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Linking animal and human health burden: challenges and opportunities

B. Devleesschauwer* (1, 2), S. Babo Martins (3), C. di Bari (1, 2), C. Fastl (1),
N. Venkateswaran (4) & D.M. Pigott (4)

(1) Department of Epidemiology and Public Health, Sciensano, Rue Juliette Wytsman 14, 1050 Brussels, Belgium

(2) Department of Translational Physiology, Infectiology and Public Health, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium

(3) Institute of Infection, Veterinary and Ecological Sciences, University of Liverpool, Leahurst Campus, Neston, Wirral, CH64 7TE, United Kingdom

(4) Department of Health Metrics Sciences, Institute for Health Metrics and Evaluation, University of Washington, 3980 15th Ave NE, Seattle, WA 98195, United States of America

*Corresponding author: brecht.devleesschauwer@sciensano.be

Summary

Quantifying the impact of poor animal health outcomes on human health represents a complex challenge. Using the disability-adjusted life year (DALY) metric as an endpoint, this article discusses how animal health outcomes can impact humans through three key processes: directly through zoonotic disease, indirectly via changes in yields and their impacts on nutrition and wealth, and finally, through indirect features associated with the agricultural industry, such as pharmaceuticals and climate change. For each process, the current state of the art and feasibility of global DALY-associated estimates are discussed.

Existing frameworks for zoonoses already consider some key pathogens; ensuring completeness in the pathogens considered and consistency in methodological decisions is an important next step. For diet, risk factor frameworks enable a calculation of attributable DALYs; however, significant economic methodological developments are needed to ensure that local production changes are appropriately mapped to both local and global changes in dietary habits. Concerning wealth-related impacts, much work needs to be done on method development. Industry-related impacts require a focus on key research topics, such as attribution studies for animal antimicrobial resistance contributing to human outcomes. For climate change, a critical next step is identifying to what extent associated industry emissions are amenable to change should animal health outcomes improve.

Allocation of finite funds to improve animal health must also consider the downstream impact on humans. Leveraging DALYs enables comparisons with other human health-related decisions and would represent a transformative way of approaching animal health decision-making should the obstacles in this article be addressed and new methods be developed.

Keywords

Antimicrobial resistance – Climate change – DALYs – Disability-adjusted life years – Global metrics – Nutrition – One Health – Zoonotic diseases.

Introduction

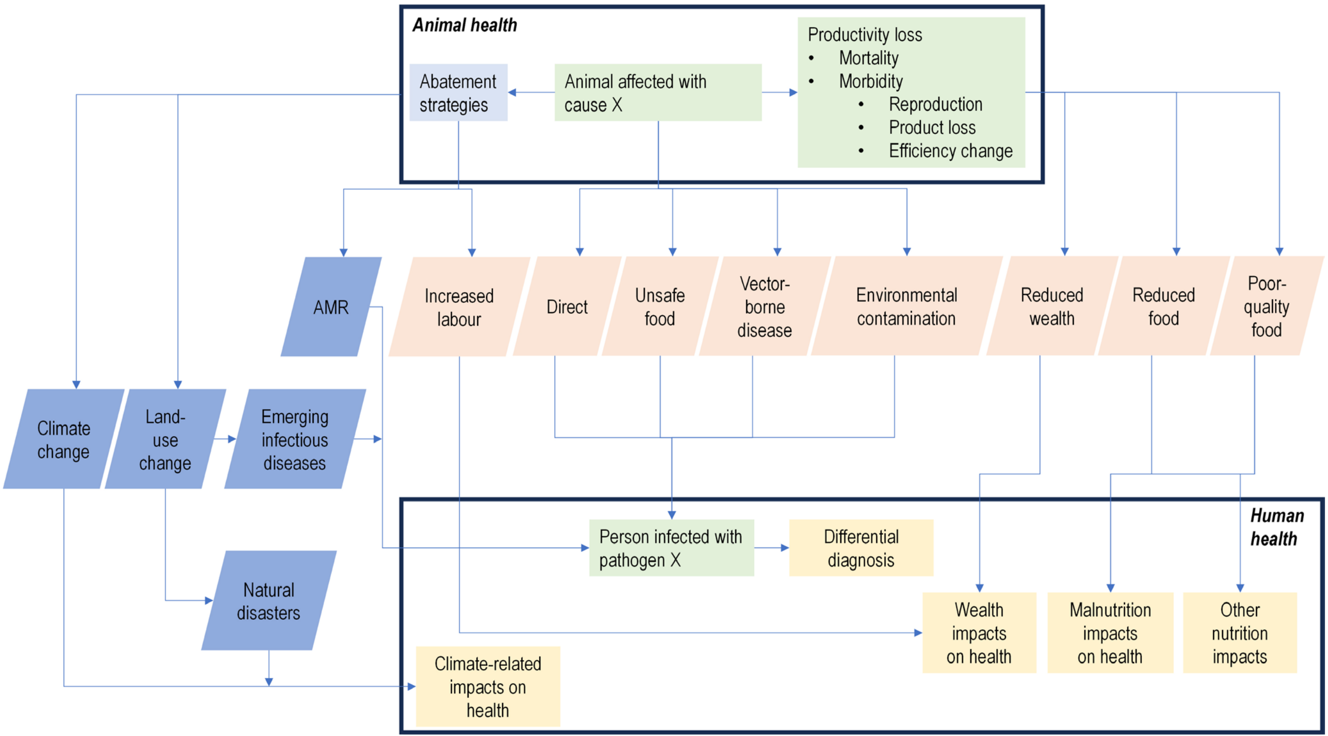
The means by which poor animal health can impact humans are many and varied, including the direct impacts of transmission of pathogens from infected animal hosts into humans, the role of livestock as disease reservoirs, and indirect aspects of animal health and agricultural outputs and their consequences for individual-level and population-level diets and wealth. Similarly, the livestock industry itself, and associated pharmaceutical activities, can create downstream changes in human health outcomes.

Over the last 30 years or so, metrics such as the disability-adjusted life year (DALY) have proven to provide a powerful perspective in evaluating decisions affecting human health. The DALY measure grew out of the desire to quantify and equate not only those conditions that cause mortality, but also those with high morbidity, such as chronic diseases that impact individuals over decades of their life [1,2]. The DALY consists of the sum of the years of life lost (YLLs) and the years lived with a disability (YLDs) due to a specific cause. YLLs refer to prematurely lost years due to death, calculated by subtracting the age of death from life expectancy based on a model life table [3]. YLDs are a measurement of morbidity and reflect the number of healthy years a person loses due to illness. An essential part of this component is disability weights, where each health state related to an illness is assigned a value between zero (perfect health) and one (equivalent to death) [4].

Studies such as the Global Burden of Disease (GBD) and those conducted by the World Health Organization's Foodborne Disease Burden Epidemiology Reference Group (FERG) have demonstrated the ability to use DALYs to calculate the burden of disease at national, regional and global levels for all causes of death and disability, and also to indicate to what extent these causes are attributable to certain risk factors (such as tobacco smoking) or risk pathways (such as food safety) [5,6]. In examining the effects of unfavourable animal health outcomes on humans, it is essential to explore how to convert animal-related metrics into alterations in DALYs. This translation facilitates comparisons within the larger context of human health.

A key objective of the initial phase of the Global Burden of Animal Diseases programme is to investigate the feasibility of quantifying the various mechanisms by which human health is adversely impacted by animal diseases. While other features of impact, such as the cost of illness associated with human disease, are important, this article focuses on DALY-based assessments. As a first step, the authors aimed to produce a framework whereby these various pathways could be accommodated and impact a human DALY (Fig. 1). Here, three core features of the livestock agricultural system are emphasised: those animals currently infected with a pathogen with human transmission capabilities; the subsequent translation of animal infections (both zoonotic and those afflicting only livestock) into production losses that could be either consumable commodities or goods for sale; and the work of the agricultural industry itself, with pharmaceutical products used to support growth and treat disease, emissions, effluent and land-use changes all taken into account.

The authors identified key human health-related endpoints of primary interest, including individuals infected with specific zoonotic pathogens, as well as populations experiencing changes in health outcomes due to changes to their wealth or diet, or the impact of agricultural systems on the land surrounding human habitats and the broader environment. Each of these pathways represents a unique challenge with respect to necessary data, appropriate methodologies and feasibility of quantifying their role in affecting human health, both negatively and positively, at a global scale. The following sections



AMR: antimicrobial resistance

Figure 1

A conceptual framework for associating poor animal health outcomes with human health

will focus on specific linkages and discuss the current opportunities and challenges present in their possible quantification.

Direct impacts of zoonotic disease on human health

Zoonoses encapsulate a diversity of pathogens associated with a variety of health outcomes. They include diseases originating from wild animals as well as other vector-borne diseases and food-borne illnesses. In this article, zoonotic diseases have been grouped together for the sake of a comprehensive approach. DALY-based burden estimates therefore provide an essential tool for comparing their direct impact on population health.

A recent review examined the different existing DALY estimates for a selection of 26 zoonotic diseases, selected from a summary of national prioritisation exercises [7]. The review revealed that the landscape of burden estimates for these diseases remains scattered and incomplete. Several diseases lack estimates, including West Nile virus, avian influenza, Marburg virus disease, plague, Lassa fever and glanders. Conversely, numerous estimates were retrieved for non-typhoidal salmonellosis (24 studies), campylobacteriosis (22 studies) and toxoplasmosis (16 studies). Globally, discrepancies emerged between how often countries prioritised certain diseases and the number of estimates for those diseases. For example, rabies, the most frequently mentioned disease in prioritisation exercises (highlighted 94 times), was the subject of only 12 associated studies, while *Campylobacter* spp., stated five times as a priority, had a higher number of associated studies. Some of these diseases are also part of other domains, such as food safety, antimicrobial resistance (AMR), diarrheal disease and maternal or neonatal health, which might contribute to their higher number of estimates. Only 16 diseases detailed the burden of disease at the global level, leaving diseases such as anthrax and Q fever without estimates despite national-level prioritisation. Indeed, most estimates were conducted at a national or subnational level, with limited global-level data available.

Two international initiatives calculated global-level DALYs: GBD and FERG [5,6]. While these projects encompass zoonotic diseases within broader categories, such as food-borne or diarrheal diseases, neither project exclusively focuses on zoonoses. The GBD study has a wider scope, whereas FERG estimates DALYs for food-borne diseases, encompassing transmission routes. The FERG approach includes a structured expert elicitation for determining burden proportion by exposure route [8]. Other methodological differences are incidence-based *versus* prevalence-based and outcomes-based versus pathogen-based approaches. The 2019 GBD study adopted an outcome- and prevalence-based approach, assigning disease burden to clinically defined categories in the reference period resulting from past and present incident events [5]. On the contrary, FERG employs a pathogen- and incidence-based approach that captures the major outcomes attributable to a specific pathogen, including long-term sequelae [6]. These differences impede direct comparisons of the two studies' results, but such focuses promote the need for ongoing source attribution research to better tease apart how pathogens use specific pathways.

Methodological decisions and assumptions can hinder cross-study comparability and interpretation in general. As a result, disease burdens may be misjudged when estimates are compared from various sources, or their relevance as prioritisation tools for policy-makers may be reduced. For instance, a comparison of different brucellosis burden of disease estimates revealed methodological differences [9]. Some studies omitted mortality estimates (due to data scarcity or the assumption that brucellosis is not fatal). In addition, studies used disease models with variable health states and corresponding disability weights. Variations in disease durations also emerged, ranging from 2 weeks to 4.5 years.

DALY estimates demand high-quality data for all the different parameters, posing challenges for many zoonoses due to data gaps. Coping with uncertainties and data gaps significantly influences estimates, with global studies, like the GBD and FERG studies, addressing missing data and uncertainty using extrapolation and stochastic models. These choices impact the estimates produced and could lead to underestimation or overestimation of disease burden, a common issue in estimating zoonotic disease burden. However, not all local studies consider uncertainty and missing data. A recent review of the methodological choices for cysticercosis revealed that only four of eight national or subnational studies included scenario analysis to reflect epidemiological parameter uncertainty or preferences for time discounting and age weighting [10]. Similarly, in the review analysing brucellosis burden of disease studies, 4 out of 13 studies conducted a scenario analysis using different life expectancy tables, discounting and age weighting, and degrees of underestimation [9]. Uncertainties and data gaps can be expected in all pathways connecting animal to human health. Experience addressing these issues in studies assessing the direct impacts of zoonotic disease on human health can serve as a valuable guide for other pathways for which methods have been less well established.

While global estimation of the direct impact of some zoonotic disease already occurs, future efforts at a global scale should aim to converge not only in terms of the composition of pathogens considered, but also in terms of key methodological decisions and parameter values that influence model-to-model differences just as much as different data inputs do. The highlighted reviews underscore the importance of enhancing routine reporting, collecting improved national data and conducting further research on parameters essential for estimating disease burdens, including source attribution estimates.

Agricultural industry-related impacts: considering antimicrobial resistance and climate change

AMR is on the rise and a leading global health threat, with estimates indicating that 1.27 million human deaths worldwide in 2019 were due to bacterial AMR alone [11]. AMR resistance genes can spread within and between microorganism species, which facilitates their transmission across human, animal and environmental domains. AMR links human and animal health directly via the transmission of resistant pathogens or mobile genetic elements carrying resistance genes either through consumption of animal products or through direct contact between humans and animals. Animals can also indirectly contribute to the rise of AMR in humans, for example via the excretion of antimicrobial residues into the environment following antimicrobial use (AMU), which fuels the development of environmental resistance reservoirs [12,13]. These links are especially relevant given that several antibiotic classes have been classified as having high or critical importance in both the human and animal sectors, such as third- and fourth-generation cephalosporins and fluoroquinolones [14,15]. There is evidence that AMU-reducing interventions in livestock have a decreasing effect on AMR in humans, and associations between AMU and AMR in different livestock species and humans have been found for many pathogen–antibiotic drug combinations [16,17].

To quantify the relative importance of animals for human AMR, sound data from both domains is needed. As outlined in the World Health Organization's global action plan on AMR resistance, integrated surveillance programmes are key to obtaining these data [18]. To guide future research and data collection efforts, it is thus important to map out the current status of data availability for AMR in the animal and human sectors around the globe, as well as opportunities and obstacles in linking them. Source attribution studies and risk assessments are important avenues for assessing the extent of the contribution of animals to human AMR and help provide specificity in identifying the animal sources that are most relevant in AMR transmission [19].

Climate change similarly represents an important consideration that is only relatively recently starting to be quantified in a manner amenable to integration into DALY frameworks. Estimates of global emissions associated with the livestock industry are being produced, but the extent to which these emissions are compounded by animal health losses remains to be determined. DALY estimates have not yet been made for all climate-sensitive conditions. While for specific diseases estimates have shown how different climate pathways may alter the range and prevalence of certain conditions, within the GBD study, treating temperature as a risk factor, a variety of non-communicable conditions have been evaluated as having currently attributable burden from non-optimal temperature [20,21]. As such, there is no single resource for characterising all possible impacts.

Both these aspects of livestock production demonstrate the complexity in how some features related to animal health impact human health outcomes. Even within the animal health space, it is not necessarily clear how mitigating animal health losses will directly impact industry-related mechanisms for changing human health.

Nutrition and wealth as key pathways for indirect impacts on human health

In contrast to zoonotic disease, for which global estimation pathways exist, indirect impacts have not been considered at a global scale. Given the key role that livestock has served throughout human civilisation, it is important to consider the relationship between poor animal health and subsequent human consumption patterns and ability to contribute to local and global economies. Whether livestock die prematurely, are culled to mitigate further spread or are afflicted by disease such that yields or the quality of yields is reduced, much animal health loss can be translated into some sort of commodity. Either through direct estimation, leveraging of economic approaches, or more simulation-based assessments of how perturbations in local, regional and global commodities result in the redistribution of existing resources, and possible gaps where there is a deficit, it is possible to translate animal health loss into changes in available food, individual-level wealth and national-level economic measures [22].

Existing DALY-related frameworks typically consider diet as a metabolic risk factor, leveraging relative risks calculated for intake of specific macro- and micronutrients, as well as foodstuffs such as red meats, and pair these relative risks with consumption surveys to evaluate the prevalence of certain consumption patterns, in order to derive a summary exposure value that enables a calculation of a population attributable fraction [23,24]. Given these requirements, if it is possible to provide estimates of the change in yield, a series of calculations can be initiated to translate these estimates into DALYs associated with this loss of yield. Addressing yield losses and altering subsequent diets have the potential both to mitigate health loss due to undernutrition and to exacerbate already poor diets by allowing further over-nutrition. However, frameworks like the GBD can estimate the opportunity space for gains, or the negative consequences of continued excesses, using the DALY.

With micronutrient-related risk factors, it is necessary to leverage food composition tables to convert units of product into units of nutrients [25]. While global production losses can be used to determine a total amount of lost nutrients, determining the potential for that loss to change the health of a specific population, in the absence of strong assumptions, requires the leveraging of global supply chain models and further diet intake statistics. This is because owing to wastage, overconsumption in some communities, and global inequities in trade, food losses in a specific location do not necessarily translate into poor diet-related health outcomes in that same community [26]. Different communities are more or less dependent on local food production chains, and if that point is not accommodated, statistics may be produced whereby poor animal health in highly mechanised livestock production systems is naively translated into possible health losses in the local community, when in reality those losses mean reduced exports to other communities reliant on imported produce.

Beyond consumption, livestock and their outputs can play an important role in wealth generation for people and households, supporting the livelihood of an estimated 1.3 billion people worldwide [27]. Livestock can contribute food, income and draught power, as an input to other agricultural activities, and can provide insurance and asset storage. In low- and middle-income countries, livestock keeping has been recognised as a pathway out of poverty [28].

Disease in animals and losses in animal production can therefore have multiple negative ramifications for household economic status that go beyond short-term losses of outputs. One of those pathways of impact extends to access to healthcare, particularly affordability of out-of-pocket payments for healthcare services. For households facing financial constraints due to animal diseases, out-of-pocket health spending might translate into financial hardship or forgone healthcare, indirectly leading to mortality and morbidity [29]. In communities heavily reliant on livestock as a main livelihood stream, continuous losses of livestock due to disease, disasters, predation and other causes can perpetuate a cycle of poverty for livestock owners, which is in itself an important social determinant of health, with consequences for exposure to disease and access to healthcare [30].

Quantifying the contributions of these wealth effects at a global scale is not currently a feature of global estimation exercises such as the GBD or FERG studies. These frameworks often consider socio-economic features as covariates (such as the socio-demographic index within the GBD framework) and, as such, the consequences of changes in wealth for the various activities outlined above are indirectly manifested in estimation exercises through these covariate effects [5]. Currently, wealth is not featured as a risk factor within the GBD or FERG frameworks.

For these key indirect mechanisms as they relate to health, two very different pictures of estimation feasibility emerge. For wealth, no methodology exists to tap into existing DALY frameworks; other forms of evidence, such as tracking healthcare expenditure profiles, seem to offer a more feasible way of tracking impact, and this problem space has specific importance for universal health coverage, particularly when one considers agricultural communities and their ability to avoid catastrophic healthcare expenditure when also facing substantial animal losses [31]. For diet-related impacts, there are existing approaches that can be co-opted; however, recommendations related to taking specific actions require further integration of economic aspects in order to more realistically account for market dynamics and consumption patterns. Regardless, even with strong assumptions on the mapping of losses to diet change, a DALY perspective can serve as a powerful accompanying framing of the consequences of this wastage.

Conclusions

Quantifying animal health outcomes in a manner comparable to that which has resulted from the last three decades of human health metrics represents an ambitious challenge. However, should this be achieved, there is a large opportunity space to integrate human health measures with those of animals to begin to more comprehensively quantify the totality of global One Health outcomes. For some of the major pathways indicated in Figure 1, either existing mechanisms for quantifying their impacts (along with their constraints) are outlined, or it is indicated where current methods could be newly associated or repurposed to produce global estimates of the translation of animal health outcomes into human health metrics, such as the DALY. For some potential linkages, evidence is currently mixed or inconsistent; nevertheless, there are comparable analytical blueprints that could incorporate evidence as it becomes available or stronger, thus resulting in global estimates.

When faced with decisions on where to allocate finite resources to improve animal health outcomes, it is essential to consider associated human health impacts. While complex and multidimensional, some of these impacts may feasibly be calculated if existing approaches in population health research are emulated. The ability to quantify animal health decisions in terms of DALYs and other related human health measures will represent a transformative means of approaching animal health decision-making that fully acknowledges the interdependent nature of livestock and humans.

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Faire le lien entre les impacts respectifs de la santé animale et humaine : défis et perspectives

B. Devleesschauwer, S. Babo Martins, C. di Bari, C. Fastl, N. Venkateswaran & D.M. Pigott

Résumé

La quantification de l'impact des problèmes de santé animale sur la santé humaine constitue un défi d'une grande complexité. En se servant de l'indicateur des années de vie ajustées sur l'incapacité (DALY) comme critère d'évaluation, les auteurs examinent trois processus essentiels illustrant l'impact que la situation zoosanitaire peut avoir sur la santé humaine : impact direct résultant des maladies zoonotiques, impact indirect résultant des mauvaises performances des animaux et de leurs conséquences sur la nutrition et la création de richesses, et enfin, effets indirects résultant de facteurs en lien avec le secteur agricole, par exemple l'utilisation de produits pharmaceutiques et le changement climatique. Pour chacun de ces processus, les auteurs font le point sur l'état actuel des connaissances et sur l'applicabilité des évaluations mondiales basées sur l'indicateur DALY.

Les cadres existants relatifs aux zoonoses recouvrent déjà certains agents pathogènes majeurs ; la prochaine étape importante consistera à assurer une couverture complète des agents pathogènes et à veiller à la cohérence des décisions méthodologiques. S'agissant de l'alimentation, les cadres basés sur l'analyse des facteurs de risque permettent de calculer les DALY imputables à l'alimentation ; toutefois, d'importantes avancées méthodologiques sur les aspects économiques de cette corrélation seront nécessaires pour s'assurer que tout changement intervenant localement en matière de production animale est correctement mis en correspondance avec les modifications des habitudes alimentaires dans ce même contexte local mais aussi à l'échelle mondiale. S'agissant des impacts liés à la création de richesses, il reste beaucoup à faire dans le domaine méthodologique. La détermination des impacts liés aux filières d'élevage requiert des travaux axés sur des sujets précis, par exemple des études visant à déceler les sources de la résistance aux agents antimicrobiens qui contribuent à l'apparition d'antibiorésistances chez l'être humain. Enfin, pour ce qui concerne le changement climatique, une étape cruciale consistera à déterminer dans quelle mesure les émissions associées à l'élevage sont susceptibles de changer en cas d'amélioration de la situation zoosanitaire.

Dans un contexte de ressources limitées, l'affectation de fonds à l'amélioration de la santé animale doit également prendre en compte l'impact en aval sur la santé humaine. L'utilisation de l'indicateur DALY permet des comparaisons avec d'autres décisions de santé publique et représenterait une approche transformative de la prise de décision en santé animale, dès lors que les obstacles mentionnés dans cet article sont surmontés et que de nouvelles méthodes sont mises au point.

Mots-clés

Années de vie ajustées sur l'incapacité – Changement climatique – DALY – Indicateur mondial – Maladies zoonotiques – Nutrition – Résistance aux agents antimicrobiens – Une seule santé.

Asociar el impacto de la sanidad animal y la salud humana: desafíos y oportunidades

B. Devleesschauwer, S. Babo Martins, C. di Bari, C. Fastl, N. Venkateswaran & D.M. Pigott

Resumen

Cuantificar el impacto de una mala sanidad animal en la salud humana es un desafío complejo. Utilizando el parámetro de años de vida ajustados en función de la discapacidad (AVAD o DALY) como criterio de valoración, en este artículo se examina cómo la sanidad animal puede repercutir en los seres humanos a través de tres procesos clave: directamente, a través de las zoonosis; indirectamente, a través de cambios en los rendimientos y sus repercusiones en la nutrición y la riqueza; y, por último, a través de factores indirectos asociados a la industria agropecuaria, como los fármacos y el cambio climático. Para cada uno de estos procesos, se examinan el estado actual y la viabilidad de estimar AVAD a escala mundial.

Los marcos existentes para la zoonosis ya tienen en cuenta algunos patógenos claves; garantizar la exhaustividad de los patógenos considerados y la coherencia en las decisiones metodológicas es un próximo paso importante. En lo que respecta a la alimentación, aunque los marcos de factores de riesgo permiten calcular los AVAD atribuibles, se necesitan importantes avances metodológicos en el ámbito económico para asegurar que los cambios en la producción local se correspondan adecuadamente con los cambios locales y mundiales en los hábitos alimentarios. En cuanto a las repercusiones en la riqueza, queda mucho trabajo por hacer en el desarrollo de métodos. Para abordar las repercusiones relacionadas con la industria, es necesario centrarse en temas clave de investigación, como los estudios de atribución relativos al impacto en la salud humana de la resistencia a los antimicrobianos en los animales. En lo que se refiere al cambio climático, un próximo paso crucial es determinar en qué medida las emisiones de la industria podrían cambiar, en función de la mejora de los resultados en materia de sanidad animal.

Al asignar fondos limitados para la mejora de la sanidad animal también se deben tener en cuenta las repercusiones correspondientes en los seres humanos. Utilizar los AVAD permite hacer comparaciones con otras decisiones importantes relacionadas con la salud humana y representaría una forma transformadora de enfocar la toma de decisiones en materia de sanidad animal, en caso de que se aborden los obstáculos presentados en ese artículo y se desarrollen nuevos métodos.

Palabras clave

Años de vida ajustados en función de la discapacidad – AVAD – Cambio climático – Enfermedades zoonóticas – Nutrición – Parámetros globales – Resistencia a los antimicrobianos – Una sola salud.

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