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Global antimicrobial use in livestock farming: an estimate for cattle, chickens, and pigs

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ABSTRACT

Livestock farming substantially contributes to the global economy and food security. However, it poses crucial environmental, animal welfare, and public health challenges. The main objective of this study is to quantify the global antimicrobial use (**AMU**) in cattle, chicken, and pig farming. This information is important for understanding the potential impact of farm AMU on the emergence and spread of antimicrobial resistance among animals and humans. Using the United States Department of Agriculture Production, Supply, and Distribution and the Food and Agriculture Organization databases, we estimated the total supply of cattle (in heads) and its distribution into four weight categories: calves (26%), cows (41%), heifers (4%), and bulls of more than one year (29%). Similarly, we calculated the total supply of pigs (in heads) and divided it into two weight categories: pigs (96%) and sows (4%). For chickens, we considered one weight category. We attributed to each category a standard weight according to the parameters set by the European Medicines Agency (**EMA**) to determine the animal biomass at risk of antimicrobial treatment, or population correction unit (**PCU**). Finally, we estimated the global PCUs and then the global AMU based on the average administered to the three species (in mg of active ingredients per kg PCU). With this method, we estimated a global annual AMU of 76 060 tonnes of antimicrobial active ingredients (2019–2021 average), of which 40 697 tonnes (or 53.5%) for cattle, 4 243 tonnes (or 5.6%) for chickens, and 31 120 tonnes (or 40.9%) for pigs. According to our assessment, global AMU leads to almost 20 000 tonnes less than the previous estimates due to a different evaluation of PCUs. In previous studies, PCUs were calculated on the liveweight at slaughtering of animals, while our method considers the age and sex of animals and their average weight at treatment. Our results are consistent with the World Organization for Animal Health (**WOAH**) estimate of 76 704 tonnes of veterinary antimicrobials globally consumed in 2018 for the total of food-producing animals (the WOAH estimation is based on sales and import data).

Implications

The biomass of animals receiving antibiotics is measured by the population correction unit and helps to estimate the total antibiotic use. Using the average weight of animals at the time of antibiotic treatment and the number of animals by age and sex, we calculated the total population correction unit. We established reference values to estimate the total supply of cattle and pigs (within one year) and divided the total supply into different weight groups of animals. These reference values help us to assess the global population correction unit and the total antibiotic use in livestock more accurately.

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Introduction

Antimicrobial resistance (**AMR**) is a property of microorganisms achieving the capacity to resist the effects of the medicines created to neutralize them or prevent their development. Because of AMR, antibiotics and other antimicrobial active substances lose efficacy against the infections they are expected to treat. AMR can occur naturally, but it is also induced by antibiotic treatments in both humans and animals and is accelerated by the misuse and overuse of such substances (World Health Organization, 2021). Antibiotics can promote the emergence and spread of resistant bacteria, threatening animal, and human health (Brault et al., 2019). Hence, it is crucial to monitor antimicrobial use (**AMU**) in humans and livestock farming and to evaluate its transmission possibility from livestock to humans (Góchez et al., 2019; Brault et al., 2019).

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Cattle, chickens, and pigs, which account for roughly 94% of all food animals, are the most common livestock animals in the world to provide meat, eggs, milk, and other products for human consumption. The rapid increase in urban population worldwide boosts the global demand for food of animal origin and the animal farming industry (Tiseo et al., 2020; Mulchandani et al., 2023), which relies on the AMU for both therapeutic and non-therapeutic purposes, such as prophylaxis, metaphylaxis, and to promote animal weight growth in some parts of the world. Estimates show that, globally, AMU in animal farming largely overcomes the AMU for human health care (Van et al., 2020; Patel et al., 2020).

Estimating AMU in livestock farming is challenging because most countries either do not collect or do not release data on veterinary antibiotics (Malijan et al., 2022). Moreover, no global surveillance system monitors and regulates AMU in livestock farming (Price et al., 2015). Despite these limitations, some efforts have been made to estimate global veterinary AMU. For example, the World Organization for Animal Health (**WOAH**) monitors and reports the use of antibiotics in animals, especially those intended for human consumption. The sixth report of WOAH presents an analysis of the AMU reported by 109 participant countries for 2018. The data were based on sales and import records showing that 69 455 tonnes of antimicrobial agents were used in food animals in 2018. WOAH estimates the adjusted total amount could be 76 704 tonnes (World Organization for Animal Health, 2022).

Boeckel et al. (2015) tackled the challenge of estimating global AMU in livestock production using a regression (Boeckel et al., 2015). They collected data from 37 countries, primarily high-income. They applied a Bayesian linear regression to compute the coefficients of AMU in terms of mg of active substance per kg of animal biomass at treatment for cattle, chickens, and pigs. They then extrapolated these coefficients globally and estimated 63 151 tonnes for the total AMU for cattle, chickens, and pigs in 2010. Similarly, the global AMU in cattle, chickens, and pigs was estimated at 93 309 tonnes in 2017 (Tiseo et al., 2020), and Mulchandani et al. (2023) estimated that the same animal groups, along with sheep, consumed 99 502 tonnes of antibiotics in 2020 (Mulchandani et al., 2023).

All three studies applied a common method for estimating animal biomass in a country. One kg of animal biomass corresponds to one population correction unit (**PCU**) (European Medicines Agency, 2022). They calculated the national PCU as a function of living animals (stocks), total meat production, and quantity of meat per animal (yield). This formula uses live weight, not the weight of animals at the time of treatment, which could lead to biased outcomes. Hence, the objective of our study was to produce an estimate of the global AMU that considers the different weights at treatment of the zootechnic categories in animal populations.

Material and methods

We need to estimate the PCU to measure AMU in animal farming. PCU measures the amount of biomass in a group of animals (alive and slaughtered) over a certain period. According to the European Medicines Agency (**EMA**), PCU is obtained by multiplying the number of animals by their standard weight when treated with antibiotics (EMA, 2022). However, the weight of the animals can vary depending on their age and whether they are alive or slaughtered. Therefore, it is critical to identify the number of animals by weight at the global or any aggregate level to calculate PCU and then estimate the AMU. Our analysis is based on global data from the Production, Supply, and Distribution (**PSD**) database (PSD Online, 2023) maintained by the United States Department of Agriculture (**USDA**). The PSD offers data regarding the livestock population in major producing countries worldwide for the principal farmed species. Each year, for every country, the PSD provides the total supply by summing up the beginning stocks, production, and imports, whereas the total distribution is obtained by summing up the ending stocks, animals slaughtered in-country, exports, and losses.

The PSD covers 44 countries for most of the world's cattle production. Since it does not provide a complete picture of the global situation of cattle, to assess the accuracy and representativeness of the PSD data, we compared it with the Food and Agriculture Organization of the United Nations (**FAO**) database, which reports data on cattle for all the countries in the world. We used data from both sources for 2010–2020 and calculated the average percentage of world cattle production that PSD represents. We found that PSD covers 65% of the world's cattle production. We did the same process for pigs. The 38 pig-producing countries (in the PSD database) produce 80% of the world's pig production.

In this section, we describe how we derived the figures for the weight variation in cattle and pigs globally, where the weight distribution of animals is often unknown. Then, we present the PCU formula and data we used to estimate the global AMU for cattle, chickens, and pigs.

Weight variation in the cattle population

From the patterns in the PSD database, we first derived a ratio between the total supply and the ending cattle stocks, averaging over the last five years. This ratio helps us to estimate the total supply of cattle in each period using the available information on the stocks. Then, we examined the data to find the weight variation in the total cattle supply at the global or any aggregated level as follows:

(1) We derived the initial cow population in a year from the sum of the dairy and beef cows at the start of the year. This number was labeled as beginning stocks, indicating the year's potential calf producers.
(2) Our model assumed that the number of cows slaughtered in the previous year could be equivalent to the number of heifers in the current year.
(3) The production value in the current year was defined to be equivalent to the calves born in the current year.
(4) We obtained the number of male cattle older than one year in the current year by subtracting the beginning stocks, heifers, and calves from the ending stocks in the current year.
(5) We estimated the number of bulls older than one year that were slaughtered in the current year by deducting the calves and cows slaughtered in the current year from the total slaughtered in the current year.
(6) Finally, we divided the cattle population into four groups (calves, cows, heifers, and bulls of more than one year) and calculated the proportion of each group in the total cattle supply.

The assumptions and figures discussed above are summarized in Fig. 1. All the calculations were justified by the percentage of the losses that occurred in the current year. The percentage of losses considers the current year's losses and export values. We assume that the losses and export values represent the amount of production that left the production cycle in the current year. The import values were also included in the calculation but were already adjusted to be in the slaughtered values.

Weight variation in the pig population

Like the calculations for cattle, we first derived a ratio between the total pig supply in a year and the number of stocks, which is

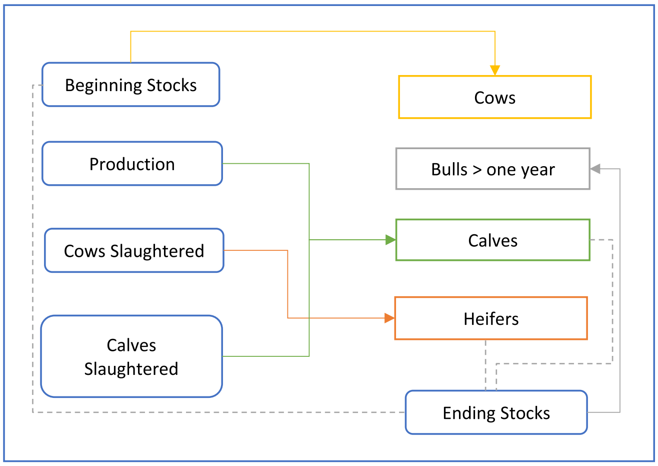

Fig. 1. Weight variation in cattle population from the available data on PSD (blue rectangles). The outputs (colorful rectangles) are the zootechnic categories in a cattle population. Solid arrows have a positive sign, while dash arrows have a negative sign. *Source:* our elaboration from PSD (PSD Online, 2023). Abbreviations: PSD = Production, Supply, and Distribution.

calculated based on the average of the last five years of PSD data. Then, we found the weight variation in the total pig supply as follows:

(1) We assumed that the sows that were present at the end of a given year (ending stock) would be the same as the ones that started the following year (beginning stock).
(2) By subtracting the number of sows slaughtered from the total slaughtered, we estimated the number of pigs slaughtered for meat production.
(3) To calculate the number of pigs not used for breeding at the end of a period (ending pig stock), we subtracted the beginning sow stock from the total ending stock.
(4) Finally, we divided the pig population into two groups (pigs and sows) and calculated the proportions of each zootechnic group in the total supply.

Fig. 2 summarizes the above assumptions and figures discussed. Following the same approach used for cattle calculations, the percentage of losses that accounted for both the losses and the export values of a year were used to justify the calculations for each year.

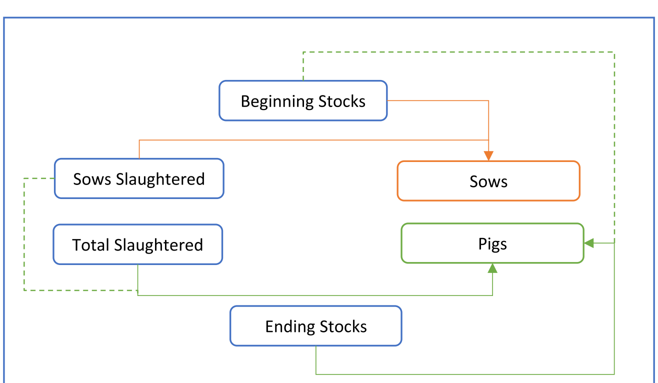

Fig. 2. Weight variation in pig population from the available data on PSD (blue rectangles). The outputs (colorful rectangles) are the zootechnic categories in a pig population. Solid arrows have a positive sign, while dash arrows have a negative sign. *Source:* our elaboration from PSD (PSD Online, 2023). Abbreviations: PSD = Production, Supply, and Distribution.

The import values were also part of the calculation but were already included in the slaughtered values.

Antimicrobial use estimation

We pursued the following process to calculate global AMU in livestock farming:

(1) We converted the world stock heads of cattle and pigs to the total supply in a particular year by the ratios that we found from PSD. The total supply of chicken (broilers) each year is determined by the total production of chickens (broilers). We made this assumption because all the chickens that are distributed to the market are produced in the same year.
(2) Using the proportions we established from the PSD, which show weight variation in cattle and pigs' populations, we found the number of animals by weight in the total supply in a specific year.
(3) We multiplied the number of animals by the average weight at treatment (**AWT**) in each zootechnic category to calculate the total PCU for each animal type.
(4) To quantify the global AMU, we multiplied the estimated PCU by the global average of milligrams per PCU ($mg.PCU^{-1}$) for the chosen species.

These processes are shown by formulas (1) and (2) below:

$$PCU_{ij} \cong \sum_{1}^{n} TS_i \times P_{ij}W_{ij} = \sum\nolimits_{1}^{n}(EN_i \times R_i) \times P_{ij}W_{ij} \quad (1)$$

$$AMU \cong \sum\nolimits_{1}^{n} PCU_i \times mg.PCU_i^{-1} \quad (2)$$

where i is animal type, j is animal zootechnic category, n is the number of zootechnic categories, TS_i is the total annual supply of the animal type, P_{ij} is the proportions of the weight of each zootechnic category in the total supply, and W_{ij} is the AWT by zootechnic category. EN_i is the ending stock of the animal type each year. R_i reflects the ratio between ending stock and the total supply of a particular animal type.

Data

We collected the data on the ending stock of cattle and pigs and the total production of chickens from FAO online database (FAOSTAT, 2023). Data on the AWT for different zootechnic categories of the chosen farmed animals were obtained from the EMA (EMA, 2022). The proportions of each weight zootechnic category in the total supply and the ratio values to convert ending stock to total supply are our estimated values from information available on the PSD online database. Table 1 reports the quantities of AWT (obtained from the EMA), P (estimated from the PSD online database), and R (estimated from the PSD online database) for each zootechnic category. We collected the quantity of antibiotics administered per animal biomass from the existing literature that estimated coefficients on AMU for cattle, chickens, and pigs in 2010, 2017, and 2020 (Table 2) (Boeckel et al., 2015; Tiseo et al., 2020; Mulchandani et al., 2023).

Results

To illustrate the changes in the global AMU in major livestock sectors over the last decade, we used FAO data on livestock numbers for 2010, 2017, and 2020 and calculated the PCU using our approach. We picked these years because we have the estimated amounts of antibiotics per PCU for them. Then, we multiplied the

Table 1
Quantities of AWT, P, and R for the zootechnical categories of cattle, chickens, and pigs; *Source:* (European Medicines Agency, 2022), and our elaboration from PSD (PSD Online, 2023).

Zootechnic categories	AWT (kg)	P (%)	R (ratio)
Cattle	–	–	1.31
Calves	140	26	–
Cows	425	41	–
Heifers	200	4	–
Bulls > one year	425	29	–
Chickens	–	–	1
Broilers	1	100	–
Pigs	–	–	2.72
Pigs	65	96	–
Sows	240	4	–

Abbreviations: PSD = Production, Supply, and Distribution; AWT = average weight at treatment[1]; P = proportions[2]; R = ratio[3].
[1]Average weight at treatment is the average weight of each animal category at the time of treatment with antibiotics estimated by the European Medicines Agency (2022).
[2]Proportions are the distribution of each zootechnic category in the global population of each species according to our estimations.
[3]Ratio is the relation between the total supply of an animal to the ending stocks within a year according to our estimations.

Table 2
Global average of quantities of antibiotics measured (mg.PCU^{-1}) for cattle, chickens, and pigs; *Source:* (Boeckel et al., 2015; Tiseo et al., 2020; Mulchandani et al., 2023).

Years vs. animal types	Cattle	Chickens	Pigs
2010	45	148	172
2017	42	68	193
2020	59.6	35.4	173.1

Abbreviations: PCU = Population Correction Unit.

PCU estimates by the amounts of antibiotics per PCU and showed the global AMU trends. Fig. 3 illustrates the variations in global PCU (a), global average of mg.PCU^{-1} (b), and global AMU (c) for the chosen livestock farming in the last decade.

The global cattle PCU and AMU have both increased between 2010 and 2020. The PCU of cattle, which measures the biomass of animals that may receive antibiotics, rose 8% from 2010 to 2020, reaching 684.90 million tonnes (**mt**) from 634.65 mt. The AMU coefficient, which measures the amount of antibiotics used per PCU, increased by 32% in the same period, reaching 59.6 mg.PCU^{-1} from 45 mg.PCU^{-1}. As a result, the total amount of antibiotics used in the cattle sector was estimated at 40 820 tonnes in 2020, a 43% increase from 2010. Most of this increase was driven by the higher AMU coefficient rather than the higher PCU.

Despite increasing production, the chicken industry has shown remarkable progress in reducing AMU over the past decade. According to the data, the total PCU of chickens rose 38% from 96 942 mt in 2010 to 133 811 mt in 2020. However, the global AMU in this sector dropped by 67% from 14 347.37 mt in 2010 to 4 736.91 mt in 2020, meaning that the average AMU in the chicken sector decreased 76% from 148 mg.PCU^{-1} in 2010 to 35.4 mg.PCU^{-1} in 2020. This decline in AMU shows the effort of the chicken industry to a more responsible and prudent use of antimicrobials.

According to the data, the global PCU of pigs rose slightly from 190.48 mt in 2010 to 191.52 mt in 2017 but dropped to 183.77 mt in 2020 because African Swine Fever in 2019 reduced pig production (Mason-D'Croz et al., 2020). The average AMU per pig also fluctuated, increasing from 172 mg.PCU^{-1} in 2010 to 193 mg.PCU^{-1} in 2017, and then decreasing to 173.1 mg.PCU^{-1} in 2020. As a result, the total AMU in the pig sector increased from 32 763 tonnes in 2010 to 36 964 tonnes in 2017 and then decreased to 31 811 tonnes in 2020. The changes in AMU reflect the combined effects of changes in PCU and mg.PCU^{-1}.

Finally, using the data available at the FAO for the last three years (2019–2021) and the latest available value of mg.PCU^{-1} for

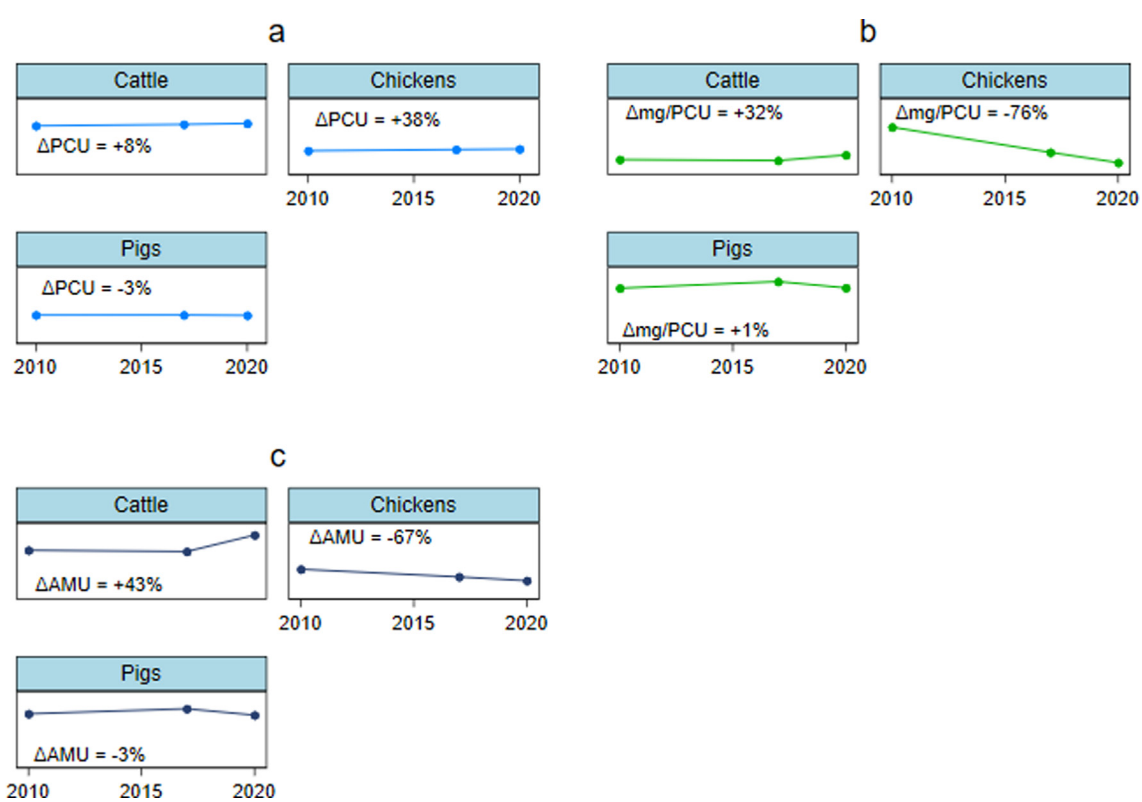

Fig. 3. (a) Changes in global PCU (million tonnes), (b) changes in global antibiotic use in mg per PCU, and (c) changes in global AMU (thousand tonnes) for cattle, chickens, and pigs; between 2010 and 2020. *Source:* own calculations. Abbreviations: PCU = Population Correction Unit; AMU = Antibiotic Use.

each of the selected species (cattle, chicken, and pig) in 2020, we quantified the global PCU and AMU in cattle, chicken, and pig farming. We adjusted the PCU calculation by considering the weight variation within each animal category. Fig. 4 illustrates that the selected livestock farming consumed 76 060 tonnes of antibiotics on average from 2019 to 2021, corresponding to 982 million tonnes of PCU. Among the three types of livestock, cattle accounted for the largest share of AMU, with 40 697 tonnes, representing 53.5% of the total AMU and 683 million tonnes of PCU. Pigs followed with 31 120 tonnes of AMU, equivalent to 40.9% of the total, and 180 million tonnes of PCU. Chickens had the smallest AMU of 4 243 tonnes, only 5.6% of the total, and 120 million tonnes of PCU.

Discussion

Based on the latest information available at the FAO (FAOSTAT, 2023), the production of beef increased from 65 mt in 2010 to 72 mt in 2021, while the production of milk increased from 597 mt in 2010 to 746 mt in 2021. The production of eggs and chicken meat also increased from 70 mt and 99 mt in 2010 to 93 mt and 138 mt in 2021, respectively. The pig meat production increased from 108 mt in 2010 to 120 mt in 2021. The figures show how the rise in production satisfies a growing global demand of animal products, especially from the cattle, chicken, and pig sectors (Torres et al., 2021; Gil, 2023).

The overuse and misuse of antibiotics have major implications for the emergence and spread of AMR, which threatens global health (Torres et al., 2021). Consequently, monitoring AMU is essential for developing effective regulations and policies to prevent or reduce the misuse or overuse of antibiotics in livestock farming (Patel et al., 2020), and in human health care (Shallcross and Davies, 2014). In this study, we aimed to develop a new approach to quantify the global AMU in livestock farming more accurately and consistently. One of the ways to measure the amount of AMU in livestock farming is to calculate the PCU. The PCU is a standard unit that represents animals' estimated weight when they are treated with antibiotics. It can be obtained by multiplying the number of animals by their average weight during antibiotic treatment. We then multiplied the PCU and the quantity of antibiotics in mg.PCU^{-1}, to estimate the AMU in livestock farming at global or aggregated levels.

The calculation of PCU for different types of animals can vary depending on their production cycle and purpose. The PCU calculation can be easy for animals such as broilers that are raised and slaughtered within a year. However, the PCU calculation can be more complex and challenging for animals that are kept for extended periods or have multiple purposes, such as dairy cows, laying hens, or breeding sows. For these animals, the PCU may only reflect the actual exposure to antibiotics or the potential risk of AMR if we include the weight variation of these animals in the PCU calculation (Brault et al., 2019). Using the PSD time series database, we have developed an approach to estimate the distribution of cattle and pigs in an animal population by weight variation. This approach splits the total supply of cattle into four categories: calves, cows, heifers, and bulls of more than one year, and the total supply of pigs into pigs and sows. It helps us to address the gap where the data do not provide the number of animals in the different livestock categories.

Our estimations on AMU in global cattle, chicken, and pig production, 76 060 tonnes of antibiotic active ingredients, are lower than those of Mulchandani et al. (2023), who reported a total of 99 502 tonnes used for the same animal species and sheep in 2020. We also calculated the PCU for the three main species in 2017 using the same methodology, obtaining a global AMU of 73 291 tonnes, less than the 93 309 tonnes estimated by Tiseo

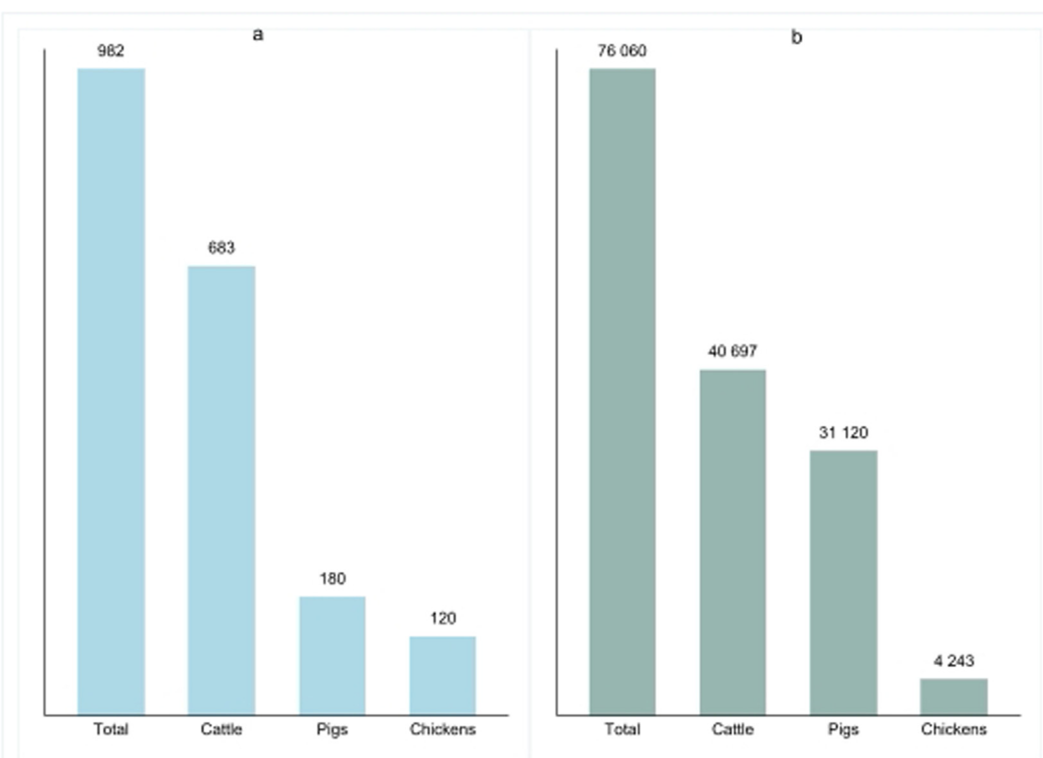

Fig. 4. (a) Global PCU (million tonnes) and (b) Global AMU (tonnes) quantified in livestock farming, averaged from 2019 to 2021. *Source:* own calculations. Abbreviations: PCU = Population Correction Unit; AMU = Antibiotic Use.

et al. (2020) for that year. The WOAH AMU assessment calculated the global AMU on food animals at 76 704 tonnes in 2018, based on sales and import data, which strengthens our results.

Moreover, we tested our approach on the Danish pig industry. We got the total number of pigs in Denmark on 1 January 2020 from the Danish Agriculture and Food Council, 12 728 (Danish Agriculture and Food Counsil, 2021), AWT for pigs (50 kg) and sows (200 kg), and the specific mg.PCU^{-1} (43.27) from Moura et al. (2023). Using this information and our method, we estimated the total AMU in the Danish pig industry at 83.97 tonnes, slightly more than Moura et al. (2023) reported at 75.9 tonnes (Moura et al., 2023) and 74.38 tonnes by DANMAP (DANMAP, 2021) but still similar.

Among the main limitations of our study, we can mention the use of the EMA standards of AWT as a global proxy; however, such standards may vary across different countries and regions. Furthermore, lacking alternatives, we adopted the same coefficients of global average AMU on farmed animals in mg.PCU^{-1} for cattle, chickens, and pigs calculated by Boeckel et al. (2015), Tiseo et al. (2020), and Mulchandani et al. (2023), which could not be calibrated for the AWT estimated by the EMA. These elements (AWT and mg.PCU^{-1}) may impact our findings.

Conclusions

The lack of data on veterinary antibiotics makes it difficult to estimate AMU in livestock farming. Many countries do not collect or release such data in a standardized and disaggregated way. Therefore, researchers must rely on data from a few countries, mainly developed countries, and extrapolate them to the rest of the world using different assumptions and methods. These limitations and uncertainties can affect the accuracy and validity of the estimates and limit the ability to monitor and evaluate the progress and outcomes of actions taken to address AMR. In this study, we derived age and sex distributional benchmarks for cattle and pigs that can be applied at any level of aggregation without the need for age-specific animal numbers. Our global AMU estimate for cattle, chickens, and pigs differed substantially from previous estimates, showing a lower value. The main reason for this discrepancy was that our PCU calculation considered the average weight of the animals by age and sex when they received antibiotics, while the previous studies used the live weight of the animals at slaughter.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data and models that support the study findings are available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

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CRediT authorship contribution statement

Zahra Ardakani: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Maurizio Aragrande:** Writing – review & editing, Validation, Investigation, Conceptualization. **Massimo Canali:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization, Funding acquisition.

Declaration of interest

None.

Acknowledgements

None.

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