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A systematic literature review on the economic impact of endemic disease in UK sheep and cattle using a One Health conceptualisation

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ABSTRACT

Endemic sheep and cattle diseases represent a constant strain and impact to animal health and welfare, the environment, public health, and the economy. Quantifying this impact helps to inform decisions on surveillance and control of livestock diseases. This systematic literature review had two objectives; to describe the economic impact of endemic sheep and cattle diseases in the United Kingdom using a broad conceptualisation of impact, and to investigate what variables (e.g. medication costs, loss of production) and methods are included in these calculations. The Prisma protocol for systematic literature reviews was followed. Searches were performed in Pubmed, Scopus and Web of Science using selected and trialled search terms. A total of 1129 papers were identified and screened for relevancy; 38 papers were selected for full review extracting and analysing data on disease, impact and methods. From this final selection of papers it was found that; 1) research in this area is mainly focused on the dairy sub-sector, 2) the most mentioned diseases were mastitis and lameness in dairy cattle; bovine viral diarrhoea in beef cattle; and ectoparasites in sheep with reported animal-level costs of £ 77-£ 548/cow/year, £ 26-£ 185/bovine animal/year and £ 40-£ 47/ewe/year, respectively, 3) numerous methods and variables were used to calculate or estimate the economic impact with most studies focussing on the direct producer impacts and less on the wider implications and affected stakeholders; and 4) it was common for studies to look at one disease in isolation rather than consider disease impact on the farm as a whole. It is recommended that future economic impact calculations on livestock disease include wider implications to estimate the true cost of disease. To generate the necessary data, a wider, more inclusive conceptualisation of impact will be needed to support the collection of data and facilitate communication between stakeholders. Systematic health data recording combined with assessment calculations and metrics that allow comparability within or across livestock sub-sectors will increase the informative value of these impact calculations.

1. Introduction

Long-term and stable food security (utilisation, access and availability) is one of the major outcomes expected from food systems (Ericksen, 2008). However, we also desire that food systems deliver thriving livelihoods, good health, welfare and environmental outcomes as well as ecosystem services, e.g., food, aesthetics, water, air or pollination (Birkhofer et al., 2015; Daily and Matson, 2008). All while minimising negative consequences, for instance further environmental degradation and diet-related human disease. The term food system refers to the many actors, organisations and processes that form a complex interconnected web of activities from production through to consumption of food and waste management. These “core” food system activities sit within the human, animal and environmental systems, which include factors such as socioeconomic conditions, population structures, science and technology, climate change and natural resource capital. The systems are highly interconnected where impacts and feedbacks within and between systems can occur from multiple directions making them complex and adaptive.

The cattle and sheep sub-sectors in the UK held 9.6 million cattle and 32.7 million sheep, respectively, in 2020 (Defra, 2020). This livestock production provides macro- and micronutrients as well as other valuable by-products for an increasing human population and creates livelihoods for individuals, especially in rural areas with lower job opportunities. In the UK, a reported 472,000 people were working on agricultural holdings in 2020 (Defra, 2020). Livestock production is also an important part of the UK’s culture and heritage, with media and anecdotal reports that livestock in the countryside is quintessentially British and a sight

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people enjoy seeing (Rust et al., 2021). Arguments against ruminant production for human consumption include greenhouse gas emissions, water use, soil degradation, animal welfare, biodiversity, and foodborne and non-communicable diseases (Garnett and Godfray, 2012; Goodland and Anhang, 2009; Gummow, 2010; Lake and Barker, 2018; Thornton and Herrero, 2010).

As the human population increases and demand for nutrients and protein grows, livestock sub-sectors face pressure to adopt strategies that increase outputs while staying within the planetary boundaries. The livestock sector is reported to contribute up to 90% of the planetary nitrogen cycle and over 30% of greenhouse gas emission globally (Bowles et al., 2019) for both of which the UK is already outside the per capita boundaries (O'Neill et al., 2018). Therefore, livestock sub-sectors are exploring how they can provide access to nutritious and safe food without compromising the ability of future generations to meet their own needs (FAO, 2018). Control of endemic livestock disease can contribute positively to these outcomes and ease pressure on scarce resources.

Endemic diseases apply constant pressure to the cattle and sheep food systems by increasing labour and medicine use and decreasing productivity and efficiency of converting feed to energy (Delabouglise et al., 2017). Endemic disease is of particular concern for sheep and cattle production, because of their comparatively long production cycles and their high contribution to UK livestock output. Because ruminants contribute to greenhouse gas emissions, have a life span that allows time for health improvements and are exposed to a multitude of pathogens compared to, for example monogastric species, information on disease impact allows understanding of the strain it puts on efficiency and sustainability. Consequently, this review focused on the impact of endemic diseases in cattle and sheep. It can be difficult to achieve complete disease-free status on cattle and sheep farms, particularly from endemic diseases and with trading and moving animals it is likely they will often come in contact with other infected animals (Carslake et al., 2011). In addition, some diseases may go unnoticed as physical signs of diseases are little to none, such as subclinical mastitis in sheep (Grant et al., 2016). McInerney et al. (1992) was one of the first to stress that animal disease is not only a veterinary, but also an economic problem. A recent study estimated an approximate annual cost of sheep scab and bovine viral diarrhoea alone at £ 51 million (Defra, 2019) accentuating that endemic diseases warrant attention and provide scope to increase the value of livestock production.

Economic impacts of livestock diseases can be observed across all the connecting systems, for example; a decrease in animal productivity through direct impacts of disease, human health expenditures through zoonoses (Zinsstag et al., 2007; Martins et al., 2014) and environmental impact through the increased use of drugs leading to residues and resistance in nature (Boxall, 2004). These externalities necessitate the use of metrics spanning different sectors. McInerney et al. (1992) stated that the economic cost of disease is the sum of the losses and expenditures, defining losses as a benefit that has been taken away (such as discarding mastitic milk) or a potential benefit not realised (such as reduced output yield), and expenditures as the resources allocated to counteract the disease threat (such as veterinarian treatment). He also expressed that the inclusion of any benefits caused by disease, such as reduced feed costs, is necessary to have the correctly calculated output losses. Bennett et al. (2010) extended McInerney's framework to include animal welfare and human health costs, both as qualitative scores. Rushton et al. (2015) further described production animal health impact in two categories; *health losses* including visible (e.g. thin or dying animals) and invisible (e.g. fertility) losses, and *expenditure/human reaction* including additional costs (e.g. medication) and lost revenue (e.g. change in access to markets). Torgerson et al., 2018 introduced the zoonotic disability adjusted life years (zDALY). The zDALY is a modification of the well-used human health assessment metric disability adjusted life years (DALY) and was developed to estimate the societal burden of zoonotic diseases that have human and non-human animal consequences (Torgerson et al., 2018). Barratt et al. (2018) and Weldegebriel et al. (2009) examined the economic burden of livestock disease from a societal position taking the consumer as well as the farmer perspectives. Notably, very few studies include the health of the environment along the health of humans and animals (Zinsstag et al., 2021). This may be because environmental impacts are less directly or easily measurable.

For the true, or full, impact of endemic livestock disease to be understood and aid better decision making, wider implications (beyond the livestock animal) need to be considered. In addition, many studies have focused on single diseases or syndromes in isolation and not considered the total burden of disease on a defined unit (e.g. farm) through secondary consequences or disease combinations. In order to explore both aspects, a systematic literature review was performed with two objectives: 1) to describe the economic impact of endemic sheep and cattle diseases in the UK, and 2) to investigate what impact methods and variables were used and the breadth of wider considerations integrated.

2. Method

2.1. Search strategy and criteria

An adaption of the Cochrane protocol (Higgins et al., 2022) to suit a veterinary-based search (Sargeant et al., 2006) was used to perform the systematic literature review in line with the PRISMA guidelines (Page et al., 2021). Trial searches were performed within three databases; PUBMED, Scopus and Web of Science, using a combination of different search terms to ensure the most inclusive search term combination was used. No publication date restriction was placed on the search. Sentinel papers (studies known to contain the relevant information therefore should be captured by the search term) were used to test the efficiency and suitability of the proposed search terms (appendix I). Boolean operators were used to combine the categories and phrases to build the final search term that was approved by all authors (Table 1).

The publication searches in the bibliographic databases were completed on 27/08/2021 by the first author.

2.2. Selection process, risk assessment, data collection and analysis

The results from the final searches in all three databases were exported to Mendeley (Mendeley Desktop Version 1.19.4). Duplicates were automatically removed; a manual check was completed to identify any missed duplicates. The abstracts from the remaining papers were screened for relevancy by the first author using the criteria that they must be concerning; the UK, endemic diseases in sheep or cattle and a quantitative estimate of the impact relating to the disease. In addition, only peer reviewed papers written in English were included. Full publications for the resulting papers were obtained for a second screening; if it was not possible to retrieve the full study it was removed from the final selection. The references from the selected papers were checked for any missed studies and any found that passed the above criteria were added

Table 1
Words and phrases used to build the final search term.

Topic	Population	Location	Focus	Exclude
disease* OR illness* OR infection* OR virus*	sheep OR ewe* OR ovine OR ram* OR lamb* OR cow* OR cattle OR livestock OR calf OR calv* OR bull* OR heifer OR bovine* OR dairy OR beef OR suckler OR animal*	gb OR "great britain" OR uk OR "united kingdom" OR Scotland OR england OR wales OR English OR Scottish OR welsh OR british	econom* OR cost* OR financ* OR impact	"New South Wales" OR "bullosa"

to the final selection.

The lead author screened all abstracts and full articles. Author BH independently screened 10% of the articles included in the abstract screening and 10% of the articles included for full article screening. Between LW and BH there was 93.2% and 90% observational agreement, respectively, which resulted in an interrater reliability Cohen's kappa of 0.75 and 0.78 indicating substantial agreement. The one paper that was differing in the full text was discussed and combined agreement made. With high agreement between the authors, it was deemed acceptable that the lead author carried out bias/quality assessment and data extraction independently.

Data were extracted from the final selection of papers using a standardised form in Microsoft Excel (Microsoft Excel 2016). They included target population, method, variables and unit of measuring economic impact, description of outcome and results.

For reviews, the references that appeared in the published article were searched for, checked, and – if fulfilling the inclusion criteria – remained in the final list of articles. All papers were assessed using the Drummond checklist (Drummond, 1996). This checklist has 35 steps and is suggested by the Cochrane review for use to critically appraise methodological quality of health economic studies.

Data extracted by the lead author were used to describe the published economic impact of endemic sheep and cattle diseases in the UK. The framework shown in Fig. 1 was used to identify and categorise the impact variables and to analyse the data. It categorises the variables into sub-themes based on the concepts of McInerney et al. (1992) and Rushton et al. (2015) and applying the same logic to the environment.

All economic values from the articles analysed were converted to 2022 prices using https://iamkate.com/data/uk-inflation/.

3. Results

3.1. Summary of articles

From the initial searches performed in the three databases, 1129 papers were identified. After automatic and manual duplication removal this was reduced to 878 papers. Initial title and abstract relevancy screening resulted in 91 records being retained for further screening and a further three added from reference screening. Of the papers full text was available for, it was noted that three papers were actually reporting the same results therefore the most detailed paper was retained and the others excluded. Of the remaining records that were identified to fit the criteria, 38 were included in the final selection (Fig. 2).

The 38 papers were assessed for bias/quality (appendix III) and all scored at least 20 out of 35 which indicates high quality economic evaluations (Carter et al., 2017). Authors were particularly good at expressing the economic importance of their research question, relating to productivity changes and stating methods to estimate benefits. Use of discount rates was seldom mentioned.

Primary data (data collected by the author/s of the selected papers) only were used in five of the 38 papers (13.2%) to calculate economic impacts. A total of 33 (86.8%) of the papers used secondary data, gathering information from various sources to estimate economic impact either as the only source of information (76%) or in conjunction with primary data (24%). Of these 33 papers, two (6.1%) were reviews/ summaries of other works' analysis and results.

The papers spanned over 37 years from 1983 to 2020, with no observable trend. The number of papers per year ranged from one to six across the years, with the maximum of five in 2017. The livestock production systems related to the disease studied, were; dairy cattle only = 14, sheep only = 12, beef cattle only = 7, beef and dairy cattle = 1, and sheep and cattle = 4 (Fig. 3). Cattle were the primary focus in 22 papers (57.9%) while sheep were the main concern in 12 studies (31.6%). Almost half of the total 38 papers (47.3%) focussed on the UK, nine papers (23.6%) looked at just Scotland, four (10.6%) referred to Great Britain, three (7.9%) to England, two (5.3%) to Wales and two looked at England and Wales together (5.3%).

3.2. Description of the economic impact of endemic diseases from the 38 papers

A full list of the endemic diseases mentioned and the corresponding papers are listed in Appendix II. The number of papers covering a certain disease and its economic impact on a species or production system varied greatly. The most reported diseases for each production system were mastitis and paratuberculosis (Johne's disease) in dairy cattle;

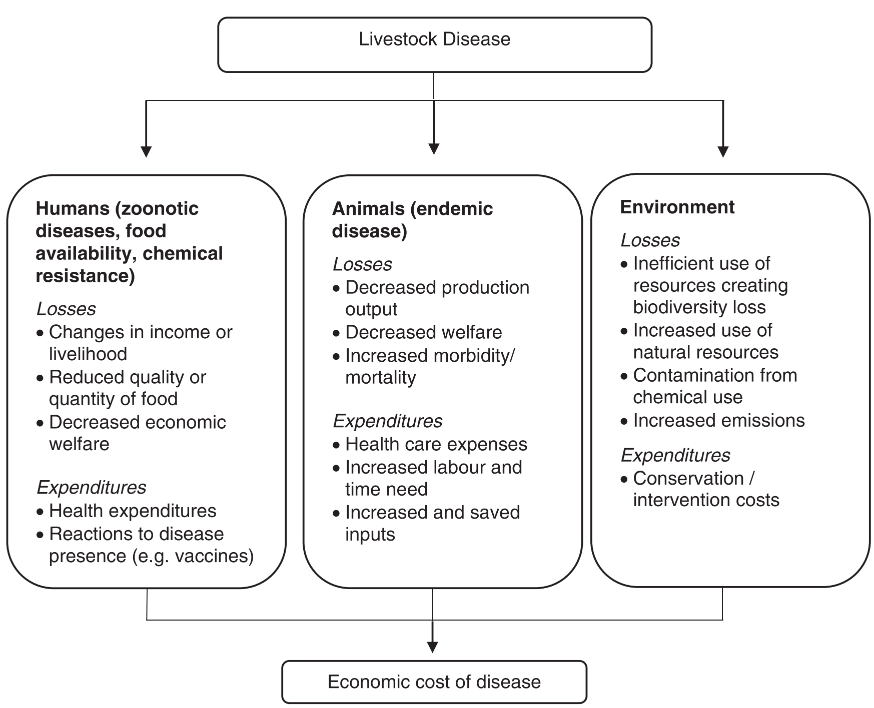

Fig. 1. Framework used to assess what impact variables have been included in the papers reviewed

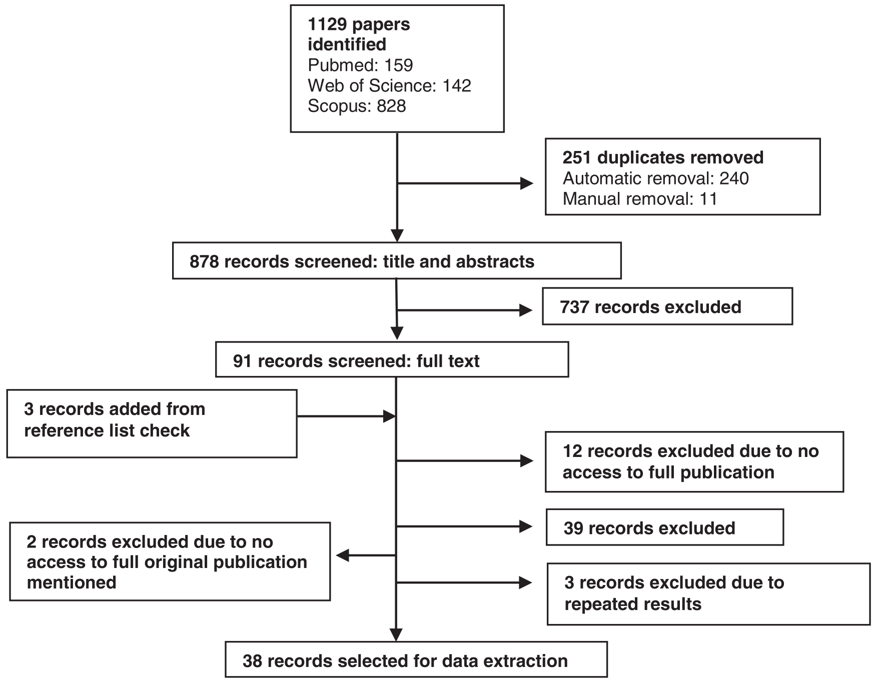

Fig. 2. Flow diagram of search protocol and numbers of papers identified in the systematic review of economic impact of endemic diseases in UK sheep and cattle.

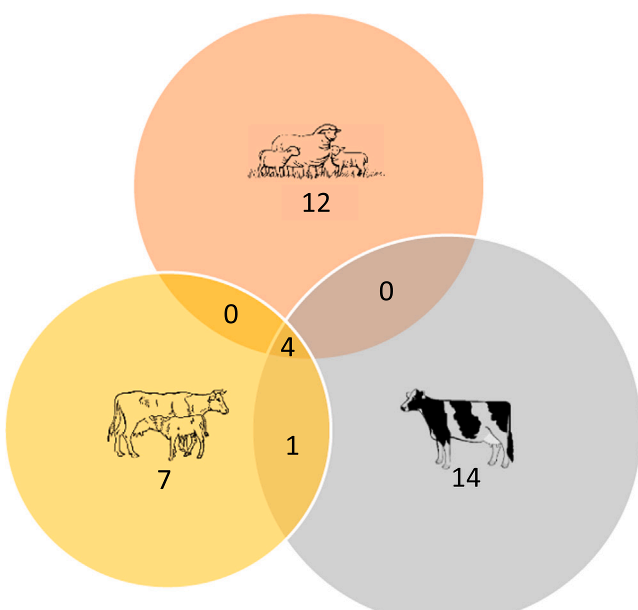

Fig. 3. Venn diagram of the specie/s focus in the final 38 papers.

bovine viral diarrhoea in beef cattle; and ectoparasites, endoparasites, orf and toxoplasmosis in sheep (Fig. 4).

With just under half of the papers (17/38, 44.7%) the most common reporting unit was the farm level although various outcomes calculations were undertaken; the annual loss/cost per farm (9/17, 52.9%), cost per farm for each outbreak (5/17, 29.4%), cost per farm over a set number of years (3/17, 17.6%). Reports at animal level were not far behind with 15/38 papers (39.5%). The majority of these 15 papers (11/15,73%) expressed impact per animal per year, whereas three papers (20%) reported per animal per case and the remaining paper expressed impact at the animal level but for five years rather than one. National level reporting was used in nine of the papers (23.7%) with 77.8% stating impact at national level per year, one paper looking at national cost per disease outbreak and the remaining one looking at the cost per tonne of carbon emission saved. Finally, one paper (2.6%) also reported at household level annually.

The costs, and the range of these costs, varied annually per nation, farm, household and animal; they are summarised in Fig. 5. The diseases ranking with the highest reported annual values at national level were mastitis and lameness for cattle animals, endoparasites for beef and psoroptic mange (sheep scab) for sheep. Gastrointestinal worms (in particular nematodes), for all sectors and BVD for beef also ranked high. At farm level, tuberculosis (TB) and liver fluke were the highest values for dairy and beef (liver fluke was one study), and similarly high values for scrapie, blowfly strike, sheep scab and worms for sheep, although the impact of worms had a greater range. Lameness, Johne's and mastitis were the higher values for dairy per animal per year, Johne's disease and BVD for beef, and sheep scab for sheep. Fig. 6 shows the diseases grouped by syndromes: Abortive (enzootic abortion, leptospirosis, toxoplasmosis), respiratory (IBR, parasitic bronchitis, pasturellosis, enzootic pneumonia, OPA, MV, calf respiratory disease, bTB), ectoparasites (blowfly strike, sheep scab) and endoparasites (fasciolosis and gastrointestinal worms and helminths). Abortive causing diseases and endo- and ecto-parasites were found to be important to all species and production systems.

3.3. *Identification of economic methods and impact variables used*

A variety of economic assessment methods were used that focussed on different populations and, space and time considerations, with some papers using a combination of methods. The most utilised method was cost-benefit analysis (16/38, 42.1%) with impact being a means to generate a baseline allowing to estimate benefits. Of these 16 papers, seven (43.7%) stated the use or adaptation of the McInerney et al. (1992) framework: C= (L+E), where: L = the losses due to disease and E = the expenditures on resources due to disease. The second most used economic assessment methods were partial budget and economic costs analysis with 6 studies each (15.8%) using these methods. This was followed by gross margin analysis which was used by three studies (7.9%). Economic welfare, optimisation and cost-effectiveness analysis was used by 2 papers each (5.3%). Finally, one paper used marginal

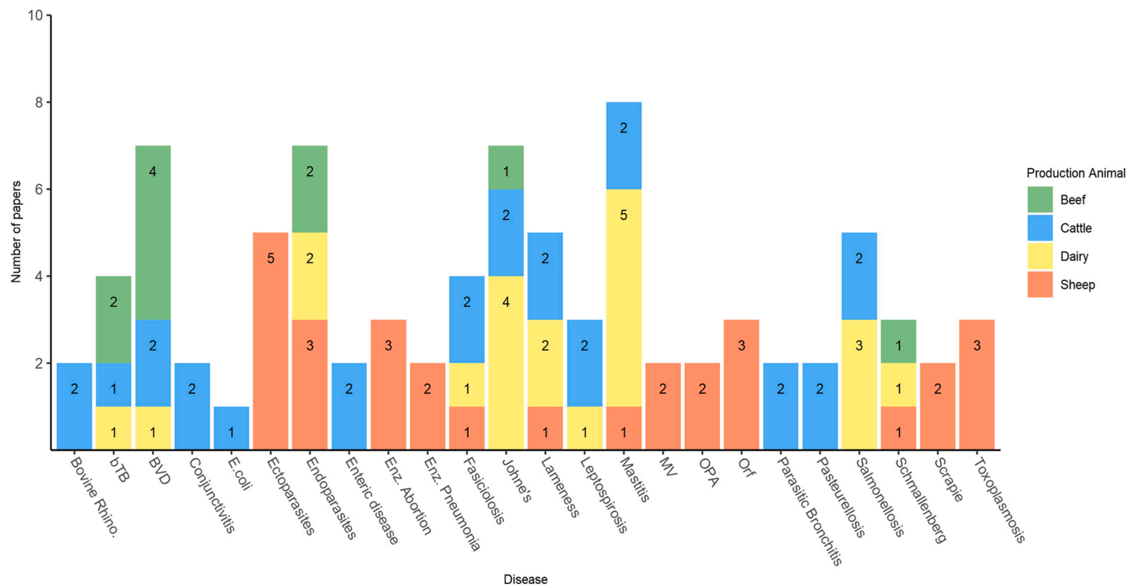

Fig. 4. Number of papers by production animal and disease. Cattle = papers where dairy and beef systems are reported together. Bovine Rhino. = bovine rhinotracheitis, bTB = bovine tuberculosis, BVD = bovine viral diarrhoea, Enz. Abortion = enzootic abortion, MV = maedi visna, OPA = ovine pulmonary adenocarcinoma.

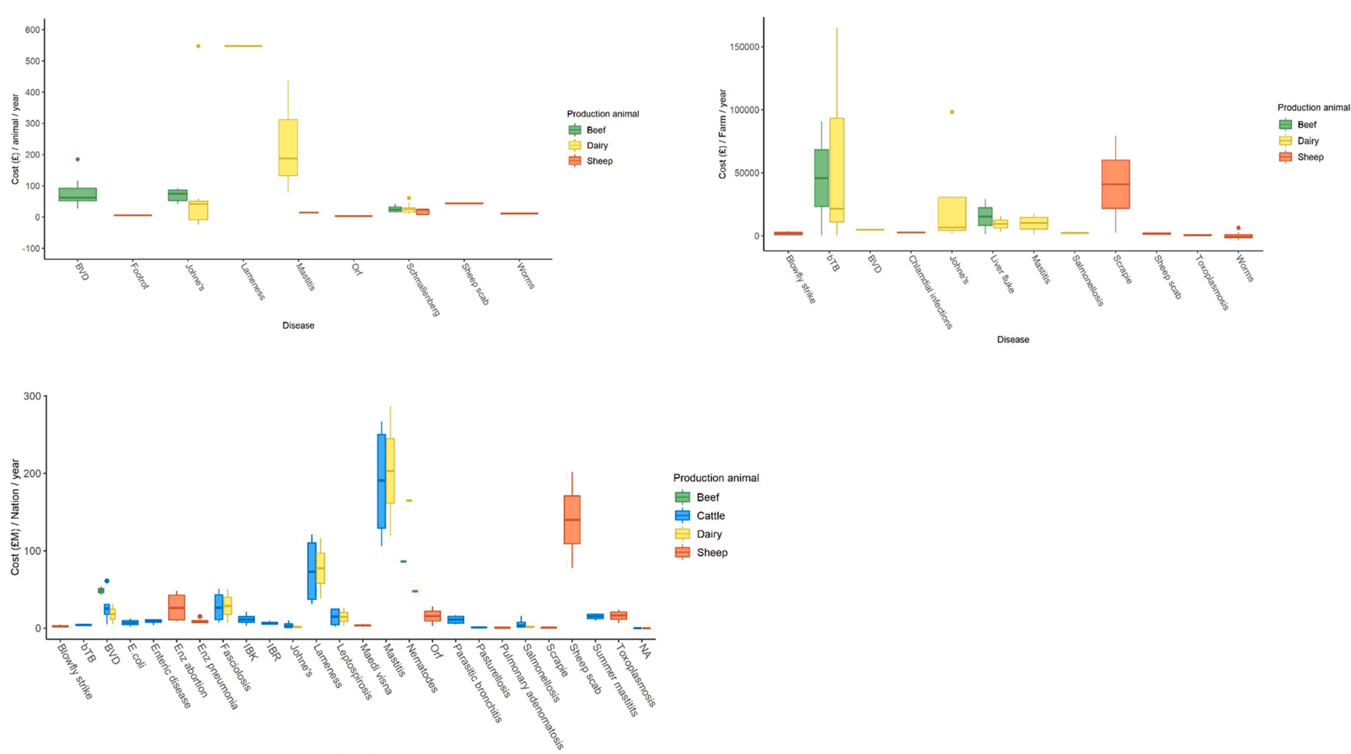

Fig. 5. Cost (adjusted to 2022 values) of disease reported in the 38 papers by production animal and split by reporting level. a) costs reported at animal level, b) costs reported at farm level, c) costs reported at national level. Note: costs could be cost of treatment alone, or costs of syndrome/disease or both. Cattle = papers where dairy and beef systems are reported together. BVD = bovine viral diarrhoea, IBK = infectious bovine keratoconjunctivitis, TB = bovine tuberculosis. The box bounds the IQR divided by the median and the Tukey-style whiskers extend to a maximum of 1.5 x IQR beyond the box.

abatement cost analysis (2.6%) and another game theory (2.6%). The use of Monte Carlo simulation was often mentioned in conjunction with the different economic methods (Appendix II).

All of the 38 papers included parameters involving human reaction through human or animal expenditures, and by a greater degree than that of animal disease loss parameters, particularly invisible losses (Fig. 7). After the variables were grouped, 19 different variables were identified that spanned the human, animal and environmental spectrum (Table 2).

Variables used to calculate the impact varied widely between the studies/papers, even those that stated the same economic method and in some cases the same disease. Most of these studies focussed on using variables that are a direct cost from the disease, e.g. increased veterinarian and medicine expenditure, others added indirect factors such as

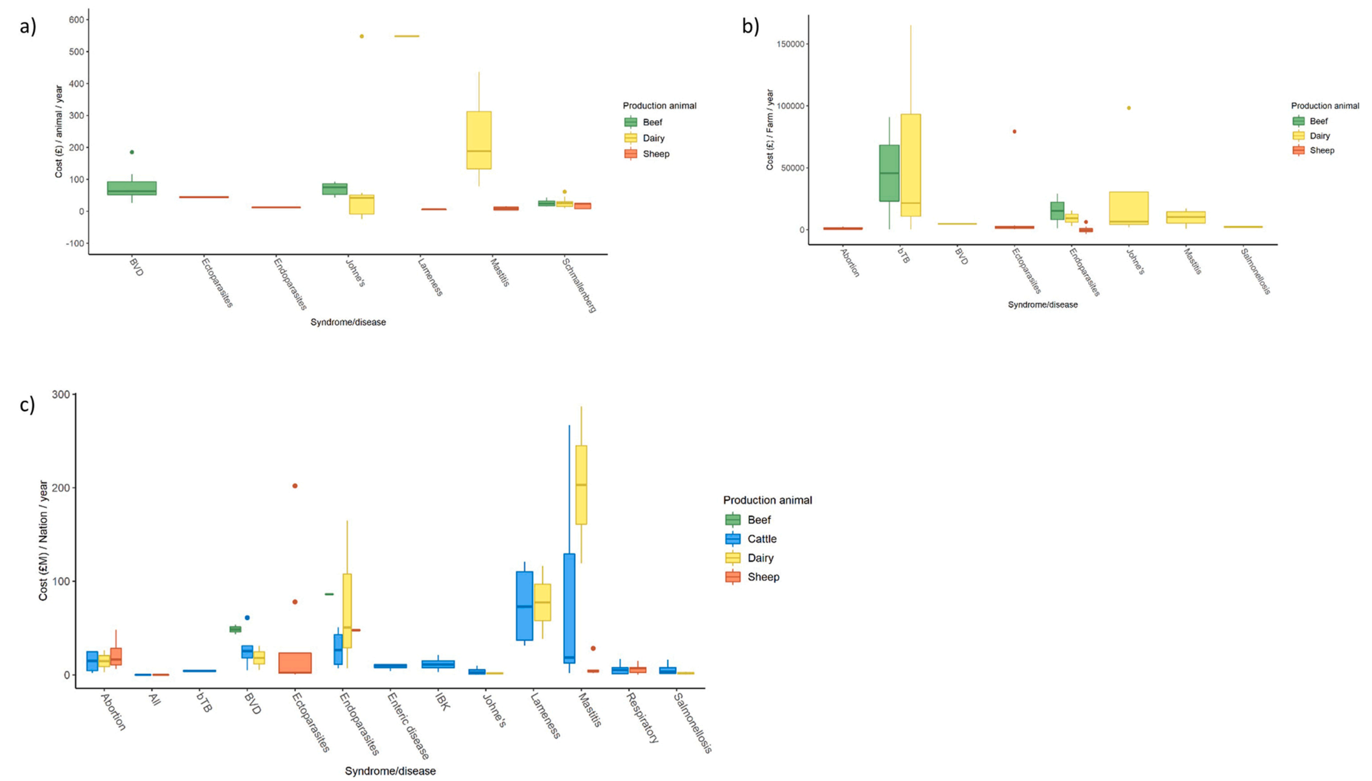

Fig. 6. Cost (adjusted to 2022 values) of syndromes (or single disease if it could not be grouped) reported in the 38 papers by production animal and split by reporting level. a) costs reported at animal level, b) costs reported at farm level, c) costs reported at national level. Note: costs could be cost of treatment alone, or costs of disease or both. Cattle = papers where dairy and beef systems are reported together. BVD = bovine viral diarrhoea, Enz. = enzootic, IBK = infectious bovine keratoconjunctivitis, IBR = infectious bovine rhinotracheitis, TB = bovine tuberculosis. The box bounds the IQR divided by the median and the Tukey-style whiskers extend to a maximum of 1.5 x IQR beyond the box.

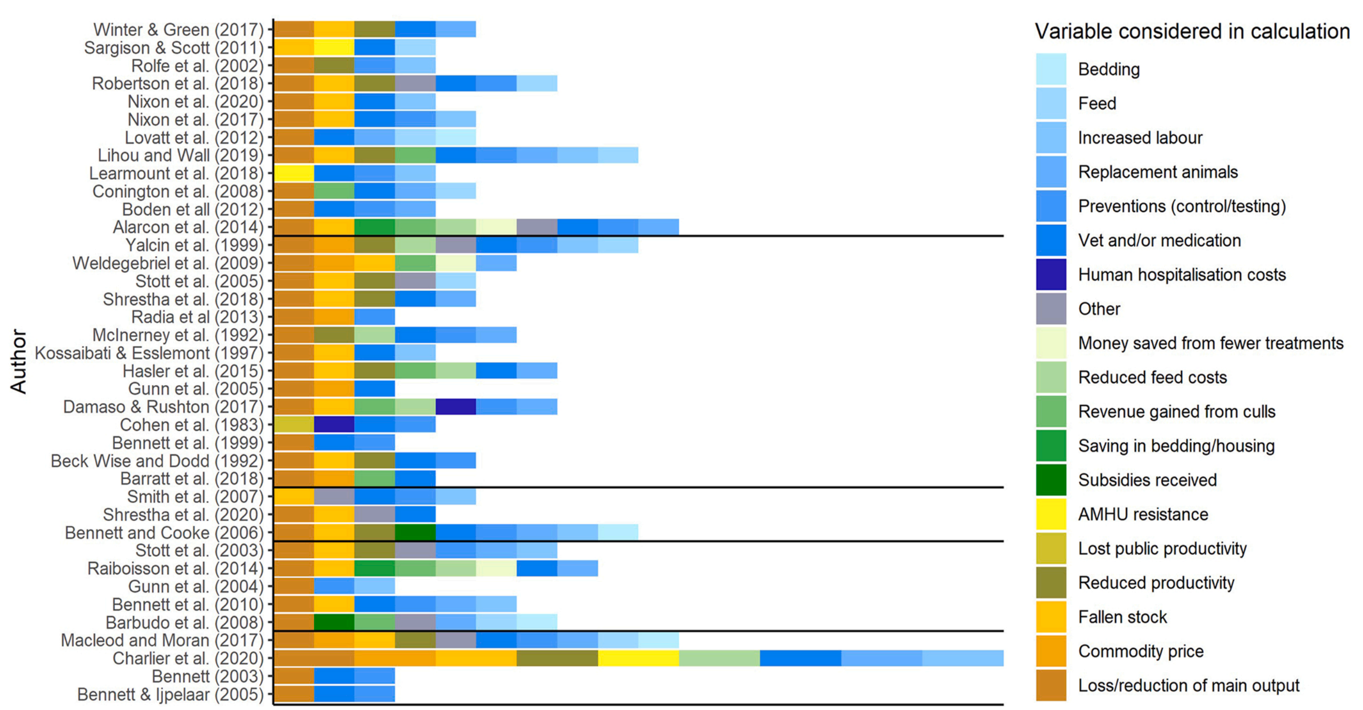

Fig. 7. Variables considered per study to calculate the economic impact. Variables have been categorised into four groups across two broad themes: 1) Impact caused by reaction; blue boxes = additional costs; green boxes = additional costs (benefits). 2) Impact caused by disease; yellow boxes = invisible losses and orange boxes = visible losses.

Table 2
Broader implication themes and sub-themes included in the 38 papers.

Framework theme included in calculations	Number of papers
Human losses	4
Human expenditures	5
Non-human losses	36
Non-human expenditures	38
Environment losses	4[a]
Environment expenditures	1

[a] Three concerning anthelmintic resistance.

costs saved (e.g. having less animals to feed as they died) or resource gain (e.g. money from culls). Variables categorised as non-human losses were also included by almost all of the papers, with most papers (37/38) opting for variables for that are visible losses compared to invisible losses (20/38). Only two other papers mentioned other health consequences (not related to fertility); Bennett and Ijpelaar (2005) and MacLeod and Moran (2017), who also included a score/price for animal welfare impacts (and human welfare impacts). Macloed and Moran (2017) were also the only paper that had an estimate that included environmental costs and losses such as released land.

A total of 34 studies focussed and included only impacts at the farm/producer part of the food system. Of these exceptions one included environmental impact of overall sheep and cattle health in relation to CO_2 reduction (MacLeod and Moran, 2017), one paper focussed on just the human costs, such as illness, medication and transport costs (Cohen, 1983) and the remaining two included the impact on the consumer, as well as the producer, from a commodity price perspective (Barratt et al., 2018; Weldegebriel et al., 2009). Although the focus was on the producer part of the food system, three papers could be said to have considered some wider implications; with two papers (Learmount et al., 2018; Sargison and Scott, 2011) investigating anthelmintic resistance on sheep farms and another that considered climate change effects on liver fluke impact on dairy farms (Shrestha et al., 2020).

4. Discussion

This systematic literature review described the economic impact of endemic diseases of cattle and sheep in the UK and the methods and impact variables used in these studies. It was found that few studies consider effects and impacts of farms/animals suffering from more than one disease simultaneously. Moreover, the impact is often narrowly conceptualised and does not consider wider effects (in particular on the environment). This indicates that the true cost of disease is not being captured comprehensively, which undermines efficient decision making and resource allocation for animal disease.

Disease makes food production less efficient, requiring increased resource use and inducing value loss, for example using the figures reported from the papers in this review mastitis alone costs the dairy and beef cattle industries respectively 6.7% and 10.2% of its total annual worth. The endemic diseases, mentioned in the selected 38 papers are mostly all diseases with obvious clinical signs, for example lameness and abortion, or are zoonotic (i.e. salmonella). There are also large ranges in costs within and between diseases, demonstrating that there is still work to be done to understand better the true impact of these diseases. The costs to the farms, the industry and ultimately society mentioned in these papers ranged from thousands to millions per year. The value of milk in 2019 was £ 4.43 billion, approximately 30% of the total livestock output in the UK in 2019, whereas cattle meat was £ 2.8 billion (approx. 19%) and sheep meat £ 1.3 billion (approx. 9%) (Defra, 2020b). This monetary aspect may be the reason why the dairy cow production system has had more research publications compared to the beef and sheep sub-sectors.

The use of multiple methods and input/calculated variables to measure disease and economic impact provides an obstacle for comparison even if the same disease is considered. Consequently, traditional meta-analysis could not be carried out. The impact documented by animal or by sub-sector, may suggest there are potential large avoidable losses currently present and could be improved upon for a more sustainable and efficient system. In addition, no paper discussed the differences, or the importance, of acknowledging different enterprise levels, e.g. finisher, lowland, and that impacts could be different within species and farms at this level.

A total of twenty-seven diseases were mentioned in the papers selected for this review, but all 38 papers in this systematic review only discussed the impact of one disease at a time and the possible impact this may have on, for example, farm management decisions regarding expenditure on improved housing. However, often farms will be burdened with, or susceptible to, more than one endemic disease at one time point (Carslake et al., 2011), therefore confounding effects should be considered as some impacts, such as reduced productivity, could also be affected by another disease. Therefore, there could be over estimation of impacts per disease if the whole disease burden is not considered (Rushton et al., 2021). Similarly, the identification of management practices that would be of increased benefit for many diseases may be missed. However, for this to occur efficiently there is a need for more empirical data and either a standard approach to measuring impact, i.e. which variables to include (to allow easier comparisons), or greater transparency and agreement of what to include. Systematic production animal health recording along with, at least, nationally accepted metrics and calculations at societal level would simplify and allow comparisons and disease burden calculations.

A harmonised approach for the burden of livestock disease would ideally also include impacts in other sectors. Many different methods were adopted to measure the economic impact of the disease in the papers of this review, as were many different levels of reporting. However, the majority of papers identified through this review focussed on the direct animal/producer perspective effects and impacts, and excluded other wider implications. Although what should also be noted is that this systematic literature review only focussed on endemic diseases and the UK, which may mean economic methods that consider wider effects may have been missed if they used a case study on a disease that is not classed as endemic in the UK. With review searches there is always a risk and limitation that the search term used excludes certain results and that a gap occurs in information identified in the final search. However, with the search terms included in this review we expect that any form of impact would come up, e.g., public health, environmental health, animal health. Impact is a broad term and there are frameworks for impact assessments in all fields. Furthermore, the variables included in the calculations convened around human reaction (expenditures) and animal loss impacts (mostly visible) with only two papers estimating or considering environmental implications (MacLeod and Moran, 2017; Shrestha et al., 2020). Endemic diseases impact across the non-human animal, animal and environment systems, this is often in "invisible" or indirect, e.g. reducing animal and human productivity (Charlier et al., 2020; Cohen et al., 1983), influencing GHG emissions (MacLeod and Moran, 2017) and affecting commodity price (Barratt et al., 2018; Weldegebriel et al., 2009). However, as highlighted by this systematic review the inclusion of animal health data in economic calculations of wider implications (e.g. more than just direct output and input farm costs) appears to be uncommon and generally lacking. Due to the profound interconnectedness of our food systems and their connections to the environment, it is vital to take wider implications into consideration when developing interventions to prevent unintended consequences. Having a more complete picture of the impacts of disease and their contribution to economic burden across the different interconnecting systems (human, environment and non-human animals) is necessary to support decision-making (Barratt et al., 2018). Therefore, linking animal disease data to already developed and validated impact modelling, as well as integrating them into future calculations could provide useful insights. For example, integrating animal health data with livestock emission modelling data (MacLeod and Moran, 2017), or land use modelling to understand the impact of disease on herd/flock dynamics and farm management coping methods on the environment.

In addition, if true cost of diseases are calculated then it is possible that the investment case for disease control shifts as well, as the net cost of mitigation may well be matched by previously excluded or non-priced benefits (Häsler, 2011). Endemic diseases are a constant pressure, therefore understanding which disease, where and when impacts occur across the systems will provide an idea of the magnitude of the problem.

5. Conclusion

As it is becoming increasingly likely that the way the UK farms livestock and the used land is managed will change and society moves to identify more sustainable practices, it is important to incorporate fully the impact of livestock disease in decision making. The range in costs of the diseases captured in this review demonstrate that there is still work to be done to reduce avoidable costs of endemic diseases on cattle and sheep farms in the UK. This review highlighted that few externalities are captured in economic calculations of livestock diseases thereby underestimating the societal impact. Wider implications need to be included in these calculations to ensure that allocations of scare resources, be that at farm or national level, are undertaken with the most informed decisions. Disease interactions also need to be considered to ensure that overestimations are not occurring, and to identify efficient practices that reduce impact of multiple diseases simultaneously.

Funding and declaration of interests

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Declarations of interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2022.105756.

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