Oxford Analytica
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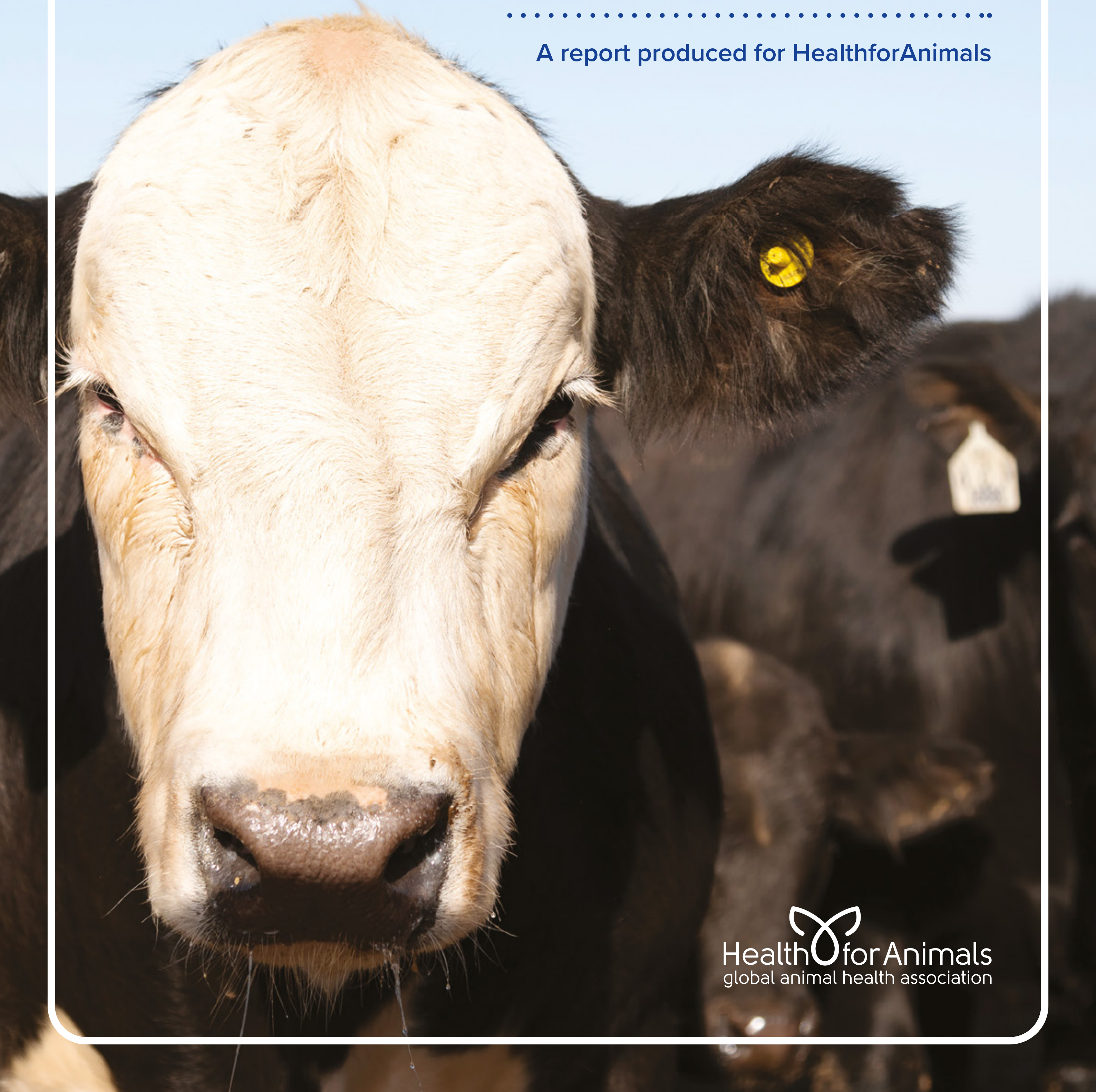
Animal health and Sustainability:

A Global Data Analysis

A report produced for HealthforAnimals



HealthforAnimals
global animal health association

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Acknowledgements

Review Board

As part of developing this report, Oxford Analytica and HealthforAnimals assembled a three-person 'Review Board' to provide input to and feedback on this report. Participants offered significant and diverse expertise that helped strengthen the findings and analysis. Review Board members included:

- Dr Jonathan Rushton, Professor of Animal Health and Food Systems Economics, University of Liverpool, Director of the Global Burden of Animal Diseases programme (https://animalhealthmetrics.org);
- Dr Ulf Emanuelson, Professor in Veterinary Epidemiology, Swedish University of Agricultural Sciences; and
- Dr Greg Thoma, Director of Agricultural Modelling and Lifecycle Assessment, Colorado State University.

Oxford Analytica and HealthforAnimals thank Review Board Members for their participation.

As a leading independent research and analysis firm, Oxford Analytica was asked to conduct independent research and original data modelling on the link between animal health and economic, environmental and social sustainability. The firm's work centred on establishing a set of independent, robust and compelling insights that would contribute to global knowledge in this area. Oxford Analytica consulted leading experts and animal health professionals in developing this project, and thanks them for their time and input.

Interpreting report results

The results presented in this report are the outputs of Oxford Analytica's unique model measuring the effects of different animal health indicators. Below are notes that readers should keep in mind in order properly to review, interpret and apply the results.

- **Regression Modelling:** Oxford Analytica relied upon regression modelling to measure the impact of animal disease on various indicators, which provides valuable data estimates. However, these are estimates and should not be considered a definitive measurement of real-world impacts. For example, when the model measures the impact of an 'additional case of disease' in a certain species, this indicates an estimated, average effect at the national level -- not what one would expect from every instance of disease.

  Generally, the value of regression modelling is its ability to identify statistically significant data correlations that indicate clear associations. These do not prove causation, but they do allow a reader to consider the nature of the relationship.

- **Data Limitations:** The primary data sources for this report were the United Nations' Food and Agriculture Organizations' FAOSTAT and the World Organisation for Animal Health's WAHIS Portal. Both are world-leading databases with robust data on animal disease, productivity, environment, and the like. However, gaps do exist. For instance, WAHIS addresses notifiable diseases, which means certain endemic diseases such as mastitis are not reflected in the model, or underlying disease counts could be incomplete if country-level reporting is not exhaustive. Oxford Analytica's model relies upon WAHIS and FAOSTAT as these are widely recognised as the most robust global disease data currently available. However, potential gaps may mean some findings are directionally correct, but the final magnitudes could change if more granular data were available. Looking ahead, projects such as the Global Burden of Animal Disease (GBAD) may offer opportunities for others to build upon the Oxford Analytica model to create more granular insights.

- **'Disease' Definition:** Oxford Analytica aggregated data on the impacts of livestock disease when developing regression models. This approach avoided limitations and/or gaps in the data for specific diseases (e.g. data only being available in a subset of countries) and provided results that outline the 'average' impact of disease in a species. Therefore, results should be interpreted as a general indicator and the exact impact of a given disease in a real-world scenario will, of course, vary depending upon the specific illness, virulence and related factors.

- **Impact of a 'case of disease':** The regression model measures the impact of disease by quantifying the marginal impact of a single additional case of disease on productivity, emissions and the like within a livestock species. This impact accounts for the primary impact on the animal, but also the secondary impacts such as disease spread to other animals. Therefore, readers should not view data on the impact of a 'single case of disease' solely in the context of the individual animal.

- **'Vaccination' Definition:** The Oxford Analytica regression model used aggregated vaccination data to measure its effects. As with disease, this approach avoided limitations and/or gaps in data for specific disease (e.g. data only being available in a subset of countries) and provided results that outline the average impact of 'vaccination' on a species. Therefore, results should be interpreted as a general indicator and the exact impact of vaccination in a real-world scenario will vary depending upon the disease type, disease strain, efficacy of the vaccination, and so on.
- **Impact of Vaccination:** The regression modelling measures the impact of vaccination upon a host of indicators. It is important to note that increases in vaccination are often accompanied by other investments in veterinary care (eg., better husbandry practices). Therefore, the associative relationships identified for vaccination in this report can be interpreted as reflecting the impact of increased investment in overall veterinary care and advanced animal husbandry practices.
- **Disease Levels & Vaccination Rate:** At times, data in this report evaluates the impact of a certain level of disease or vaccination rate. These findings measure the effect compared to a base level of 0%. For example, when the report measures the impact of a 60% vaccination rate in a given year for beef cattle, the subsequent percentage increase in productivity levels is in comparison to expected production with a 0% vaccination rate.
- **Case Studies:** Oxford Analytica has offered a series of case studies in this report. These calculations are outside the regression modeling and rely upon combining existing literature and extrapolating results to generate new data. These case studies should not be viewed as a product of the regression models.

Oxford Analytica views the research presented here as a useful contribution to global knowledge on animal health and its effects on the environment, economies and society, while recognising that there will be significant opportunities for others to build upon it in the future. Increasingly robust data from sources such as WAHIS, FAOSTAT and the Global Burden of Animal Disease programme will enable researchers to overcome some of the data gaps / limitations in this project and provide more granular results. This report strives to explain the methodology and processes behind calculations in full so that others may leverage this approach in their work.

Executive summary

The objective of this report is to develop a broader understanding of the relationship between animal health and the economy, environment, and society. The report was produced by Oxford Analytica -- a non-partisan international risk consultancy -- for HealthforAnimals. The report leverages a combination of Oxford Analytica research and original data modelling, as well as input from subject matter experts including leading academics in relevant fields and animal health professionals.

The data used in this report are primarily drawn from the United Nations Food and Agriculture Organization's FAOSTAT and from the World Organisation for Animal Health's WAHIS platform. Using these datasets, Oxford Analytica created a model to evaluate numerous independent and control variables using robust multiple regression analyses. This included variables such as vaccination, cases of disease and production levels within livestock species, and were selected based on the availability and reliability of data. A full list can be found in the 'Data sources' section towards the end of this report. This approach identified associative relationships between variables that indicate when one may be affecting another. For instance, an associative relationship between increased levels of livestock disease and reduced production can suggest that disease reduces livestock productivity.

Economic sustainability

The research on economic sustainability centres on the effects of diseases and vaccination on four types of national meat production -- cattle, poultry, pigs, and sheep -- and egg and milk production. Oxford Analytica's analysis and modeling found that animal disease is associated with significant reductions in global livestock productivity each year, particularly in developing regions where protections against disease may be minimal. Implementation of preventative measures such as vaccination or deworming potentially offers greater productivity levels, which leads to higher farm incomes and more food availability for consumers. Subsequent application of the technical findings provides compelling insights.

Animal disease is associated with significant reductions in global livestock productivity.

Oxford Analytica modelling estimated that in one year (2018):

- Global poultry production was likely reduced by 2.8 million tonnes due to disease, which, based on per capita poultry consumption of 15.8 kilograms (kg), could have met the consumption needs of up to 180 million people for an entire year.
- In low-income countries, poultry production levels were likely reduced by up to 22% due to disease.
- Global egg production was likely reduced by 3.0 million tonnes by disease, which from a revenue perspective equated to a loss of $5.6 billion USD. That figure is the equivalent of wiping out the United Kingdom's £1.2-billion GBP egg market nearly four times over.

A case study analysis of Kenya determined that improved deworming practices in dairy cattle could increase farm revenue by up to $1,248 USD -- a significant increase in a country where gross domestic product (GDP) per capita is $2,006 USD -- and reduce GHG emissions by up to 7.8 billion kgCO2eq, or 'kilograms of carbon dioxide (CO2) equivalent'. This is equal to the CO2 output of 90% of Kenya's registered vehicles.

When modelling the average effect of vaccination in any given year, Oxford Analytica's research found that:

In upper-middle income countries, a 60% vaccination rate for beef cattle is correlated with a 34.7% rise in production.

- A 60% global vaccination rate for beef cattle is associated with a 52.6% rise in production. Based on global productivity levels, this rise is equivalent to the beef consumption needs of 3.1 billion people.
- In upper-middle income countries (eg., Argentina, Brazil), a 60% vaccination rate for beef cattle is associated with a 34.7% rise in production. Based on global productivity levels, this rise is equivalent to the beef consumption needs of 900 million people.

Moreover, in key markets the modelling found that:

In Brazil, every 1% increase in beef cattle vaccination correlates with a 0.7% increase in production.

- In Brazil, one of the world's largest beef producers, every 1% increase in beef cattle vaccination correlates with a 0.7% increase in production. Based on Brazilian production levels, this is equivalent to a 70,000-tonne increase.
- In Argentina, another major beef producer, an 80% vaccination rate for beef cattle in a given year is associated with a 43.8% rise in production over the baseline expected without vaccination. Based on production and price levels, this enhances sector revenue by $3 billion USD or $23,000 USD per farm (130,800 farms according to the national census).

As noted in the 'Interpreting report results' section above, increases in vaccination are typically accompanied by other investments in veterinary care and the adoption of advanced husbandry practices. Therefore, production increases correlated with vaccination are likely the result of an overall improvement in animal care.

Environmental sustainability and animal health

The research on environmental sustainability and animal health focuses on the impacts of disease and vaccination on the environmental footprint of four types of national meat production -- cattle, poultry, pigs, and sheep -- and on egg and milk production. Oxford Analytica's analysis found that animal disease is associated with significant increases in livestock GHG emissions and land use, while vaccination adoption is correlated with reductions in both.

Key results from the regression modelling on GHG emissions included:

- A 10-percentage point decrease (e.g. 20% to 10%) in global livestock disease levels in a given year is associated with an 800 million tonne decrease in livestock GHG emissions. This is equivalent to the average annual GHG footprint of 117 million Europeans.

- The effect of disease on GHG emissions is most pronounced in low-income countries. For instance, an outbreak of cattle disease affecting 20% of a herd is associated with an estimated 60% increase in GHG emissions in low-income countries compared to 42% in high-income countries.

When analysing land use, Oxford Analytica modelling found significant associative relationships with vaccination such as:

- A 40% global vaccination rate for cattle in a given year is associated with a 5.2% reduction in land required for livestock production.
- In specific countries this relationship can be more pronounced. For example, a 40% vaccination rate for Brazilian livestock is associated with a 12.8% reduction in livestock land use.

Modelling results also found strong associations between land use and disease, for example:

- When 20% of poultry globally are affected by disease each year, 8.6% more land is estimated to be necessary to maintain expected production levels.
- In the United States, if 30% of beef cattle nationally are affected by disease in a given year, the modelling estimates that 2.3% more land would be needed to maintain expected production levels.

Finally, a case study analysis of United Nations data found that scaling up existing practices in animal health and husbandry means livestock could serve a world population of over 9 billion in 2050 while holding emissions to current levels. The 'Case study: Sustainable cattle practices and reducing global greenhouse gas emissions' on page 42 provides a detailed calculation.

Scaling up existing practices in animal health and husbandry means livestock could serve a world population of over 9 billion in 2050.

Social sustainability and animal health

Oxford Analytica's data analysis of the relationship between social sustainability and animal health demonstrated clear correlations between animal disease and vaccination, on one hand, and levels of undernourishment and food insecurity, on the other. The modelling found that higher rates of disease among livestock are associated with higher levels of undernourishment and food insecurity among the world's population, while vaccination among livestock is associated with lower levels of undernourishment and food insecurity.

For instance, Oxford Analytica's model found when analysing national beef and dairy cattle herds, that each additional cattle vaccinated in a given year is correlated with a decline of 0.674 in the number of undernourished people nationally. This suggests that:

- At a global level, on average, every two cattle vaccinated is associated with one person avoiding hunger.

Note: As explained in the 'Interpreting report results' section, vaccination is typically accompanied by other livestock health investments, which is likely helping drive this significant result.

Other findings from Oxford Analytica's social calculations include:

- Poultry disease was associated with a 2.0% increase in global hunger in 2018 and 5.0% in 2019. This is equivalent to global hunger increasing by 13.6 million people in 2018 and 34.39 million in 2019.
- At a national level, the level of disease among poultry was associated with a 5.9% increase in the number of undernourished people in Vietnam.
- In Nigeria, where an estimated 29 million out of a population of 206 million people in 2018 were classified as being in severe food insecurity, the modelling suggests that achieving a country level vaccination rate of 40% for cattle in a given year is associated with an 8.1% reduction in severe food insecurity. In other words, this is associated with 2.4 million people who would be lifted out of severe food insecurity.

Finally, an Oxford Analytica case study analysis found livestock disease reduces global production by an equivalent of 80 billion kg of meat and 180 billion kg of dairy, enough to meet the dietary needs of 1.6 and 2.0 billion people, respectively. These losses translate to a combined annual revenue loss of $358 billion USD for meat and dairy producers. These findings are based on WOAH's estimate that 20% of livestock production is lost to disease each year.

If this 20% disease rate could be reduced, Oxford Analytica's analysis found:

- Every 1 percentage point reduction in beef cattle disease rates would increase production enough to meet the average annual consumption needs of 317 million people and increase producer revenue by 3.2 billion USD.
- Every 1 percentage point reduction in dairy cattle disease rates would increase production enough to meet the average dairy needs of 80 million people and increase producer revenue by almost $4 billion USD.

1. Research overview and methodology

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Overview of research

Most findings about the relationship between animal health -- specifically disease and vaccination -- and the economic, environmental and social benefits are anecdotal or specific to a particular country and issue.

Using a variety of data techniques, the objective of this report is therefore to develop a broader understanding of the relationship between animal health and the economy, environment and society at global level. The aim is then to translate these findings in a way that is easily understood in terms of impacts on meat and egg production, GHG emissions, land use and consumption.

Data sources and characteristics

The primary data used in this project are drawn from the FAOSTAT database and the WAHIS platform -- WAHIS stands for 'World Animal Health Information System'. The World Organisation for Animal Health was formerly known as the Office International des Epizooties, or 'OIE', but in this report the organisation is referred to by the acronym of its current name, 'WOAH', as noted above.

Data from WOAH is available for both semesters of every year for most countries and is at either the subnational or national level, depending on the country. FAO data, in contrast, is almost exclusively available at the annual and country level.[1] To merge the desired variables from the WOAH and FAO datasets, all data was summed to the national level. WOAH variables were kept at the semester level, with annual data from FAO-sourced variables imputed to both semesters in a year.

The resultant dataset produced for this report contains data for 180 countries, 18 years (2005-22), and 35 semesters (the 'missing' semester being the second half of 2022).

Methodology

Regression analysis

The regression results detailed in this report were obtained using robust multiple regression analysis. Multiple independent and control variables were included in each regression model to identify as accurately as possible the relationships between the independent and dependent variables of interest, by holding constant the values of other variables that also affect the dependent variable. For example, the regression model used to assess the impact of vaccination and cases of any disease on national cattle meat production controls for the impact of -- in other words, holds constant the values of -- the carcass weight of cattle, the price of cattle meat, the number of cows, the number of cases of other diseases among cattle, and the number of cattle culled due to disease in a country in a given semester.[2]

1 The one exception among the variables included in this report's dataset was data on the price of cattle, pig and sheep meat, as well as eggs, which was available for every month of the year. Since other FAO variables were only available at the annual level, however, this report relies on annualised price data that the FAO also offers.

2 Most of these control variables only have annual data, so their values are the same in both semesters each year, but different across years.

The report relies on robust regression models due to the large number of outliers in the FAO and WOAH datasets -- robust regression models are better suited than ordinary-least-squares (OLS) regression models when working with data that contain many outliers, because outliers distort parameter estimates in OLS regression models. Robust regression models, on the other hand, iteratively identify outliers and minimise their impact on parameter estimates. Specifically, this report relies on robust regressions with maximum-likelihood estimators, or 'M-estimators'.

Country and time-fixed effects are included in every model. Specifically, the time-fixed effects are at the semester level, and therefore control for variables that are constant across countries but vary by semester. Semester-level rather than annual-level time-fixed effects are chosen in order to capture the potential impact of seasonality on the independent and dependent variables of interest. For example, it is possible that disease cases are consistently higher for a same country and species in the winter than in the summer, because of the climate.

Lagging variables

To account for the delayed impact on meat and egg production of disease outbreaks and disease control measures such as vaccination, this report has 'lagged' the independent variables by two years for cattle meat production and by one year for poultry, pig and sheep meat production, and egg production. In other words, cattle meat production is regressed on data for the independent and control variables of interest from two years earlier, whereas egg production and meat production for other species are regressed on data for the variables of interest from one year earlier.

This reflects the fact that the economic impact of disease will not be visible until the end of a production cycle. For instance, beef cattle require approximately two years to be raised to reach the necessary weight for them to be slaughtered for meat. Therefore, if 30% of a herd is lost to illness early in life, the economic impact will not be seen until the remainder of that herd is raised and brought to market. Cattle meat production cycles are longer than those of eggs and other kinds of meat, hence the independent variables for cattle meat production are lagged by two years instead of one.

None of the independent variables in the report's environmental and social sustainability chapters were lagged, however. This is because, according to the research conducted in the preparation of this report, disease outbreaks and disease control measures have a more immediate impact on variables such as GHG emissions and the number of undernourished people in a country than on meat and egg production.

Missing data

Many variables sourced from the FAO contain missing data for a number of species-country-year combinations (for example, cattle in Spain in 2020).[3] Missing data was handled through pairwise deletion, which consists in only deleting rows (that is,

3 Years are referred to here instead of semesters because every variable sourced from the FAO has annual data instead of data by semester.

species-country-year combinations) in the dataset that contain missing values for one or more of the variables used in a specific regression model. Pairwise deletion -- as opposed to listwise deletion, whereby rows containing missing data for any variable in the dataset are removed -- retains as much of the data that is relevant to a regression model as possible.

Taking the example of the regression model produced for the impact of vaccination and disease cases on national cattle meat production, pairwise deletion entails deleting rows in the dataset that contain missing data for one or more of the following variables: number of animals vaccinated; number of animals infected with a disease; the carcass weight of cattle; the price of cattle meat; the number of cows; the number of cases of other diseases among cattle; and the number of cattle culled in a country in a given semester.

In the exceptional cases where data was missing in every row of the dataset for a variable that was supposed to be included in a regression model, this variable was excluded from the model. Thus, in contrast to the models for cattle, pig, and sheep meat production, the model for poultry meat production does not include data on the price of poultry meat, as this data is not available from the FAO.

Disease clusters

Each regression model includes as a control variable for each species the number of cases of other diseases in the same semester and country. Due to the large number of diseases in the dataset that underpins this report (98), controlling for the number of cases of each disease was impractical. Thus, to preserve some degree of granularity, this report groups diseases into three categories and controls for the number of cases of diseases in each category.

The categories of diseases were determined via ‘K-Means clustering’ -- an unsupervised machine learning algorithm which splits data into ‘k’ separate groups. This report provides the clustering algorithm with the morbidity and mortality rates of each disease in a semester and country.[4] Data points (that is, incidences of disease in a semester and country) are then allocated by the algorithm to one of k groups, based on how similar their morbidity and mortality risks are to diseases in each of the k groups. The number (k) of groups is manually set before the algorithm splits the data, and the algorithm then provides a score between -1 and 1 -- known as the ‘silhouette coefficient’ -- indicating how distinct the k groups are to one another, where 1 represents a perfect separation of the data.[5]

After experimenting with different numbers of groups, the decision was taken to split the data into three groups, as this maximised the silhouette coefficient (0.83). The three groups correspond to:

4 The nominators of the morbidity and mortality risks are the number of cases and deaths reported to WOAH for each disease, respectively. The denominator for each risk is the number of animals susceptible to each disease as reported to WOAH.

5 Selecting the number of clusters with silhouette analysis on K-Means clustering, Scikit learn. The formula used to calculate the silhouette coefficient is $\frac{b-a}{\max(a,b)}$, where a represents the average distance between each point within a cluster, and b represents the average distance between all clusters.

- Diseases with low morbidity and low mortality risks. This group contains 25,029 observations. The average morbidity and mortality risks of diseases in this group are 8.8% and 2.4%, respectively.
- Diseases with high morbidity and low mortality risks. This group contains 9,377 observations. The average morbidity and mortality risks of diseases in this group are 96.64% and 3.6%, respectively.
- Diseases with high morbidity and high mortality risks. This group contains 2,575 observations. The average morbidity and mortality risks of diseases in this group are 94.9% and 86.4%, respectively.

Multicollinearity

Every regression model was tested for multicollinearity, which is when independent variables in a model are correlated with each other. Multicollinearity needs to be avoided in order to obtain an accurate estimate of the parameter, or coefficient, which describes the relationship between dependent and independent variables.

Models were tested for multicollinearity using the Variance Inflation Factors (VIF) test. This test assigns a value to each independent variable based on how correlated it is to other variables in the model, with higher values denoting a higher degree of correlation. VIF values between 1 and 5 suggest only a moderate degree of correlation, whereas values higher than 5 signal a high level of multicollinearity.

In cases where the VIF value of an independent variable was higher than 5, the variable was removed from the model. If the VIF value of a control variable was higher than 5, however, it was retained. This is because multicollinearity only affects the coefficients of variables that are highly correlated -- that is, that have VIFs higher than 5 -- but not those of other, non-correlated variables. Since this report is only interested in discerning the impact of vaccination and disease cases on a range of dependent variables, it only removed variables when these were correlated with either vaccination or disease cases and would thus otherwise obfuscate their coefficients.

Model selection

The regression models included in this report pass three tests: first, at least one of the independent variables of interest (that is, number of animals vaccinated or number of cases of any disease) is statistically significant; second, the models residuals are normally distributed; third, the models have a low residual standard error (RSE).

The RSE measures the standard deviation of the residuals (that is, the differences between a model's estimates and the data used to train the model) in a regression model. The smaller the RSE, the better the model fits the data.

Choosing any threshold of RSE above or below which a model is considered inaccurate or accurate, respectively, is arbitrary. However, it is necessary to filter out models that are obviously inaccurate -- in other words, those that have a large RSE. The decision was therefore taken to exclude from this report and its underlying analysis the cases where the RSE is equivalent to 20% or more of the mean of the dependent variable used in the model.

Scenarios

This report uses scenario analysis to support the practical interpretation of the regression findings. For example, for sheep, where the model found a statistically significant coefficient for upper-middle income countries, this report's findings indicate that each additional case of any disease is associated with a decline of 0.265 tonnes in sheep meat production one year after the onset of disease.

To understand the meaning of this finding, based on FAO data, it is possible to assess the extent to which different rates of disease might affect production using data on national herd size (count), reported production (tonnes), meat yield per animal (hectogram, Hg per animal) and producer price (USD per tonne). This information provides everything that is required to estimate how many animals would be affected given a specified rate of disease among the national herd (eg., 5%, 10%, 20%, and so on), and in turn, what this would mean in terms of lost meat production in absolute and percentage terms. Given known animals yields and producer prices by year and country, lost production can then be expressed in terms of equivalent number of animals and value of lost production, or revenue impact.

Using the identified coefficient, the scenario analysis throughout this report leverages FAO data and simple algebra to generate practical examples of the underlying regression-based findings.

Limitations

A number of limitations regarding the quality and availability of data on animal health and diseases should be kept in mind when interpreting this report's research findings.

With regards to the availability of data, it was not possible to find data for some variables that are important in assessing the impact of diseases and disease control measures on indicators such as national meat production, GHG emissions from the agricultural sector, and the number of undernourished people in a country.

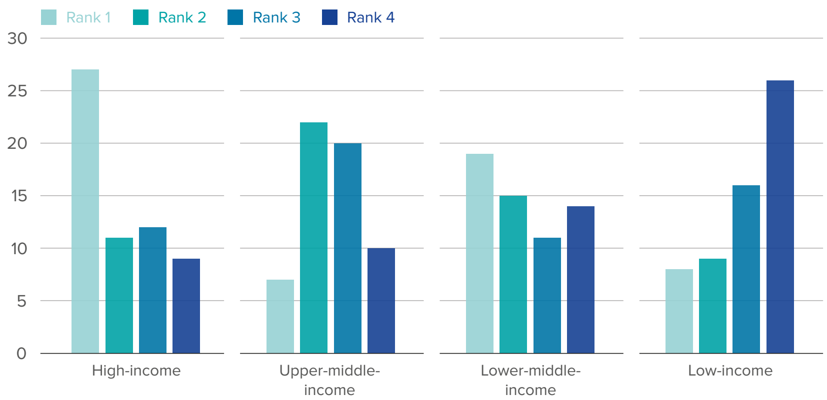
First, there was no publicly available data identified on the extent to which disease control measures other than vaccination were implemented in each country. WOAH only provides data on the number of animals that have been vaccinated against and culled due to certain diseases. The report controls for the number of animals culled in each country and semester when assessing the impact of vaccination on the dependent variables of interest, but it was not possible to control for the presence of other disease control measures that may have been implemented simultaneously. The impact of vaccination, therefore, should likely be interpreted as a proxy for investments in animal care and disease prevention more generally.

Second, publicly available data on the age at which animals became infected by, or died from, a disease could not be identified. WOAH only provides data on the number of animals that were infected by, or that died from, a disease. The age at which animals became infected or died is relevant to assessing the impact of disease cases and vaccination on indicators such as national meat production. The death of a fully grown cow, for instance, will cause a larger drop in a country's meat production than the death of a calf.

Third, given reliance on data from WOAH, this study focuses on the impact of transboundary, notifiable diseases. Table 1 below highlights the top five diseases per species considered in this study according to data from WOAH on numbers of cases. These listings may not correspond to the actual top five diseases per species when non-transboundary diseases are included.

As for the quality of the data, this report identified signs in the data sourced from WOAH that suggest that certain countries, especially low-income countries, systematically under-report numbers of cases of disease.[6] This under-reporting reduces the accuracy of estimates from regression models that include data from countries prone to under-reporting.

Figure 1. Number of diseases that each income group ranks first, second, third or fourth for by morbidity risk.



Source: Oxford Analytica

Figures 1 shows how many times each income group was ranked as the group with the highest, second highest, third highest or, fourth highest morbidity risk of a disease.[7] According to Figure 1, the group of low-income countries was ranked as the group with the lowest morbidity risk many more times than any other income group. Conversely, the group of high-income countries, which is likely to report more accurate data on cases of disease to WOAH, was ranked as the group with the highest morbidity risk many more times than any other income group.

This report tries to remedy this issue by, in the report's preparation, performing separate regressions on data from each income group, in addition to the regressions on data from all countries. This should mean that estimates from models that only include high-income or upper-middle-income countries, for example, are less vulnerable to biases induced by under-reporting of cases.

6 This report classifies every country into one of four groups based on its national income: high income, upper middle income, lower middle income, or low income. The thresholds of each category are based on the World Bank's income group classification in the relevant year.

7 Figure 1 shows this ranking for diseases that have data on cases for each of the four income groups.

Many countries may also under-report how many animals have been vaccinated against a disease. WOAH only provides data on the number of animals vaccinated by public authorities and does not include data on the number of animals vaccinated by private providers. In high-income countries in particular, where most animals are vaccinated under such private schemes, this will also bias estimates of the relationships between vaccination and the dependent variables of interest in this report.

Besides under-reporting of cases and vaccination data, there are also instances where WOAH's reporting guidelines have clearly not been followed by some countries. WOAH asks countries to report, for cases, the sum of the number of infected animals and animals that have died from a disease, and for deaths the number of animals that have died from a disease.[8] This means that the number of cases of a disease should always be higher than the number of deaths, and that one should therefore be able to obtain the number of animals that have been infected by a disease by subtracting the number of deaths from the number of cases. However, there are hundreds of rows (that is, species-country-semester combinations) in the WOAH dataset where the number of deaths is higher than the number of cases.

This report's approach was permanently to remove from the underlying datasets all rows where the number of deaths was higher than the number of cases, and to assume that, for the remaining rows, WOAH's guidelines had been followed. This is a contestable assumption, but one that retains as much data as possible for the regression models constructed in the preparation of this report.

Two more points are worth noting when interpreting the results of the regression models. First, the results aggregate the impact of all notifiable diseases for that species, which provides a general indicator of the overall impact of 'disease'. These figures would certainly vary depending upon the exact disease and virulence.

Second, in the case of the regression models for egg production and cattle, poultry, pig and sheep meat production, the results are measuring the impact of cases on overall production, not the cost of production, so they should not simply be compared to the average weight of a single species. In other words, this report's hypothesis is that the results account for the secondary impacts of disease in terms of contagion risks to other animals, lasting effects on animal productivity and yield, and so on.

8 GUIDELINES – Immediate notification and follow-up reports of a disease, an infection, an infestation or any other significant epidemiological event – Terrestrial Animals, 2014, p.15

2. Economic sustainability

HealthforAnimals
global animal health association

Animal agriculture is a pillar of the global food system -- meat, dairy and eggs provide 18% of the world's calories and 39% of protein, alongside important micronutrients for development.[9] Moreover, animal-derived products are a significantly valuable segment of the agricultural sector, constituting 40% of agriculture output in developed markets and 20% in developing markets, while employing at least 1.3 billion people worldwide.[10] However, the growing risk of animal disease, driven by critical contemporary issues such as climate change, is putting increasing pressure on the livestock sector.

This chapter focuses on the impacts of diseases and vaccination on four types of national meat production -- cattle, poultry, pigs and sheep -- and on egg and milk production. These aspects were chosen because of the availability and reliability of the data, compared with other metrics such as producer prices.

The chapter begins with an analysis of the impact of disease on meat and egg production before moving to assess the benefits of disease control measures, using scenario analysis informed by the findings of our regression analysis.
At the end of this chapter a case study is provided, to illustrate the benefits of effective animal husbandry on economic outcomes. This case study focuses on the benefits of cattle deworming in Kenya.

Overview of key findings

Animal disease significantly reduces global productivity of livestock farming each year.

The analysis found animal disease significantly reduces global productivity of livestock farming each year, particularly in developing regions where protections against disease may be minimal. Implementation of preventative measures such as vaccination or deworming offers greater productivity levels. This leads to higher farm incomes and more food availability for consumers.

Some of the key supporting findings from the present analysis include:

- *In one year (2018), disease in poultry was associated with a 2.8 million tonne reduction in global poultry production compared to expected outputs without disease impacts. Based on global per capita poultry consumption of 15.8 kg, this could meet the poultry meat needs of 180 million people for an entire year. In low-income countries, production levels in 2018 were reduced by up to 22%.*
- *Globally, when 60% of the world's beef cattle are vaccinated in a given year, the model found that this was associated with a 52.6% increase in beef production. This increase is equivalent to addressing the beef consumption needs of 3.1 billion people, just under 40% of the world's population.*
- *In 2018, disease was associated with a 3.0-million-tonne reduction in global egg production, which cost producers $5.6 billion USD in revenue. That is the equivalent to roughly four times the United Kingdom's £1.2 billion GBP egg market.*[11]

In 2018, disease was associated with a 3.0-million-tonne reduction in global egg production, which cost producers $5.6 billion USD in revenue. That is the equivalent to roughly four times the United Kingdom's £1.2 billion GBP egg market.

9 UNFAO, https://www.fao.org/3/i8384en/I8384EN.pdf
10 UNFAO, https://www.fao.org/news/story/en/item/1157729/icode/
11 https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/data

- *In upper-middle income countries (eg., Argentina and Brazil), this report estimates that a 60% vaccination rate for beef cattle in a given year is associated with a 34.7% increase in beef production when compared to expected productivity levels without vaccination. This is equivalent to an increase in production of 10.1 million tonnes -- enough to meet the needs of nearly 900 million people.*
- *In Brazil, this report estimates that a 1% increase in beef cattle vaccination is associated with a 0.7% rise in production, which is equivalent to a 70,000-tonne increase based on 2018 production levels. Meanwhile, in Argentina, when 80% of beef cattle are vaccinated in a given year, production increases by 43.8%, which is estimated is equivalent to an increase in sector revenue of $3 billion USD or $23,000 per farm USD.*
- *Based on the assessment of the benefits of deworming in Kenya (see the case study provided below), among an estimated 1.8 million smallholder farmers, it is estimated that effective deworming could equate to additional revenue of between of $434 USD and $1,248 USD per farmer -- and that is in a country with a GDP per capita of just $2,006 USD.*

Impact of disease on meat and egg production

Animals suffer from various diseases, some of which can be fatal. Yet those diseases that are not fatal are nonetheless still harmful to both animal welfare, productivity and farmer livelihood. For instance, a cow that is ill could be unable to produce its full yield of milk or might be rendered unsafe to harvest for meat for consumption. This results in constrained supply chains, potential shortages for consumers and, for the original cattle farmer, wasted investment and lost earnings. On the other hand, well-managed livestock can be expected to live longer, healthier lives, and thus be more productive and environmentally sustainable.

Innovation in areas such as veterinary care has proven successful in improving the survival rates of livestock, which improves farmer returns and reduces GHG emissions. For instance, vaccines offer a reliable way for farmers effectively to prevent disease in their animals, and the results below provide clear data indicating the economic returns this provides. These findings are corroborated by other sources such as the FAO, which estimates that "advanced genetics, feeding systems, animal health controls and other technologies over the past four decades allowed industrialized countries to reduce their overall land requirements for livestock by 20 percent while doubling meat production".[12]

"Advanced genetics, feeding systems, animal health controls and other technologies over the past four decades allowed industrialized countries to reduce their overall land requirements for livestock by 20 percent while doubling meat production" - UN Food and Agriculture Organisation

Disease rates and prevalence will vary widely across the globe. In many developed markets, damaging diseases such as Foot and Mouth have been effectively eliminated. However, they remain endemic in developing regions, or warmer climates that can allow a disease such as bluetongue to thrive.

As noted in the methodology chapter above, WOAH maintains the WAHIS database, where nations may provide reports on incidents of notifiable diseases. These are often diseases of consequence to trade and other global factors, where it is therefore important that countries exchange information.

12 UNFAO, https://www.fao.org/news/story/en/item/1157729/icode/

This report leveraged WAHIS data to analyse the burden of notifiable diseases upon nations and the subsequent impact on economic indicators. The results are only a fraction of the total burden of disease, particularly as there are diseases that can have significant economic impacts that are not notifiable, such as mastitis in cattle.

However, the results nonetheless provide a valuable indication of how the burden of disease disproportionately applies across regions and of where opportunities exist to reduce disease levels. Doing this can significantly improve farmers' livelihoods and help achieve key Sustainable Development Goals (SDGs). Table 1 outlines the most common diseases reported by WOAH Member Countries to WAHIS. Note -- these are provided as 'common' examples; Oxford Analytica's modelling reflects the full array of diseases in the WAHIS platform.

Table 1. Five most common diseases by species included in the WAHIS database (2018-22)

To see the full list of diseases in the WAHIS platform visit woah.wahis.org

Species	Disease
Cattle	Echinococcus granulosus Foot and Mouth disease Brucella abortus Lumpy skin disease Mycobacterium tuberculosis complex
Poultry	High pathogenicity avian influenza Newcastle disease Avian infectious bronchitis Low pathogenic avian influenza Infectious bursal disease
Pigs	African swine fever Transmissible gastroenteritis Foot and Mouth disease Porcine reproductive and respiratory syndrome virus (PRRS), Swine Echinococcus granulosus
Sheep	Echinococcus granulosus Foot and Mouth disease Sheep pox Goat pox, Peste des petits ruminants Porcine cysticercosis

Regression analysis results

Note: *See the section on 'Interpreting report results' for additional context on how certain terminology are used in this report.*

Table 2. Economic Regression Analysis: Cattle Meat Production

Cattle meat production			
	All countries (1)	**High income (2)**	**Upper middle income (3)**
Vaccinated animals	0.040*** (0.027, 0.054)	0.022 (-0.123, 0.166)	0.032* (-0.0001, 0.064)
Infected animals	-0.113* (-0.230, 0.004)	-0.305*** (-0.436, -0.173)	-0.075 (-0.403, 0.254)
RSE as % of mean of dependent variable	3	1.6	4.4
Observations	4,776	1,131	1,923
Residual Std. Error	21,488.780 (df = 4681)	6,749.068 (df = 1077)	47,641.990 (df = 1866)

*Note: *p<0.1; **p<0.05; ***p<0.01*

The regression model for cattle meat production finds that, across all countries, an additional vaccinated cow is associated with an increase in national cattle meat production of 0.04 tonnes two years later, whereas an additional case of any disease in the national herd of cattle is associated with a decline in cattle meat production of 0.113 tonnes nationally two years later.[13];[14]

When only high-income countries are included in the model, it is found that an additional case of any disease in the national herd of cattle is associated with a decline in national cattle meat production of 0.305 tonnes two years later. The coefficient for the impact of vaccination in this group of countries is statistically insignificant.

When only upper middle-income countries are included in the model, it is found that an additional vaccinated cow is associated with an increase in national cattle meat production of 0.032 tonnes two years later. The coefficient for the impact of cases in this group of countries is statistically insignificant.

Table 3. Economic Regression Analysis: Poultry Meat Production

Poultry meat production			
	All countries (1)	**High income (2)**	**Upper middle income (3)**
Vaccinated animals	0.001 (-0.0003, 0.001)	-0.018 (-0.046, 0.010)	-0.001** (-0.001, -0.0002)
Infected animals	-0.112*** (-0.131, -0.094)	-0.089* (-0180, 0.002)	-0.058*** (-0.089, -0.027)
RSE as % of mean of dependent variable	4.7	6.4	2
Observations	4,807	1,013	1,520
Residual Std. Error	97,717.950 (df = 4647)	56,030.410 (df = 940)	88,018.140 (df = 1443)

*Note: *p<0.1; **p<0.05; ***p<0.01. Price control variable excluded due to insufficient data*

The model for poultry meat production finds that, across all countries, an additional case of any disease is associated with a decline of 0.112 tonnes in national poultry

13 Meat production here refers to total output and not output per animal (that is, productivity).

14 As noted in the 'Interpreting Report Results' section, this calculation and others here account for the primary impact and secondary impacts of disease (eg., spread to other animals).

meat production one year later. The coefficient for the impact of vaccination on poultry meat production across all countries is statistically insignificant.

When only high-income countries are included, it is found that an additional case of any disease is associated with a decline of 0.089 tonnes in national poultry meat production one year later. The coefficient for the impact of vaccination in this group is statistically insignificant.

When only upper middle-income countries are included, it is found that an additional case of any disease is associated with a decline of 0.058 tonnes in national poultry meat production one year later. The coefficient for the impact of vaccination in this group is statistically significant, but essentially equal to 0.

Table 4. Economic Regression Analysis: Poultry Meat Production

Poultry meat production		
	Lower middle income (1)	Low income (2)
Vaccinated animals	0.0001 (-0.0001, 0.0003)	-0.001** (-0.002, -0.0001)
Infected animals	-0.047*** (-0.055, -0.038)	-0.181*** (-0.247, -0.115)
RSE as % of mean of dependent variable	1.5	11.2
Observations	1,122	1,021
Residual Std. Error	31,422.240 (df = 1039)	23,841.950 (df = 948)

*Note: *p<0.1; **p<0.05; ***p<0.01. Price control variable excluded due to insufficient data*

When only lower middle-income countries are included, it is found that an additional case of any disease is associated with a decline of 0.047 tonnes in national poultry meat production one year later. The coefficient for the impact of vaccination in this group is statistically insignificant.

When only low-income countries are included, it is found that an additional case of any disease is associated with a decline of 0.181 tonnes in national poultry meat production one year later. The coefficient for the impact of vaccination in this group is statistically significant, but essentially equal to 0.

Table 5. Economic Regression Analysis: Pig Meat Production

Pig meat production		
	High income (1)	Low income (2)
Vaccinated animals	-0.230 (-0.791, 0.330)	0.083 (-0.155, 0.320)
Infected animals	-0.985*** (-1.537, -0.434)	-0.382*** (-0.490, -0.273)
RSE as % of mean of dependent variable	2.6	3.4
Observations	343	169
Residual Std. Error	41,679.160 (df= 290)	1,516.078 (df = 124)

*Note: *p<0.1; **p<0.05; ***p<0.01*

None of the estimates produced by Oxford Analytica's model on the impact of cases and vaccination on pig meat production when all countries are included were statistically significant.

When only high-income countries are included, it is found that an additional case of any disease in the national herd of pigs is associated with a 0.985 tonnes decline in national pig meat production one year later. The coefficient for the impact of vaccination in these countries is statistically insignificant.

When only low-income countries are included, it is found that an additional case of any disease in the national herd of pigs is associated with a 0.382 tonnes decline in national pig meat production one year later. The coefficient for the impact of vaccination in these countries is statistically insignificant.

Table 6. Economic Regression Analysis: Sheep Meat Production

Sheep meat production	
	Upper middle income
Vaccinated animals	-0.007 (-0.018, 0.003)
Infected animals	-0.265*** (-0.457, -0.073)
RSE as % of mean of dependent variable	4.7
Observations	679
Residual Std. Error	7,260.862 (df = 625)

*Note: *p<0.1; **p<0.05; ***p<0.01. Price control variable excluded due to insufficient data*

None of the estimates produced by our model on the impact of cases and vaccination on sheep meat production when all countries are included were statistically significant.

When only upper middle-income countries are included, it is found that an additional case of any disease in the national herd of sheep is associated with a 0.265 tonnes decline in national sheep meat production one year later. The coefficient for the impact of vaccination in these countries is statistically insignificant.

Table 7. Economic Regression Analysis: Egg Production

Egg production			
	All countries (1)	Upper middle income (2)	Low income (3)
Vaccinated animals	0.00005 (-0.0001, 0.0002)	-0.0002 (-0.001, 0.0002)	-0.001*** (-0.001, -0.0003)
Infected animals	-0.124*** (-0.131, -0.117)	-0.039*** (-0.063, -0.015)	-0.092*** (-0.116, -0.068)
RSE as % of mean of dependent variable	1.4	1.6	6.9
Observations	4,807	1,520	1,021
Residual Std. Error	32,622.110 (df = 4648)	74,517.940 (df = 1444)	8,947.901 (df = 949)

*Note: *p<0.1; **p<0.05; ***p<0.01*

The modelling for egg production finds that, when all countries are included, an additional case of any disease in the national flock of birds is associated with a decline of 0.124 tonnes in national egg production one year later.

When only upper middle-income countries are included, the model finds that an additional case of any disease in the national flock of birds is associated with a 0.039 tonnes decline in national egg production one year later. The coefficient for the impact of vaccination in these countries is statistically insignificant.

When only low-income countries are included, it is found that an additional case of any disease in the national flock of birds is associated with a 0.092 tonnes decline in national egg production one year later. The coefficient for the impact of vaccination in these countries is statistically significant, but essentially equal to 0.

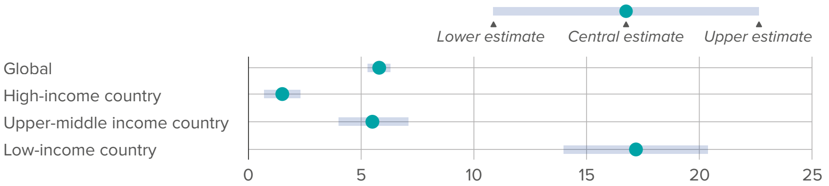
Disease and poultry production

Globally in 2018, as a result of disease levels in 2017 and the impact of managing through these case levels, it is found that optimal poultry production was likely reduced 2.8 million tonnes, which, based on global per capita poultry consumption of 15.8 kg, could have met the needs of 180 million people for an entire year.

For poultry meat, using data from the WOAH and the FAO as underlying sources for the regression analysis, the model indicates that each additional case of any notifiable disease globally is associated with a 0.112 tonne fall in production one year later. As outlined earlier, similar relationships were also found between disease and production across other income groups -- with the impact of disease most pronounced across low-income countries, likely due to these countries having fewer resources with which to address and manage disease outbreaks.

Globally in 2018, as a result of disease levels in 2017 and the impact of dealing with these case levels, it is found that optimal poultry production was likely 2.8 million tonnes less than it would have been without disease impacts, which, based on global per capita poultry consumption of 15.8 kg, could have met the needs of 180 million people for an entire year.

Figure 2. Negative impact of disease on poultry meat production, 2018 (share of production %)



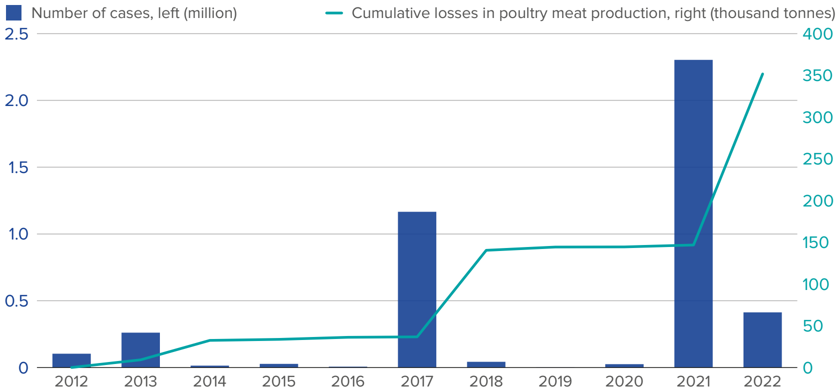
Source: Oxford Analytica, WOAH, FAO

Similarly telling findings were revealed across different income groups. In low-income countries, due to disease levels in 2017, it is found that optimal production levels in 2018 were likely reduced by up to 22% -- losses that could have fed the needs of 50 million people in places such as Ethiopia, Afghanistan and Somalia.

In upper middle-income countries such as Argentina and South Africa, the estimated production loss in 2018 due to disease outbreaks one year earlier equated to up to 1.3 million tonnes and 850 million birds wasted.

These estimated losses can be acutely felt when looking at individual countries. For instance, Italy suffered the greatest losses among high-income countries, losing as much as 12.3% of production in 2018 due to disease.

Figure 3. Number of cases and cumulative losses in poultry meat production in Italy due to outbreaks of diseases, 2012-22



Source: WAHIS, Oxford Analytica

Between 2012 and mid-2022, Italy experienced several acute outbreaks of diseases among its poultry bird populations, especially in 2017 and 2021. According to Oxford Analytica's estimates -- which, as mentioned above, suggest that high-income countries suffer a decline of 0.089 tonnes in poultry meat production for each additional case of any disease among their poultry bird populations -- this means that Italy suffered a cumulative loss of around 350,000 tonnes in its poultry meat production during this period.

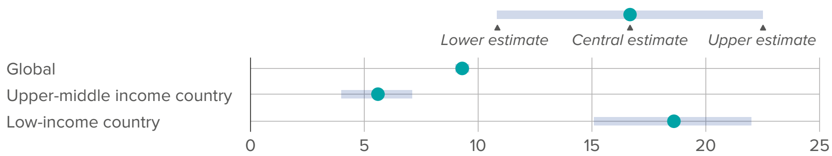
Moreover, given the average carcass weight of a poultry bird in Italy in 2020 (the figure is 2.3kg), Italy's cumulative losses in poultry meat production in the last ten years are equivalent to the combined weight of around 153 million poultry birds.

Disease and egg production

In 2018, for eggs, as a result of disease levels in 2017 and the impact of managing through these case levels, the modelling found that optimal egg production was reduced by up to 9.6% or 3.0 million tonnes, which from a revenue perspective equated to a loss of $5.6 billion USD. That is the equivalent of wiping out the United Kingdom's £1.2 billion egg market nearly four times over[15].

Optimal egg production was reduced by up to 9.6% or 3.0 million tonnes, which...equated to a loss of $5.6 billion USD

Figure 4. Negative impact of disease on egg production, 2018 (share of production %)



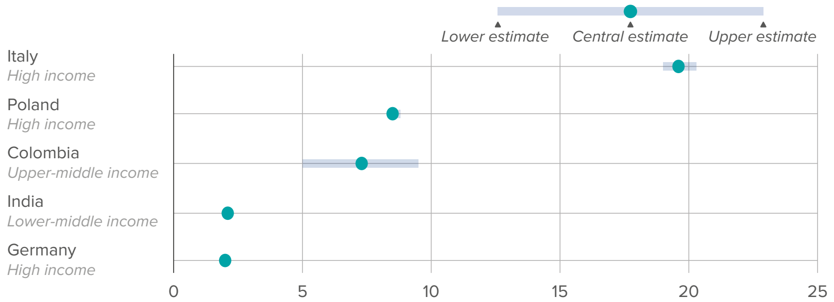
Source: Oxford Analytica, WOAH, FAO

15 GBP to USD Exchange rate of 1:1.2 (Nov 2022). UK market size source: https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/data

As with poultry production, likely due to high levels of production but less sophisticated farming practices in terms of quality of feed, medication and monitoring when compared to high-income countries, the present findings suggest that upper middle-income countries bore a disproportionate share of the impact of disease on egg production. By the present estimates, in 2018, due to disease levels in 2017, upper middle-income countries likely witnessed an equivalent production loss of up to 1.3 million tonnes and a loss of revenue of $2.3 billion USD, or about 41% of the global total.

At a country level, by Oxford Analytica's estimates, some of the countries that witnessed the largest impacts on egg production due to disease were Italy, with a central estimated loss of 19.6%, with an upper bound of 20.3% and a lower bound of 19%. Italy is followed by Poland, whose estimated lower bound loss was 8.3%, upper bound 8.8% and central estimate 8.5%. Next behind Poland was Colombia, with a central estimated loss of 7.3%, with an upper bound of 9.5% and a lower bound of 5%.

Figure 5. Sampling of negative impact by country of disease on egg production, 2018 (share of production %)



Source: Oxford Analytica, WOAH, FAO

Disease and other commodities

Based on different levels of disease outbreaks, in the case of Spain, a major swine producer, the regression result suggests that a disease outbreak that affected 20% of pigs in a given year would be associated with a, on average, 130 tonnes decrease in production one year later[16]. This is equivalent to the loss of nearly 6 million pigs and would result in revenue losses of almost $92,000 USD per farm.

For sheep, where Oxford Analytica only found a statistically significant coefficient for upper middle-income countries, the findings indicate that each additional case of any disease is associated with a decline of 0.265 tonnes in sheep meat production one year after the onset of disease -- the higher disease levels, the lower production one year later.

Based on different levels of disease outbreaks, in the case of Algeria -- a leading sheep producer in Africa -- it is found that a disease outbreak that affected 20% of sheep in the country would likely reduce production by 1,500 tonnes, or the equivalent loss of more than 76,000 sheep, and result in revenue losses for the sector of nearly $14.5 million USD, based on average prices in 2018.

16 As noted in the 'Interpreting Report Results' section, these findings represent the average effect of disease. Real-world results would vary depending upon the specific disease, strain, virulence, and related similar factors.

Figure 6. Estimated impact of disease on pig meat production in Spain

(pig icon) = 1mn

Vaccination rate	Impact on meat production	Equivalent number of animals	Revenue impact	Production impact (metric tonnes)	Revenue impact per farm
5%	5%	1.5mn	$2.0bn	33	$23,025
10%	10%	3.0mn	$4.0bn	65	$46,051
20%	20%	5.9mn	$8.0bn	130	$92,101
40%	30%	8.9mn	$12.0bn	195	$138,152
60%	40%	11.8mn	$16.0bn	261	$184,202
80%	50%	14.8mn	$20.0bn	326	$230,253

Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

Figure 7. Estimated impact of disease on sheep production in Algeria

(sheep icon) = 10,000

Vaccination rate	Impact on meat production	Equivalent number of animals	Revenue impact	Production impact (metric tonnes)
5%	5%	19,097	$3.6mn	376
10%	10%	38,194	$7.2mn	752
20%	20%	76,389	$14.5mn	1,505
40%	30%	114,583	$21.7mn	2,257
60%	40%	152,778	$29.0mn	3,010
80%	50%	190,972	$36.2mn	3,762

Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

The effects of disease control measures

There are various methods to protect animals from disease. In the case of cattle for instance, farms can leverage vaccination, biosecurity measures, improved housing and nutrition, and modern genetics. Evidence shows the benefit of actively controlling common diseases. For instance, Salmonella in poultry is a disease that negatively affects humans and can be passed on via contaminated food and contact with infected animals and people.

According to this report's country and income level estimates, economically poorer countries' meat and egg production is disproportionately affected by the spread of disease. In other words, as a country develops, disease outbreaks tend to have a smaller impact on meat production. This is because more developed countries have more sophisticated agricultural infrastructure, including mechanisms to identify and treat disease among animals rapidly, and because well-kept animals have a higher degree of resilience towards the impact of diseases.

The impacts of increased vaccination

Note: *See the section on 'Interpreting report results' for context on the variables likely captured within vaccination measurements in the model.*

Globally, when 60% of the world's beef cattle are vaccinated in a given year, this was associated with a 52.6% increase in beef production two years later. This would be equivalent to the beef consumption needs of 3.1 billion people -- or just under 40% of the global population.

As outlined previously, the modelling based on WOAH and FAO data has uncovered the relationship between disease and production as well as vaccination and production. It is found, for instance, that vaccinating an additional cow is associated with an increase of 0.032 tonnes in beef production two years later in upper middle-income countries[17;18]. This suggests that the more a country vaccinates its cattle and invests in overall veterinary care (higher vaccination rates are typically accompanied by other forms of care as outlined in the 'Interpreting report results' section), the higher the levels of production can be in subsequent years.

In leveraging the findings of the regression analysis, it is possible to assess the association between different levels of disease and vaccination rates with production. Globally, when 60% of the world's beef cattle are vaccinated in a given year, this was associated with a 52.6% increase in beef production two years later. Based on global production levels in 2018, this would be equivalent to the beef consumption needs of 3.1 billion people, just under 40% of the global population. These estimates were arrived at by multiplying the regression coefficients by the number of vaccinated animals under various scenarios -- that is, the equivalent number of animals if 5%, 10%, 20% or more of cattle were vaccinated globally or in a country.

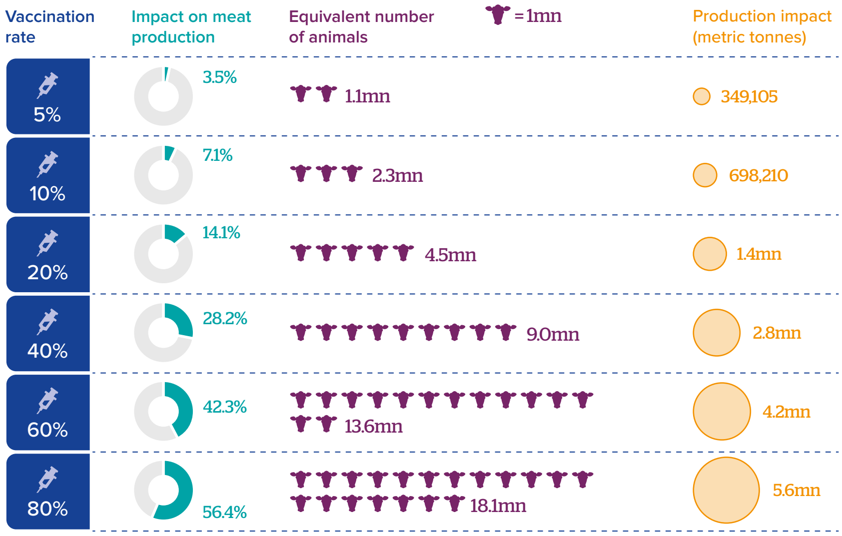
At a country level, taking Brazil -- one of the world's largest beef producers -- as the example, based on the findings for 2018, it was discovered that vaccinating 1% of beef cattle in a given year would be associated with a 0.7% increase in beef production two years later. Based on Brazil's production levels in 2018, this would

17 As noted in the 'Interpreting Report Results' section, these findings represent the average effect of vaccination. Real-world results would vary depending upon the specific disease, product efficacy, and similar factors.

18 See 'Lagging Indicators' within the methodology section for a detailed explanation as to why the model relates vaccination in a given year with production levels two years later.

be equivalent to an increase of almost 70,000 tonnes or the addition of 226,000 beef cattle.

Figure 8. Estimated impact of vaccination on beef production in Brazil



Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

In Argentina, another major beef producer, vaccinating 80% of beef cattle in a given year is associated with a 43.9% increase in beef production two years later. Based on production levels and prices in 2018, this would be equivalent to an increase of more than 1.4 million tonnes and enhance the sector's producer revenue by $3 billion USD. At the farmer level, where there are an estimated 130,800 cattle farmers, this equates to an additional $23,000 USD per annum.

Figure 9. Estimated global impact of vaccination on beef production

Vaccination rate	Impact on meat production	People served (1 icon = 100mn)	Revenue impact	Production impact (metric tonnes)
5%	4.4%	259mn	$11.4bn	2.7mn
10%	8.8%	518mn	$22.8bn	5.5mn
20%	17.5%	1.0bn	$45.6bn	10.9mn
40%	35.1%	2.1bn	$91.2bn	21.9mn
60%	52.6%	3.1bn	$136.8bn	32.8mn
80%	70.2%	4.2bn	$182.4bn	43.8mn

Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

Figure 10. Estimated impact of vaccination on beef production in Argentina

Vaccination rate	Impact on meat production	Equivalent number of animals (1 icon = 100,000)	Revenue impact	Production impact (metric tonnes)	Revenue impact per farm
5%	2.7%	369,543	$188mn	84,219	$1,436
10%	5.5%	739,086	$376mn	168,438	$2,871
20%	11.0%	14.8mn	$751mn	336,875	$5,742
40%	22.0%	29.6mn	$1.5bn	673,751	$11,484
60%	33.0%	44.3mn	$2.3bn	1.0mn	$17,226
80%	43.9%	59.1mn	$3.0bn	1.4mn	$22,968

Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

Case Study:
The benefits of deworming in Kenya

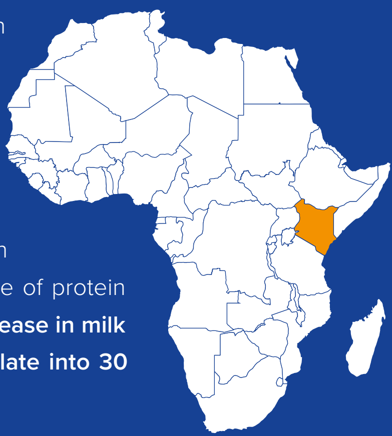
In Kenya -- a country where deworming is a common practice but implementation is uneven and often only in response to signs of infestation -- the FAO estimates that deworming dairy cattle could reduce GHG emissions intensities by between 8% to 20%, thereby reducing the CO2 equivalent footprint of producing 1 litre of milk from 3.15 kgCO2eq to a range of 2.52 to 2.90 kgCO2eq.

Modelling the benefits

Building on this finding, based on FAO production estimates, this report sought to estimate the resultant benefits across the Kenyan dairy herd. It found that in 2020, when total milk production in the country was 4 billion kg, or 791.8kg per cow per year based on a dairy herd of about 15.7 million, **effective and large-scale deworming could reduce the average dairy cow's CO2eq footprint from 2,494 kgCO2eq to within a range of 1,995 to 2,295 kgCO2eq -- a cumulative reduction in the range of 3.1 billion to 7.8 billion kgCO2eq each year.**

In other words, deworming would support higher milk production without increasing Kenya's current dairy cattle environmental footprint. By this report's calculations, holding the environmental footprint constant and assuming an average producer price of 72 cents per litre of milk, the equivalent increase in milk production would equate to additional annual revenue for the Kenyan dairy sector of between $0.8 billion USD and $2.2 billion USD. **Among an estimated 1.8 million smallholder farmers, this corresponds to additional revenue of between of $434 USD and $1,248 USD per farmer in a country that has a GDP per capita of only $2,006 USD.**[19]

The per capita supply of milk production in Kenya (110 litres each year) would also increase within a range of 20 to 58 litres. Taking the upper end of the per capita milk supply increase estimate, which in total is 168 litres annually, the average Kenyan would gain 1.8kg more protein annually. Based on an average daily intake of protein of 60.88 grams (estimated in 2017) **the increase in milk production from deworming would translate into 30 days of addition protein per capita.**



Key takeaways

Deworming cattle can reduce the CO2eq footprint of Kenyan milk production by 8-20%.

If all Kenya's dairy cattle were to be dewormed, it could reduce CO2eq emissions by 3.1-7.8 billion kgCO2eq.

The deworming-based emissions reductions would be equivalent to the annual emissions of 36-90% of all Kenya's registered vehicles.[20]

The increase in milk production from deworming would translate into 30 days of additional protein per capita.

Among an estimated 1.8 million smallholder farmers, the production benefits of deworming could equate to additional revenue of between of $434 USD and $1,248 USD per farmer in a country with a GDP per capita of $2,006 USD.

19 https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=KE
20 Kenya Number of Registered Vehicles | Economic Indicators | CEIC (ceicdata.com)

3. Environmental sustainability

With climate change rising in importance globally, finding ways to limit and reduce the environmental footprint of animals in agriculture while continuing to feed a growing population will be a top priority, in concert with other emissions reduction efforts in other industrial sectors. Improving the health of animals offers a potential avenue for increasing the productivity of livestock production while holding emissions to a socially acceptable level.

This chapter focuses on the impacts of disease and vaccination on the environmental footprint of four types of national meat production -- cattle, poultry, pigs, and sheep -- and on egg and milk production. These aspects were chosen because of the availability and reliability of the data. For the same reason, this section does not consider the impact of disease and vaccination on biodiversity.

The chapter begins with an overview of findings and the regression results before moving to assess the impacts of disease and vaccination on the environment using scenario analysis informed by the findings of Oxford Analytica's regression analysis. At the end of this chapter, two case studies are provided, to illustrate the benefits of cattle practices for the environment.

Overview of key findings

The analysis found that animal disease is associated with significant increases livestock GHG emissions and land use, while annual rates of vaccination among livestock are associated with reduced GHG emissions and land use among livestock.

Some of the key supporting findings from the model include:

- *Among all major livestock species, the model found that a 10-percentage point decrease (e.g. 20% to 10%) in global livestock disease in a given year is associated with an 800-million-tonne decrease in livestock GHG emissions. EUROSTAT estimates that the average EU citizen emits 6.8 tonnes of emissions per year, therefore this is equivalent to the emissions of 117 million Europeans.*
- *It was found that the impact of disease on GHG emissions varies by species and country type, with emissions increasing most for low-income countries. For cattle, an outbreak of disease that affects 20% of cattle in low-income countries is associated with an estimated 60% increase in GHG emissions compared to 42% in high-income countries.*
- *It was also found that if 20% of global poultry are affected by disease in a given year, an equivalent increase in livestock land use of 8.6% is likely needed to maintain production levels. This rises to 21.6% at a disease level of 50%.*
- *In the United States, the modelling shows that a 30% outbreak of disease in a given year among beef cattle is associated with a 2.3% increase in available land to maintain production constant..*
- *Globally, the modelling found that a 40% global vaccination rate for cattle in a given year is associated with a 5.2% reduction in land required for production.*

A 10% decrease in global livestock disease...is associated with an 800 million tonne decrease in livestock GHG emissions.

- *Based on the modelling, it is estimated that in Brazil, a 40% vaccination rate for cattle in a given year is associated with a 12.8% reduction in land required for production.*
- *The FAO estimates that livestock GHG emissions could be reduced by 18-30% by expanding use of existing best practices and technologies in animal health and husbandry. Our calculations indicate that this reduced emissions intensity means livestock could meet the protein needs of an additional 1.6 billion people without increasing livestock's overall GHG emissions level. Therefore, livestock could comfortably serve a world population of 9.8 billion by 2050 without an increase in emissions from current levels through better adoption of existing best practices and technologies.*

Regression analysis results

Note: *See the section on 'Interpreting report results' for additional context on how certain terminology are used in this report.*

Table 8. Environmental Regression Results: GHG Emissions & Cattle

GHG emissions from the agricultural sector		
Cattle		
	High income (1)	Upper middle income (2)
Vaccinated animals	0.305 (-0.596, 1.205)	0.259 (-0.094, 0.612)
Infected animals	9.517*** (6.192, 12.842)	5.908*** (4.632, 7.184)
RSE as % of mean of dependent variable	0.8	0.6
Observations	2,700	4,501
Residual Std. Error	184,701.200 (df = 2597)	438,982.900 (df = 4380)

*Note: *p<0.1; **p<0.05; ***p<0.01*

The model on the impact of vaccination and cases among the national herd of cattle on GHG emissions from the agricultural sector finds that, among high-income countries, an additional case of any disease is associated with an increase of 9.517 tonnes in national emissions.

As for upper middle-income countries, it is found that an additional case of any disease in the national herd of cattle is associated with an increase of 5.908 tonnes in national emissions.

Table 9. Environmental Regression Results: GHG Emissions & Poultry

GHG emissions from the agricultural sector			
Birds			
	All countries (1)	Upper middle income (2)	Low income (3)
Vaccinated animals	-0.001 (-0.006, 0.005)	-0.001 (-0.006, 0.005)	-0.001 (-0.014, 0.012)
Infected animals	0.405*** (0.285, 0.524)	0.130* (-0.018, 0.278)	0.637* (-0.013, 1.287)
RSE as % of mean of dependent variable	0.5	0.3	0.8
Observations	4,471	1,424	1,031
Residual Std. Error	539,376.800 (df = 4286)	481,910.700 (df = 1314)	306,194.700 (df = 934)

*Note: *p<0.1; **p<0.05; ***p<0.01*

Meanwhile, the model on the impact of vaccination of and cases among the national flock of birds on GHG emissions from the agricultural sector finds that, when all countries are included, an additional case of any disease is associated with an increase of 0.405 tonnes in national emissions.

When only upper middle-income countries are included, it is found that an additional case of any disease in the national flock of birds is associated with an increase of 0.13 tonnes in national emissions.

When only low-income countries are included, it is found that an additional case of any disease in the national flock of birds is associated with an increase of 0.637 tonnes in national emissions.

Table 10. Environmental Regression Results: GHG Emissions & Pigs

GHG emissions from the agricultural sector	
Pigs	
	All countries
Vaccinated animals	0.017 (-0.035, 0.070)
Infected animals	1.473* (-0.265, 3.211)
RSE as % of mean of dependent variable	0.4
Observations	3,642
Residual Std. Error	432,416.000 (df = 3468)

*Note: *p<0.1; **p<0.05; ***p<0.01*

The model on the impact of vaccination of and cases among the national herd of pigs on GHG emissions from the agricultural sector finds that, when all countries are included, an additional case of any disease is associated with an increase of 1.473 tonnes in national emissions.

Table 11. Environmental Regression Results: GHG Emissions & Sheep

GHG emissions from the agricultural sector	
Sheep	
	High income
Vaccinated animals	-0.909 (-4.055, 2.237)
Infected animals	1.644*** (0.573, 2.714)
RSE as % of mean of dependent variable	0.7
Observations	1,320
Residual Std. Error	164,175.600 (df = 1219)

*Note: *p<0.1; **p<0.05; ***p<0.01*

The model on the impact of vaccination of and cases among the national herd of sheep on GHG emissions from the agricultural sector finds that, when only high-income countries are included, an additional case of any disease is associated with an increase of 1.644 tonnes in national emissions.

Disease and the environment

The existing footprint of livestock to GHG emissions can be accentuated by the onset of animal diseases due to the knock-on effects on yield, productivity, and in situations that require animals to be put down, the resulting waste and replacement considerations.

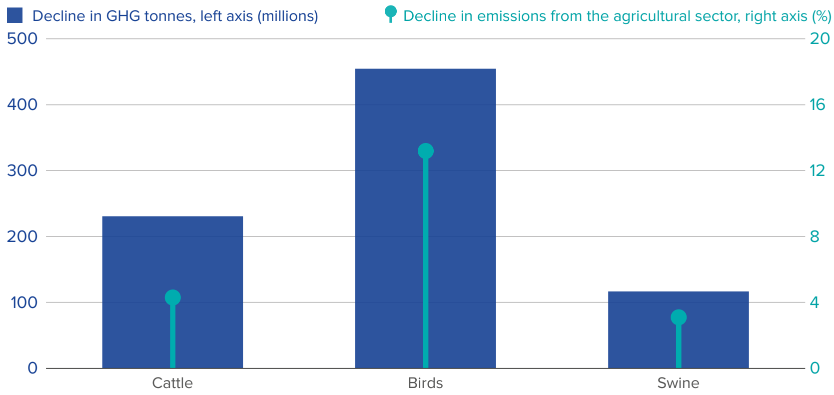
In Gambia, for example, analysis of WOAH and FAO data reveals that disease in 2018 added 12.7% to beef producers' GHG emissions. Meanwhile, in South Korea -- a high-income country with a strong, professionally managed livestock sector -- by Oxford Analytica's estimates disease levels among poultry in 2018 still increased GHG emissions by 3%.

While these country level impacts might not seem significant, when considered on a global and reoccurring and multi-year basis, the effects on disease can be substantial. Among all major livestock species, the modelled analysis suggests that when disease levels for all countries globally falls by ten percentage points in a given year (eg., from 20% of the national herd being infected to 10%) GHG emissions fall by over 800 million tonnes overall (summarised for cattle, birds, and swine below).[21] This is equal to the annual carbon footprint of approximately 117 million European Union citizens, which is estimated to be 6.8 tonnes by EUROSTAT[22], and indicates a notable opportunity to reduce emissions through animal disease reductions.

21 As noted in the 'Interpreting Report Results' section, these findings represent the average effect of disease. Real-world results would vary depending upon the specific disease, product efficacy, and related factors.

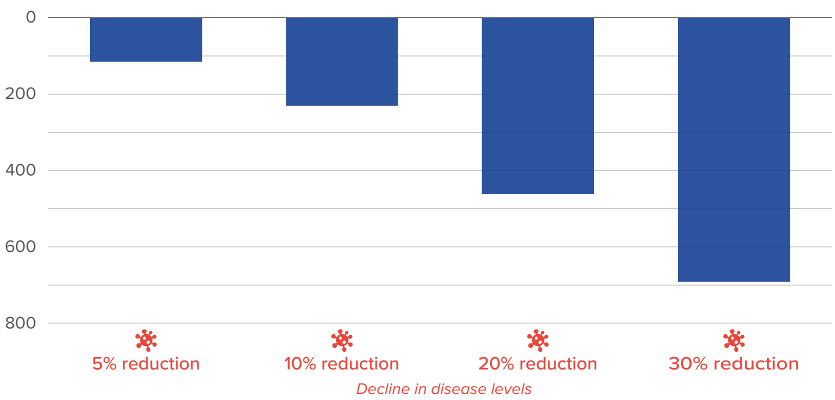
22 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Greenhouse_gas_emission_statistics_-_carbon_footprints

Figure 11. Estimated impact of reducing global livestock disease levels by 10 percentage point decrease in GHG emissions (eg., 20% to 10%)



Source: Oxford Analytica, WOAH, FAO

Figure 12. Estimated impact of declines in disease levels among cattle on GHG emissions

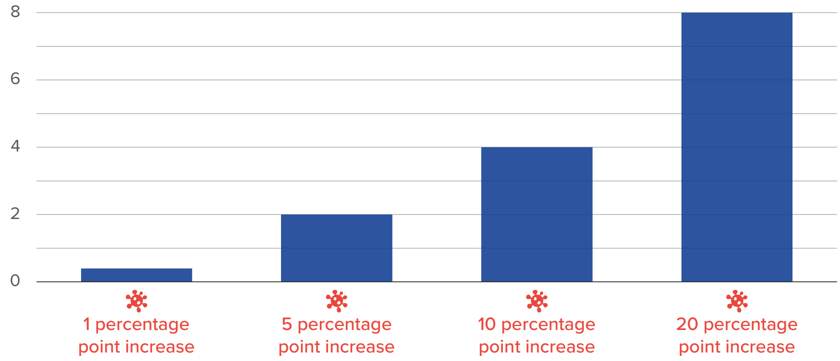


Source: Oxford Analytica, WOAH, FAO

As part of the research for this report, it was also found that the impact on GHG emissions of reducing disease levels varies by country type, with emissions falling the most in low-income countries. This is likely because while high-income countries tend to be larger producers, on a per capita basis the environmental footprint of animals raised in these countries is lower. For cattle, on a global basis, reducing the infection rate of national herds from 40% to 20% is associated with an 8.5% reduction in cattle GHG emissions.

In the United States, where disease levels among cattle are generally very low, the relationship between GHG emissions and rising disease levels is similarly telling. The modelling for this report found that disease levels of 1% among beef cattle was associated with a 0.4% increase in agricultural animal sector emissions. At 30% disease levels, the associated increase in agricultural animal sector emissions stands at 12.1%.

Figure 13. Estimated increase in GHG emissions due to rising infection rates among cattle in the United States (%)



Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

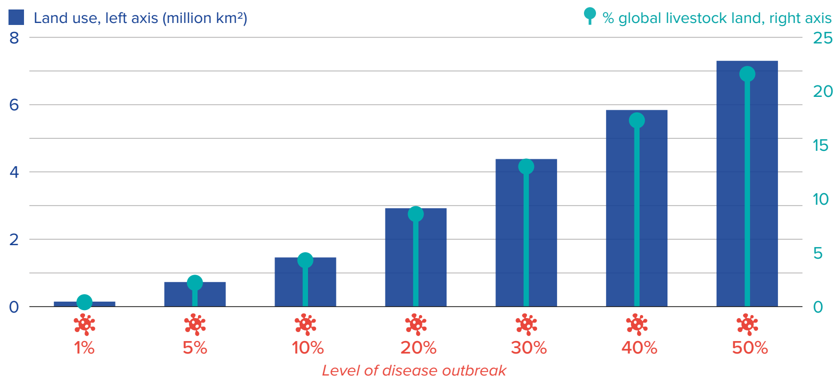
The impact of disease on land use

Farmers that confront significant levels of disease, but still aim to maintain or increase production levels, inevitably require more land to do so. The impact of disease on land use varies by species, with this analysis suggesting that the impact is acutely felt among poultry producers.

When 20% of global poultry are affected by disease in a given year, this is associated with, on average, an equivalent increase in livestock land use of 8.6%.

Using estimates from the FAO, which indicate that 26% of the earth's terrestrial surface is used for livestock grazing (including land used for feed production) or almost 34 million kilometres squared (km2), and the results presented in Chapter 2, holding production levels constant, this report finds that when 20% of global poultry are affected by disease in a given year, this is associated with, on average, an equivalent increase in livestock land use of 8.6%. This rises to 21.6% at a disease level of 50%. This increase in land use is likely driven by the need for more feed and / or production areas for replacement flocks.

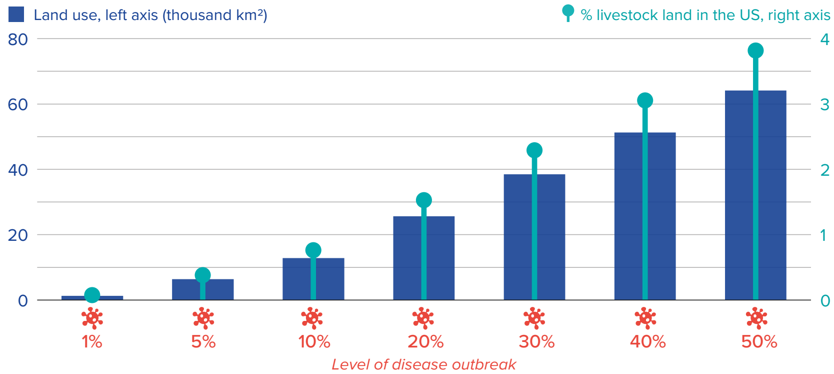
Figure 14. Estimated impact of disease outbreaks among poultry on share of global livestock land used across all species (km2)



Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

For beef cattle and swine, for which there are also found significant relationships between disease and production, holding meat production constant, the modelling findings reveal that if 30% of animals in a given year were affected by disease, livestock land use by beef cattle and swine would be required to increase by 1.7% and 1.5%, respectively. Depending on the country, these impacts can vary. For example, in the United States, where land use by animals is estimated at 415 million acres, or about 1.7 million kilometres squared, the present modelling shows that a 30% outbreak of disease in a given year among beef cattle would require a 2.3% increase in available land to hold production constant.

Figure 15. Estimated impact of disease levels among beef cattle on share of livestock land in the United States (km2)



Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

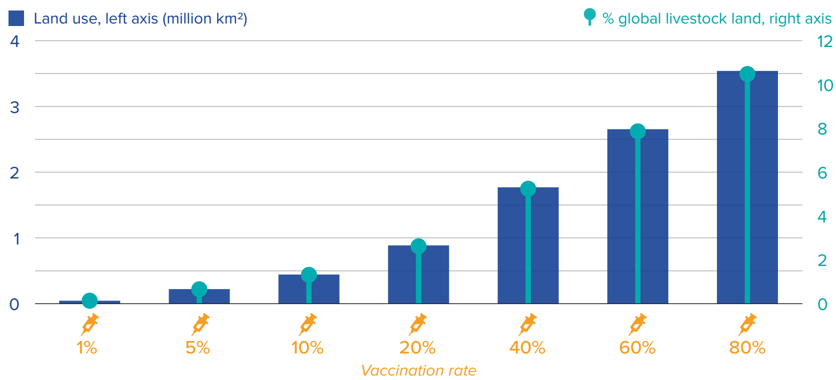
The impact of vaccination on land use

Note: *See the section on 'Interpreting report results' for context on the variables likely captured within vaccination measurements in the model.*

Due to level of significance, the findings for vaccination and land use were limited to cattle. However, when compared to those for disease, the results were more telling. Holding production constant, at a global level, this report estimates that when 40% of cattle are vaccinated in a given year, this is associated with an approximately 5.2% reduction in land required for global livestock production. This is likely due to reduced losses and fewer replacement herds due to investments in vaccination and other care, which reduces the need for grazing land and feed.

This report estimates that when 40% of cattle are vaccinated in a given year, this is associated with an approximately 5.2% reduction in land required for global livestock production.

Figure 16. Estimated impact of cattle vaccination on share of global livestock land (km2)



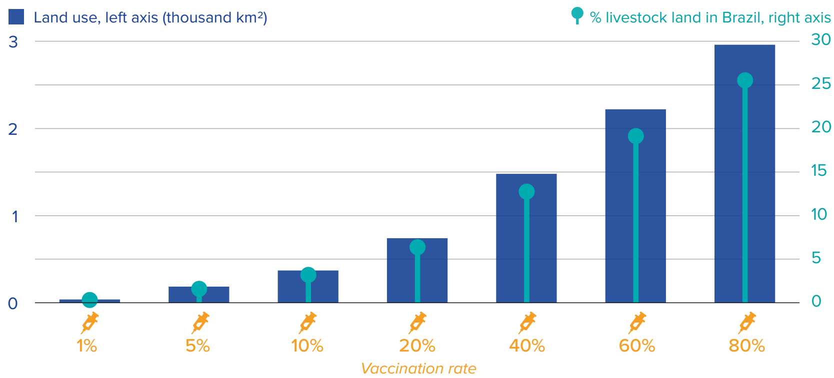
Source: Oxford Analytica, WOAH, FAO | Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

High vaccination levels and the associated adoption of other health practices to help reduce the need to put unused lands into production.

This is not to suggest that vaccination will lead to reduction of land used to livestock production. Rather, and more likely, it points towards the opportunity for high vaccination levels and the associated adoption of other health practices (See "interpreting report results" for more detail) to help reduce the need to put unused lands into production. For example, in Brazil the modelling discovered that vaccination could potentially reduce the need for additional land to support the growth of the cattle industry.

Assuming that about 1.2 million km2 of land in Brazil is currently devoted to livestock, holding production constant, this report estimates that a vaccination rate of 80% is associated with a 26% reduction in livestock land use. At lower rates of vaccination, such as 40%, this falls to 12.8%.

Figure 17. Estimated impact of cattle vaccination on share of Brazilian livestock land (km2)



Source: Oxford Analytica, WOAH, FAO I Findings represent an average impact of disease (See 'Interpreting report results' for more detail)

Case Study:

Sustainable cattle practices and reducing global GHG emissions

Effective animal husbandry practices can play their part in reducing carbon emissions. Oxford Analytica used existing calculations from the United Nations to determine to what extent livestock emissions can be reduced using existing practices:

- At present, the total CO2 emissions from cattle, poultry and other food-related animals are estimated at 7.1 gtCO2eq (gigatonnes of CO2 equivalent).
- The FAO has said that these emissions could fall by between 18% and 30% if, holding production constant, producers working in food and agriculture took up the same working practices as their colleagues who are already the lowest emissions producers.[23]
- Meanwhile, the total number of human-induced CO2 emissions is 49 gtCO2eq. Therefore, if the 18% reduction in livestock-related emissions noted in the previous paragraph was achieved, this would equate to a reduction of 1.3 gtCO2eq. If the 30% reduction figure was achieved, this would be equivalent to a reduction of 2.1 gtCO2eq.
- **Therefore, scaling up existing practices in animal health and husbandry could reduce global human-induced gtCO2eq emissions by 2.6% (1.3 gtC02eq) to 4.4% (2.1gtCO2eq).**

As human populations continue to grow, additional production of animal-sourced foods will be necessary. Therefore, if a 30% reduction in livestock emissions intensity could be achieved, Oxford Analytica analysed how much more protein could be produced while holding current global CO2 emissions constant (7.1 gtC02eq):

- If livestock emissions intensity (that is, GHG emissions per unit of production) falls by 30%, the global protein supply could increase by up to 76.1 billion kg. Assuming a world population of 7.9 billion people, this is equivalent to additional protein of 9.6kg per person while holding emissions to their current overall level (7.1 gtCO2eq).
- Assuming global per capita protein intake remains constant at 80.1 grams per day, this increase in protein supply is equivalent to offering protein to an additional 2.6 billion people. However, recognising that not all animals will be slaughtered and used for meat and dairy in a single year, if it is assumed a 60% 'protein conversion rate', this is equivalent to serving the protein needs of an additional 1.6 billion people per year.
- **Therefore, scaling up existing practices in animal health and husbandry means livestock could comfortably serve a world population of over 9 billion in 2050 while holding emissions to current levels.**

Key takeaways

UN Food and Agriculture Organisation estimates increase uptake of existing animal health and husbandry practices could reduce livestock emissions by 18-30%.

This would allow livestock producers to increase production and meet the needs of an additional 1.6 billion people while keeping emissions at current levels.

Therefore, scaling up existing practices in animal health and husbandry means livestock could comfortably serve a population of 9 billion in 2050 without increase emissions

23 https://www.fao.org/news/story/en/item/1157729/icode/

4. Social sustainability

HealthforAnimals
global animal health association

Global economic development has reduced the number of people worldwide living in extreme poverty over the past half-century -- since 1990 alone, more than a billion people have moved out of the ranks of extreme poverty. Nonetheless, poverty persists, with more than 500 million people projected to be living on less than $1.90 USD per day in 2030.

Food insecurity will also be a major problem around the world for the foreseeable future. More than 828 million people were affected by hunger in 2021, a number which is rising as the disruptions of the COVID-19 pandemic and its shadow, and now of rampant inflation, make it increasingly difficult for some of the world's poorest to afford enough to eat. Furthermore, malnutrition continues to be a significant challenge with 462 million people underweight, 149 million children under 5 years of age stunted each year, and 45% of deaths of children under 5 linked to undernutrition.

Proper management of livestock can play an important role in addressing the world's food needs. If herds are not properly managed, the loss of food output reduces the supply of food -- and, importantly, the supply of complete proteins and micronutrients -- available to people.

This chapter focuses on the impact of animal disease and vaccination on social outcomes, namely levels of undernourishment and food insecurity. As with the preceding chapters, these aspects were chosen because of the availability and reliability of the data. At the end of this chapter, two case studies are provided, to illustrate the human benefits of improving animal health and the link between animal and human health.

Overview of key findings

This analysis discovered a strong associative relationship between levels of animal disease and vaccination and human nutritional outcomes. It found that higher rates of disease among livestock are associated with higher levels of undernourishment and food insecurity among the world's population, while vaccination among livestock is associated with lower levels of undernourishment and food insecurity.

Some of the key supporting findings from the regression analysis and case studies include:

- *The modelling shows that the associated impact of vaccinating cattle on the number of undernourished people is -0.674. In other words, this suggests that at a global level, on average, every two cattle vaccinated is associated with one person avoiding hunger.*
- *For poultry, the most widely consumed meat globally, the modelling found that reported levels of disease in 2018 were associated with a 2% increase in the number of undernourished people, while this rose to almost 5% in 2019.*

- *In 2018, the analysis found that the level of disease among birds was associated with a 5.9% increase in the number of undernourished people in Vietnam.*
- *In Nigeria, where an estimated 29 million out of a population of 206 million people in 2018 were classified as being in severe food insecurity, the modelling suggests that achieving a country level vaccination rate of 40% for cattle in a given year is associated with an 8.1% reduction in severe food insecurity. In other words, this is associated with 2.4 million people who would be lifted out of severe food insecurity.*
- *The report's analysis of WOAH data found that their estimate that 20% of livestock production is lost to disease each year is equivalent to 80 billion kg of meat and 180 billion kg of dairy, enough to meet the dietary needs of 1.6 and 2.0 billion people, respectively. These losses translate to a combined annual revenue loss of $358 billion USD for meat and dairy producers.*

Regression analysis results

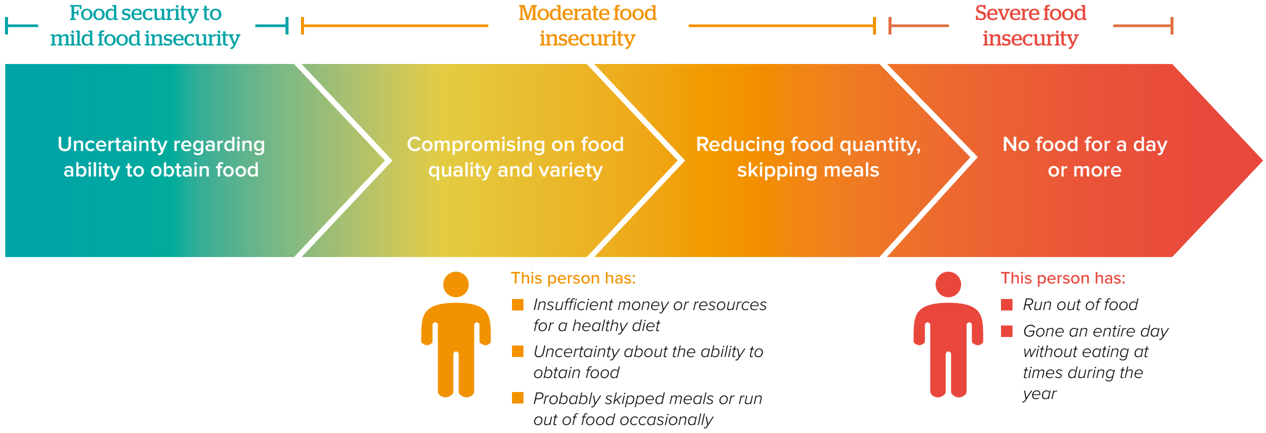
Note: *See the section on 'Interpreting report results' for additional context on how certain terminology are used in this report.*

This report's findings aim to reveal the relationship between animal disease and vaccination levels and the number of undernourished people, and people in moderate or severe food insecurity. These are defined by the FAO as[24]:

- **Number of undernourished people:** An estimate of the number of people whose habitual food consumption is insufficient to provide the dietary energy levels that are required to maintain a normal active and healthy life. NOTE: The United Nations states that "hunger" may also be referred to as "undernourishment". Therefore, in this section these two words are used interchangeably, and "global hunger" is used to refer to the number of undernourished people.
- **People in moderate or severe food insecurity:** For those who are moderately food insecure, access to food is uncertain. They might have to sacrifice other basic needs, just to be able to eat. When they do eat, it might be whatever is most readily available or cheapest, which might not be the most nutritious food. When someone is severely food insecure, they have run out of food and gone a day or more without eating. Population in severe food insecurity is expressed as a percentage.

24 https://www.fao.org/hunger/en/

Figure 18. Definition of food insecurity



Source: FAO

Table 12. Social Regression Results: Number of Undernourished People & Cattle Results

Number of undernourished people		
Cattle		
	All countries (1)	Upper middle income (2)
Vaccinated animals	-0.674*** (-0.803, -0.544)	-0.472*** (-0.798, -0.146)
Infected animals	-1.770*** (-2.513, -1.027)	-0.502 (-1.196, 0.193)
RSE as % of mean dependent variable	5.6	11.4
Observations	3,976	2,112
Residual Std. Error	307,245.700 (df = 3873)	279,137.800 (df = 2041)

*Note: *p<0.1, **p<0.05, ***p<0.01*

The model on the impact of vaccination of and cases among the national herd of cattle on the number of undernourished people, when all countries are included, finds that vaccinating an additional cow against any disease is correlated with a decline of 0.674 in the number of undernourished people nationally. As explained in the 'Interpreting report results' section, vaccination is typically accompanied by other investments in veterinary care, which likely is helping to drive this significant result.

Furthermore, the model also finds that an additional case of any disease in the national herd of cattle is associated with a decline of 1.77 in the number of undernourished people nationally, which can appear counterintuitive at first review. However, when a disease starts to spread in cattle herds, some farmers will slaughter their remaining animals and sell the produce before the entire herd is infected. This 'dumping' of meat onto the market therefore leads to a short-term increase in the supply of meat, which may contribute to reducing the number of undernourished people. However, in the long-term, this dynamic can reduce supplies as animals are slaughtered before reaching full development. This practice is more common in developing regions, which is likely why modelling finds the effect is diminished (-0.502) in upper middle-income countries.

Table 13. Social Regression Results: Number of Undernourished People & Birds Results

Number of undernourished people		
Birds		
	All countries (1)	Lower middle income (2)
Vaccinated animals	-0.086*** (-0.116, -0.055)	-0.472*** (-0.798, -0.146)
Infected animals	1.303*** (1.116, 1.491)	-0.502 (-1.196, 0.193)
RSE as % of mean dependent variable	4.9	3.2
Observations	1,173	2,112
Residual Std. Error	532,169.100 (df = 1073)	279,137.800 (df = 2041)

*Note: *p<0.1, **p<0.05, ***p<0.01*

The model on the impact of vaccination of and cases among the national flock of birds on the number of undernourished people, when all countries are included, finds that vaccinating an additional bird against any disease is associated with a decline of 0.086 in the number of undernourished people nationally. The model also finds that an additional case of any disease is associated with an increase of 1.303 in the number of undernourished people nationally.

When only lower middle-income countries are included, it is found that vaccinating an additional bird against any disease is associated with a decline of 0.472 in the number of undernourished people nationally. The coefficient for the impact of cases is statistically insignificant.

Table 14. Social Regression Results: Number of Undernourished People & Pigs Results

Number of undernourished people	
Pigs	
	All countries
Vaccinated animals	-0.116 (-0.398, 0.166)
Infected animals	3.235*** (0.466, 6.004)
RSE as % of mean dependent variable	4.4
Observations	1,144
Residual Std. Error	334,994.200 (df = 1052)

*Note: *p<0.1, **p<0.05, ***p<0.01*

Meanwhile, the model on the impact of vaccination of and cases among the national herd of pigs on the number of undernourished people, when all countries are included, finds that an additional case of any disease is associated with an increase of 3.235 in the number of undernourished people nationally. The coefficient for the impact of vaccination is statistically insignificant.

Table 15. Social Regression Results: Population in severe food insecurity & Cattle Results

Population in severe food insecurity	
Cattle	
	All countries
Vaccinated animals	-0.291** (-0.551, -0.030)
Infected animals	-0.368 (-2.015, 1.280)
RSE as % of mean dependent variable	3.5
Observations	1,794
Residual Std. Error	65,139.460 (df = 1708)

*Note: *p<0.1, **p<0.05, ***p<0.01*

The model on the impact of vaccination of and cases among the national herd of cattle on the number of people in severe food insecurity, when all countries are included, finds that vaccinating an additional cow against any disease is associated with a decline of 0.291 in the number of people in severe food insecurity nationally. The coefficient for the impact of cases is statistically insignificant.

Table 16. Social Regression Results: Population in moderate and severe food insecurity & Cattle Results

Population in moderate and severe food insecurity	
Cattle	
	Upper middle income
Vaccinated animals	-1.573 (-4.608, 1.463)
Infected animals	6.653*** (5.259, 8.047)
RSE as % of mean dependent variable	1
Observations	524
Residual Std. Error	108,345.600 (df = 484)

*Note: *p<0.1, **p<0.05, ***p<0.01*

None of the estimates produced by the modelling on the impact of vaccination of and cases among the national herd of cattle on the number of people in moderate or severe food insecurity, when all countries are included, were statistically significant.

When only upper middle-income countries are included, it is found that an additional case of any disease in the national herd of cattle is associated with an increase of 6.653 in the number of people in moderate or severe food insecurity nationally. The coefficient for the impact of vaccination is statistically insignificant.

Table 17. Social Regression Results: Population in moderate and severe food insecurity & Birds Results

Population in moderate and severe food insecurity	
Birds	
	All countries
Vaccinated animals	-0.011 (-0.148, 0.125)
Infected animals	0.075* (-0.004, 0.154)
RSE as % of mean dependent variable	1.5
Observations	566
Residual Std. Error	169,201.500 (df = 490)

*Note: *p<0.1, **p<0.05, ***p<0.01*

The model on the impact of vaccination of and cases among the national flock of birds on the number of people in severe or moderate food insecurity, when all countries are included, finds that an additional case of any disease is associated with a decline of 0.075 in the number of people in moderate or severe food insecurity nationally. The coefficient for the impact of vaccination is statistically insignificant.

The impact of disease and vaccination on food security

Note: *See the section on 'Interpreting report results' for context on the variables likely captured within vaccination measurements in the model.*

> [Poultry] disease in 2018 was associated with a 2% increase in the number of undernourished people, while this rose to 5% in 2019. This is equivalent to increasing global hunger by 13.6 million people in 2018 and 34.39 million in 2019.

At a global level, the modelling for this report uncovered strong associative relationships between levels of animal disease and vaccination and human nutritional outcomes. For birds, the most widely consumed meat globally, the modelling found that reported levels of disease in 2018 were associated with a 2% increase in the number of undernourished people, while this rose to almost 5% in 2019. This is equivalent to increasing global hunger by 13.6 million people in 2018 and 34.39 million in 2019.[25]

Based on disease levels among beef cattle and swine in 2018, the modelling also revealed respective increases in the number of undernourished people of 0.8% and 0.6%. When combined with poultry, this indicates that 3.4% or 23.1 million more people may have gone hungry in 2018 due to livestock disease.[26]

At a country level, the impact of animal disease and vaccination on human outcomes is similarly noteworthy, particularly among countries with large populations. In India, for example, in 2018 there were an estimated 190 million people classified as undernourished. Based on the research for this report using data from the WOAH and the FAO as underlying sources for the regression analysis, it was found that the level of disease among birds in 2018 in Vietnam was associated with a 5.9% increase in the number of undernourished people. While in the same year, the level

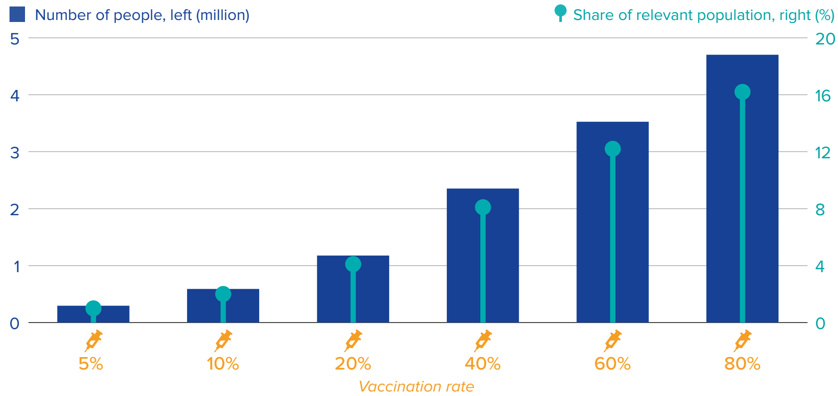
25 According to United Nations, global hunger (defined as the number of undernourished people) was 678.1 million in 2018 and 687.8 million in 2019: https://www.fao.org/3/ca9692en/ca9692en.pdf

26 See Footnote 19 for data on global hunger in 2018.

of vaccination among birds was associated with an 8% reduction in the number of undernourished people, or almost 520,000 people. This finding is likely related to the benefits that vaccination offers in disease control and the resulting availability of meat supply.

In leveraging the findings of the regression analysis, it is possible to assess the impact of different levels of disease and vaccination levels on levels of food insecurity. In Nigeria, where an estimated 29 million out of a population of 206 million people in 2018 were classified as being in severe food insecurity, the modelling suggests that achieving a country level vaccination rate of 40% for cattle in a given year reduces severe food insecurity by 8.1% . In other words, the model indicates that vaccinating 40% of cattle in a given year is associated with lifting 2.4 million people out of severe food insecurity. This achievement cannot be fully attributed to vaccination as it is typically accompanied by other investments in veterinary care (see 'Interpreting report results' for more detail). Nonetheless, it offers a strong associative relationship that indicates a clear benefit of animal vaccination to food and nutrition security.

Figure 19. Impact of vaccination rate among cattle on population in severe food insecurity in Nigeria



Source: Oxford Analytica, WOAH, FAO

Key takeaways

According to WOAH, 20% of livestock production is lost to disease each year. If this loss is translated, it is equivalent to the annual meat consumption needs of about 1.6 billion people and dairy consumption needs of 2.0 billion people. It also represents a revenue loss of $358.5 billion USD across meat and dairy producers.

When applied to meat production, a 1 percentage point reduction in current livestock disease losses would bolster producer revenue by $11 billion USD.

When applied to dairy production, a 1 percentage point reduction in current livestock disease losses would be equivalent to meeting the yearly dairy consumption needs of 80.5 million people and bolster producer revenue by $4 billion USD.

Case Study:
Reducing disease among livestock

According to estimates by the WOAH, 20% of livestock production each year is lost to disease. In practice, this reduces the total production of foodstuffs from livestock and availability to the end consumer. Below we estimate the impact of this 20% loss rate on meat and dairy production, as well as the subsequent impact of every 1-percentage point decrease in this loss rate

Meat Production

WOAH's estimate of 20% losses due to disease means that, on average and holding all else equal, global livestock production typically operates at 80% of its potential. In 2020, for the major livestock categories, meat production equated to around 320 billion kg. Without a 20% loss due to disease, it could have been about 400 billion kg, equalling an annual production 'loss' of 80 billion kg. Based on average annual global meat consumption per capita of 48.7 kg, which includes all types of meats, this 80 billion kg annual loss is equivalent to the annual meat consumption needs of 1.6 billion people per year. Moreover, based on the average prices charged by producers, the value of lost meat production in 2020 (that is, at the rate of 20% referred to above) was $264 billion USD.

If positive improvements were made in disease control, each 1 percentage point reduction in current disease losses (i.e. 20% to 19%, 19% to 18%, etc) would equate to an additional $11 billion USD for the producer. For a specific commodity such as beef, each 1 percentage point reduction would be equivalent to meeting the annual consumption needs of just over 317 million people.

*Dairy Production**

A similar picture is evident for dairy cattle. In 2020, dairy production equated to around 720 billion kg[27]. Without a 20% loss due to disease, it could have been 900 billion kg. Based on an average global dairy consumption per capita of 90 kg per year, this 180 billion kg loss is equivalent to the annual dairy consumption needs of 2.0 billion people per year. Moreover, based on the average price charged by producers, the value of lost dairy production in 2020 was $94 billion USD.

If positive improvements were made in disease control, each 1 percentage point reduction in current disease losses would equate to an additional $4 billion USD for the producer and serve the needs of 80.5 million people per year.

27 This case study does not include global buffalo milk production in its calculations.

Figure 20. Equivalent consumption needs served by 20% lost production, population billion

Species	Estimated production lost to disease per year (billion kg)	Equivalent consumption needs served by lost production*, population (billion)	Value of lost production (billion dollars)	Value of a 1% reduction in current disease loss rates (billion dollars)
Beef cattle	17.0	1.6	78.8	3.2
Pigs	27.5	1.9	72.8	2.9
Poultry	29.9	1.5	77.2	3.1
Small ruminants	4.0	1.4	21.4	0.9
Other poultry	2.0	1.4	13.9	0.6
Dairy cattle	179.5	2.0	94.3	3.8

**Estimates in 'Equivalent consumption needs served by lost production' are based on average consumption habits per capita by product*

Data sources

Table 1 summarises where the dependent and independent variables included in the regressions were sourced from. All the data was sourced from publicly available sources, or derived from these sources.

Variable type	Variable name	Unit	Source
Dependent variables	Cattle meat, poultry meat, pig meat and sheep meat production	Tonnes	FAO
	Egg production	Tonnes	FAO
	Greenhouse gas emissions	Tonnes of CO_2e (GWP100)	Our World in Data
	Undernourished people	Number of people	FAO
	Population in moderate or severe food insecurity	Number of people	FAO
	Population in severe food insecurity	Number of people	FAO
Independent variables	Cases per disease for cattle, birds, pigs and sheep	Number of animals	OIE-WAHIS
	Vaccinated cattle, birds, pigs and sheep per disease	Number of animals	OIE-WAHIS
Control variables	Cattle, birds, pigs and sheep ‘culled’ per disease	Number of animals	OIE-WAHIS
	Livestock count	Number of animals	FAO
	Disease clusters	Ordinal variable with three classes	Oxford Analytica estimations based on K-Means clustering
	Crop production	Tonnes	FAO
	Area harvested for crop production	Hectares	FAO
	Meat producer prices	USD/tonne	FAO
	Meat exports	Tonnes	FAO
	Meat yield	Hg/animal	FAO

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About HealthforAnimals

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