensive, labour intensive as well as extensive (pastoralist) systems across economic settings. Reasons for not implementing good animal health and welfare practices may be due to a lack of resources or competence among producers or authorities, traditions or cultural issues, or doubts about whether they contribute to increased profit. In the preparation of the MSP meeting in Kansas the following areas were identified as particularly important for sustainability within the animal health and welfare realm: Impact of animal disease, Zoonoses and pandemics, Foodborne diseases, Antimicrobial resistance and Animal welfare. In this paper we elaborate on ways to improve animal health and welfare under these five headings, both in general terms and some times by using specific examples from around the world.

Issues, opportunities and risks

Impact of animal diseases

The OIE-listed diseases, infections and infestations as of 2019 include 117 different listings (OIE, 2019a). Several high-profile transboundary diseases (TBDs) serve as examples of the risks of animal diseases, challenges in quantifying their effects, and the associated opportunities with their control.

The complex nature of evaluating economic impacts of diseases is illustrated in an assessment of the economic impacts of the 2013 Porcine Epidemic Diarrhea Virus (PEDV) outbreak on the U.S. pork industry and allied industries (Schulz and Tonsor, 2015). The authors concluded that pig losses and reduction in productivity experienced by producers were likely smaller proportionally than the accompanying price increase; this relationship may have actually resulted in higher net returns as compared to expectations prior to the outbreak. They further observed that the most likely parties with direct economic damage from the outbreak were packers, processors, distributors, and retailers. In addition, consumers likely paid higher prices than they would have otherwise, and other proteins also benefitted from a price increase. This example demonstrates that only characterizing risks on a macroeconomic basis without consideration of all the stakeholders may be misleading; opportunities, at least localized, may be created from infectious disease. However, these situations of opportunity are largely outweighed by risks that tend to be much more common and significant.

Perhaps the greatest of these risks are in areas with widespread subsistence food animal production, where the introduction of a highly contagious, high case fatality disease has the effect of systematically removing accumulated economic and food resources which may be impossible to replace, or that require an extended time period to replace. An example is the rapid decimation of the swine population due to African Swine Fever (ASF) in Vietnam where from the first report of ASF in February 2019 to a reporting date of April 25, 2019, outbreaks had been reported in 24 provinces and cities with culling of an estimated 89,600 pigs (FAO, 2019).

Another example of a disease resulting in rapid decimation of a livestock population is foot and mouth disease (FMD). The OIE reports that FMD is estimated to be present to some extent in 77% of the livestock population worldwide and that an estimated 75% of the costs attributed to FMD are incurred by low and lower-middle income countries (OIE, 2019b). The total costs of the 2001 United Kingdom FMD outbreak, affecting approximately 10 million animals, have been estimated to comprise 20% of total farm income for that year Thompson et al., 2001). The loss of business to local providers, including veterinarians, were not quantified. The personal toll of a catastrophic event of this magnitude is much harder to quantify, although studies have demonstrated that life after the U.K. FMD epidemic "was accompanied by distress, feelings of bereavement, fear of a new disaster, loss of trust in authority and systems of control, and the undermining of the value of local knowledge. Distress was experienced well beyond the farming community" (Mort et al., 2005).

Significant disease impacts are not only attributable to TBDs. Anaplasmosis, an endemic disease of cattle in many countries, has been expanding in the geographic range of diagnosed cases in the United States with one example being in Kansas (Hanzlicek et al., 2016). The authors of a Bayesian space-time pattern analysis in concert with climatic determinants evaluated 478 diagnosed cases at the Kansas State Diagnostic Laboratory from 2005-2013. They found that the risk of anaplasmosis was associated with the minimal land surface temperature, and range of relative humidity and diurnal temperature. These factors may be associated with the range and population of the primary tick vector. Costs associated with this disease beyond morbidity and mortality include costs and labor to control active infection of anaplasmosis. In all of these scenarios, an infectious disease outbreak has the capacity to jeopardize all four domains of sustainability.

Zoonoses and pandemics

About two thirds of human infectious diseases are zoonotic and account for a significant global health burden. Livestock is the main reservoir for many of these zoonoses, but there may also be an intermediate reservoir for zoonotic diseases that have originated in wildlife. Some zoonoses, primarily viruses, are highly contagious and may have a pandemic potential. They can spread rapidly over the world through the global trade of livestock or foods of animal origin and by international travelling. The severe acute respiratory syndrome (SARS) and the Swine influenza in 2009-10 are prominent examples of pandemic zoonoses. The economic impact from zoonotic outbreaks is substantial, it is estimated that six major outbreaks of highly fatal zoonoses between 1997 and 2009 caused economic losses of at least 80 BUSD (World Bank, 2012).

Apart from the public health risks, the risks related to zoonoses with a pandemic potential are very similar to those of other non-zoonotic TBDs, including: trade restrictions, direct production losses and indirect losses resulting from control measures, such as pre-culling and stamping-out of non-infected animals. Thus, there might be very severe effects on the producers' economy and livelihood, especially in countries with few opportunities to provide economic compensation to the farmers. In low and middle income countries (LMIC,) fighting pandemic zoonoses may also result in negative consequences for food security. Also, given the impact on public health by zoonoses, the livestock production may be blamed as a biohazard, like the pig production in Malaysia during the Nipah outbreak in the 90's (Chua, 2013)

The endemic zoonotic diseases may, in some settings, be overlooked as being among the background hazards of livestock keeping. This might be particularly true if there are no dramatic effects on the livestock, "just" poor production performance, like endemic brucellosis in LMICs. Other such endemic zoonoses that pose risks to public health, but have little or no negative effect on animal health is campylobacteriosis in poultry or Shiga toxin-producing *Escherichia coli* in cattle. For these diseases there might be limited incentives for farmers to take measures, unless demanded by public health and food agencies, or by stakeholders in the food value chain. Regardless whether the zoonosis has a pandemic potential or not, farmers and their families in low income countries (LIC) are often those at most risk as they often live close to their livestock and have poor resources to contain the disease.

Both for the pandemic and for the endemic zoonoses, the control and containment measures are very much the same as for other infectious diseases in livestock. One opportunity though, is that zoonotic diseases usually get more attention from the public and authorities– especially pandemic ones - and therefore, there are more financial and organizational resources put in place to control them. Generally, it is also more cost-efficient to put resources for detection and control of zones in animals – "at source" – than in people (World Bank, 2012). Finally, the control of other infections in livestock may benefit from this resource mobilization, as in the case for the avian influenza.

Food borne diseases

Food borne diseases (FBD) are threat to public health, but also to sustainable livestock production. Sustainability challenges related to FBD have changed during the last decades. Some examples are that the traditional food chains, from farm to fork, are being replaced by complex food webs (Boqvist et al., 2018), and the global consumption of animal sourced food is increasing (Steinfeld and Gerber, 2010).

Some of the most important FBDs originate from livestock, for example campylobacteriosis and salmonellosis (Havelaar et al., 2015). This reflects the importance of animal health, welfare and management systems that prevent the spread of FBD. The importance of FBD was recently highlighted when it was shown that the burden of FBD were of similar magnitude as those of the major communicable diseases: HIV/AIDS, malaria and tuberculosis (Havelaar et al., 2015). The global burden of FBD was estimated to 33 million Disability Adjusted Life Years (DALY) and the highest burden falls on Africa, particularly on children below the age of five. The costs for FBD are very high and include costs related to the healthcare sector (direct costs), resources used by patients and non-healthcare-related resources (indirect costs) used, including absence from work, permanent or long-term disability or premature mortality.

Improving animal health will have a positive impact on public health as healthy animals are less prone to carry and shed zoonotic pathogens. This will lead to less contaminated food products on the market contributing to higher consumer trust, improved access to markets for the producers and thereby better economic benefit for them and other business operators.

Antimicrobial resistance

The emergence of antimicrobial resistance (AMR) is currently the greatest threat to the advances that have been made in human health and well-being as well as animal health, welfare and production over several decades. It has been estimated that AMR will contribute to millions human deaths per year in the world and the production in the livestock sector in low income countries is at particular risk with an estimated loss of 10% by 2050, if the emergence and spread of AMR is not curbed (O'Neill, 2016; World bank, 2017).

The development of resistance occurs naturally but is very much enhanced by the extensive use of antimicrobials. So, to protect the efficiency of antimicrobials it is critical to reduce the use and limit it to medically rational use. Currently, the livestock sector is a significant contributor to the global pool of resistant genes and bacteria in the biota given that the sector is a large user of antibiotics (Van Boeckel et al 2015). Except for cases where farm workers have been infected with resistant bacteria from livestock, the importance of the sector as a contributor to resistant microbes to the human population as a whole is not known (Tang et al., 2017). Even so, for the sake of animal health and for the risk of transmission of resistance to humans, it is reasonable to reduce the use of antibiotics in the livestock sector in several settings (e.g. Robinson et al., 2016).

Notably, there is very large geographic differences in access to and use of antibiotics, varying from hard to get access to, to freely and easily available. The same holds true for differences in farming systems, where most antibiotics are used in intensive poultry and pig systems (Van Boeckel et al., 2015). Adding to this complexity, there are significant differences between states regarding regulations about use and supply of antibiotics as well as the capacity to enforce these regulations. Also, the public's awareness and attitudes towards the use of antibiotics in the livestock sector varies.

Animal Welfare

Extending from animal health and disease, animal welfare is an essential part of the production system, from farm to consumer, regardless of industry scale, farm size or species. Animal welfare acts as the umbrella term that considers the health, nutrition, housing and behavioural needs of animals, and how they are managed, and is linked to the pillars of sustainable agriculture (Broom, 2010; Appleby and Mitchell, 2018). The Food and Agriculture Organization' (FAO) vision for sustainable livestock production treats animal welfare as a priority in all livestock systems globally (FAO, 2018). Preliminary work by the Animal Welfare Action Network group of the Global Agenda for Sustainable Livestock and collaborators have currently mapped production animal welfare and the role and welfare of working equids to eight of the UN's Sustainable Development Goals (SDGs) directly (Doyle et al., 2018; World Horse Welfare and The Donkey Sanctuary, 2018), and these sit across the breadth of the four domains of sustainability.

Focusing on animal welfare can produce additive improvements to reduce wastage, including animal mortality, restricted production and produce losses, that benefits the environment. Opportunities outlined in the sections below include positive impacts on worker satisfaction, along with occupational health, food safety and food security. Economic benefits are also possible; with improved animal welfare contributing to improving livelihoods and creating the opportunity to access higher value markets. However, in some cases there may also be trade-offs between animal welfare and other societal goals, that also need to be identified and managed.

Animal welfare is becoming of increasing concern to communities, which is influencing consumer behaviour, governmental processes and international expectations. Failure to recognise and incorporate animal welfare into practice and policy therefore risks the viability and sustainability of global production systems. Without genuine improvement of animal welfare, many of the SDGs will not be realised (Euro Group for Animals, 2018) and the livestock systems, the people that rely on them, and the animals within them will suffer.

Innovation to enhance sustainability

The impacts of animal disease

Common themes for needed innovation throughout food animal infectious disease management, are improved vaccine technology, the increased availability of accurate and robust diagnostic tests, improved knowledge of disease transmission leading to opportunities for fomite and vector control (biosecurity), and improved techniques to address and control these fomites and vectors. Examples of the use of testing and control measures which have been used to eradicate diseases in domestic animal populations include bovine brucellosis and porcine pseudorabies in the United States (USDA 2019 a,b). Several disease-specific challenges illustrate the need for continued innovation to reduce the impact of animal diseases.

In controlling an outbreak of FMD, the current state of control measures in non-endemic areas is often to euthanize affected animals and susceptible in-contact animals (USDA, 2019c). An alternative is to ring vaccinate around the index cases if the appropriate vaccine is available in sufficient quantities; however, the seven recognized strains of FMD, each requiring a specific vaccine for protection, make it very important to select the appropriate vaccine strains for control and for preparation for a potential transboundary incursion (Diaz-San Sequndo et al., 2017)

Control of the effects of ASF is made difficult by the absence of an approved vaccine, although a recent report describes successful testing of an oral vaccine in wild boar and multiple organizations and companies are working towards a vaccine (UPI, 2019; Barasona et al.2019). Use of antiviral compounds for control has implications in both cost and the potential for selection of resistant viral strains.

Clinical cases of anaplasmosis are controlled in persistently infected cattle in endemic areas, but these animals then serve as sources for fomite or vector-mediated spread of the disease. Clearance of infected animals is inconsistent and should not be considered a certainty even with published regimens reported to do so (Aubry and Geale, 2011). If clearance is successful, animals again become susceptible to infection with no demonstrated immunity. Much needed innovations include a vaccine with demonstrated multiple strain immunity and improved approaches for control of the primary vector, a tick, is also important to control the spread of the disease.

The source of PEDV in the United States has been associated with feedstuffs, emphasizing that biosecurity measures must not only focus on animal movement and the people and equipment responsible for animal production, but also must evaluate all potential entry points for the virus (Dee et al., 2016). Continued advances in rapid and affordable tests which may be accurately employed in the field for evaluation of potential fomites are critical for advancing biosecurity.

Zoonoses and pandemics

Innovations needed to mitigate and/or prevent zoonotic infections of pandemic potential vary depending on livestock production system and region. In large-scale intensive livestock systems, the biosecurity is usually very high, which reduces the risk of introduction of contagious diseases. However, once an infection enters such a premise it may spread quickly resulting in large economic consequences for the farmer and a reduction in animal welfare, resulting from control and eradication measures as well as from clinical disease. As the majority of these farms are located in HIC there is likely a minor or negligible effect on food security. In small-scale extensive livestock systems in rural areas the biosecurity is generally low. These farms often have several livestock species, which is a way for the farmer to mitigate risks. If these small-scale farms are affected by a zoonotic disease of pandemic potential it might be of high severity for the individual farm, but not for the society. The most challenging situation appears at small scale commercial farms with poor biosecurity in LMIC as in the case with highly pathogenic avian influenza (FAO/OIE, 2008). Contagious diseases might spread quickly at these premises and also to other farms through direct and indirect transmission, especially if the farms are located in urban or peri-urban areas. It is believed that these farms are important for emergence of new influenza viruses. Different innovations are needed for different livestock systems, for example, how to increase biosecurity, reduce occupational health risks, and prevent and control contagious diseases.

Innovations directed towards endemic zoonotic infections are very similar to those described under the section Food borne diseases in livestock systems, especially since some diseases fall within both categories of diseases. Even so, the fight against one such zoonosis, Brucella in ruminants, provides some historical and current reflections that might be useful when designing innovations. Brucellosis in cattle was eradicated in Sweden in the 1950's, based on the robust diagnostics available at that time (Cerenius, 2010). Key factors were that communal grazing and mixing of herds was very limited and farmers organization were strong and well organized, making compliance to external biosecurity measures effective. Also, there was a very present veterinary authority and service closely interacting with the farmers. Thus, innovations are not just about new technical solutions when it comes to fight animal diseases; it is equally about structures, organizations and compliance to agreed measures and partnership.

In many of the countries where we find brucellosis in ruminants today the control of the disease faces several challenges (Plumb et al., 2013). One is that there is often communal grazing and thus very hard to implement biosecurity measures. Another is that in some of the countries the productivity of the animals is low and the symptoms of the disease is vague, such as sporadic abortions and low milk production, making the farmers not motivated to invest in control measures like vaccination. A third is that the culling of the few seropositive carriers after vaccination campaigns – this is a standard procedure for eradicating the disease – might be very controversial if there is no compensation scheme in place. Again, innovations for reducing the impact of endemic zoonotic disease cannot rely entirely on new technical innovations like improved vaccines or diagnostics – it is equally critical to improve organization and governance of animal and public health including various stakeholders.

Food borne diseases

When food systems become more complex they also become less robust, there is for example increased risk for food fraud when the food supply chains have been lengthened and more complicated (Spink and Moyer, 2011). This points to the need for new innovations to improve traceability of food products.

There is a need for innovations enabling proactive, rapid and evidence informed decisions to improve food safety. This is particularly true as recent FBD outbreaks have been widely distributed, affecting multinational food systems. One example is the Shiga toxin-producing E. coli (STEC) outbreak within EU in 2011, which resulted in more than 3800 cases of illness (Frank et al. 2011). Releasing of the preliminary test results led to withdrawal of food products from the market that were unrelated to the outbreak. This mistake resulted in economic losses amounting to over 800 million EUR for the producers. Further challenges in identifying the causative agent led to delay of appropriate risk and crisis management. In this case, the cause of the outbreak was contaminated sprouts, but it highlights the need for innovations to improve reliable and rapid diagnostic tests to facilitate informed decisions and technologies that improve traceability of food products.

As the food system gets more complex new innovative thinking is needed on how to ensure that a One Health (OH) perspective is applied when controlling FBD. One Health includes a range of synergistic disciplines, including, for example, food safety, public health, health economics, ecosystem health, social science and animal health, for addressing complex health challenges. One example when the OH perspective was applied too late, was during the outbreak of vCJD (variant Creutzfeldt-Jakob disease) in humans and Bovine spongiform encephalopathy (BSE) in cattle, starting in the UK in the 1980's (Ducrot et al. 2008). BSE is a zoonotic disease in cattle causing variant Creutzfeldt-Jakob's disease (vCJD) in people. The ability to spread, and the magnitude and severity of the BSE epidemic was only fully grasped when the OH approach was applied. This revealed that important aspects, such as food safety, public health and the ability of the BSE agent to spread through the food and feed chains, were overlooked. Timely preventive and prophylactic measures would likely have had positive effects on preventing the spread of BSE across Europe and reduced exposure of consumers.

To control FBD new innovations for more efficient monitoring and surveillance systems are needed, for example using big data and information science approaches. Such innovations could, for example, be relevant in urban livestock systems in LMIC.

In an urban setting livestock is often kept in close proximity to people. Value chain mapping has shown significant structural differences between different livestock value chains, varying product quality and lack of biosecurity and food safety standards (Carron et al., 2018). Urban livestock production may be an important pathway out of poverty, especially for women, and increase food security for the poor; however, there are also high risks for FBD in these settings. Improved monitoring and surveillance, using for example new on-site technology such as smart phone applications, might provide data that can be used to improve animal and human health. This is particularly true in settings with large informal sectors (Roesel and Grace, 2015). However, it should be acknowledged that urban and other informal livestock production systems (for example milk cooperatives) usually 'fly under the radar' with regard to official regulatory processes and policy, and hence there may be conflicts of interest to be addressed when it comes to monitoring and surveillance. This technology could also be used to improve knowledge and awareness amongst the actors along the value chain.

Antimicrobial resistance

The regular use of antibiotics, prophylactic or as growth promotors, is a way mitigate against sub-optimal animal husbandry. Interestingly, in several HICs it has been shown that it is possible to maintain good health and productivity when reducing the use of antibiotics. In low and middle-income countries, a more medically rational use of antibiotics leading to a lower use may improve animal health and increase productivity. Wholesalers, retail distributors, animal health professionals, livestock producers, policymakers, governmental agencies and academia all play important roles in the transition to replace excessive and medically non-rational use of antimicrobials with good animal husbandry and disease prevention measures.

The global attention on antimicrobial resistance including the livestock sector, provides traction to implement innovative solutions to improve animal health management with low use of antibiotics. Some of the solutions described here are innovative in some settings and already applied in other. Some are skills/management related and others need capital investment. Thus, some might only be applicable in high-income settings. However, the entry point common for all innovations to be introduced is that they must either maintain or improve the productivity of the livestock of concern. The overall principle is to substitute excessive, medically non-rational, use of antibiotics with medically rational use matched by effective disease preventive measures.

Medically rational use (relating to EC guidelines (European commission,2015)) in this context means: i) just use quality assured medicines; ii) don't use antimicrobials as growth promotors and avoid regular preventive use of antibiotics; iii) avoid using Highest Priority Critically Important Antibiotics for human medicine in livestock; iv) only use antibiotics based on a diagnosis of the disease by a veterinarian or other animal health professional and only for authorized indications; and, v) strive for individual treatment of animals with the correct dose and duration, and avoid using antimicrobials for group treatments, especially via feed.

Besides having adequate preventive measures in place, the medically rational use requires certain regulatory, technical and managemental components to be in place. In many settings these are challenges for innovative solutions. For instance, the lack of regulations for quality assurance of veterinary medicines is a major issue in low income countries, where falsified and substandard drugs are common (Kelesidis and Falagas, 2016). Also, the access of antibiotics over-the-counter for layman opens for inadequate and excessive use of antibiotics, whereas antibiotics by prescription may make adequate use more likely. In several countries regulations about these aspects are not in place or there is not resources to enforce them. Another regulatory aspect contributing to restrictive use of antibiotics is the withdrawal period after antibiotic treatment where meat, milk or egg is not allowed as food. However, for this to work properly efficient monitoring programmes must be in place along the food chain. Another area where innovations are taking place and applied is diagnostics, both for diseases and for resistance of bacteria. These must be cheap and rapid in order to be feasible for practical use. Currently, there are some "pen-side" tests and several basic laboratory test in common use. These practices may be more commonly used in middle and high income countries.

The infection-preventive measures may be divided into three, hierarchically ordered, components. Firstly, good animal husbandry and welfare including clean and comfortable housing, nutritious feed, free access to clean drinking water, good air quality and adequate temperature etc. This forms the basis for keeping robust animals that may resist several infections. The second step is biosecurity, which is a means to protect the livestock from infectious agents in general. This applies both within the herd, like between age-categories of animals, as well as so called external biosecurity, that aim to protect the entire herd from intrusion of infectious agents by other livestock, wild birds and animals or humans. Finally, adequate vaccination programs protect the herd from specific infections.

The good animal husbandry is in place in many places around the world but is more commonly missing elsewhere. For instance, in most low-income countries, the lack of feed and water makes the livestock extremely susceptible to diseases. Innovative solutions for improved biosecurity, both within the farm, including movement of animals and humans, as well as the external biosecurity with emphasis on movement of animals is been applied in many HICs. The latter includes avoiding livestock-markets, providing new genetic material to the herd only by artificial insemination or embryo transfer, strict quarantine procedures, reduction of mixing young animals from different farms etc.

The prospect for new antibiotics in veterinary medicine to which bacteria are susceptible is limited in a near future, as such antibiotics will very likely in the first place be reserved for humans. However, there are examples from several countries, starting in northern Europe, how medically rational use of antibiotics combined with efficient disease prevention has significantly lowered the use of antibiotics in the livestock sector and at the same time, maintained productivity of the animals and the profitability for the producer (Bengtsson and Wierup, 2006). Finally, there are several promising global initiatives, like the WHO-FAO-OIE tripartite arrangement and the CGIAR-hub for AMR, promoting innovative approaches to fight AMR.

Animal welfare

The scope for animal welfare innovation to enhance sustainability is huge. The connection between animal welfare and other components of sustainability means welfare-focused innovation gains can be made at the same time as other sustainability improvements.

According to some calculations, the highest rates of losses in the global food system come from livestock production (Alexander et al., 2017). Agriculture waste has become an important issue but is sometimes narrowly defined as food that is not used. Other definitions of waste include lost opportunities. Wastage can be counted as on-farm mortalities, death during transport, condemnation at slaughterhouse, and consumption wastage; all reflect lost input and environmental impact. While the causes of wastage differs between developed and developing regions (FAO, 2011), a focus on animal welfare has the opportunity to positively influence all areas.

The development of animal welfare standards at a global level is raising the bar for animal welfare and welfare assessment programs are providing tools for system evaluation. The OIE has developed codes for the welfare of terrestrial and aquatic animals (OIE, 2004), including dairy, beef, chickens, pigs and working equids, and for post-farmgate transport and slaughter for food and for disease control. The codes are based on science and gather consensus among all Member Countries to support their adoption, making it inclusive and accessible to all involved (Sinclair, 2016). Despite these structures, in many countries there is often a wide gap between regulation and implementation. By connecting with different stakeholders in the production system, and with consumers, this can be addressed at least in part through communication, incentives and changes in choice architecture.

Valid and reliable welfare indicators for sheep, goats, horses, donkeys, turkeys (AssureWel, 2010; AWIN, 2015); broilers, laying hens, pigs, beef and dairy cattle (AssureWel, 2010; Blokhuis et al., 2010) have been well researched. While evaluation of indicators for different systems are needed, these tools allow for comparison within and between systems and environments over time. Together these codes and indicators provide a platform from which evidence for animal welfare within a sustainable system can be gathered.

Animal and human health and welfare go hand in hand. Poor animal welfare contributes food borne disease, with increased shedding of contaminating zoonotic bacteria (*E. coli, Salmonella and Campylobacter*) from stress and poor management (European Food Safety Authority, 2012). Improved welfare practices on farm and post-farm gate therefore can improve productivity and food safety, risk to human health, and, so, lead to economic benefits (Appleby and Mitchell, 2018).

During disease outbreaks, like those described in the sections above, humane management of sick animals and humane culling for control can ease animal suffering and the psychological stress on the farming families and animal health workers (Hall et al., 2004; FAO, 2009; Whiting and Marion, 2011). As an example, the current outbreak of ASF in parts of Asia, which has already seen the death and culling of more than one million pigs (conservative estimates from May 2019; OIE, 2019; Xinhua News Agency, 2019). Ensuring humane management, as outlined for example the OIE guidelines on killing of animals for disease control purposes (OIE, 2009), would benefit human and animal wellbeing. However, organised culling and disposal is not suitable for all notifiable diseases in low and middle-income countries (LMICs) because of cost, feasibility and compliance issues (Mutua, 2018).

The smallholder settings that dominate LMIC agricultural production can have positive behavioural welfare for animals. Typically, animals receive much greater individual attention than in larger systems. Welfare challenges instead come from scarce feed and health resources, or an absence of knowledge, not an absence of care (Godfray and Garnett, 2014; Abubakar et al., 2018). Opportunities to incentivize the welfare friendly potential of smallholder systems are developing. For example, UpTrade is a start-up creating incentives for smallholder farmers to improve traceability, feeding and health management. Meat Naturally, an initiative by Conservation International, encourages environmental management by pastoralist farmers in systems that also have welfare and productivity benefits. Both are connecting farmers with higher value markets and value chains that encourages time and resource investment.

Good animal feeding and integrated approaches to land use, like silvopastoral systems, have sustainability benefits as they can be positive for feed efficiency, biodiversity, and human and animal welfare (Broom et al., 2013; Chará et al., 2018). They also provide animals with opportunities to perform behaviours they're naturally motivated to perform. Fostering natural behaviours are essential for both the needs of the animal and community perceptions of what constitutes good animal welfare (Fraser, 2008). Freehold land that is traditionally used in pastoralist and smallholder systems, in LMICs and HICs, could have similar benefits if managed appropriately.

Synergies and trade-offs

Impacts of animal disease

Common development of anti-infective (e.g., antimicrobials and antivirals), vaccine, and diagnostic approaches for both animal and human use has the potential for synergy in development of common platforms which provides increased economic pull incentives for private development. In the case of anti-infectives, the tradeoff involves concerns as to use in food animals resulting in decreased effectiveness in humans. The blanket application of the precautionary principle can erase this potential synergy if all new anti-infectives are held only for human use. The preservation of anti-infectives for both human and animal use is promoted by a focus on vaccines, diagnostics for early diagnosis of animal disease and evaluating paths of transmission, and biosecurity measures.

Educational initiatives on animal health practices are very similar to educating about human health. Many of the principles of epidemiology, biosecurity, and hygiene are the same, providing a synergistic opportunity to link best practices for both animals and humans together in a manner where examples in each realm reinforce the other.

Zoonoses and pandemics

As indicated above, the control and containment measures of pandemic zoonoses synergize with those of other very contagious livestock infections. These measures are very much of "the command and control"- nature (see below) and there might be a difficult trade-off between the hazard the zoonoses as such pose and the negative effects for the farmer, often economic, from the authorities' control measures.

The control of endemic zoonoses are very much the same as the measures taken to improve animal health in general at farms and to reduce the need for antibiotics and improving animal welfare. Thus, good animal health supports good public health. However, for the zoonoses with limited negative effects on production, the cost-benefit analysis for the individual farmer may be not be in favor for controlling the zoonoses.

Obviously controlling and fighting zoonoses and pandemics have strong synergies with all other sustainability domains dealt with at the MSP in Kansas: a) In self-sustaining farming it protects food and nutrition security; across economic settings it 2) secures livelihoods and economic growth and 3) contributes to a more emission-efficient production of animal source foods.

Food borne diseases

There are synergies between control of FBD and the optimizing the sustainability domains. This is particularly true for the domains: 1. food and nutrition security, 2. livelihoods and economic growth and 3. animal health and welfare.

In HIC, food that is suspected to be contaminated with pathogenic microorganisms is likely condemned and thereby contributes to food wastage. However, there is a trade-off because of the global demand to reduce food waste, which may lead to sale of food that is un-healthy to consume. In low income countries (LIC) there is also a trade-off between food safety and nutrition since potential food condemnation may have a direct impact on nutrition security.

There are synergies between improved animal health and welfare, and reduced risk for FBD. In general terms, animal sourced food from healthy animals in sustainable production system reduces the risk for FBD. However, as there might be several steps in the value chain from production to consumer, food safety standards have to be applied at all steps to avoid cross contamination with food borne pathogens.

When controlling FBD either a risk-based or a hazard-based approach can be used, with both approaches having trade-offs (Barlow et al. 2015). From a public health perspective, it might be tempting to focus on specific hazards as this has been the traditional way to target food safety challenges. However, by using a hazard-based approach the impact on human health is unknown. A risk-based approach assess impact in the incidence of human illness and the greatest health benefits are thus achieved using this approach.

There are also trade-offs when it comes to responsibility and funding of mitigations and control measures. Some of the FBD originating from livestock do not cause clinical disease in animals, for example verocytotoxin-producing *Escherichia coli* O157:H7 (Berry ED et al. 2006). In these cases, there are few incentives for the farmer to invest money in controlling FBD. Control measures/programs are costly, especially at modern complex large-scale farms. This might also be true in LMIC with small production units with poor biosecurity.

Antimicrobial resistance

A focus on promoting medically rational use of antibiotics generates synergies and call for trade-offs within all the four domains of sustainability of the sector (Food and nutrition security, Livelihoods and economic growth, Animal health and welfare and Climate and natural resource use). In other words, the animals' productivity, welfare and natural resources use and emission efficiency are largely depending on the animals' health, which in turn depends on how antibiotics are used.

In low income countries, a more medically non-rational, and reducing the sometimes arbitrary, use of antibiotics will improve animal health. This in turn will increase animal productivity at a low cost and therefore also the profitability for the producer and making the use of natural resources more efficient. Thus, all the four domains of sustainability of the livestock sector put forward here will in low-income countries benefit from a more medically rational use of antibiotics.

In high income countries, the animal health status is in general, and for several reasons, better. Sometimes, this good status is attributable to the fact that poor animal health management is substituted by medically non-rational, and thus excessive, use of antibiotics. To reverse this (i.e., provide good animal health management procedures and apply a more medically rational use of antibiotics) may jeopardize the animal health status if not carefully implemented. The change in antibiotic use must be tightly matched with improved animal health management in a stepwise manner over time. If properly implemented, this transition will maintain the animal health status and productivity, with limited and transient reduction in profit for the producers (Wierup, 2001). Thus, the economic sustainability of the sector will be maintained and the social and environmental sustainability will be enhanced in HICs by applying a medically rational use of antibiotics.

Animal welfare

Synergies between animal welfare and the four domains of sustainability are clear because of the broad value improved animal welfare has on sustainable livestock production. Evidence of these combined metrics are limited however because animal welfare has not been a focal point until recently (Pinillos, 2018).

There are cases when animals are not in good health and welfare but are still counted as ‘productive’. Lame cows still produce milk, but yields eventually decline, and cull rates increase (Oltenacu and Broom, 2010). Broiler flocks with high rates of digital dermatitis still can be used for meat, but the chances of *Campylobacter* contamination after slaughter are higher (Bull et al., 2008). In developing countries, animals which are used for human food are often slaughtered at the first signs of severe illness, but animals which are not used for food (e.g. working equids in LMICs) may remain chronically ill. In these situations, a broader perspective of sustainability beyond productivity needs to be considered for synergies to be clearly captured. Economic modelling could be one tool for this, but needs to take into account down-side economic risk and risk to social licence from poor welfare.

In systems where efficiency gains are yet to be made, animal welfare improvements and economics can both rise; however, it costs more to improve welfare in systems that have been industrialised or commercialised. This is because in many instances the welfare restrictions are the result of infrastructure (e.g. restricted behavioural opportunity for laying hens in cages), require inputs (e.g. enrichment in barren environments; increased staff). Opportunities in market differentiation, segmentation, and quality production exist, but in situations of improving minimum standards, improving welfare can act as a trade barrier or restriction, rather than value-adding opportunity (Euro Group for Animals, 2018). The impact of this on livelihoods and economic growth must be realized and managed, so that it does not become a tradeoff that unduly disadvantages groups, particularly smaller scale farming systems.

Many of the solutions proposed for improving health and welfare are long term. As outside pressure on livestock management pushes solutions like further intensification of production, or dramatic reduction in consumption, risks to animal welfare, livelihoods and economic growth, and nutrition security also increases. Demonstrating action and improving animal welfare as a part of sustainability is critical to avoid these suggested trade-offs

Implications for policy

In this section we take different kinds of policy drivers into account such as i) 'command and control' regulation, operating through legal instruments and generally with sanctions in the event of breach; ii) 'cross-compliance' regulation, under which conditions are attached to direct payments at various points in livestock agrifood systems; iii) 'soft law' in the form of guidance and recommendations on best practice from authoritative bodies, corporations, NGOs, professional associations, for example; and iv) 'the market', incorporating consumer concerns and also accommodation of those concerns by retailers.

Impact of animal disease

Control of movement of animal products is integral in preventing the spread of transboundary diseases. For example, in the United States 50 containers of illegally imported pork products from China were seized at a port in New Jersey on March 15, 2019, making this the largest agricultural seizure on record in the U.S. (SHIC, 2019). If ASF were allowed to enter the U.S., an estimated $10 billion impact on the U.S. pork industry is predicted should ASF enter the United States. As demonstrated in the case of PEDV, the movement of feedstuffs must also be considered in the spread of TBDs. The international trade of inputs and outputs of animal production makes the balance of biosecurity and preservation of import and export markets a pivotal focus. A policy challenge in implementing animal and animal product movement restrictions related to biosecurity is that while these restrictions may be in the best interest of society as a whole, they may be against the short term and local economic interests of some parties. A balance of economic incentives and regulatory enforcement must be struck in these cases.

Financial barriers to innovation are often substantial. The narrow economic margins typically found in food animal production necessitate that new technology be economically viable within this environment. The concept of delinkage addresses using government funding to compensate development costs when the value to society exceeds the value to the marketplace. Delinkage of development costs with market drivers for development of human anti-infectives is being discussed in multiple countries, with England recently committing to this process for antibiotics destined for human use, although without specifics as to source or nature of funding (UK Gov, 2019). Providing an economic safety net for innovation in vaccines, diagnostic tests, and other disease control measures has policy implications requiring evaluation of the economic value of preservation of animal resources.

Zoonoses and pandemics

Managing zoonotic diseases with pandemic potential is highly complex and requires multi-institutional and multi-sectoral collaboration. For zoonotic diseases with high pathogenic potential both the human and animal sector has to take responsibility for efficient control by using 'command and control'. High income countries have already implemented integrated control systems across animals, foods and humans. However, in many LICs there is poor integration between the different sectors and absence of functioning contingency plans do not allow these countries on the global market for animal sourced products. The coordination of multi-national and multi-sectoral work to fight pandemics is often led by FAO, OIE and WHO. Pandemics put restrictions on international trade of animal sourced products. For other zoonotic diseases there is a mixture of 'command and control' and 'soft laws', depending on if the disease in question is endemic or absent, severity of production losses and public health risks.

For an endemic disease with high prevalence in a country with weak veterinary service, there are few disease control options. However, by using 'soft laws', farmers can be motivated to implement simple biosecurity and management measures to control/strop spread of these diseases and to increase occupational health protection. The opposite might be true for a zoonotic disease that is newly introduced in an area, or if the prevalence in the animal population is not too high to allow for control and/or eradication. In these cases, control/eradication can be reach by using 'control and command'. However, this requires well-functioning veterinary service and multi-institutional and multi-sectoral collaboration. A strong pressure from the public health sector is also needed that pushes the livestock sector towards 'control and command'. In these settings eradication of a zoonotic disease can also be possible by starting with 'soft laws' to initiate a reduction of the prevalence based on voluntary actions, followed by 'control and command' for final eradication. This is, for example, how brucellosis was eradicated in some high-income countries, for example Sweden (Cernius, 2010). The pressure from the public health sector to control zoonotic diseases in livestock is of particular importance for diseases showing few or no clinical signs in livestock, for example campylobacteriosis. In these cases, it might be difficult to motivate the farmers using 'soft command', instead a combination of 'self-compliance', 'the market' and 'control and command' can be more effective.

Food borne diseases

Food borne diseases in livestock and food safety are best approached using a One Health perspective (Xiet et al., 2017). Furthermore, food safety resources should be allocated where they contribute the most to reduced risk for FBD. Interventions cannot be successful unless they build upon profound knowledge about the socio-economic contexts of farmers, food business operators and consumers, using a combination of the policy drivers 'cross-compliance' and ‘soft law’. Future achievements in food safety, public health and animal welfare will largely depend on how well politicians, researchers, industry, national agencies and other stakeholders manage to collaborate.

Improvement in animal production practices and animal welfare (pre-harvest interventions) are important for reducing risks of FBD. Data on occurrence of FBD and disease burden in food producing animals are crucial in assessing costs and benefits of control measures aiming to reduce transmission and shedding of food borne pathogens. Post-harvest interventions are required to reduce the risk for cross contamination, survival and multiplication of disease-causing pathogens. This require efficient control and monitoring of targeted diseases by well-functioning regulatory bodies using ‘command and control’ and ‘cross-compliance’. This approach will, however, likely work only in HIC. In LIC ‘soft laws’ will also be an important policy driver.

The ability of governments to take effective regulatory measures has been identified as a factor that can contribute to reduced burden of FBD (Quested et al., 2010). In HIC ‘cross-compliance and ‘the market’ are likely important drivers to develop improved standards and regulations to meet the demand of increased access to safe food. In LIC, enforcing regulations and standards developed for high-income countries are not likely to be very effective. Under these circumstances ‘soft laws’ in the form of recommendations and guidance might be more effective.

Antimicrobial resistance

The “command and control” regulation demand compliance to the set policies in order to be effective. However, not all states have the capacity to make this happen and too harsh regulations about antibiotic use in the sector may jeopardize the profitability and livelihood of livestock producers and be detrimental to the social and economic dimensions of sustainability.

The “cross-compliance regulation” approach do also demand capacity to enforce regulations. This approach is facilitated by a functional market, where consumers demand animal source foods produced with a medically rational use of antibiotics. The added value for farmers, additional payment, depends on consumers’ willingness to pay or governmental subsides. Likely, this approach will only work in HICs, but may there support all three dimensions of sustainability in the livestock sector.

“Soft law” may work in LMICs as well as in HICs. In the LMICs there is an option to improve animal health by applying guidelines for a more medically rational use of antimicrobials which may on the total reduce the development and emergence of AMR. However, it is crucial to provide attractive guidelines for the best practices in order to make this a valid incentive. In high income countries, livestock producers may respond to market-pressure by consumers demand for low use of antibiotics in livestock production by applying guidelines for a restrictive medically rational use – perhaps including a certification. Over-all the “soft-law” approach will promote all three dimensions of sustainability – social, economic and environmental, in the livestock sector.

Animal welfare

Animal welfare improvements focused on both raising the minimum standard as a 'bottom line' and promoting higher welfare are both important actions for welfare in a sustainable system. Regional strategies for animal welfare now cover all continents (Cox and Bridgers, 2018). This is a critical step in raising minimum standards of animal welfare and enabling sustainability improvements to occur. Creating accountability to improve practices, across the production system, from on-farm, to transport and then slaughter, is the next step to have genuine health, welfare and broader sustainability improvements. This requires a combination of 'command and control' regulation from governments, and can be effectively supported by 'cross-compliance' regulation (soft law) that can come from industry and the supply chain whereby a level of welfare must be achieved for participation to occur.

In many governmental and compliance systems there are large and acknowledged gaps between policy, regulation and implementation. Understanding the interests of different stakeholders helps understand why policies may be agreed but not implemented. Policies which are not demanded by farmers and consumers but developed by experts and adopted in response to international pressure, or because of perceived augmentation of professional mandate, may be especially likely to experience gaps in implementation (Pritchard et al., 2018). Political economy and behavioural economics can offer insights to close these gaps.

Investment in inclusive, practical education and capacity building for animal welfare has a clear benefit for all species and all systems, regardless of scale. Building the capacity of government extension providers in animal welfare to then connect with communities as needed is a key step. Industry, Non-profit/Non-Governmental Organisations and corporate/retail groups play a role in this, and can often be more agile and connect with farmers faster than governments, depending on the systems in place. Ensuring this knowledge is grounded in science is important so that shared knowledge makes genuine differences to animal welfare. Promoting multi-stakeholder dialogue and connecting public and private sectors on animal welfare is required if SDGs are to progress and animal health and welfare issues are to be addressed.

Key Messages for Policy Makers

The role of innovation in sustainable livestock systems

I. Knowledge of disease epidemiology is absolutely key and is a major basis for policy development.

II. Diagnostics for surveillance, early detection of disease, and evaluation of intervention outcome are crucial.

III. Education and promotion of biosecurity techniques based on sound epidemiological principles is key. These biosecurity principles must be made economically viable and advantageous to producers.

IV. Immunological tools such as vaccines (the most obvious) and maintenance/optimization of immune status also remain a vital defence against animal disease.

V. To reduce occupational health risks and to prevent and control contagious diseases, different innovations are needed for different livestock systems and for different economic settings. “One size” doesn’t always fits all.

VI. Innovations relating to prevention and control diseases is not only about technological solutions, it is equally much about structures, organisation and compliance to agreed measures and partnership.

VII. To improve food safety, innovations are need for monitoring and control at pre-harvest (animal production and health) and post-harvest (i.e., at processing, retail and consumer levels)

VIII. Hiding poor animal husbandry under a blanket of antimicrobials is detrimental for the emergence of AMR. There is room for technical, animal managemental and organisational innovations to prevent infections with regards to general animal husbandry, biosecurity and vaccinations.

IX. Animal welfare improvements focused on both raising the minimum standard as a ‘bottom line’ and promoting higher welfare are both important actions for welfare in a sustainable system.

X. Innovations for improved animal welfare will be demand driven, coming from industry and the supply or value chain, leading to higher welfare systems; or it will come from more traditional ‘command and control’ regulation from government/international regulation that will raise minimum standards.

The role of trade in sustainable livestock systems

I. Several of the zoonotic diseases, including those with a pandemic potential, are listed within the OIE framework for WTO-member states guiding the trade with animals and animal products.

II. In addition to these restrictions, there might be private sector standards – driven by consumer’s fear – that affects trade.

III. The food systems become more complex and multinational because of increased trade. Innovations are thus needed to improve traceability of food products for securing safe food and for controlling food borne pathogens.

IV. The increasing awareness of the AMR-threat may push the retailers or regulators to demand that animal source food should come from livestock raised with low use of antibiotics. Such a demand will influence trade – however, to tailor such a certification or control system will be a challenge.

V. Animal welfare will play an increasingly important role in trade. Animal welfare has the potential to create market differentiation, segmentation, and higher quality products, whilst also having the potential to act as a trade barrier or restriction, rather than value-adding opportunity.

References

Abubakar, M., Manzoor, S., Iqbal, A., 2018. Introductory Chapter: Animal Welfare—Global Perspective, Animal Welfare, IntechOpen

Alexander, P., Brown, C., Arneth, A., Finnigan, J., Moran, D., Rounsevell, M.D., 2017. Losses, inefficiencies and waste in the

Appleby, M.C., Mitchell, L.A., 2018. Understanding human and other animal behaviour: ethology, welfare and food policy. Applied Animal Behaviour Science.global food system. Agricultural systems 153, 190-200.

AssureWel, 2010. Advancing animal welfare assurance, Collaborative project of University of Bristol, RSPCA and Soil Association of UK, http://www.assurewel.org/

Aubry P, Geale DW. A Review of Bovine Anaplasmosis. *Transboundary and Emerging Diseases* 2011; 58:1-30.

AWIN, 2015. AWIN welfare assessment protocol, Retrieved on 01 April 2016

Barasona JA, Gallardo C, Cadenas-Fernández E, Jurado C, Rivera B, Rodríguez-Bertos A, Arias M, Sánchez-Vizcaíno JM, 2019. First Oral Vaccination of Eurasian Wild Boar Against African Swine Fever Virus Genotype II. Front Vet Sci. 2019 Apr 26;6:137. doi: 10.3389/fvets.2019.00137. eCollection

Barlow SM et al. 2015. The role of hazard- and risk-based approaches in ensuring food safety. Trends in Food Science & Technology. 46: 2, 176-188. https://doi.org/10.1016/j.tifs.2015.10.007

Bengtsson B and Wierup M., 2006. Antimicrobial resistance in Scandinavia after ban of antimicrobial growth promoters. Anim Biotechnol. 17(2):147-56

Berry ED et al. 2006. Influence of genotype and diet on steer performance, manure odor, and carriage of pathogenic and other fecal bacteria. II. Pathogenic and other fecal bacteria. Journal of Animal Science, 84:9, 2523–2532, https://doi.org/10.2527/jas.2005-747

Blokhuis, H.J., Veissier, I., Miele, M., Jones, B., 2010. The Welfare Quality® project and beyond: Safeguarding farm animal well-being. Acta Agriculturae Scandinavica, Section A Animal Science 60, 129-140.

Boqvist et al. 2018. Food safety challenges and One Health within Europe. Acta Vet Scand. 60:1. https://doi.org/10.1186/s13028-017-0355-3

Broom, D., Galindo, F., Murgueitio, E., 2013. Sustainable, efficient livestock production with high biodiversity and good welfare for animals. Proc. R. Soc. B 280, 2013-2025.

Broom, D.M., 2010. Animal welfare: an aspect of care, sustainability, and food quality required by the public. Journal of Veterinary Medical Education 37, 83-88.

Bull, S.A., Thomas, A., Humphrey, T., Ellis-Iversen, J., Cook, A.J., Lovell, R., Jorgensen, F., 2008. Flock health indicators and Campylobacter spp. in commercial housed broilers reared in Great Britain. Appl. Environ. Microbiol. 74, 5408-5413.

Carron M et al., 2018Cmpylobacter, a zoonotic pathogen of global importance: Prevalence and risk factors in fast-evolving chicken meat systems of Nairobi, Kenya. PLos Negl Trop Dis, 13;12(8):e 0006658

Cerenius F, 2010. The history of biosecurity in Swedish Livestock. In Swedish GOV survey SOU 2010:106 Section C, annex 6 (125 ppp (in Swedish) 1.

Chará, J., Reyes, E., Peri, P., Otte, J., Arce, E., Schneider, F., 2018. Silvopastoral Systems and their Contribution to Improved Resource Use and Sustainable Development Goals: Evidence from Latin America. FAO, CIPAV. Editorial CIPAV.

Chua KB, 2003. Nipah virus outbreak in Malaysia. Journal of Clinical Virology 26, 265–275.

Cox, J., Bridgers, J., 2018. World Animal Net: Why is Animal Welfare Important for Sustainable Consumption and Production? UNEA Report.

Dee S, Neill C, Singrey A, Clement T, Cochrane R, Jones C, Patterson G, Spronk G, Christopher-Hennings J, Nelson E. Modeling the transboundary risk of feed ingredients contaminated with porcine epidemic diarrhea virus. BMC Vet Res 2016 Mar 12;12:51. doi: 10.1186/s12917-016-0674-z.

Diaz-San Sequndo F, Medina GN, Stenfeldt C, Arzt J, de Los Santos T. Foot-and-mouth disease vaccines Vet Microbiol 206;102-112, 2017

Doyle, R.E., Wieland, B., Roesel, K., Grace, D., 2018. Animal welfare and the Sustainable Development Goals, UFAW: Animal welfare across borders, Hong Kong.

Ducrot C et al. 2008. Review on the epidemiology and dynamics of BSE epidemics. Vet Res. 39:15. DOI: 10.1051/vetres:2007053.

Euro Group for Animals, 2018. Achieving the sustainable development goals: The role of animal welfare in Trade Policy.

European Commission, 2015: COMMISSION NOTICE: Guidelines for the prudent use of antimicrobials in veterinary medicine (2015/C 299/04) at https://ec.europa.eu/health/sites/health/files/antimicrobial_resistance/docs/2015_prudent_use_guidelines_en.pdfhttps://ec.europa.eu/health//sites/health/files/antimicrobial_resistance/docs/2015_prudent_use_guidelines_en.pdf. Also available in other languages at:https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ%3AC%3A2015%3A299%3ATOC

European Food Safety Authority, 2012. EU Animal Welfare Strategy 2012-2015.

FAO, 2009. Livestock in the balance.

FAO, 2011. Global food losses and food waste–Extent, causes and prevention, Food and Agriculture Organization of the United Nations.

FAO, 2018. Shaping the future of livestock sustainably, responsibly, efficiently.

FAO, 2018. Shaping the future of livestock. http://www.fao.org/3/i8384en/I8384EN.pdf

FAO, 2019.ASF Situation in Asia Update: Food and Agriculture Organization of the United Nations, 2019.

FAO/OIE, 2008. BIOSECURITY FOR HIGHLY PATHOGENIC AVIAN INFLUENZA Issues and options of 2008. http://www.fao.org/3/a-i0359e.pdf

Frank C et al. 2011. Epidemic profile of Shiga-toxin-producing Escherichia coli O104:H4 outbreak in Germany. N Engl J Med. 365:1771–80.

Fraser, D., 2008. Toward a global perspective on farm animal welfare. Applied Animal Behaviour Science 113, 330-339.

Godfray, H.C.J., Garnett, T., 2014. Food security and sustainable intensification. Philosophical transactions of the Royal Society B: biological sciences 369, 20120273.

Hall, M.J., Ng, A., Ursano, R.J., Holloway, H., Fullerton, C., Casper, J., 2004. Psychological impact of the animal-human bond in disaster preparedness and response. Journal of Psychiatric Practice® 10, 368-374.

Hanzlicek GA, Raghavan RK, Ganta RR, et al. Bayesian Space-Time Patterns and Climatic Determinants of Bovine Anaplasmosis. *PLOS ONE* 2016;11:e0151924...

Havelaar AH et al. 2015. World Health Organization Global Estimates and Regional Comparisons of the Burden of Foodborne Disease in 2010. PLoS Med. 3;12:e1001923. doi: 10.1371/journal.pmed.1001923

Kelesidis T, Falagas ME., 2015 Substandard/counterfeit antimicrobial drugs. Clin Microbiol Rev. 2015 Apr;28(2):443-64

Mort M, Convery I, Baxter J, et al. Psychosocial effects of the 2001 UK foot and mouth disease epidemic in a rural population: qualitative diary based study. *British Medical Journal* 2005;331:1234-1237

Mutua, B.M., 2018. Challenges facing indigenous chicken production and adoption levels of biosecurity measures in selected areas of Makueni county, Kenya.

OIE, 2004. Terrestrial Animal Health Code, Paris.

OIE, 2009. Slaughter of Animals, Terrestrial Animal Health Code, World Organization for Animal Health, Paris, France.

OIE, 2019a. OIE-Listed diseases, infections and infestations in force in 2019. *World Organisation for Animal Health* 2019.

OIE, 2019b Information on aquatic and terrestrial animal diseases: Foot & Mouth Disease (FMD). *World Organisation for Animal Health* 2019.

OIE, 2019c. Situational updates of ASF in Asia and the Pacific.

Oltenacu, P.A., Broom, D.M., 2010. The impact of genetic selection for increased milk yield on the welfare of dairy cows. Animal welfare 19, 39-49.

O' Neill J., 2016. Tackling drug-resistant infections globally https://amr-review.org/sites/default/files/160525_Final%20paper_with%20cover.pdf

Pinillos, R.G., 2018. One Welfare: A Framework to Improve Animal Welfare and Human Well-being. CABI.

Plumb GE, Olsen SC and Buttke D, 2013. Brucellosis: "One Health" Challenges and opportunities. *Rev. sci. tech. Off. int. Epiz.*, 2013, 32 (1), 271-278

Pritchard, J., Upjohn, M., Hirson, T., 2018. Improving working equine welfare in 'hard-win'situations, where gains are difficult, expensive or marginal. PloS one 13, e0191950.

Quested TE et al. 2010. Trends in technology, trade and consumption likely to impact on microbial food safety. International Journal of Food Microbiology. 139:30, S29-S42. https://doi.org/10.1016/j.ijfoodmicro.2010.01.043

Roesel and Grace (Eds). 2015. Food Safety and Informal Markets. Animal products in sub-Saharan Africa. Internationals Livestock Research Institute. ISBN:978-1-315-74504-6CP Group (UK) Ltd, Croydon.

Robinson TP, Bu DP, Carrique-Mas J, Fèvre EM, Gilbert M, Grace D, Hay SI, Jiwakanon J, Kakkar M, Kariuki S, Laxminarayan R, Lubroth J, Magnusson U, Thi Ngoc P, Van Boeckel TP, Woolhouse ME. Antibiotic resistance: mitigation opportunities in livestock sector development. Animal. 2017 Jan;11(1):1-3. doi: 10.1017/S1751731116001828. Epub 2016 Aug 13

Schulz LL, Tonsor GT. Assessment of the economic impacts of porcine epidemic diarrhea virus in the United States. *J Anim Sci* 2015;93:5111-5118

SHIC, 2019. Swine Health Information Center Global Swine Disease Global Surveillance Report April 1, 2019.

Sinclair, M., 2016. Internationalization of animal welfare standards. Encyclopaedia of Food and Agricultural Ethics.

Singer RS et al. 2007. Modeling the relationship between food animal health and human foodborne illness. Preventive Veterinary Medicine. 79: 2-4, 186-203

Spink and Moyer, 2011. Defining the public health threat of food fraud. Journal of Food Science, 76(9)

Steinfeld and Gerber. 2010. Livestock production and the global environment: Consume less or produce better? PNAS, 107:43, 18237-18238. https://doi.org/10.1073/pnas.1012541107

Tang KL, Caffrey NP, Nóbrega DB, et al. 2017. Restriction in the use of antibiotics in food-producing animals and its associations with antibiotic resistance in food-producing animals and humans – a systematic review and meta-analysis. Lancet Planetary Health 2017 Nov; 1(8): e316–e327.

Thompson D, Muriel P, Russell D, et al. Economic costs of the foot and mouth disease outbreak in the United Kingdom in 2001. *Rev Sci Tech* 2002;21:675-687.

UK Gov, 2019. Development of new antibiotics encouraged with new pharmaceutical payment system. July 9, 2019. Gov.UK Accessed 8-5-2019 at https://www.gov.uk/government/news/development-of-new-antibiotics-encouraged-with-new-pharmaceutical-payment-system

UPI, 2019. https://www.upi.com/Top_News/US/2019/07/12/World-races-to-develop-African-swine-fever-vaccine/6711562880159/

UpTrade.

USDA 2019 a APHIS National Brucellosis Eradication Program. Accessed 8-5-2019 at https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/animal-disease-information/!ut/p/z0/fY7LDoIwFES_hiVpMQZ1SdSAj7iGbppLKXC1tNAWo38vISzc6PLMnEyGMJITpuGJDXg0GtTEBYv5LdqndLuOrunxENEk250u2SamNF2RM2H_hWkB78PAEsKE0V6-PMmhb9HxGbXnCksL9h1QB9yMltdGjG4m0NiB4q0E5dvvpEInwUmOuja2m88GVID3SgZUL-fD0o5CKmUculBaqFAs5o8i7K1pLHSkf7DiAzDdKdg!/

USDA, 2019b. APHIS Pseudorabies (PRV) Accessed 8-5-2019 at https://www.aphis.usda.gov/aphis/ourfocus/animalhealth/nvap/NVAP-Reference-Guide/Control-and-Eradication/Pseudorabies

USDA, 2019c APHIS Foot and Mouth Disease Response Plan: The Red Book. Section 4.3 Accessed 8-5-2019 at https://www.aphis.usda.gov/animal_health/emergency_management/downloads/fmd_responseplan.pdf

Van Boeckel TP, Brower C, Gilbert M, Grenfell BT, Levin SA, Robinson TP, Teillant A, Laxminarayan R. 2015. Global trends in antimicrobial use in food animals

Proc Natl Acad Sci U S A. 2015 May 5;112(18):5649-54. doi: 10.1073/pnas.1503141112. Epub 2015 Mar 19.

Whiting, T.L., Marion, C.R., 2011. Perpetration-induced traumatic stress—A risk for veterinarians involved in the destruction of healthy animals. The Canadian Veterinary Journal 52, 794.

Wierup M. 2001. The Swedish experience of the 1986 year ban of antimicrobial growth promoters, with special reference to animal health, disease prevention, productivity, and usage of antimicrobials. Microb Drug Resist. Summer;7(2):183-90.

World Bank 2012: PEOPLE, PATHOGENS AND OUR PLANET Volume 2: The Economics of One Health Report No. 69145-GLB

World Bank. 2017. “Drug-Resistant Infections: A Threat to Our Economic Future.” Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO http://documents.worldbank.org/curated/en/323311493396993758/pdf/114679-REVISED-v2-Drug-Resistant-Infections-Final-Report.pdf

World Horse Welfare, The Donkey Sanctuary, 2018. Sustainable Development Goals: How the welfare of working equids delivers for development.

Xie T et al. 2017. A system dynamics approach to understanding the One Health concept. PLoS ONE. 2017;12:e0184430.

Xinhua News Agency, 2019. The responsible person of the Ministry of Agriculture and Rural Affairs and international organizations talked about the prevention and control of African swine fever