INTERDISCIPLINARY APPROACHES TO ANTIMICROBIAL USE IN LIVESTOCK FARMING

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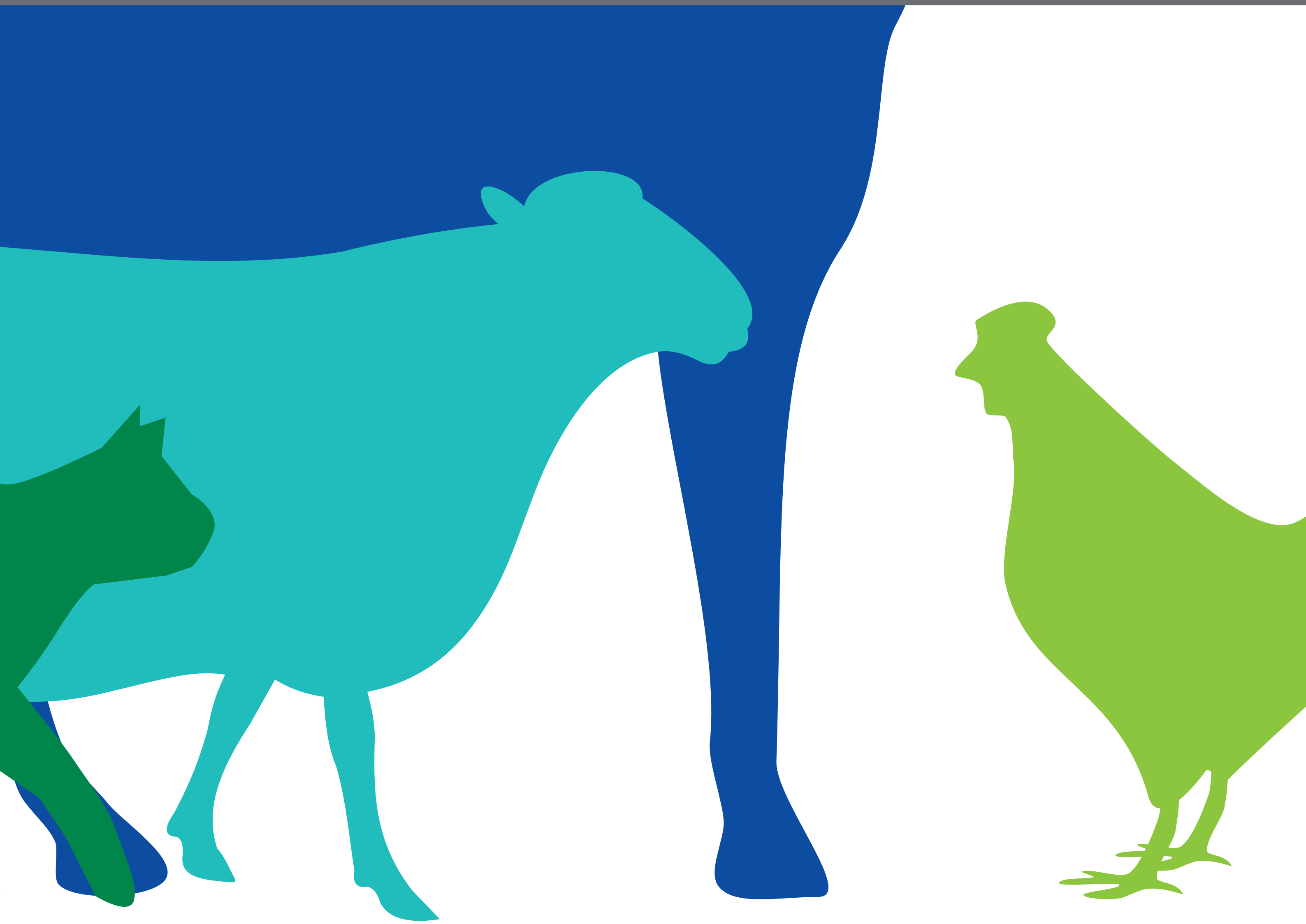

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INTERDISCIPLINARY APPROACHES TO ANTIMICROBIAL USE IN LIVESTOCK FARMING

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Editorial: Interdisciplinary approaches to antimicrobial use in livestock farming

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KEYWORDS

antimicrobial resistance, livestock farming, social sciences, interdisciplinarity, complexity

Editorial on the Research Topic
Interdisciplinary approaches to antimicrobial use in livestock farming

When we first set out to put together a collection that reflected interdisciplinary scholarship on antimicrobial resistance (AMR) in livestock agriculture settings, we wanted to weave together two research threads that seemed to have been running in parallel. The first one, mostly built by veterinarians experimenting with qualitative methods, looks to understand the human contribution to a problem of evolutionary genetics and public health. The second, developed mostly by social scientists, explores the ways in which the AMR problem is framed and what its governance approaches reveal about our ideas of nature, politics, and health. Both strands have continued to grow.

Veterinarians have continued to explore stakeholder perceptions and practises and assess governance landscapes and interventions. Landfried et al. (1) for example, expanded the geographical scope of case studies by looking at veterinarians' prescriptions decisions in Missouri and added goats to the list of species-specific articles. Their study problematises the causal relationship between prescriptions and residue levels as the latter are higher than in other U.S. states even though antibiotics are prescribed in <50% of veterinary visits in Missouri. Meanwhile, Bennani et al. (2) examined the intricacy of UK surveillance systems and revealed inconsistencies in the integration of its 30 key organisations, processes, data sources and working relationships with six international networks.

On the other hand, sociologists Cañada et al. (3) also looked at governance approaches but used ethics as a lens. Their study denounced the intrinsically anthropocentric nature of the public health framing of AMR and argued for alternative ethics that are not founded on human exceptionalism. This interest in how and with what consequences AMR has been framed is recurrent. Hughes et al. (4) for example, take issue with the targets-approach of public and private regulators along the food supply chain and its governing bodies. Similar to Cañada et al., Chandler (5) identifies how the emphasis on individual behaviour change is inconsistent with the connectedness implicit in the One Health approach with which AMR is persistently presented. Chandler shifts the focus from those who prescribe or use antibiotics to antibiotics themselves as materials that harness interspecies relations and make them governable and examines their roles in weaving together the fabric of modern medicine and health systems, and invites us to take seriously the problems that AMR has made visible: our dependence on antibiotics, the risks, and demands of commercial farming and the conditions of increased density in populations, be they animal or human [see also Jamie and Sharples (6)]. This call to understand AMR as a problem that emerges within structural processes of neoliberalisation and the injustices of the global economic system is also made by Dutescu (7) who lays the blame squarely on neoliberalism not only for the emergence of AMR but also for the ineffective behavioural interventions favoured by national and international approaches. Likewise Doron and Broom (8), warn of us of the disproportionate impact of AMR that will deepen global inequalities. Helliwell et al. (9) offer an additional set of warnings, this time related to how the governance of agricultural AMR in the UK places the responsibilities for both the problem and its solution on farmers and veterinarians yet limits their agency when no other elements of the context in which they operate are changed because its concern with animal health is about productivity rather than actual health and welfare.

There are four main ideas that are common to both research strands. First, AMR is a complex problem. Second, dealing with it requires more than behavioural and regulatory approaches because, third, on-farm decisions are not only contingent on context but are also deeply entangled with global and national food systems, agricultural support structures, and veterinary medicine regimes. Thus, and fourth, dealing with AMR calls for a critical and interdisciplinary examination of these systems, structures, and regimes and the inequalities embedded within them. These themes also run through the articles in this Research Topic.

Adam et al. identify external factors that affect transitions to different practices, including the role of slaughterers and distributors as well as that of tangible and intangible objects and materials such as feed and chick quality, vaccines, and alternative medicines. Complexity, they argue, is not limited to the decision to change but extends to the long-term process of transition. Baudoin et al. echo this conclusion and add that success will not only be a matter of long-term support but also of working with temporal and spatial contexts. Doidge et al. add emotions as an additional dimension of complexity, while Hellec et al. bring gender into the picture. Bâtie et al. reveal that in Low and Middle Income Countries this complexity is amplified by structural issues like the number and distribution of veterinarians and their lack of monopoly over the prescription and sale of veterinary medicines. The other two papers looking at LMICs add further elements to this complexity. Jaime et al. step away from behavioural characterisations of AMU as rational, prudent, or responsible and focus instead on the global, national and local agricultural systems through which antibiotics and other veterinary medicines circulate. The logic behind these systems has been transformed from a population health to a market approach where antibiotics have become commodities rather than public goods. In these market economies, Masud et al. elaborate, access appears more determinant than usage attitudes: there is indiscriminate access to too many medicines by too many actors, who at the same time have little access to knowledge and information. Begemann et al. document how market approaches have also led to interventions with unexpected consequences like farmers using residue tests to optimise waste milk management. In turn, Buller et al. tell us that, in their own relationship to the market economy, veterinarians are conflicted about the potential role of diagnostic tools at the farm: farmers making evidence-driven decisions about antibiotic usage is good news but being replaced as figures of authority in health management decisions is not. Redding et al. and Skjølstrup et al. focus too on the farmer-vet relationship, the former looking at the individual factors in play in prescription decisions while the latter adds the external factors to create a model of decision-making complexity.

This Research Topic covers multiple species and locations with a variety of theoretical and methodological approaches that mirror the diverse disciplines and fields the authors represent and the complexity of the problem itself. To deal with this complexity, all the authors agree, inter-and multidisciplinary approaches are essential.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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ORIGINAL RESEARCH
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Drivers of Antibiotic Use in Poultry Production in Bangladesh: Dependencies and Dynamics of a Patron-Client Relationship

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Background: There is increasing concern around the use of antibiotics in animal food production and the risk of transmission of antimicrobial resistance within the food chain. In many low and middle-income countries, including Bangladesh, the commercial poultry sector comprises small-scale producers who are dependent on credit from poultry dealers to buy day-old chicks and poultry feed. The same dealers also supply and promote antibiotics. The credit system is reliant upon informal relationships among multiple actors as part of social capital. This paper aims to describe dependencies and relationships between different actors within unregulated broiler poultry production systems to understand the social and contextual determinants of antibiotic use in low-resource settings.

Methods: We used a cross-sectional qualitative design including in-depth interviews among purposefully selected commercial poultry farmers ($n = 10$), poultry dealers ($n = 5$), sales representatives of livestock pharmaceutical companies ($n = 3$) and the local government livestock officer as a key-informant ($n = 1$). We describe the food production cycle and practices relating to credit purchases and sales using social capital theory.

Findings: Poultry dealers provide credit and information for small-scale poultry farmers to initiate and operate their business. In return for credit, farmers are obliged to buy poultry feed and medicine from their dealer and sell their market-ready poultry to that same dealer. All farms applied multiple antibiotics to poultry throughout the production cycle, including banned antibiotics such as colistin sulfate. The relationship between dealers and poultry farmers is reciprocal but mostly regulated by the dealers. Dealers were the main influencers of decision-making by farmers, particularly around antibiotic use as an integral part of the production cycle risk management. Our findings suggest that strategies to improve antibiotic stewardship and responsible use should exploit the patron-client relationship which provides the social and information network for small-scale farmers.

Conclusion: Social capital theory can be applied to the patron-client relationship observed among poultry farmers and dealers in Bangladesh to identify influences on decision making and antibiotic use. Within unregulated food production systems, strategies to promote the prudent use of antibiotics should target commercial feed producers and livestock pharmaceutical manufacturers as a first step in developing a sustainable poultry value chain.

Keywords: small-scale commercial poultry farms, antibiotics, credit, dependencies, patron-client relationship, antimicrobial resistance

INTRODUCTION

Demand for animal sourced protein for human consumption has increased from 7 to 25 g per capita per day between 1960 and 2013 (1) due to increased access to information on meeting nutritional requirements and higher purchasing ability in low and middle-income countries (LMICs) (2).

In Bangladesh, ∼37% of all animal protein meat consumption originates from poultry (3). Small-scale commercial broiler poultry farms, defined as those having <5,000 birds in each batch (4), comprise 81% of the commercial poultry sector (3) providing about 78% of the total poultry meat supply in Bangladesh (5). Small-scale broiler farms are typically traditional open system broiler houses with natural ventilation, manual feeding and open-sided walls. They are usually built on the land surrounding the homestead with locally available low-cost materials and often rely on family labor (6).

These poultry farmers have limited working capital, poor access to formal credit and also have limited information on market opportunities or new technologies (7). For example, small-scale commercial poultry farmers cannot afford to buy day-old chicks and poultry feed directly from the hatcheries or feed manufacturing companies and thus depend on dealers or agents who provide a credit system (8). This credit system in turn provides social networks and relationships, described in social capital theory, through which information can flow. For example these networks can convey useful information about opportunities and choices, as well as information about market needs (9, 10).

Social networks can also affect decision making, influenced through the credit system (9). Within the food value chain, there are multilevel relationships among different actors which can be defined as social capital captured in the form of social relationships with expected returns, either formal or informal, generated by individuals in their interaction with other individuals (11). Social capital can also facilitate access to information, allowing the coordination of activities, and ultimately influencing decision-making (12).

There is increasing concern around the use of antibiotics in animal food production and the risk that poses antimicrobial resistance transmission in the food chain (13). In small-scale commercial broiler farms in Bangladesh, antibiotics are more likely to be used without veterinary supervision for therapeutic purposes. Antibiotics are also used in sub-therapeutic doses by adding them to feed and water for prophylaxis, growth promotion and as a risk-management strategy (4). Sub-optimal antibiotic prescribing and use is prevalent in both human medicine and livestock production as a means of managing risk (14). In Bangladesh, the Animal Feed Act prohibits the use of antibiotics in feed (15). However, anecdotally poultry farmers circumvent the law by including antibiotics in drinking water provided to broilers. Moreover, governance and monitoring of small-scale producers is weak.

The scientific community assigns both social context and entrepreneurs' behavior a central role in the growth and development of the global economy. However, the relationships between these two factors have not been sufficiently studied in business and economics (9). Few studies have examined the social and economic drivers of antibiotic use in unregulated food production systems. As part of a study to determine drivers of antibiotic use in poultry production, this paper aims to describe the nature of dependencies and reciprocal relationships between different actors in small-scale broiler poultry production (social networks) and how the dependent relationships influence farmers' decisions to use antibiotics to raise broilers. We aimed to examine the social and contextual determinants of antibiotic use in low resource settings where antimicrobial resistance poses increasing health risks to socially and economically disadvantaged populations.

MATERIALS AND METHODS

Study Area, Study Participants, and Sample Size

Small-scale non-intensive poultry farming is predominantly located in rural and peri-urban areas of Bangladesh. Our study was conducted in a rural area of *Mirzapur Upazila* (sub-district) under *Tangail* district, ∼70 km from the capital city, Dhaka, where the poultry industry constitutes a significant part of the local economy. *Mirzapur* has a total area of 373.88 km^2 and has a population of 423,708 (16). Small-scale poultry farms in this area were made of rudimentary housing structures with bamboo or concrete or mud floors which were covered with rice bran as bedding. Walls were typically built with tin and chicken wire for ventilation. A plastic cover on top of the chicken wire, could be folded up or down for protection (17).

We used cross-sectional qualitative methods. We used purposive sampling to enroll participants for face-to-face in-depth interviews. We collected a list of broiler poultry farms and identified 10 small-scale commercial poultry farms (<5,000 birds) from different unions within *Mirzapur Upazila* and interviewed farm workers ($n = 10$) in their poultry premises. We asked poultry farmers to name some leading livestock pharmaceutical companies who had been marketing their products in the local market. We also collected mobile phone numbers of the sales representatives of the respective companies from the farmers. We ranked top three pharmaceuticals companies from the list and communicated them by phone. We interviewed sales representatives ($n = 3$) in their convenient time and locations within their working areas. We conducted in-depth interviews with poultry dealers ($n = 5$) representing each of the top five poultry feed brands cited by farmers. Poultry dealers supply day-old chicks, poultry feed, and medicines. They also purchase mature market-ready birds from the poultry farmers.

Additionally, the local sub-district *(Upazila)* government livestock officer was interviewed as a key-informant ($n = 1$) in the local government livestock office. The livestock officer was a government recruited qualified veterinarian with responsibility to ensure the deployment of government poultry development policies such as; formation of poultry smallholder groups, community based organizations and producer associations, quality control of poultry feeds, and feed ingredients, supervision of the veterinarian prescribing antibiotics and other medications, registration of all commercial poultry farms with the department of livestock services, support in planning and implementation of all livestock related extension activities at the grass-root level and ensuring biosafety and biosecurity on farms.

Data Collection

Data collection was performed during July–September, 2017 by a trained single researcher who had a social science background. In-depth and key-informant interview guidelines were developed based on the research objectives and relevant literature. In addition, a checklist was developed for use for spot observations to record medicines, supplements, additives used together with poultry feed products on the farms. Both interview guidelines and checklist for spot observation were field-tested before implementing the study. Interviews were conducted after obtaining informed consent from the study participants. Data collection was carried out in Bengali language. Interviews with participants were audio-recorded and field notes used for additional information. Medicines used by farmers were photographed to help complete the checklist. During analysis, a veterinary physician categorized all the items into antibiotic and non-antibiotic medicines.

Data Analysis

Anonymized transcription of audio-recordings was carried out in Bengali language. Based on our literature review and research questions, we used a thematic data analysis, which is a systematic approach to data analysis used to analyze classifications. This provides the opportunity to code and categorize data into themes; present themes (patterns) that relate to the data; illustrate the data in great detail, and deals with diverse subjects via interpretations. In addition, the thematic analysis allows the researcher to determine precisely the relationships and coherence between concepts (18). In thematic analysis, we used both inductive and deductive approaches (19). We prepared deductive codes based on research questions and existing literature and inductive codes identified from the interview transcripts. Transcripts were coded using both deductive and inductive approaches and compiled in MS Excel. We followed the recommended steps of thematic approach namely: data familiarization; generating initial codes; searching for themes; reviewing potential themes; defining and naming themes and producing the report (19). To check the coding reliability, two individual researchers independently coded the same data and reviewed the codes applied.

We described findings under key components of social capital theory; information flow and decision making. Additionally, a conceptual framework for the patron-client relationship between farmers and poultry dealers was developed. We reached data saturation within the sample size.

RESULTS

Characteristics of Study Participants

The poultry farmers were male, aged between 20 and 47 years and had worked in poultry farming for between 1 and 24 years. Among the 10 farmers, 8 had high school education. For all participants, poultry farming was the main income source with some supplementary income from seasonal crops. The majority reported a monthly income between 10,001 and 20,000 Taka (US$ 121–241) from their poultry business. The flock size of the farms ranged from 500 to 1,300 birds on the day of interview. Interviewed poultry dealers had been in the trade from 7 to 17 years and their age was between 39 and 47 years all being male. Three out of 5 dealers had completed secondary education. The pharmaceutical sales representatives were male, completed graduation from university and had been in the field of livestock medicine marketing from 2 to 5 years. The sub-district *(Upazila)* government livestock officer who interviewed as a key-informant was male and had been working in the *Mirzapur* sub-district for 2 years.

Role of Farmers and Poultry Dealers/Credit Based Marketing

Poultry farmers reported that while starting up their farm, they usually consulted with other farmers and poultry dealers to determine the estimated cost required for installation of poultry sheds and equipment. Most interviewed farmers started poultry production with only a poultry shed/pen and some basic equipment such as; water feeders, feeding tray and brooders (heating equipment). They usually bought day-old chicks, poultry feed, medicines and additives from a poultry dealer based on their personal relationship and a credit facility. Poultry dealers reported that they also informed new farmers about the support that they can provide (e.g., credit purchase, selling poultry). *"Few years back, I have shown my interest to start farming and consulted with a dealer. He said, if I feel encouraged enough, then he will give full support to start a poultry farm. Then I started my farm and purchased everything on credit from dealer."* [Commercial poultry farmer, age-35].

The key-informant reported that dealers often impose some preconditions to the credit receivers such that the farmers are bound to buy all feeds and medicines from that respective dealer for the entire period of poultry nurturing and that the farmers sell all mature, market-ready poultry to that respective dealer. *"If you receive any favor from any person, you will naturally have a good impression about that person and take his advice."* [Livestock officer of sub-district].

Farmers reported that they did not have many options when choosing poultry feed, because it was determined by what was offered by their respective poultry dealer. Poultry feed was also obtained on credit. *"I started my business with a small capital and purchased day-old chicks and feed from a dealer on credit…Therefore, we have no opinion or option to choose… We purchase whatever they have and whatever they suggest. We repay our credit by selling all ready-for-sale poultry to them."* [Commercial poultry farmer, age-28].

Poultry dealers reported that when they started their business, they sold a range of poultry feed brands. Based on the comparisons among different brands and feedback from poultry farmers, dealers decided on the most popular and profitable brands to market; feed companies also provided dealers with reasonable credit facilities for their business. *"First, I started my business with some different brands. Finally, I tied up with a particular brand, when they assured me that they will provide products with highest credit facilities, because we sell most of the products on credit."* [Poultry dealer, age-40]. Poultry dealers reported that they have direct interactions with poultry hatcheries, poultry feed and pharmaceutical manufacturing companies. Feed companies give credit purchase facilities by fixing a sales target for one poultry dealer, who acts as the sole distributor of that feed brand in one *upazila*. For example, one dealer reported that 50 tons (1,000 bags) of poultry feed was the sales target for 1 month. If a dealer achieves the sales target, they receive Taka 20–25 (US$0.23–0.29) per bag of feed sold. The amount of commission is around US$250 to 300 per month for 50 tons of feed. Poultry dealers also reported that for renowned and popular medicine brands, they usually pay cash, but a credit facility is also available for up to 30 days. If dealers pay cash for medicines instead of credit, they get different percentages of commission for different products. *"As we sell everything on credit to the commercial poultry farmers, we therefore prefer credit purchase from the medicine company."* [Poultry dealer, age-40].

Both dealers and farmers reported that credit facilities, both for sales and purchase, depend on "a good relationship" which they consider a bilateral requirement that stands upon "trustworthiness" and previous "healthy" financial transactions. The key-informant reported that over the last 10 years there has been an increasing trend of credit-based business established through the entire supply chain to sustain a competitive market. Feed and pharmaceutical manufacturers often provide credit facilities to the dealers so that they can expand their business.

Role of Pharmaceutical Company Sales Representatives

Sales representatives are another group participating in the broiler production social network. They reported that the pharmaceutical company set sales targets. The target varied by season, but the average sales target was Taka 600,000−800,000 (∼US$ 7,000–10,000) per month. There were peaks in demand for antibiotics by season for poultry and other farm animals. *"We are often given some targets. In the case of poultry, the target is higher during winter when disease occurrence is higher than other months. We are bound to achieve the target"* [Pharmaceutical sales representative, age-31].

Sales representatives reported that they perform a range of activities to achieve their sales targets. They arrange workshops for the farmers and dealers to provide basic information about the application of different medicines including antibiotics. Sales representatives visit government staff including *Upazila* livestock officers, *Upazila* veterinary surgeons, veterinary field assistants, and poultry dealers on a regular basis and brief them on the latest products and provide promotional offers or incentives. *"The company will never give you any target that is easily achievable. Meeting targets mostly depends on how we can motivate veterinarians to prescribe our medicine."* [Pharmaceuticals sales representative, age-30].

Sales representatives reported that feed companies, pharmaceutical companies and hatcheries provide farmers with veterinary treatment service for their broilers free of cost. Sales representatives facilitate these services to the farmers through the poultry dealers. Sales representatives reported that "a good relationship" with dealers and veterinarians often helps them achieve sales targets.

Information Flow- Farmers' Knowledge on Antibiotic Application for Poultry Raising

Some poultry dealers reported that they learn how to treat common diseases by following veterinarians' prescriptions. Others learned through feedback from other farmers after applying antibiotics for a specific disease. Dealers apply this combined knowledge whenever any farmer reports concern over poultry disease to them. If the antibiotic does not work or the disease spreads rapidly, then they ask veterinarians from the feed or pharmaceutical company for possible solutions. *"About 80% of poultry farmers maintain their poultry by gathering experience from dealers and sales representatives. Only 20% of farmers consult with the veterinarians when they are unable to control disease and death of poultry."* [Pharmaceuticals sales representative, age-30].

The key-informant reported that in most instances, sales representatives also provide treatment advice directly to the farmers. Sales representatives reported that pharmaceutical companies provide product manuals for distribution among poultry dealers, which list symptoms of the disease and the appropriate treatment. Small-scale commercial poultry farmers were able to identify very few medicines as antibiotics among all medicines that they apply everyday to poultry; instead they explained the purpose of using medicines. *"We describe the symptoms of the disease to the dealers or sales representative and they suggest medicine accordingly."* [Commercial poultry farmer, age-28].

Decision Making- Antibiotic Application for Broiler Production

Spot observations and interviews showed that all commercial poultry farmers used antibiotics throughout the poultry production cycle (**Table 1**, **Figure 1**). The most common antibiotics observed at the time of interview were ciprofloxacin and doxycycline (7/10 farms), followed by tylosin and doxycycline (combination), oxytetracycline, enrofloxacin, and erythromycin (6/10 farms). Colistin sulfate was used by 5 of the 10 surveyed farms. Multiple antibiotics were used on the same farm.

Administration of antibiotics started from day 1 and continued until sale of mature live birds, based on recommendation by dealers. **Table 2** summarizes the antibiotics administered routinely, according to the age of poultry and the reasons given by farmers and dealers for their use. *"I use medicine routinely for the entire period from day one to the last day to prevent my poultry from disease and for better growth."* [Commercial poultry farmer, age-45]. Use of antibiotics was therefore for prevention of diseases in some cases. Poultry dealers and farmers reported that some diseases occur seasonally; hence different antibiotics were applied in each season. For example, *Gumboro* (a highly contagious acute viral infectious disease in chickens) occurs at the end of the rainy season (August/September). Dealers reported that, during winter (December to February), farmers fear "bird" (avian) flu and therefore apply antibiotics for prevention. This was confirmed by the poultry farmers who reported that they apply antibiotics more during winter compared to other seasons, because winter is the bird flu season. Farmers reported that they fear epidemics and said once a disease breaks out; it is difficult to save the flock. If any poultry appear unwell, farmers apply antibiotics to all birds. During spot observations we found a wide spectrum of antibiotics that farmers had used for disease prevention in all farms (**Table 2**).

TABLE 1 | Antibiotics used in small-scale commercial poultry farms during spot-checks.

Generic name	Number of farms using antibiotics ($N = 10$)
Ciprofloxacin	7
Doxycycline	7
Tylosin + Doxycycline	6
Oxytetracycline	6
Enrofloxacin	6
Erythromycin	6
Amoxicillin	5
Colistin sulfate	5
Levofloxacin	4
Erythromycin + Trimethoprim + Sulphadiazine	4
Gentamicin + Enrofloxacin	4
Telcomycin	4
Sulphamethoxazole + Trimethoprim	3

TABLE 2 | Antibiotics routinely used in small scale commercial poultry farms reported during in-depth interviews.

Time of antibiotic application	Generic name of the antibiotic	Reported reason for use
Within first 10 days	Amoxicillin	To prevent bacterial infections
Within first 10 days	Endocyn	To prevent fungal infections
Anytime but especially in first 10 days	Oxytetracycline Hydrochloride	Growth promotion
Second 10 days	Doxycycline	To prevent respiratory disease
Day 18–20 (high use during winter)	Erythromycin Thiocyanate, Sulfadiazine Sodium, Trimethoprim composition	To prevent flu and cold
During rainy season	Ciprofloxacin	To prevent *Gumboro* (Highly contagious acute viral infectious disease in chickens)
When one or two poultry identified with symptoms	Ciprofloxacin	To prevent watery lime feces

FIGURE 1 | Application of antibiotics in poultry feed and drinking water.

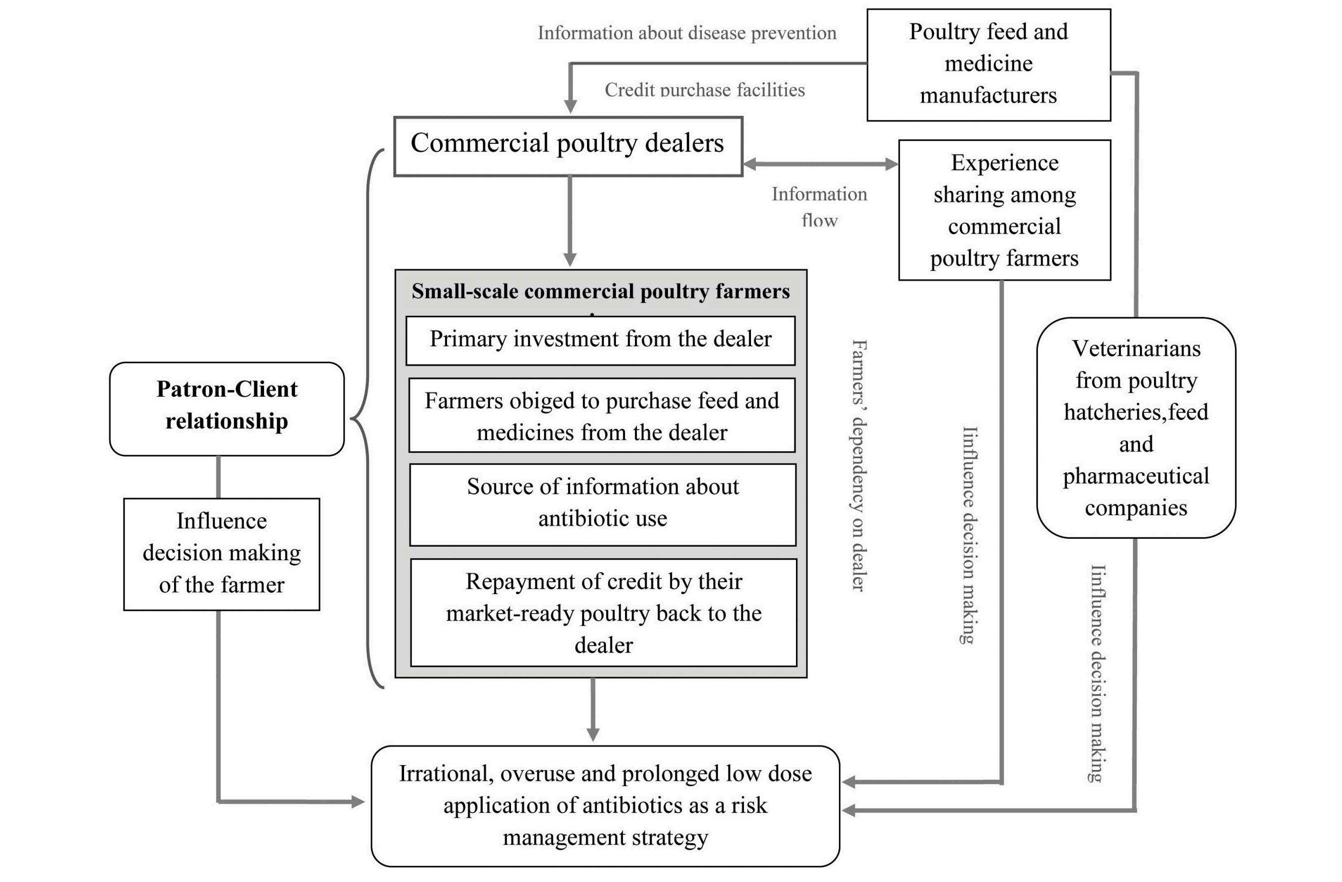

FIGURE 2 | Factors that influence farmers' decisions on antibiotic use in broiler production.

Pharmaceutical sales representatives reported that the reliance on antibiotic use is higher among small poultry farmers who have limited capital, small investment and receive substantial credit from the dealer. *"Small and medium-scale poultry farmers use more antibiotics because they have small capital and huge credit, therefore they do not want to take any risk."* [Pharmaceuticals sales representative, age-31].

Patron-Client Relationship

The roles of farmers, dealers, and pharmaceutical company sales representatives in poultry rearing were intimately linked; these data were used to develop a conceptual framework of the patron-client relationship (**Figure 2**). Dealers invest in the poultry farms from start up through credit purchase with preconditions that the farmers buy all feed and medicines from them for the entire production cycle. Farmers are also obligated to sell the mature, market-ready poultry back to the same dealer. The credit arrangement therefore provides an unwritten contractual agreement between the credit receivers (poultry farmers) and a specific dealer. The dealers control information flow from pharmaceutical companies regarding disease prevention and growth promotion. In addition, they provide information of the retail market about how to maximize the farmer's return on investment. Both the information about disease prevention and market information impact farmer's decision making.

The key informant defined this relationship between dealers and poultry farmers as a "gentleman's agreement," where both parties protect their own benefit *"The relationship among poultry dealers and poultry farmers seems very harmless. That's why I say it is a 'gentleman's agreement', where both dealers and farmers look for their own benefits and never complain about each other. The relationship stands on a gentleman's agreement so the government and any authority can't get access to this relationship."* [Livestock officer of sub-district].

Both the key informant and farmers reported that when there is an adverse outcome (such as: mortality, epidemic, low bird weight) the farmer bears the full cost *"We buy everything on credit from the dealer. If I face any loss of my business, I will alone be liable for that."* [Commercial poultry farmer, age-45].

We asked poultry dealers about how they recover money from farmers if they face losses. Poultry dealers said that they often extend the credit facility to farmer so that they can purchase necessary commodities for another batch of broilers to overcome the previous loss. *"All batches are not equally profitable for a farmer. Sometimes they face loss. In that situation we sometime give another credit to overcome the losses. Because, we also depend on the farmer, if farmers live then we live."* [Poultry dealer, age

40]. Farmers reported that when they sell mature, market-ready poultry to the dealer, the amount in credit is deducted and they receive the remaining amount.

The key informant compared this dealer-farmer relationship to a micro financing institute and credit receiver relationship, whereby dealers have a long-term business plan similar to that used by micro-financing institutes but in a different format. If a farmer gets a profit from the first broiler batch, then he will take a larger amount in credit from dealers for a second batch to expand the farm and maximize profit. On the other hand, if farmers make a loss, they make all the next purchases on credit to recover from the loss. This credit system is an integral part of the poultry food value chain, where dealers also get support from the poultry hatchery; poultry feed manufacturer and pharmaceutical companies.

DISCUSSION

Our study revealed a critical key relationship between poultry dealers and farmers in the provision of credit to farmers that is essential for their livelihoods and a critical driver for antibiotic use during poultry rearing. Poultry dealers act as the sole supplier of a single poultry feed brand, receive credit, and commission from poultry feed suppliers and manufacturers, and obtain antibiotics on credit from pharmaceutical company representatives. Dealers create functional connections between the input producers and the small-scale farmers by sourcing the production inputs from the large companies through their networks and self-credibility. They purchase production inputs on credit and distribute it to farms and purchase harvested products from the small farmers, thus keeping the production cycle moving (20). Pharmaceutical representatives always focus to achieve the sales target and maintain a continuous liaison with dealers. Pharmaceutical companies provide their own veterinarian's support through dealers to the small farmers. There is a substantial penetration and promotion of animal drug use by pharmaceutical companies and their agents (21). Social science research on antimicrobial resistance has revealed how antibiotic use in livestock and food production has been driven by the global pharmaceutical industry more than the practices and knowledge of end-users, such as farmers (22).

This study found that farmers routinely used antibiotics, including those banned for use in animals such as colistin. Multiple antibiotics were applied from day 1 of the production cycle until the point of sale. Farmers use antibiotics ubiquitously for growth promotion and prophylaxis as a risk-management measure (4). The supply chain of antibiotics distributes antimicrobial products to the wholesalers, retail pharmacies and feed dealers and even to commercial poultry farmers. Most commercial poultry farmers use antibiotics themselves directly from feed dealers or even directly from companies (23). Other studies show that most farmers (>60%) used antibiotics without the prescription of the veterinarians (24). Another study in Bangladesh among small-scale layer farms of *Mymensingh* district revealed that almost all (94%) farmers were using antibiotics without maintaining the minimum withdrawal period before marketing (25). Residues of ampicillin, ciprofloxacin and enrofloxacin have been detected in liver and meat of broilers (26). The presence of antibiotic residues in meat poses further risks to human health (27). Similar to our findings, antibiotics were considered an essential element for disease prevention and treatment in Cambodia, where farmers focused on the benefits to their food production system rather than concerns about the consequences of antibiotic use (28). Prophylactic use of antibiotics in commercial poultry production is also common in other countries in Asia including Cambodia, Indonesia, Vietnam, and Thailand (29). Poultry farmers using antibiotics as a growth-promoters perceive the costs of antibiotics to be paid off by rapid growth rates (30). Using more, or different types of antibiotics is also perceived by farmers as keeping their farm more secure and productive (24).

Our study found that the major poultry production inputs are purchased from dealers on credit. Dealers control the information flow to farmers and, in the absence of any other sources of information, farmers follow these recommendations without question. In contrast, poultry farmers from central Uganda were found to make decisions about antimicrobial use themselves; either based on previous experience, with guidance from dealers or from previous veterinary advice (31). Despite concerns around antibiotic use in food production, the growing poultry sector in Bangladesh is highly valuable to the economy through the creation of direct and indirect employment opportunities, improved food security and increased access to animal-source protein (3).

As described in social capital theory, social networks include a range of relationships that can offer access to production resources that include information, credit purchase facilities, physical or human capital. This in turn affects decision-making processes and collective action through reciprocity and mutual trust (9). Important social networks have been highlighted among small broiler farmers in a high income country setting, but in this case, the social networks involve farmers' cooperatives that have ready access to qualified veterinary practitioners and technicians, who share the decision-making with farmers, and empower the farmers with greater autonomy through knowledge-sharing (32). Due to limited capital and market information channels, we found that small-scale farmers are highly dependent on dealers for the entire process of poultry production and marketing in a credit based reciprocal relationship. Dealers, who obtain income through sales commission, forcedly push so-called nutrient-ready feed and antibiotics through credit facilities and farmers are economically tied to buy chicks and feed from same dealers (8). These farmers face the challenges of limited access to institutional credit, inadequate knowledge of poultry rearing practices, loss of profit due to death or disease outbreaks among flocks. They have no access to production and marketing information or poultry marketing channels (33).

Our findings also resonate with anthropological theory such as Social Lives of Medicine which proposes medicines as important political and economic actors within society (34), In viewing antibiotics as "things" they become commodities that have their own social life and consequences, aside from their medicinal or biochemical properties (34). In broiler poultry farming they play a particularly salient role in both the transactional aspects of antibiotics, and the symbolic meaning attributed to antibiotics. Anthropological approaches also highlight that professional practices of veterinarians and animal technicians are shaped by their economic value within a given market. These professions now have to develop economic models that do not rely on drug use. Anthropological and social science approaches can play an important role in developing alternative economic models and reducing antibiotic use in livestock production (22).

In many developing countries, a large proportion of the broiler poultry farms benefited from contract farming (6) which provides day old chicks, feeds, veterinary services, and technical supports on credit and ensures purchase of the output (35). Vertically-integrated poultry contract farming was introduced in Bangladesh in 1994 by a single company as an experimental extension program and later, a limited number of companies initiated contract farming (7). However, the growth of contract farming has been very slow and is still undertaken by only a small number of companies. Self-regulated small-scale broiler farming still dominates the broiler industry (6). A disorganized marketing system prevails in Bangladesh that further disadvantages small farmers. A multi-country systematic review highlights that most small-scale commercial poultry farms in LMICs rely on an informal marketing system based on verbal contracts to sale-purchase agreements. In this verbal agreement, farmers are less likely to have the choice of technology, input supplies or any service support (36). The influence of social capital on the decision making for the small and medium entrepreneur is reasonably important because for the access to production resources and market information. Therefore, the decision is mostly carried through the social networks (37, 38).

In Bangladesh, the use of antimicrobials for sub-therapeutic purpose (growth promotion) has been prohibited (15). However, research has revealed antibiotic residues are still present in poultry meat and eggs. Low veterinary regulation and low enforcement of the Act may be the root cause of this situation (23). Food safety administration and inspection does not include the monitoring the entire chain of production (39). Likewise a multi-country study suggested that poor state governance is associated with less effective controls of antibiotic use in the human and animal sectors (40). In most instances, the absence of a clear legislative framework on the use of antimicrobials in livestock production in LMICs may result in increased irrational consumption (1). Other factors that adversely impact the capacity to control antibiotic use in food animals include limited technical staff in agriculture departments to monitor farming practices as well as over-the-counter availability of antibiotics (28).

Some limitations in our study include the inclusion of broiler farms from only one region of Bangladesh, although we consider commercial poultry farming in this area to be similar to most areas of the country. We also interviewed a limited number of key informants and pharmaceutical company representatives. Further research is needed to gain qualitative insights into ways of engaging farmers, dealers and agents in antibiotic stewardship initiatives, to improve biosecurity of small-scale production systems, and reduce the financial risk to farmers of reducing their reliance on antibiotics.

In conclusion, in a setting where governance is weak, relying on law enforcement to reduce antibiotic use in livestock farming is inadequate. Investigating ways to exploit the patron-client relationship for improved antibiotic stewardship is a logical next step in developing a sustainable poultry value chain (4). Regulation, monitoring, and control programs for the prudent use of antibiotics in food-producing animals must begin with feed manufacturers and small/medium-scale poultry industries and must address or exploit the strong bonds within the patron-client relationship.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available. Original data are available at: https://doi.org/10.5285/630759ac-b0ca-4561-8eec-414b47e14829.

ETHICS STATEMENT

The study was approved by the Institutional Review Board (IRB) of icddr,b (protocol number PR16071) and Loughborough University, UK (R17-P037). Prior to taking part, all participants received information about the study (verbally and in writing) and signed consent forms for interview and for the publication of any photographs taken.

AUTHOR CONTRIBUTIONS

ER, MI, and LU conceptualized the study, secured funding, conceived, and designed the original protocol. All authors were involved in designing the data collection instrument, and selection of field sites. AMas developed data collection instruments and supervised the data collection. AMas, AMam, and SS analyzed and summarized the data. AMas led the writing of the first draft of the manuscript with LU and ER. MI, M-UA, MA, and MR provided input on data interpretation and analysis. LU guided the writing as the senior author and all authors contributed to writing the first draft of manuscript. The authors are grateful to the study participants for providing their time and invaluable information.

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CONCEPTUAL ANALYSIS
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Addressing Individual Values to Impact Prudent Antimicrobial Prescribing in Animal Agriculture

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Antimicrobial resistance is a growing public health threat driven by antimicrobial use—both judicious and injudicious—in people and animals. In animal agriculture, antimicrobials are used to treat, control, and prevent disease in herds of animals. While such use generally occurs under the broad supervision of a veterinarian, individual animals are often treated by farm owners or managers. The decision to administer antimicrobials is therefore influenced not only by the clinical situation but also by the motivations and priorities of different individual actors. Many studies have examined the drivers of external forces such as costs, workload and time constraints, or social pressures on antimicrobial use by veterinarians and producers, but none have explored the role of individually held values in influencing decision-making related to antimicrobial use. Values are deeply held normative orientations that guide the formation of attitudes and behaviors across multiple contexts. Values have been shown to be strongly tied to perceptions of and attitudes toward polarizing topics such as climate change, and preliminary evidence suggests that values are also associated with attitudes to antimicrobial resistance and stewardship. In this article, we draw on lessons learned in other fields (human health care, climate change science) to explore how values could be tied to the extrinsic and intrinsic factors that drive antimicrobial use and prescribing in animal agriculture. We also provide suggestions for ways to build a bridge between the veterinary and social sciences and incorporate values into future research aimed at promoting antimicrobial stewardship in animal agriculture.

Keywords: antimicrobial, social science, communication, values & beliefs, animal agriculture

INTRODUCTION

Antimicrobial resistance is a growing public health crisis, driven, in part, by the widespread use of antimicrobials in both people and animals (1). Addressing this crisis within animal agriculture must account for multiple levels of decision-making by prescribers (e.g., veterinarians) and users (e.g., farmers), considering the influencers of those decisions at each level. Considering both the prescriber and the user as distinct agents for change is critical, as the prescriber is seldom present when the end-user administers an antimicrobial treatment (2, 3). In such cases, the decisions regarding antimicrobial use are less influenced by expert veterinary knowledge and more significantly influenced by other factors such as policy, guiding principles of practice, or social pressure (including social capital) (4). Changing the behavior of an antimicrobial prescriber or user is a complicated and difficult task that requires more than the passive transfer of knowledge. Knowledge alone is not sufficient to decrease use or improve antimicrobial stewardship (5, 6). Accordingly, antimicrobial stewardship efforts must focus on addressing the beliefs, perceptions, and values held by these agents to most effectively influence behavioral change in antimicrobial prescription and usage.

This article aims to build a bridge between the veterinary and social sciences by exploring the role of individual values in the decision-making process around antimicrobial prescribing and use. This article evaluates insights gained from values-based research in other healthcare and social examples, and considers how these values-based inferences intersect with sociologic impacts on social and cultural capital. Connecting these bodies of knowledge will help us to better achieve our antimicrobial stewardship objectives.

ANTIMICROBIAL USE IN ANIMAL AGRICULTURE: CURRENT PRACTICES AND MOTIVATORS

In animal production systems, antimicrobials are used for disease treatment, control, prevention, and, in parts of the world, growth promotion. While global best practices for treating individual diseases among veterinarians and animal producers have not been instituted, guidelines of judicious use have been put forth and include, among others, preventing disease occurrence through improved livestock management systems or vaccination, reducing unnecessary antimicrobial use by assuring appropriate drug selection and dosing, assuring veterinary oversight of antimicrobial use in animals, and restricting the use of antimicrobials for growth promotion purposes (7, 8). While the evidence for these recommendations is admittedly low-quality (8), it does suggest that reducing overall antimicrobial usage in animal agriculture results in modestly decreased antimicrobial resistance in animals and arguably people (9, 10). Since all uses of antimicrobials, including prudent use, impart selective pressure for the emergence of resistant organisms, a major focus of research in veterinary medicine, public health, and policy involves finding ways to improve antimicrobial stewardship and use in animal agriculture.

Most of the knowledge related to interventions targeting antimicrobial prescribing behavior is derived from human medicine. Antimicrobial prescribing by physicians has been shown to be strongly influenced by behavioral and cultural determinants (11, 12), and a systematic review of antimicrobial stewardship interventions in human medicine suggested that persuasive measures (e.g., aimed at achieving voluntary behavior change) generally resulted in more sustained changes than restrictive measures (5). More recent work has argued that there is a critical need in human medicine to reframe the antimicrobial stewardship efforts based on the underlying values that drive prescribing behavior (13). While there is overlap between how human and veterinary medicine is practiced, animal agriculture represents a fundamentally different antimicrobial prescribing ecosystem, where population medicine and economics play a more significant role in treatment and management decisions. Interventions designed to improve antimicrobial stewardship in animal agriculture are further complicated by the fact that, while veterinarians provide oversight of antimicrobial prescribing, individual treatment decisions are often made by farm owners or employees following standard operating procedures outlined by the veterinarian. For example, in the United States, farm personnel may be involved in identifying individual animals or groups of animals that require antimicrobials based on predetermined guidelines for antimicrobial use established by the veterinarian. While veterinary oversight is broadly present, the majority of individual treatments are often initiated without consulting a veterinarian about that specific case (2, 3) and by different actors (e.g., farm owner, employee) who may be influenced in that decision process by varying motivations and priorities, such as the cost of diagnostic tests, prior experience, and risk avoidance treatments (14, 15).

From a social science perspective, studies have examined antimicrobial users' and prescribers' perceptions of antimicrobial resistance and antimicrobial stewardship. As might be expected, producers, and veterinarians appear to hold a wide range of beliefs and perceptions on antimicrobial use and resistance in food animal production, with views often differing both across study contexts and within regions where farming practices are comparable (16–21). Respondents most often report external driving forces on their prescribing/using behavior, including economic factors (3, 15, 22–24), workload and time pressures (18, 21, 25), social pressures such as perceived expectations of other parties (e.g., clients, patients, product purchasers, and other farmers) (18, 25–31), and previous experiences (15, 22). Personal factors such as desire for recognition, fear of shame among peers, and the intrinsic satisfaction of doing a good job (32, 33) have also been found to influence decision-making among farmers. These concepts are perhaps best embodied in the sociologic concept of the "good farmer," whereby farmers also value non-economic rewards or "capital" in decision making. Founded on Bourdieu's theory of capital (34, 35), "good farmers" are not only identified by economic capital (market sales and other mercantile transactions) but also strive for social capital (perception of social networks and ability to meet mutual obligations) and cultural capital (measured by perceived prestige derived through certification programs and symbolic measures such as how the livestock appear) (36–38). At a practical level this cultural capital of the "good farmer" is derived from the everyday practices and skills of the farmer, but most importantly is measured by external observation of peers. Herein, lies the concept of gaining cultural capital by having the tidiest farmstead, straightest planting rows and healthiest, biggest livestock— all of which are measures that can be easily assessed by knowledgeable peers observing the operation (36, 38). Even though the measures might not have positive economic gain (and in some cases, such as spending more money on keeping the property tidy, might actually decrease net revenue), farmers consider these intrinsic motivators in their decision making (36–38). These intrinsic motivators often stem directly from an individual's underlying value set. While a significant body of research has addressed extrinsic and some intrinsic factors in relation to antimicrobial prescribing and use (17, 23, 29, 39), far fewer studies have examined the deeper underlying values of these factors, especially with regards to their influence on how knowledge related to antimicrobial resistance and use is interpreted and applied. This knowledge gap is critical to address if we are to truly understand and change human behaviors that contribute to antimicrobial resistance in animal agriculture.

WHAT ARE VALUES?

Values have been defined in a number of ways in the psychosocial literature, but in essence, they are conceptions of desirable end states that reflect what is important to us in our lives (40, 41). They transcend specific situations, inform the selection, or evaluation of behavior and events, and guide the formation of attitudes and behaviors across multiple contexts (41). Values are thought to be cognitive representations of the biological, social interactional, and social institutional needs of an individual (41) and are thus inherently socially driven. Thus, the "good farmer" is driven by what he or she perceives as a desirable end state within the context of the social interactions and social institutions that govern his or her life.

Attitudes and behaviors about scientific topics come from applying scientific knowledge in service of an underlying value system (42). In short, science may describe and explain the world, but it can never tell society what ought to be done. Thus, for many controversial scientific issues such as antimicrobial resistance, climate change, or vaccinology, additional scientific knowledge does not always lead to a greater consensus. In fact, the individuals most knowledgeable about the science are also often the most polarized (42), as the same scientific knowledge is being applied to serve different values. Knowing what values an audience will likely use to interpret a message offers the communicator an avenue to align the message around something that already matters to the audience. Therefore, identifying the values of the antimicrobial end-user is relevant in judicious use and implementation of antimicrobials on farm operations.

WHAT CAN WE LEARN FROM OTHER EXAMPLES?

While few studies have explored the role of normative values in the decision-making of antimicrobial prescribers and users in animal agriculture, a body of literature has examined this topic in relation to other topics such as human health care and climate change. Insights from this literature can be derived to better understand the interactions between values, perceptions, and decision-making of farmers and veterinarians related to antimicrobial use.

Values in Health Care

While improving antimicrobial stewardship in human medicine might be thought of as a natural parallel to improving antimicrobial stewardship in animal agriculture, there are many differences that exist between the two—the most obvious being in the different values we hold for human life vs. animal life. While all veterinarians and farmers likely place animal welfare high on the list when treating with antimicrobials, culling economically inefficient animals is common, and occasionally entire flocks or herds may be depopulated if disease is rampant (43). Obviously, these decisions would be unimaginable for a physician. Consequently, while physicians and veterinarians both want to ensure the best health for their patients, it may be challenging to apply the insights learned from values-based research related to antimicrobial stewardship in human medicine to animal agriculture. Nonetheless, values-based research in human medicine can offer important insights to antimicrobial stewardship in general. For example, when examining the relationship between values and antimicrobial prescribing behaviors, physicians have reported being intrinsically motivated to deliver care that is grounded in the best available science and the ethics of medicine (4). However, social views or changes in policy and regulations can drive change in prescribing behaviors. For example, regulatory changes in prescribing standards may bring about attitudinal changes among physicians resulting in a need to re-examine their intrinsic motivations used in their decision-making process (4). A recent exploration of the role of values in human antimicrobial stewardship efforts identified temporal short-sightedness, individualization, marketization, and human exceptionalism as key value drivers hindering progress in human medicine (13). One proposed solution was to encourage a more solidaristic model, where responsibility for outcomes related to antimicrobial use are shared by both the individual and the broader institutional hierarchy and translated into new legal, administrative, and bureaucratic norms (13). While one might suspect that these findings could apply to veterinarians given their similarities in roles and responsibilities to physicians, such research has yet to be conducted. In contrast, some studies have demonstrated that health related government policy changes and regulatory oversight is sometimes interpreted negatively by farmers as poorly informed and not consistent with "good farmer" practices (44). In such cases, new animal health policies may be poorly adopted.

Values in Climate Change

Antimicrobial resistance in animal agriculture represents a societal type of risk, where the impacts are distant and diffuse rather than immediate to the individual making the decision. A related societal risk where research into the underlying social factors is more developed is climate change. An individual's attitude toward climate change depends on a number of values-based factors, including social risk perception, social trust, and religiosity. According to cultural theory, risk perception is a social construction that is strongly influenced by how an individual feels society should be organized across two dimensions (45). The "group" dimension ranges from individualism to communitarianism and conveys how strongly an individual feels bonded to a social group. The "grid" dimension ranges from hierarchy to equalitarianism and conveys the amount of social control and structure people desire in their social group (45). Where a person falls on these scales was found to be significantly associated with their views on climate change (42). In general, people with communitarian worldviews were more likely to accept that climate change exists than people with individualistic worldviews (42, 46), and people with egalitarian worldviews tended to be more accepting than people with hierarchical worldviews (47, 48). Both of these axes of sociality are highly correlated with political affiliation (49), and a stark divide over the perception of climate change along political ideology lines has been thoroughly demonstrated (47, 50–52). Specifically, it has been posited that people with individualistic worldviews resent restrictions on individual choices, especially with regards to decisions that could affect economics and commerce, while people with hierarchical worldviews place more value in rules and regulations from those higher up in the hierarchy.

Other factors that tend to be associated with the axes of sociality and perceptions of climate change are social trust and religiosity. People with a general distrust of social institutions and with high levels of religiosity tend to express skepticism about climate change, and vice-versa (51, 53–55). While religious beliefs are said to compete with science over "moral, epistemological, and ontological issues" (54), social trust supplements knowledge and reduces the complexity of a situation or decision-making process (56). In the face of a lack of knowledge, people turn to trusted sources for guidance on decision-making.

At this point, while there is relative consensus that values influence attitudes toward climate change, very little formal testing of different climate change education and communication strategies tailored to individual values has been performed. In an experimental study, Kahan et al. found that nearly identical newspaper articles titled and describing a solution to global warming as either "anti-pollution" or "nuclear" produced different effects on audience depending on where they fell along the grid-group dimensions (57), thus demonstrating how values impact an individual's perception of and actions related to a situation. In another study, investigators sought to use the constructive power of social norms (i.e., community mindedness) to successfully reduce energy consumption among consumers by providing them with data on energy consumption of their peers (58). However, in the absence of experimental evidence for tailored communication strategies in communicating climate change messaging, researchers have proposed ways in which such messaging could theoretically be effective (59, 60). For example, to decrease climate change skepticism in an ideologically conservative audience, Zia and Todd recommend re-framing the issue of climate change as either (1) a security issue by emphasizing the risks and impacts of drastic climate change, or 2) as a religious issue causing "pain and suffering for fellow humans, animals and plants" (61). Brownlee et al. suggest that in an audience skeptical of science and institutions (i.e., with decreased social trust), educational content should avoid charts, graphs, and references to science in favor of personal stories (62). In all cases, there appears to be a consensus that tailoring should focus on intrinsic values (such as civic duty) rather than extrinsic values (such as economic factors) (62).

Expected Impact of Values on Antimicrobial Stewardship in Animal Agriculture

Scientific literature is beginning to explore the role of social trust and values within the context of antimicrobial stewardship in animal agriculture. Several studies have assessed the relationship between social trust and attitudes toward antimicrobial use/prescribing among veterinarians or producers. These studies suggest that the variation in social trust influences perception of antimicrobial use and resistance (17, 63, 64). For example, personal experience has been shown to be a strong driver of antimicrobial use/prescribing and other health-related decision-making among some veterinarians and producers, even superseding antimicrobial use guidelines and regulations developed by experts and authority figures (65, 66). Anecdotally, individuals with limited trust in social institutions expressed the belief that the regulatory agencies developing recommendations and regulations are ill-informed about the realities faced by producers and more interested in restricting their behavior than promoting the public good (66). Additionally, while very little information is available on the association between religiosity and perceptions of antimicrobial use and resistance in the veterinary literature, one study found that farmers who identified as Amish and Mennonite generally used antimicrobials less frequently than other farmers (54). However, it is unclear whether the less frequent use of antimicrobials was specifically related to their cultural or religious background or to their preference for a different type of farming (e.g., small scale, low inputs, low outputs) that results in less disease and therefore less need for antimicrobials.

The scientific literature from other contexts allows prediction of how underlying values may relate to antimicrobial stewardship. Audiences with hierarchical worldviews would likely support the pathway to judicious antimicrobial use through increased regulation coming from authoritative experts. Audiences with individualist worldviews would likely view these same regulations as heavy handed or out-of-touch, and instead place more value on the situational knowledge of an individual operation. Audiences with egalitarian worldviews would instead likely focus on the similarities across situations and how everyone involved could do a little bit toward the larger goal. These differences in perspective have been discussed with regards to human medicine in antimicrobial stewardship (13). Differences in deeply-held values may suggest that, for instance, introducing a solidaristic model toward antimicrobial stewardship will be very difficult in the face of individualistic values. None of the views are incompatible with each other, but misaligning the message with the value would greatly diminish its impact. Qualitative studies soliciting veterinarians' and producers' attitudes toward antimicrobial use regulation provide preliminary evidence of such attitudes and perceptions:

for example, cattle producers expressing negative sentiments toward the Veterinary Feed Directive specifically described it as top-down "over-reach" by the government (67). In contrast, farmers that expressed strong desires to be perceived by their peers as "good farmers" (i.e., communitarianism worldview) were more likely to endorse measures to promote judicious antimicrobial use (29, 43).

It seems likely that the intersection of cultural theory and the "good farmer" construct (38) further impacts antimicrobial stewardship and decision making by farmers. For instance, the cultural capital and social capital perceived by an individual farmer may be unique to the worldview that aligns with their values. These differences might be manifest in different cultural capital measures based on underlying values, with some farmers most interested in being a "good farmer" by minimizing antibiotic use and others most motivated to be perceived as being a "good farmer" by having the largest, heaviest livestock or the most rapid rate of weight gain.

HOW DO WE IMPROVE OUR COMMUNICATION IN LIGHT OF THESE ISSUES?

Because an individual's values are thought to be critical to their perceptions of and attitudes toward complex phenomena such as antimicrobial resistance, future initiatives addressing these complex issues should connect the veterinary science of antimicrobial stewardship with the social science of decision making (68, 69). Every act of communication should be considered as a two-way social negotiation. In the context of climate change, for example, Ballantyne suggests that communication on this topic must be a constitutive process of producing and reproducing shared meanings, requiring a shift "to a perspective where all participants—senders and receivers—become coauthors or co-creators of meaning and where cultural and social contexts are recognized as important influential factors" (57).

What does this look like if we take a similar approach when attempting to address antimicrobial resistance? First, we call on researchers to listen to various actors in the chain of decisions leading to livestock antimicrobial exposure and explore their underlying values that drive how they interpret veterinary knowledge and act on those perceptions. High quality literature has documented attitudes held by these various stakeholders (18, 20, 21, 30, 70) but little is known on the values these actors hold. Moreover, as we have explored above, it is clear that what is known becomes fuzzier under the lens of context: antimicrobial type, farm type, and other contextual factors may alter the values held by these actors in unexpected ways. It is also necessary to develop a better understanding of the drivers of cultural and social capital (34–36) for different subsets of farmers (based on cultural theory) in order to develop effective communication campaigns. These gaps in knowledge are major roadblocks to effecting positive change with regards to the more prudent use of antimicrobials in livestock.

We also call on decision-makers to understand that attitudes and values are equally, if not more, important than the external factors of knowledge and awareness for behavioral change. One should be skeptical anytime someone claims that more information or knowledge by itself will solve the problem. Likewise, one should push back anytime someone disparages beliefs or emotions surrounding the topic of antimicrobial resistance as being unimportant. Finally, lest policy makers despair that immutable values are what ultimately dictate an individual's approach to antimicrobial use and that change is therefore unlikely to happen, one can be encouraged in observing that external influences such as education, regulation, or social pressures do appear able to change prescribers' fundamental attitudes toward antimicrobial stewardship. For example, differences in attitudes toward antimicrobial stewardship among veterinary practitioners with differing numbers of years in practice point to the ability of education and contemporaneous factors to influence values related to antimicrobial prescribing (71). Similarly, a social pressure campaign and resultant regulatory changes related to antimicrobial dispensing and prescribing in France was anecdotally able to change veterinarians' perceived responsibility for antimicrobial resistance and influence them to adjust prescribing habits (72).

In terms of concrete changes in research and policy to address this gap in knowledge, different approaches can be used. For example, evaluation of the success of antimicrobial stewardship policies should include collection of both numerical data on metrics of success as well as nuanced qualitative data to understand how individual factors such as values influence the implementation of the policy. Clack et al. (73) provide an example of how this can be done: in evaluating the effectiveness of two evidence-based healthcare associated infection reduction strategies in intensive care units across 14 hospitals in 11 European countries, these authors conducted in-depth interviews with various hospital staff and performed observations of practices prior to and 1 year after the intervention. They were able to identify how sociocultural factors (i.e., related to values) specific to each hospital influenced the success of the interventions and thus provide insight into how to improve adoption of policy measures.

There is also a need for stewardship interventions that tailor the language and delivery method of interventions to the values of the intended audience. As we discussed previously, this is already the recommended approach in climate change science communication (60–62). Additionally, such recommendations have been made in the context of human medicine (74), where it was observed that the norms and values of a specific medical specialty (e.g., collectivism in the internal medicine service vs. individualism in the surgery service) impacted decisions and outcomes related to antimicrobial stewardship (75, 76). For example, stewardship recommendations could be promoted to communitarianism-minded individuals by highlighting their potential impact on the community. Alternatively, they could be rolled out and advocated for by an authority figure to a hierarchical-minded audience.

Truly understanding the values of an audience will allow the communicator to position the relevant knowledge to allow the audience to support their values more fully. As antimicrobial resistance continues to grow worldwide, shifting our mindset, and connect the veterinary science of antimicrobial stewardship with the social science of decision making will be of utmost importance to optimizing antimicrobial stewardship efforts in animal agriculture and assure the continued utility of our limited antimicrobial resources.

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Farmers' Perceptions of Preventing Antibiotic Resistance on Sheep and Beef Farms: Risk, Responsibility, and Action

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Antibiotic resistance is one of the most serious public health risks facing humanity. The overuse of antibiotics in the treatment of infectious disease have been identified as sources of the global threat of antibiotic resistance. This paper examines how farmers perceive and manage risks associated with overuse of antibiotics. Specifically, the paper examines the role of habitus and risk in determining farmers' decisions to adopt national antibiotic reduction targets set by members of the Responsible Use of Medicines in Agriculture Alliance's Targets Task Force. Semi-structured interviews were conducted with 34 sheep and beef farmers in England and Wales. Farmers presented four scripts which illuminated reasons for limited adoption of the targets. The scripts presented the farmers as "good farmers" facing an emerging threat to their ontological security. Scripts suggested that they engaged in preventative measures but deflected responsibility for reducing antibiotic resistance to veterinarians and poorly run farms. This research provides valuable insights for policy makers and highlight the benefits of including social science research to support effective implementation.

Keywords: antibiotic resistance, sheep, perceptions, behavior, risk, antibiotic use, cattle, antimicrobial resistance

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INTRODUCTION

Antibiotic resistance has been identified as one of the most serious public health risks facing humanity (1–3). It has been estimated that by 2050 it could result in 10 million deaths a year worldwide (1, 4). Other consequences of antibiotic resistance include increased duration of hospital stays, higher medical costs, and less sustainable food production resulting in food shortages (1). Risks posed by the overuse of antibiotics in the treatment of infectious disease, in both humans and animals (companion and production), have been identified as sources of this global threat (5, 6).

Currently in the United Kingdom (UK), overall veterinary antibiotic use estimates are derived from pharmaceutical sales data (7). Antibiotic sales are calculated by using a Population Correction Unit (PCU) as the denominator, which is the standard weight of animals at treatment time multiplied by total number of animals in the population. The tonnage of antibiotics sold is then divided by the PCU to get mg/PCU. The data is published annually by the Veterinary Medical Directorate (VMD) and the most recent publication reports that there was a reduction in the sales of veterinary antibiotics in recent years, from 62.5 mg/PCU in 2014, to 29.5 mg/PCU in 2018 (7).

This was due to a large reduction in antibiotic sales indicated for use in pigs and poultry. The VMD report also includes sector specific antibiotic use for the salmon, trout, poultry meat, laying hen, and pig sectors using data submitted by farmers or veterinarians which is then collated by industry (7). Unlike the other sectors, the figures reported for the sheep and beef sectors uses small subset samples of prescription data to provide an indication of antibiotic use.

Sheep and beef production are typically extensive industries. There are over 72,000 breeding ewe holdings (8), and 59,000 beef cow holdings in the UK (9). The sheep sector is the largest livestock sector in the UK and accounts for 40% of the overall livestock biomass (10). The sheep and beef industries are highly interlinked, and the two livestock species often co-exist on farm holdings. This makes it particularly difficult to decipher use between the species when drugs licensed for use in both species are used. Furthermore, there are significantly fewer antibiotics that are specifically licensed for use in sheep, suggesting that there may be a need for the use of products not specifically licensed for sheep to be prescribed "under the cascade." The cascade allows veterinarians to prescribe antibiotics that are not licensed for use in sheep providing that they can demonstrate that this is the most appropriate antibiotic for the situation. As of yet, there are no accurate estimates of data to determine the current antibiotic consumption by the sheep and beef sectors, and unlike the other sectors, at the time of writing, plans to centrally collate on-farm antibiotic usage data are still in development, and an ongoing focus of the Responsible Use of Medicines in Agriculture (RUMA) Targets Task Force and the Agriculture and Horticulture Development Board, which is funding the development (11). To support decisions on the most effective risk reduction strategies there have been calls for greater consistency, standardization, granularity and validation of surveillance data collected on antibiotic usage and antibiotic resistance (12).

UK policy responses have focused on the setting of national targets to reduce overall use of antibiotics and on implementing restrictions on some antibiotic drugs (4, 13, 14). The use of targets to reduce antibiotic resistance is based on the precautionary principle. The precautionary principle offers a solution to the problem of coping with the mixture of limited knowledge and ethical doubts with respect to the uncertain impact of technological developments, particularly in the fields of the environment and health. As such it provides a systematic way of coping with the irreducible uncertainties of decision making and thereby providing legitimation for policy (15). In the framing of public policy governments make risk choices, for example, the UK policy response to a range of food and environmental risks such as BSE, and *Escherichia coli* outbreaks has been risk averse with risk framed as contingent and uncertain (16). It has been suggested that the consequence of this approach, within the context of antibiotic resistance in agriculture, is that governments avoid risk by shifting responsibility to the farmers and veterinarians who become accountable for risk assessment and management (16).

The UK Government has published policies which have sought to set targets for the reduction in use of antibiotics in animal production (7, 17). This drive to ensure responsible use of antibiotics in agriculture has been led by RUMA. RUMA is an independent alliance made up of many organizations representing different livestock sectors and stages of the food chain. The group was set up in 1997 with the aim of promoting best practice in animal medicine use. In response to the increasing concerns around antibiotic resistance, they identified areas where antibiotic use could be reduced, refined, and replaced without compromising animal health and welfare (18). The RUMA guidelines state that all farmers have a responsibility for the health and welfare of the animals under their control and that they must take joint responsibility, with their veterinarians, in the discharge of correct and appropriate antibiotic treatment and care (18). They are accompanied by a set of industry-developed species-specific antibiotic usage targets for eight key UK livestock sectors. In particular, the sheep and beef sectors have identified a number of challenges to achieving target reductions including: no central or uniform system to collect data; low veterinary involvement on farms; difficulty collecting on farm data; separating usage between species and possible complacency within the sector, as many farms are extensive with a low numerical usage. Particular "hotspot" areas identified by the sheep sector as potential for high use of antibiotics were in the control of lameness, abortion, and neonatal losses. In beef cattle respiratory disease, calf scour, navel ill, mycoplasma, lameness, and calving related problems were identified as areas of potential high use (11). As a result, RUMA provided sector wide targets for the sheep and beef industry which included the target to reduce antibiotic use levels by 10% between 2016 and 2020 (18). In order for targets to be met, changes in behavior of both farmers and veterinarians is required.

Risk Concepts in Social Science

Definitions of risk often specify it in terms of outcomes and probabilities that an adverse event(s) will occur within a stated time frame or as a result of a certain action. Risk assessment is the process of estimating both the probability that an event will occur and the probable magnitude of its adverse effects—economic, health, and safety or ecological over a specified period of time (19). Zinn (20) suggests that risk is used in two connected ways. Firstly, it is understood as a material or symbolic danger or harm or an alleged negative future event. Risk theorizing in this context concerns ways in which such dangers or harms are managed, prevented or attributed (or not) to decisions. Secondly, risk represents a specific form of managing uncertainty. The concept of risk is understood not as a harm or danger in governmentality but as a specific way to manage threats with calculative technologies (20). Additionally, risk refers to the possible occurrence of an adverse event, which can in turn be mathematically formalized as an expected loss. This approach to risk which is grounded in cognitive rationality involves collecting and analyzing knowledge/evidence and using it as part of a formal decision-making process to control uncertainties (21).

The way in which expert knowledge characterizes risk suggests that danger can be defined and managed or governed (22). Risk management then involves the prediction, analysis, and containment of risks so that overtime risks are converted to certainties (23). Governmentality focuses on ways in which risk should individually and collectively be managed (24). Lupton (24) argues that expert knowledges are pivotal to governmentality as they provide guidance and advice by which populations are surveyed, compared against norms and trained to conform with these norms. However, Wynne (25) argues that expert knowledge systems embody assumptions and modes of framing, using objectivist language, which implicitly treat the non-expert world as epistemically vacuous. He argues that they are incipient social prescriptions or vehicles of tacit social order. Thus, in this context, lay reflexivity is seen as having little instrumental value beyond the subjective and emotional world of its carriers when measured against a scientific world view (25). However, the rational, non-rational risk dichotomy has been criticized for not recognizing the limits of rational decision making, on the one hand and the knowledge and skills applied by lay people when making risk decisions, on the other hand (26, 27). Thus, assumptions about risk calculation through the cool deliberations of rational actors, abstracted from social and cultural settings and influences or from the impact of emotions have been called into question (23). Contexts in which judgements are made influence risky choices by both lay people and experts. Even where risk is described as "evidence based," such as in medicine or the veterinary field, the type of objectivist calculations used and criteria that are selected for examination are necessarily confounded with moral judgements and real risks are transferred into cultural or symbolic risks (20).

Thus, at a micro level, knowledge production will be understood as situated in specific and contradictory contexts of the everyday. Such embodied knowledge includes pre-rational, aesthetic, emotional, and intuitional aspects of knowledge (20, 28). Social theories of risk emphasize the context within which decisions are made and locate individual risk decision making within social reality (16). They link together accounts of the origin, probability, and severity of the risk with views about feasible solutions (29). Risk perception is influenced by the characteristics of the risks, as well as by socio structural factors—people interpret their world through their mental models—and the knowledge systems of lay people offers a valid interpretation of risk (20). Perrow (30) suggests that cultures are dependent variables—that is, they are the results of other forces that develop to explain and legitimize practices and to provide ways of seeing and thinking that are compatible with current existence and experience. Lupton (26) suggests that judgements about what phenomena should be described as risky are influenced by social and cultural contexts, personal experience, and embodied sensations or emotions. She argues that emotion and risk are intersubjective and interpreted through a social and cultural lens and influenced by past experience and by the spaces and places we encounter every day. Lupton (26) uses the concept of the *emotion-risk assemblage* to acknowledge that emotions and risk judgements, rather than being located in the individual, are fluid, shared, and collective.

Risk as Part of Farmers Habitus

The way in which Bourdieu sought to unpack the relationship between individual, agency, and wider social structures as determinants of individual behaviors or practice has been explored in the context of both farmer behaviors and human health (31–34). Crawshaw and Bunton (32) have argued that for Bourdieu actions of individuals and social groups incorporate influences from culture, traditions, and objective structures within society. These determine "practice" in unconscious and implicit ways and in turn normalize certain responses to present "a theory of practice" or habitus (32, 33). Individuals' own situated risk discourse are a product of habitus and can be characterized as practice with its own cultural logic. Shortall et al. (34) links Bourdieu's concepts of cultural capital and "habitus" to the concept of "good farmers." Farmers' habitus involves striving to be good farmers incorporating their cultural capital—which includes prestigious skills, knowledge, and experiences into their everyday practice. Good farming can be exemplified through sound stockmanship, having the skills to assess animal well-being and/or disease status and by assessing and managing risk to animal health (34).

This study builds on the relationship between risk and habitus to gain an understanding of sheep and beef farmers' decisions and actions relating to reducing antibiotic usage, in order to support successful behavior change, policy implementation, and the reduction in the risk of antibiotic resistance.

METHODOLOGY

This paper draws on a qualitative study developed as part of a larger longitudinal study which aimed to understand farmers' perceptions and use of antibiotics on sheep and beef farms in England and Wales. Semi-structured interviews were conducted with farmers on 34 farms of which eight were beef-only, four were sheep-only, and 22 were mixed species farms (**Table 1**).

Farmers who took part in the quantitative study and agreed to be interviewed were contacted by phone to arrange a suitable time for interview. All interviews were conducted on the respondents' farms and fieldwork took place between July 2018 and December 2018. The interviews were conducted by CD, lasted between 30 and 45 min, were digitally recorded and then transcribed verbatim.

The semi-structured interview guide was informed by the literature on risk and decision making (35) and target setting as a means of influencing behavior change (18). The aim of the interview schedule was to consider farmer risk taking regarding antibiotic use and resistance using the sociological domains presented by Zinn (35). Zinn reviewed the existing body of risk research to systemise the sociological domains of risk taking behavior into control, motives, reflexivity, and identity. Risk taking can depend on the level of *control* a person has or perceives. They make take risks in order to regain control of a situation, or to confirm their level of control over a situation. Level of control is often entangled with trust where social relationships are involved. Peoples risk taking can be driven by their social *motives* such as feeling of excitement, feelings of self-worth or in response to vunerability. *Reflexivity* refers to embedded human belief structures rooted in the social world including habitual risk-taking, routinized risk-taking or normalized risk-taking. Finally, a persons social *identity* can

TABLE 1 | Participants' gender, farm location, and cattle and sheep numbers.

Farm	Number interviewed on each farm	Gender	Farm location	Animal types and herd or flock size[a]
1	2	2M	West Midlands	Medium beef herd
2	1	M	West Midlands	Medium beef herd, small sheep flock
3	1	M	West Midlands	Large beef herd, large sheep flock
4	1	M	Wales	Small beef herd, medium sheep flock
5	1	M	South West England	Large beef herd
6	1	M	West Midlands	Medium beef herd, small sheep flock
7	2	1M 1F	West Midlands	Large beef herd
8	1	M	South West England	Large beef herd
9	2	2M	South West England	Small beef herd, large sheep flock
10	1	M	Wales	Small beef herd, large sheep flock
11	1	M	Wales	Small beef herd, medium sheep flock
12	2	2M	Wales	Small sheep flock
13	1	M	Wales	Small beef herd, medium sheep flock
14	1	F	South East England	Medium beef herd, large sheep flock
15	1	F	Wales	Small beef herd, medium sheep flock
16	1	M	Wales	Small beef herd, medium sheep flock
17	1	M	Wales	Small beef herd, large sheep flock
18	1	M	Wales	Large beef herd, large sheep flock
19	1	M	West Midlands	Medium beef herd
20	2	1M 1F	Wales	Small beef herd, mediums sheep flock
21	1	M	West Midlands	Medium sheep flock
22	2	1M 1F	South West England	Small beef herd, medium sheep flock
23	1	M	West Midlands	Medium beef herd, medium sheep flock
24	1	F	South West England	Small beef herd, medium sheep flock
25	1	M	South West England	Small beef herd, medium sheep flock
26	1	M	North East England	Medium beef herd, medium sheep flock
27	1	M	North West England	Large beef herd
28	1	M	South West England	Medium beef herd
29	1	F	Wales	Small sheep flock
30	1	M	Wales	Small beef herd, medium sheep flock
31	1	M	Wales	Small beef herd, small sheep flock
32	2	1M 1F	Wales	Medium beef herd, large sheep flock
33	1	M	West Midlands	Medium beef herd
34	1	M	West Midlands	Medium sheep flock

[a]*Small beef herd <100, medium beef herd 100–300, large beef herd >300; Small sheep flock <400, medium sheep flock 400–800, large sheep flock >800.*

be key to explaining their risk-taking. People may take risks in order to develop their identity, their identity may shaped what risks are deemed acceptable to take or they may take risks to protect their identity. Not all of these domains may be relevant to risk taking regarding farmers antibiotic use or resistance. Instead, we can aim to identify which of these domains are relevant through asking broad questions relating to antibiotic use and resistance. The topics covered in the interviews included general farm practices, antibiotic use, perceptions of current antibiotic use, national reduction targets, perceptions of the risk of antibiotic resistance, antibiotic use on other farms, and perceived responsibility of antibiotic use monitoring. During the discussion of targets for antibiotic use, a show card was used to indicate the national 10% reduction target set by the RUMA Targets Task Force for the sheep and beef sectors (18).

The transcribed data was coded using the constant comparative method (36) to identify emerging categories of data. Analysis was supported by the use of NVivo (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018). Validity and reliability was established through rigorous record keeping, reporting of data collection, analysis and then verification of findings by two researchers with transcripts being read and re-read by two researchers CD and AR. The researchers' analyzed the data in matrices for each respondent until data saturation was achieved. There were three steps to the coding process: initial coding, focused coding and theoretical coding. Initial coding was the first step where many codes are produced. Focused coding then narrowed down the number of codes by selecting the most suitable ones. Finally, connections are made between codes to produce categories. Categories can then be related to each other to establish a script. Enticott and Vanclay (37) describe scripts as a unique sequence of actions that define a well-known situation—scripts are learned through people's perceptions of the regular and repeated features of the world. Sociological scripts stress the flexibility and capacity of the script writer to learn and update them thus in making sense of a particular situation people develop appropriate roles for themselves that match the given situation to their actions (37).

The scripts were then used to assess the RUMA targets set for the sheep and beef sectors. This was based on recommendations from a policy analysis of target setting in the NHS (38). The policy analysis introduced five tests that must be met for targets to be appropriate and effective. If these tests are met then target-setters are more likely to achieve the desired outcome. The scripts were evaluated against these five tests to understand how RUMA targets can be more effective in the future and consequently aid behavior change around antibiotic use.

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no. 1850 160916).

FINDINGS

Scripts have been described as moral resources used by farmers to account for and justify their management of disease and as a means of farmers re-constructing their identity (39). They are situationally contingent and socially constructed (37) and have been described as a culturally shared expression, story or common line of argument which provides an explanation for a particular course of action. Respondents articulated four main scripts or lines of argument when discussing their management of the risk of antibiotic resistance on their farms:

- Antibiotic resistance—the script of an emerging threat
- Good farmer habitus—the script of experienced, knowledgeable farmers
- Adopting preventative measures—the script of controlling risk and adopting the precautionary principle
- Taking responsibility for risk—the script of risk, defense, and othering

Antibiotic Resistance—The Script of an Emerging Threat

When asked about their current use of antibiotics respondents reported administering antibiotics for a wide range of problems. In sheep these included mastitis, lameness, watery mouth, abortion, joint ill and navel ill. In beef, antibiotics were mainly used for respiratory disease, lameness, and eye infections.

Given the range of infections that were being treated with antibiotics respondents were asked about the potential of developing antibiotic resistance on their farms. When addressing this question they amplified the potential risks associated with antibiotic resistance identifying factors that had the potential to risk not only their reputation as a good, profitable farmer but also to the health and wellbeing of their animals:

> "*Well, it could end up catastrophic! I suppose because if you can't treat something that spreads and gets out of hand, I suppose you move onto the antibiotic so you're moving up the ladder all the time onto more expensive drugs, yeah I mean... it'll be bad for both animal and for pain wise, it'd bad for the farmer financially, won't it?*" Respondent 26 (Sheep and beef farmer)
>
> "*Well, they could be very serious if you have a pneumonia outbreak that you can't treat then- what are you going to do? You could lose 30 animals in the blink of an eye. Really so it's devastating potentially if we suddenly found we had no antibiotics that we could use.*" Respondent 6 (Sheep and beef farmer)
>
> "*Obviously, antibiotic resistance would have a massive impact then on the long-term profitability of farm animals. It is something that we have to be very, very careful—through overuse or through incorrect administration, under dosage we could contribute to antibiotic resistance. Weigh your animal before administering so that you are administering the correct dosage.*" Respondent 11 (Sheep and beef farmer)

Antibiotic resistance was perceived as a potentially catastrophic risk that would need ongoing risk assessment and management to protect the animals and their livelihoods.

Twelve respondents also expressed fears that they may already have observed signs of resistance on their farms and over half felt they were at high risk of developing resistance given they had encountered difficulties in treating infectious diseases in their animals:

> "*When we used to have bottles they'd last for... they'd go out of date before we use 'em, now it's sort of when you start to use 'em you use 'em and 20% of times you use 'em they just don't have effect now we're starting to see; the antibiotics haven't got the fight power against the disease what they used to have.*" Respondent 2 (Sheep and beef farmer)
>
> "*I bought a calf several years ago now which had resistance to Marbocyl, 'cause it had scours, resistant to Marbocyl, and caused quite a few problems until we found out what the problem was and obviously got on top of it and it's been fine since, but yeah, I don't want repeats of those situations.*" Respondent 17 (Sheep and Beef farmer).

Their scripts suggested that the Specter of antibiotic resistance was challenging their sense of identity as a good farmer undermining their confidence in their ability to identify and treat infections with certainty and challenging their ontological security i.e., their sense of continuity and order in life (40, 41). They reported that they were sometimes unable to determine whether they had wrongly identified disease or were subject to antibiotic resistance:

> "*I did think when I bought the bunch of sheep that introduced the CODD onto the farm, I was thinking we were getting resistance to Oxytetrin or Terramycin, whatever you wanna call the drug, because the sheep's feet... when we were treating lame sheep they weren't responding to the treatment but it wasn't that actually, it was the fact that we were not treating footrot anymore and we were using a drug that didn't really control CODD. Anyway, but*

it just took me a little while to cotton on to the fact that I was treating a different problem. So we tend to use Zactran now which is very expensive but very effective." Respondent 6 (Sheep and beef farmer).

"*And they haven't cleared up, but I don't know if that's resistance or not or just I'm probably assuming it's one type of lameness and it's another type that that antibiotic isn't, yeah. So no, I don't know if we've got any resistance to be honest*." Respondent 21 (Sheep farmer)

Respondents were concerned that rising antibiotic resistance due to inappropriate use in the industry may cause restrictions on what and how antibiotics were used on farms. This posed a threat to the farmer's way of life and the welfare of their animals. Farmers felt that it could get to the stage where only veterinarians could administer drugs to the animals on their farm. This could cause a breakdown in the trust between farmers and veterinarians, or not allow trust to develop to begin with.

"*Even if legislation came in that we had to have a vet to administer antibiotic use that would definitely cause a huge maybe reduction in the use of antibiotics. Economically it's not possible to profitable in keeping sheep and having your vet out to treat or administer antibiotics for every six sheep, so I would have thought then that there would be massive welfare issues, especially within the sheep sector if antibiotic usage was restricted to veterinary surgeons only*." Respondent 11 (Sheep and beef farmer)

"*But it's going to get very awkward when it's lambing time and you need Pen & Strep or something for a ewe with a difficult lambing and you've got to go all the way down to (town) and get it in a syringe and bring it all the way back again. That's the death of farming. They've got to trust us*." Respondent 15 (Sheep and beef farmer)

Farmers were also concerned that rising antibiotic resistance within the sheep and beef sectors could damage the public perception of agriculture and consequently they could face blame for antibiotic resistance in humans.

"*It's also the public perception of agriculture as a whole; if we're seen as a hotbed for developing resistance to antibiotics how long is it before that transfers to a human population?*" Respondent 31 (Sheep and beef farmer)

Overall, respondents presented a story of a major risk or threat to the health of their animals which was changing their relationship with risk, undermining their confidence in their ability to manage the risks encountered and threatening their ontological security—that is their sense of continuity and order in life and in the consistency of the surrounding social and material environment (41).

Good Farmer Habitus—The Script of Experienced, Knowledgeable Farmers

Habitus is formed in the context of people's social locations and inculcates them into a world view which is based on and reconciled to their position, thus serving to reproduce existing social structures (31, 33). Habitus is developed in dialogue within context and on the rules of the game, which is certain rules they have the play by to gain cultural, social, and economic capital and is subject to change over time (33).

Most respondents reported that they felt that they had the skills to identify infections and administer antibiotics or common conditions that they encountered, such as pneumonia or footrot. They argued that they were experienced stockpersons and capable of assessing symptoms, identifying the disease, and deciding on a course of appropriate action. They reported that their assessments drew on their intuition, situated knowledge and experience to assess risk to the health of the animal:

"*Well it's just years of experience of doing it really, you just know when an animal's ill and it needs antibiotic treatment....It's either severely lame or got an infection from a wound or has got breathing difficulties... So an animal that stands out to us absolutely as having pneumonia we put in the crush, you can see its breathing, you can even listen to it if you wanted to. If you're sure you know what you've got, we would treat that ourselves... Take its temperature, usually if it's pneumonia it'll have a high temperature which will give you an indication of infection there, so yeah you know what it is*." Respondent 1 (Beef farmer)

"*Well, if you've been around animals for long enough and if you've been brought up on a farm most farmers can identify a sick animal at a first glance. Yeah. You only need to look at their ears and eyes really, and the way they walk*." Respondent 11 (Sheep and beef farmer)

They suggested that most of the time their knowledge and experience was sufficient for them to decide if antibiotics were needed and that their confidence levels in terms of using antibiotics were high:

"*I feel very confident that I know when (to give antibiotics) 90% of the time I'll know when to use them and the 10% of the time I am unsure I have full confidence in my vet*." Respondent 11 (Sheep and beef farmer)

"*Oh, very confident because I know what a lame sheep looks like*." Respondent 25 (Sheep and beef farmer)

The treatment of common animal illnesses such as lameness and pneumonia were constructed as an ordinary event and part of the everyday activities on farms. The identification and treatment of such common diseases was learned through their upbringing on farms and embedded in the cultural knowledge of farming:

"*Antibiotics, just footrot in sheep, this time of year it's one of my biggest tasks probably doing sheep work; every time you get a bunch in there's always a sheep lame*." Respondent 17 (Sheep and beef farmer)

"***P2:** You're always going to get lameness.*

***P1:** You can identify the lameness so I suppose you'd have to say lameness. You get other things crop up from year to year but lameness will always be... or is always just an underlying one*." Respondent 22 (Sheep farmer(s))

Farmers considered they were experts in identifying and treating common diseases. They felt that treatment practices had changed very little over time and that it was very rare they would encounter a disease that was unknown to them. Hence, they seldom called their veterinarian out to visit the farm.

"*There's no new real need for them to come out to sheep... You know, if you have a lame sheep you know what it is and we've had vets in the past tell us what to do so it doesn't really change.*" Respondent 10 (Sheep and beef farmer)

"*Not in general healthcare I wouldn't say, maybe on something new because obviously there's the price of the vet and he's only going to probably say the same thing as what we would do, but if it's something new and we didn't know, yes the vet should be involved to understand it.*" Respondent 9 (Sheep and beef farmer)

Farmers believed that their veterinarians trusted their capabilities to identify and treat their animals. For example, one farmer expressed that their experience as a farmer meant that their level of knowledge on their animals' health was on par with less experienced veterinarians.

"*I had a cow last year in the cubicles, she was unwell, she got quite irritable and I rang up the vets and said, 'Look, I don't know what this is.' The head vet came out, the senior vet because he said, 'You know, if you don't know what's going on then there's no point in sending one of the junior vets.'*" Respondent 13 (Sheep and beef farmer)

Respondents painted a picture of themselves as self-assured, competent, and highly experienced farmers who were capable of managing disease risks appropriately. They were able to draw on a range of internal resources to support their decisions. Such resources were part of a collective of skills and expertise acquired as part of their habitus.

Preventative Measures—The Script of Controlling Risk and Adopting the Precautionary Principle

Shortall et al. (34) suggest that farmers will strive to be "good farmers" according to the rules of the game—which in the case of reducing antibiotic resistance would be minimizing the use of antibiotics. Early literature on good farming indicated that farmers could be resistant to changing their ideas and ways of working (33). Their habitus and their cultural capital (in this case ability to identify infection and administer antibiotics) ensured that their behavior remained consistent and unchanged. However, when facing new risks that potentially threaten their animals, their livelihood or ontological security (as a good farmer) farmers will change their attitudes and re-negotiate perceived good farming standards (34).

It was evident that respondents feared developing antibiotic resistance believing it would have an extremely detrimental effect on their businesses and their animals. For farmers their farm work represented a central aspect of their life. Any changes to their routine practices needed to be considered carefully:

"*It isn't a case of them feeling that by doing something might risk their business and in farming risking the business is also risking their life, so the consequences are far greater in farming.*" Respondent 24 (Sheep and beef farmer)

The prospect of antibiotic resistance was considered risky enough for farmers to start adopting new practices to minimize this risk. They reported using alternative practices in order to protect their animals and reduce the need for antibiotics. They had begun to think about or use alternative strategies for managing disease on their farms. Strategies they reported included:

Improving biosecurity

"*Well, the calves—sourcing from clean herds that give good colostrum and good healthy calves and do not mix them with any other animals from any other farms and have them in separate sheds, separate places*" Respondent 2 (Sheep and beef farmer)

Managing animal health

Farmers reported managing animal health by using alternatives to antibiotics including vaccines to prevent disease, anti-inflammatory drugs to aid with pain relief and culling to avoid breeding genetically prone animals and stop disease spread:

"*Vaccines as much as you can. That's our theory. I know people say they cost a lot of money but just so much pleasanter if they're not ill, isn't it? No, we've just got into the habit of vaccination.*" Respondent 26 (Sheep and beef farmer)

"*Sheep wise I think you have got to cull the worst ones, possibly the carriers of any disease, footrot and things like that ....I don't know I can't really...Yeah, there's not much else you can do is there?*" Respondent 30 (Sheep and beef farmer)

"*Cause I use anti-inflammatories as well so I try and cut down the use of antibiotics by using anti-inflammatories to help and hit 'em hard in one go rather than continuous use of antibiotics. I try not to keep injecting with antibiotics.*" Respondent 3 (Sheep and beef farmer)

In some cases it appeared that efforts to keep antibiotic use to a minimum had a negative impact on animal welfare. This was particularly the case for the treatment of lameness in sheep. Although prompt treatment of all sheep with footrot with injectable antibiotics is recommended by industry (42), some farmers were only treating severely lame sheep with injectable antibiotics.

"*We only use antibiotics for the ones with maggots in 'em and the hoof falling off.*" Respondent 29 (Sheep farmer)

"*Footrot is the major bugbear but like I said, we inject if they're really, really bad, if not you just trim and spray it and put 'em through a footrot bath. Yeah, we're not ruthless with it.*" Respondent 30 (Sheep and beef farmer)

Respondents presented a picture of themselves as farmers who were actively engaging in preventative measures, who were signed up to the "precautionary principle" as a way of managing risks associated with infections amongst their animals. Nevertheless, the strategies mentioned did not appear to be part of a coherent plan to manage risk but rather a risk reduction menu from which they could choose a risk reduction option. In adopting these strategies they sought to maintain their sense of ontological security, their self-identity as a good farmer.

Taking Responsibility for Risk—The Script of Risk, Defense, and Othering

Targets are a set of directed principles to identify the individual steps necessary to achieve a common goal. Given the level of concern about antibiotic resistance expressed by the respondents targets could potentially provide a benchmark for action, foster accountability and support them to achieve the goal of reducing antibiotic resistance on their farms. A target to reduce antibiotic use by 10% was set for the sheep and beef sectors. However, when respondents were asked if they considered the specific reduction aims within the RUMA targets to be feasible for sheep and/or beef farmers—they identified a range of challenges that they might face in attempting to achieve the targets. Though the RUMA targets are for sector-wide antibiotic use and are aimed at a national level, most respondents reflected on this through their own individual farm use.

The notion of having to reduce their antibiotic use by 10% was not an idea that resonated with respondents as they believed that their usage was already lower than the target set. They provided a number of justifications for challenging the idea that they needed to reduce their use and for deflecting responsibility to others.

They defended their position as very low users of antibiotics who had already made such changes and argued that they would not be able to successfully reduce them any further.

> "*Reduce mine—I don't think I could reduce it much more than I'm doing because I would say I'm probably using a very, very small percentage to most sheep farmers already because we've stopped using it. Yeah, we've already stopped using it in that sense. I mean I'm sure we could reduce it even more by probably making it even cleaner in the lambing sheds. So reducing what we're using I'm sure I can reduce it more going forward but to reduce it by 10% is probably a bit extreme because I'm not actually using that much anyway now because we changed our practice probably five years ago already. But obviously we'll carry on and try and reduce it, reduce it, reduce it but 10% is quite a lot when you're only probably using four bottles a year*." Respondent 34 (Sheep farmer)
>
> "*Well, 10% of a lot would be achievable but when you don't use a lot I think it becomes more difficult. So we'll have to wait and see on that one. I think it could give us problems in that we're starting at a low point anyway, so as I say, we'll have to wait and see*". Respondent 13 (Sheep and beef farmer)

Antibiotics were reported as being used as a last resort or only in emergency situations so any attempt to further reduce their use further would put their animals' health and welfare at risk:

> "*I couldn't really reduce it at all without losing stock- I only really use antibiotic when an animal is ill so it would result in loss of animals*." Respondent 4 (Sheep and beef farmer)
>
> *Well, we only use them when they're necessary so you're gonna have problems with disease spreading and having a worse problem*." Respondent 8 (Beef farmer)
>
> "*If you get a major breakdown of, say for instance pneumonia, you've gotta treat and it's out of your control and you've just gotta run with it because the welfare issue is the priority rather than the reduction. It's nice to have a reduction but the overwhelming animal welfare is priority to that*." Respondent 28 (Beef farmer)

The alternative of risking further or ongoing disease amongst their animals was not a risk that they could justify. Nor was a potential risk to their reputation that could result from allowing sick animals to remain untreated. Such action was considered irresponsible in terms of animal health. Their responses appeared to be based on an emotional attachment to their animals and a fear that they could be seen as irresponsible or bad farmers:

> "*I think it would be quite bad practice not to use what I use now because it would look like I wasn't caring at all. So somehow there's a line between using it irresponsibly and using it because you need to*." Respondent 34 (Sheep farmer)
>
> "*It doesn't look very good 'cause we've got a lot of footpaths and there's always somebody looking over the fence so you've gotta be careful what you do and it's in the best interests of the animal to be healthy and walking around on four legs instead of three*." Respondent 2(Sheep and beef farmer)
>
> "*I do worry that people looking from the outside say, "Actually, he's got lame sheep there, he's not treating them*"". Respondent 17 (Sheep and Beef farmer)

Respondents reported additional challenges that they felt would prevent them from protecting their livestock. They suggested that they did not necessarily know the risks they were taking when "buying in" animals that were sick or carrying resistant organisms and this made it more difficult for them to optimize or reduce their antibiotic use for newly purchased animals due to a lack of information about their disease and treatment status:

> "*Livestock is moving between farms all the time so you don't know what you are buying in when you buy breeding stock, so yes, I mean it is a concern yes*." Respondent 6 (Sheep and beef farmer)
>
> "*I wouldn't know that, would I, 'cause you don't get a history of what animals are treated with when they come*." Respondent 19 (Beef farmer)
>
> "*I guess the problem we have is that we no control on what happens before they come on farm, I think a lot problems, particularly with pneumonia I think are historic..so if they happen to have pneumonia when they're younger they're more susceptible to get it later on in life, aren't they? . . . There's no point saying 10% less when someone's probably using 20% more than us, that'd make a 30% difference*." Respondent 8 (Beef farmer)

Importantly, trying to interpret and measure progress against the targets, particularly without knowing their baseline usage was considered outside their remit or skill base so they would not be able to meaningfully reduce the risk associated with over use of antibiotics:

> "*So as a farmer I don't know what 10 milligram per PCU means*." Respondent 14 (Sheep and beef farmer)
>
> "*I don't think everyone knows what we are using now to be able to reduce it by 10%. I don't know how you're gonna use the target you've got at the moment 'cause we haven't really got a baseline target at the moment*." Respondent 5 (Beef farmer)
>
> "*Yeah, depends on what your usage level currently is, if it's really low then it's harder to get it down by 10%, isn't it? We're always trying to reduce it for sure, because it reduces costs and sick animals don't perform. So, if you can prevent 'em from being sick in the first place it's a win-win situation. Yeah, I'd have to. . . we probably*

can reduce it, whether we can do it by 10%—if we were a big user, you know, there's a lot of farms where it's easily achievable..." Respondent 32 (Sheep and beef farmer)

Having to interpret statistics so they could reduce their antibiotic use by 10% would act as a barrier to change and potentially be at odds of their habitus and their concept of themselves as good farmers who prioritize the well-being of their animals and the viability of their farm. A lack of evidence or information about how the targets were being measured prevented them from being able to decide if they were contributing to achievement of the national target to reduce usage. They reported feeling unable to fully understand the nature of targets and how to turn them into action. In such circumstances, it was difficult to "own" the targets and they sought to locate responsibility for achieving them with others.

Othering

Given the challenges respondents reported in attempting to reduce antibiotic use they sought to shift responsibility for the achieving the targets and blame for not achieving them on to others. Othering involves defining or defending self-identity by distancing oneself from individuals or other groups who are excluded or regarded as posing risks to self-identity (40). Individuals use social skills and their judgements of situations and especially of others, which might be based on hearsay or intuition and shaped by shared experience or habitus (32). Perceptions of risk among people sharing the same cultural context are related to the groups' legitimizing moral principles—thus "others" are often identified as threatening the mainstream (43).

Farms that overused antibiotics were framed as poorly run and held responsible for increasing the risk of antibiotic resistance:

"*Poor management. Simple as. Not knowing what they're doing properly. Probably not seeking professional advice through their vets. So, using excess, did you say, of antibiotic? Well, if they've got a major problem then perhaps on certain years they've got to, I mean who's to say I might have watery mouth next year. But, generally that seems a bit like poor management, poor husbandry and not consulting the vet enough. I don't know*." Respondent 21 (Sheep farmer)

"*Too high a stocking densities, mixing of age groups within buildings, unvaccinated animals coming, where they haven't got a clue where they've come from, poor hygiene and general standards so cattle aren't looked after well… full of rats and other things and various things that can spread disease and issues. Blanket antibiotic treatments and stuff like that*." Respondent 1 (Beef farmer)

"*Well the ones that do blanket treatment for abortion first of all. There are others that routinely use Spectam in every new-born lamb and penicillin when it could be achieved through better nutrition for the ewe. Well, if you have problems with mastitis that could be bred out, that is… you've not to chase yields as much and to not breed from ones who've had mastitis in the past, that could be reduced in the dairy industry. Yes, there are people using too much, definitely. And there are some who under… don't give the prescribed dose, give a half dose and I'm sure that increases resistance, does it?*" Respondent 10 (Sheep and beef farmer)

In describing poorly run farms as problematic, respondents were able to distance themselves from this type of risky behavior, even though some of the problems they attributed to others had also been described in their own experiences of the difficulties they faced in achieving the targets. Other farmers were identified as the risky others—who posed a threat to farming. Poorly run farms became unsafe places which threatened animal health and farmers' livelihood.

Responsibility for reducing the risk associated with antibiotic resistance was also ascribed to veterinarians. In the UK all antibiotics for veterinary use must be prescribed by a veterinarian. The Royal College of Veterinary Surgeons (RCVS) Code of Professional Conduct states that "The animal or herd must have been seen immediately before prescription or recently enough or often enough for the veterinary surgeon to have personal knowledge of the condition of the animal or current health status of the herd or flock to make a diagnosis and prescribe" (44). Whilst, all respondents stated that they obtained their prescriptions and antibiotics from their veterinarians, they indicated that their contact with the veterinarian could be sporadic and may not necessarily occur at the time of illness in the animal:

"*The vet is not involved generally because if you get an animal sick when I go round them in the morning I'm not going call the vet before I do it (administer antibiotics). If we've got a really sick animal that the vet has come out to then that becomes the vet's choice but it is very unusual that we'd have a vet out to an animal*." Respondent 34 (Sheep farmer)

"*But sheep farmers don't keep running down the vets, you know, we can sort out our own lambing, we hardly ever go down for a lambing. The vet comes out for a TB test or maybe a calving but they're always too busy to talk to you*." Respondent 15 (Sheep and beef farmer)

Although they reported having little contact with their veterinarians, when identifying and treating infections respondents suggested that veterinarians should shoulder responsibility for helping farmers to achieve antibiotic reduction targets:

"*No, the vets are the only ones that are gonna tell you that. And hopefully by doing this you're gonna tell me whether I am or not (over using) … the vets gonna monitor it anyhow 'cause you've gotta buy the antibiotics from the vet, you can't get it any other way*." Respondent 2 (Sheep and beef farmer)

"*Well, I would've thought the vet would be the best in the know, won't they? They provide us with the antibiotics so they're in a good position, aren't they, to monitor antibiotic use*." Respondent 19 (Beef farmer)

In attributing this responsibility to their veterinarians, respondents appeared to be deflecting responsibility away from themselves alone suggesting that vets should play a significant role in the process. They believed that veterinarians were more knowledgeable about antibiotic use and in control of the situation because antibiotics must be prescribed by them. However, some farmers noted that antibiotics could be too easily accessible from the veterinarian, and some were confused about the conflicting information received from veterinarians.

> "*It's too easy to go to the vet and ask for something and they just give it to you and can be used pretty easily*." Respondent 17 (Sheep and beef farmer)
>
> "*So I know that there are vets that perhaps maybe that give out the antibiotics without good reasoning and without a good understanding, so*." Respondent 1 (Beef farmer)
>
> "*Sometimes we're slightly conflicting 'cause we wouldn't have always vaccinated lameness, we'd have trimmed and put them in a footrot bath, unless they were really bad and then we would've, but now we're told we've got to use antibiotics. So it's sort of slightly conflicting information coming out, isn't it?*" Respondent 21 (Sheep farmer)

Respondents presented a story of themselves as good farmers who already met the targets set and who would be putting their animals and their reputation at risk if they tried to reduce them further. They portrayed themselves as responsible actors and distanced themselves from accountability for reducing antibiotic use by shifting blame onto poorly run farms and responsibility on to veterinarians. Thus, their responses to risk sought to maintain symbolic boundaries with the farming community particularly in relation to self and others (40).

DISCUSSION

This is the first study to the author's knowledge to provide insights into the way in which sheep and beef farmers in England and Wales view the feasibility of antibiotic reduction and the risks posed by antibiotic resistance. The present study used a qualitative approach and aimed to build on the relationship between risk and habitus to gain an understanding of sheep and beef farmers' decisions and actions relating to reducing antibiotic usage. Through gaining this understanding, the study aimed to support successful behavior change, policy implementation, and the reduction in the risk of antibiotic resistance. The aim was not to quantify opinions and the results do not suggest that every opinion reported is held by every sheep and beef farmer in England and Wales. However, using this approach we were able to capture the perceptions, beliefs and motivations that underpin behaviors regarding antibiotic use and the potential for its reduction.

Lupton (45) argues that both emotion and risk are inevitably configured by social and cultural processes and through interaction with others, material objects, space and place. Emotion and risk assessments are fluid, shared and collective underpinned by trust and intuition. She suggests people use an "Emotion—Risk Assemblage," which is a combination of ideas and concepts brought together to assess and manage risk or uncertainty (27, 45). In doing so Zinn (27) suggests that risk management strategies devised using a cultural perspective cannot necessarily be identified as either "rational" or "irrational." Thus, when individuals weigh up risks they are deciding how risk phenomenon cohere with their values about what is acceptable and what is threatening. They utilize "in between" strategies such as trust, intuition and emotion to manage them (26, 27). The interpretations of risk presented by Lupton (45) and Zinn (27) can be used to understand the farmers views of risk around antibiotic reduction and antibiotic resistance. Farmers in this study drew on their emotional ties to their animals, their habitus, and their sense of ontological security—as good farmers—to defend their practices and to blame others for the problem. Their views of problem farms were underpinned by emotions of fear and blame and they were seen as dangerous places (40, 43). They did not follow rational risk assessment and management strategies to deal with the potential risk of antibiotic resistance but were aware of and concerned about the potential threat to their animals and livelihood posed by antibiotic resistance. Respondents adopted a broad precautionary approach and engaged in risk management strategies associated with biosecurity. However, they did not understand the scientific basis of targets associated with reducing antibiotic use on their farms nor did they feel confident to calculate how much of a reduction in antibiotics would be needed to reduce their use. Thus, their scripts revealed that their habitus—as good farmers—influenced the way they sought to justify action and or inaction in relation to reducing antibiotic use on their farms. They described a risk response that was based on an assemblage of beliefs, ideas, emotion, intuition, and logic of practice (32)—a risk-emotion assemblage (45). Their scripts acted as a resource to normalize actions and deal with issues of accountability and reputation management (46).

Policy makers are increasingly acknowledging that the elimination of all risk presents a major challenge. Focusing on systems that more accurately identify and categorize risks and provide programmes for handling and reducing risks are considered more likely to be effective (23). The insights revealed through the scripts in this study have important implications for policy makers who adopt rational approaches to bringing about change. They illustrate how strategies for change based on evidence or on the precautionary principle could be less effective than desired. In particular this study highlights the complexities surrounding the setting of numerical targets for reduction of antibiotic use in the beef and sheep industry. The setting and monitoring of targets is one way in which governments can provide leadership, guidance, and strategic direction to achieve a reduction in risks through behavior change. Targets are expected to motivate people to achieve goals with appropriate milestones, to foster accountability and provide motivation. Nuti et al. (47) suggest that governance based on targets is a form of indirect control which requires selecting the appropriate number of indicators to measure the objectives and choosing a rigorous principle to define which indicators should be considered as priority. Targets are extensively used in UK policy particularly in relation to improving health and well-being and increasing the efficiency of hospitals. Although targets have met with success evidence suggests that this approach can also be accompanied by unintended negative consequences. For example, in the UK the 4 h waiting target for people attending Accident and Emergency services, whilst generally successful has resulted in poorer care for some patients (48). Thus, although targets can change people's behavior in order to the meet the target they may not choose to do this in the way the target setter intended (49). In addition, Elkan and Robinson (50) argued that targets focus action on those things that are most easily measured and can foster complacency on the part of providers who have already achieved target levels of performance and defensiveness from those performing badly.

Targets are just one means to achieve progress against a priority, but not all priorities lend themselves to a target. Before deciding on a new national target or whether to have a target at all, policymakers need to consider whether it is the most effective and appropriate means of achieving the desired outcome (38). Berry et al. (38) identified key questions that would need to be addressed to assess the suitability of targets and the data presented in this study provides valuable insights into the potential challenges faced in reducing antibiotic use on sheep and beef farms in the UK. These are discussed below:

Firstly, is there a widely RECOGNIZED and pressing problem, which requires policy action at a national rather than just local level?

Globally and nationally there is a persuasive need to address the unnecessary use of antibiotics to ensure responsible use in humans and animals (both production and companion). The UK sheep and beef sectors are traditionally low users of antibiotics but, nevertheless, have some "hotspots" requiring action including lameness, abortion, and neonatal diseases in sheep and pneumonia in beef cattle. Additionally, the usage figures taken from convenience samples and reported in the latest VMD and RUMA reports suggest that usage in parts of the beef sector may be higher than the dairy sector (11).

It was evident through respondents scripts on *antibiotic resistance as an emerging threat* that the sheep and beef farmers interviewed in this study were aware of the risks associated with antibiotic resistance stating that it could be catastrophic both for their livelihoods and reputations if they were to develop resistance on their farms. Some feared they may have already observed antibiotic resistance, and most felt at high risk of experiencing it in the future.

Secondly, is the problem likely to be amenable to action by those who are accountable for the target?

Farmers in their scripts of *experienced, knowledgeable farmers and of risk, defense, and othering,* provided a strong rationale for not cutting back on antibiotic usage. They believed that they were very low users already—only using them in life and death situations—and that that a reduction in use would increase the mortality in their flocks or herds and in turn, potentially risk their reputation as a good farmer. Given that they reported that they were not able to determine their exact use or calculate a 10% reduction their beliefs were based on subjective views.

Thus, while it was evident that the problem of antibiotic resistance may be amenable to action by the respondents their strong beliefs about the individual animal being a priority and their concerns about being categorized as a bad farmer may result in action that will limited the potential to reduce antibiotic resistance. Nevertheless, their scripts on *controlling risk and adopting a precautionary principle* suggested that they were signed up to the "precautionary principle" and that they had adopted alternative measures to reduce the risk of infection on their farms.

However, they did not appear to sign up to the idea that they could be held accountable for the overuse of antibiotics in farming or adopt the target of reducing their antibiotic use by 10%. Their risk rationales were fluid, relational, and contextual (45). The farmers' cultures were located within specific spaces (their farm) and Lupton (45) suggests that features of space and place are important in the production and expression of emotional states. Farmers expressed concerns that if they tried to reduce their antibiotic use any further they would put their animals and reputation at risk. These fears were based on emotional ties to their animals on the one hand and their identity as a good farmer on the others.

Experts' attempts to change risk taking behavior often fail as they do not engage with peoples' identities, the social rooting of risk taking and the social power structure. Respondents suggested that farmers who had more intensive systems, or had poorly run farms with high stocking rates were most likely to be the ones who were creating the risk associated with antibiotic resistance. The act of other-blaming around the responsibility of antibiotic resistance by both livestock farmers and veterinarians has recently been highlighted by Golding et al. (51), where blame was also directed at other farmers with poor antibiotic practices. Notions of self and risky others can be underpinned by the emotions of fear, distrust, hate, blame but rather than being irrational Zinn (20) suggests that they are simply a different intelligence about the world.

Thirdly, do the necessary resources to take action already exist or can they be developed?

The RUMA targets for increasing uptake of vaccinations for footrot and abortion have not been maintained at the proposed rate (11). Farmers in this study did not feel they had all the necessary resources to take the action needed to meet the antibiotics reduction targets. In their script on *taking responsibility for the risk* they explained that when they bought in new animals they were not supplied with their health and vaccination history making it difficult to decide on the action to take if the animal became ill. Availability of medicine records could be improved to make it easier for farmers to inspect the medicine history of potential animal purchases and this should improve as plans develop for the UK centralized medicine hub. A livestock information programme is also being developed through an industry-government partnership in order to improve animal traceability (52). Electronic medicine books are already available for pig producers with various groups exploring the development of equivalent tools in the cattle and sheep sectors (11, 53).

The main source of information to support antibiotic reduction for farmers in this study was the veterinarian. However, respondents suggested that they had limited contact for diagnosing and treating infectious disease, as also indicated in previous studies (54, 55). This implies antibiotic reduction may reach an impasse if veterinary visits do not become more regular on farms. At the moment, lack of contact with the veterinarian, or infrequent veterinarian visits, is considered normal or acceptable in the sheep and beef sector. Infrequent veterinarian visits may be even seen as a symbol of a good farmer as veterinarians are only used in emergencies or with the emergence of new diseases. Whilst quality assurance schemes in the UK require an annual veterinary visit to the farm with a herd or flock health review (56), the social conditions around the normal frequency of veterinarian visits needs to change for targets to be effective. Some respondents also felt that antibiotics were too easily accessible from the veterinarians and antibiotics could be prescribed without thorough reasoning. This highlights a potential lack of reflexivity around the use of antibiotics in the sector. If veterinarians do not attempt to question farmers who ask for antibiotics, then the farmers themselves might not reflect on and examine their own antibiotic use.

Nevertheless, within their script of *risk, defense, and othering* they suggested responsibility for achieving a reduction in antibiotic use lay with the veterinarian so there is potential for veterinarians to take a lead in supporting farmers. There is an argument for the increased use of proactive veterinary-led flock or herd health planning that encourages the application of appropriate preventative measures to manage disease risk and use antibiotics responsibly.

Fourthly, can changes in performance can be adequately measured?

RUMA (57) reported that data collection to measure progress remains challenging. Farmers in this study reported not understanding the measurements and were confused about how a reduction of 10% could be measured and achieved. Most respondents believed that the veterinarian should take responsibility for monitoring antibiotic use because they were the ones supplying the medicines. However, at the same time respondents stated that they had minimal contact with their veterinarians for the treatment of their sheep and cattle. Farmers also indicated that they did not have the skills to accurately measure their progress against the numerical targets. To ensure performance is adequately measured it is important that farmers and veterinarians work in partnership, with the farmers supplying farm management data and the veterinarians facilitating the analysis of on-farm antibiotic usage. Zinn (35) suggests that if awareness is lacking or knowledge is inaccurate, education and information strategies might be important for achieving behavior change.

Fifthly, do the targets align well with what already exists or is planned elsewhere in the system, with minimal negative consequences?

As the farmers in this study believed that they were using as little antibiotics as possible already, further reductions in antibiotics were seen as being be detrimental to production and animal health and welfare and therefore associated with negative consequences. For example, lameness is an endemic disease in British sheep flocks and the Farm Animal Welfare Committee set targets to reduce sheep lameness to less than 2% by 2021 (42). The five-point plan is a national strategy for achieving this target and one of measures for the control of lameness is to give an antibiotic injection within 3 days of the sheep becoming lame. Consequently, farmers may feel that they have to choose between achieving the lameness targets and achieving the antibiotic targets. Some farmers were minimizing their antibiotic use by only treating severely lame sheep with injectable antibiotics. This indicates that the antibiotic reduction targets could have a negative impact on animal welfare. Thus, messages need to be clearly delivered to farmers that it is entirely appropriate to treat clinically affected sheep with antibiotics with emphasis on prevention by rapid treatment and improved biosecurity, which in turn will reduce the lameness level and lead to fewer lame sheep and further reductions in antibiotic use in the long term. Veterinarians need to ensure that they take the time to explain and provide farmers with context with how using antibiotics appropriately reduces usage in the long term. As this study shows that farmers do not always their veterinarians for advice on lameness, there is also a need to use industry more widely to ensure messages around appropriate antibiotic use are conveyed.

Implications for Policy

From the evaluation of the farmers scripts against the five tests for effective targets outlined by Berry et al. (38), a number of weaknesses in the current targets are evident. Through identifying these weaknesses, we can determine how the targets can be more effective in the future and consequently aid behavior change around responsible antibiotic use.

Firstly and perhaps most importantly, the majority of sheep and beef farmers have not had their antibiotic use measured officially. Therefore, they do not know how much antibiotics they are using compared to the targets. A numerical antibiotic use target could be counterproductive if most farmers do not know their numerical use. It is suggested that until there is reliable data collection and robust metrics available there should not be a numerical target set for antibiotic reduction in the sheep and beef sectors. Targets should first focus on comprehensive collection of antibiotic consumption data. Other measures of "responsible" use which are already reported in the RUMA reports could be framed as more important until reliable antibiotic use data is achieved (11).

The lack of availability of antibiotic use data also fosters issues with accountability for the targets. As farmers believed that they were low users of antibiotics, they shifted the responsibility for reducing antibiotics onto "others." From the results of this study it is suggested that the framing of the current targets for the sector should be shifted from *reducing* antibiotic use to *responsible* antibiotic use. At present, the RUMA targets start with an antibiotic reduction target—such as reducing antibiotic use by 10%. This is then followed by responsible antibiotic use targets—such as increasing vaccine sales to prevent disease (11). The targets should instead prioritize the responsible use targets. This will help all farmers feel accountable for the targets.

By emphasizing responsible antibiotic use instead of reducing antibiotic use, this will also help to ease the conflicts faced with other recommendations. The focus on reducing antibiotic use could be especially detrimental to sheep lameness control targets. If antibiotics are to be used responsibly in the sheep sector in particular, the optimal control strategies for lameness need to be highlighted in the report using evidence based reasons, sources, and consequences

Finally, the resources available to farmers to support their responsible antibiotic use needs to be developed. As veterinarians are the main source of information for farmers, their means of communication could be developed to provide farmers with better resources. The farmers tended to interpret the sector wide targets in an individualistic manner and placed value on their situational knowledge when treating animals with antibiotics. People prefer communication that is tailor-made to them and their values (58). Thus, veterinarians could share knowledge and understanding about responsible antibiotic use with farmers based on their values (e.g., animal welfare, reputation) through personal stories. Knowing farmers values and beliefs requires a strong relationship between veterinarians and farmers, however this cannot happen when veterinary visits to the farm are infrequent. Therefore, there is a need to normalize frequent vet visits on sheep and beef farms and make infrequent veterinary visits appear less acceptable. Overall, regular veterinarian visits to sheep farmers needs to be embedded in the "good farmer" ideal.

CONCLUSION

This paper used qualitative methods to explore beef and sheep farmers' perceptions and their management of the risks associated with potential overuse of antibiotics on farms. In particular, the study used script theory to examine the potential influence of farmers' beliefs and behaviors on the achievement of national targets to reduce antibiotic use on farms. The beliefs and behaviors, reported by respondents, are of utmost importance for policy makers to consider in terms of achieving national targets set by the RUMA Targets Task Force. Respondents reported not having the technical knowledge and skills needed to measure antibiotic use and resistance, they believed their use of antibiotics was already low and they were concerned about the potential effect of further reducing use on their business, their animals and their reputations. They deflected accountability and responsibility for dealing with the problem to veterinarians and poorly managed farms. These insights are valuable for policy makers to enable them to set realistic targets, which have research-informed objectives to support farmers and their veterinarians as they aim to make progress in the achievement of the targets. Additionally, the insights may help to form a basis for providing education and training for farmers to mitigate against the risks of antibiotic resistance developing on their farms. This study demonstrates the value of social science research methods in understanding the factors that influence behavior change in farming and provides valuable insights for policy makers tasked with achieving behavior change.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available to ensure confidentiality of respondents. The data supporting the conclusions of this article will be made available by the authors, upon reasonable request, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no. 1850 160916). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CD, AR, and JK contributed to conception and design of the study and the themes generation. CD performed data collection. CD and AR performed analysis of transcripts. AR and CD wrote the first draft of the manuscript. JK wrote sections of the manuscript. FL, CH, and LK contributed to the manuscript revision and interpretation of data. All authors read and approved the submitted version.

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Perception of Drug Vendors and Pig and Poultry Farmers of Imerintsiatosika, in Madagascar, Toward Risks Related to Antibiotic Usage: A Q-Method Approach

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Antimicrobial resistance is a One Health issue that must be tackled worldwide. In order to implement effective communication strategies in Madagascar, a better understanding must be gained of practices and perceptions related to antimicrobial use at the smallholder farm level. Our study used a semi-qualitative approach, called Q methodology, to identify patterns of opinion on antimicrobial use, or its alternatives, among pig and poultry smallholders and drug vendors in the commune of Imerintsiatosika, in Madagascar. Twenty-nine breeders and 23 drug vendors were asked to rank, respectively, 38 and 45 statements, produced from semi-structured interviews and secondary data, through a 7 grade scale from −3 (totally disagree) to +3 (totally agree) about antimicrobial use, related risks and alternatives. The interview ended with a discussion around extreme statements. The *Q-sortings* were analyzed by factor analysis and Principal Component Analysis. Regarding antimicrobial use, antimicrobial resistance and alternatives, the breeders and drug vendors were divided according to three discourses: "A: confidence in antibiotics" (respectively, 13 and 6 individuals), "B: belief in alternatives" (7 and 7 individuals), and "C: moderate approach to antibiotic use" (6 and 6 individuals), explaining, respectively, 57 and 60% of total variance. Group A was associated with the use of antibiotics as a preventive measure, poor knowledge of resistance and low trust in alternatives. Group B considered the preventive use of antibiotics to be a major problem for antimicrobial resistance and believed that alternatives, such as vaccines, were useful preventive methods. Group C seemed to have a hazy opinion. The presence of three main points of view offers the possibility to adapt awareness messages. Group B might also be used as a showcase to reduce the amounts of antibiotics used by the two other groups. This study revealed different practices and risk perceptions related to antimicrobial use that must be better characterized and accurately quantified.

Keywords: antibiotic resistance, communication, livestock, Madagascar, opinions, participatory epidemiology

INTRODUCTION

Antimicrobial resistance (AMR) is currently one of the main public health threats worldwide and the misuse or overuse of antibiotics (AB) in human and veterinary medicine is one of its main drivers (1). One of the general recommendations of the World Health Organization (WHO), World Organization for Animal Health (OIE), and Food and Agricultural Organization (FAO) to tackle the problem is to improve awareness and understanding of AMR among the public and professionals.

As end-users of AB and main providers, breeders play a key role, in antimicrobial usage (AMU), toward reduction strategies and the prevention of spreading resistance (2). Veterinarians are also important actors in the fight against AMR. They act as consultants in farm management, oversee treatment, and write the prescriptions required to buy drugs in most countries worldwide. They are considered as the most legitimate persons to inform breeders on usage, risks, and alternatives to AB (3, 4). The relationship between veterinarians and farmers is also critical. Visschers et al. (5) show that, in Europe, breeders who systematically call the veterinarian use smaller amounts of AB.

Since 2014, studies have been conducted in Europe to explore the perception of breeders and veterinarians toward AMU, AMR, alternative treatments and policy measures (2, 5–7). This has enabled an evaluation of people's understanding of the issue, the identification of their motivations and an alleviation of certain barriers to change. Hence, their perceptions can be a base from which to elaborate more effective communicative strategies. However, despite the fact that low and middle income countries use large amounts of AB with, lately, a significant increase in their consumption (8), few studies have been completed on farmers' perceptions.

Madagascar is among the 10 poorest countries in the world (9). With its extreme natural wealth and great geographical diversity, agriculture is among the major economic sectors of the country. Indeed, 78% of the population live in rural areas and 60% breed animals as a source of income (10). In most families, livestock is a capital that can be used in the case of financial difficulties or for self-consumption (11). Poultry is the most commonly farmed livestock, with almost 35 million animals, followed by cattle (10 million) and pigs (1.5 million) (11). Although some intensive commercial farms do exist, most production are backyard (free-range animals, no care provided) or semi-intensive (small contained headcount, minimal care) farms (12). AMR is of public concern, with resistance reported in humans for *Staphylococcus aureus*, *Enterococcus* spp., *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, and *Enterobacteriacae* spp. The latest, including extended-spectrum β-Lactamase and carbapenemase-producing Enterobacteriaceae (ESBLE and CPE), was described by the Indian Ocean Commission (IOC) as one of the main human and animal threats (13). In Madagascar, due to the lack of sanitation, the close contact between humans and animals, and the difficulties to access medical care, resistance will become one of the highest burdens over the coming decades. Little information has been published on AMU or AMR in the livestock sector in Madagascar (13). Crépieux (12) suggests that there is poor knowledge of AB and a high percentage of self-medication. In a recent study, the prevalence of ESBLE in pigs, cows, and poultry was higher than 65% and reached 86.7% in swine (14). The situation remains unclear, and more data must be collected on knowledge and perceptions within the animal sector.

The qualitative approach, including participatory epidemiology, is an interesting method with which to establish an initial assessment of a problem. It is a *bottom-up* method (15) based on the active participation of individuals in defining their own solutions tailored to their issues (16). By identifying the major characteristics of a problem, it can be used as a baseline for the development of further studies. Usually cheaper than conventional studies, it allows the collection of information that is sometimes difficult to access (17). The most frequently used methods are informal interviews, visualization, ranking and scoring tools (18).

To evaluate the impact of AMR and develop alternatives to AB in Madagascar, our first step consisted in studying the perceptions of livestock professionals in the region of Itasy, including breeders and drug vendors, toward AMU and AMR. We used a semi-qualitative method called Q-methodology to identify patterns of opinions (19) and to understand AMU practices, the perception of related risks and attitudes toward alternatives. This method helped us to determine common and distinct opinions within our study population. As decision-making processes can be influenced by socio-demographic factors, we also studied their impact on perception.

MATERIALS AND METHODS

Study Zone and Population

This study was conducted in the commune of Imerintsiatosika, 30 km from Antananarivo (the capital city) in the region of Itasy, from April to May 2018. The high density of pig and poultry farms and easy accessibility were the main criteria used in the selection of this zone. The city is divided into 36 fokontany (the smallest administrative unit in Madagascar) and subdivided into urban or rural fokontany. An urban fokontany is defined by a certain density of urban construction and then was confirmed by the respondents during the survey (name of the fokontany and rural/urban fokontany). Our study zone included six urban (Antanambao, Antsenakely, Labrousse, Imerimandrose, Miakadaza, and Tsarafaritra) and five rural (Amboara, Bemasoandro, Malaza, Morano Nord, and Tsenamasoandro) fokontany (**Figure 1**), also chosen for their accessibility. Our first population was poultry and/or pig breeders, including family smallholdings (between 1 and 10 pigs and up to 100 poultry), semi-intensive farms (between 10 and 100 pigs and up to 500 poultry), and intensive farms (more than 100 pigs and up to 2,000 poultry) of the commune. Because most of the statements are based on the assumption that respondents have a minimum knowledge about AB, breeders who do not administer AB to their animals were excluded. Our second population was drug vendors including veterinarians, technicians, and other salesmen working with the breeders of Imerintsiatosika. Following interviews, professionals from Antananarivo and Ambatomirahavavy (between Imerintsiatosika

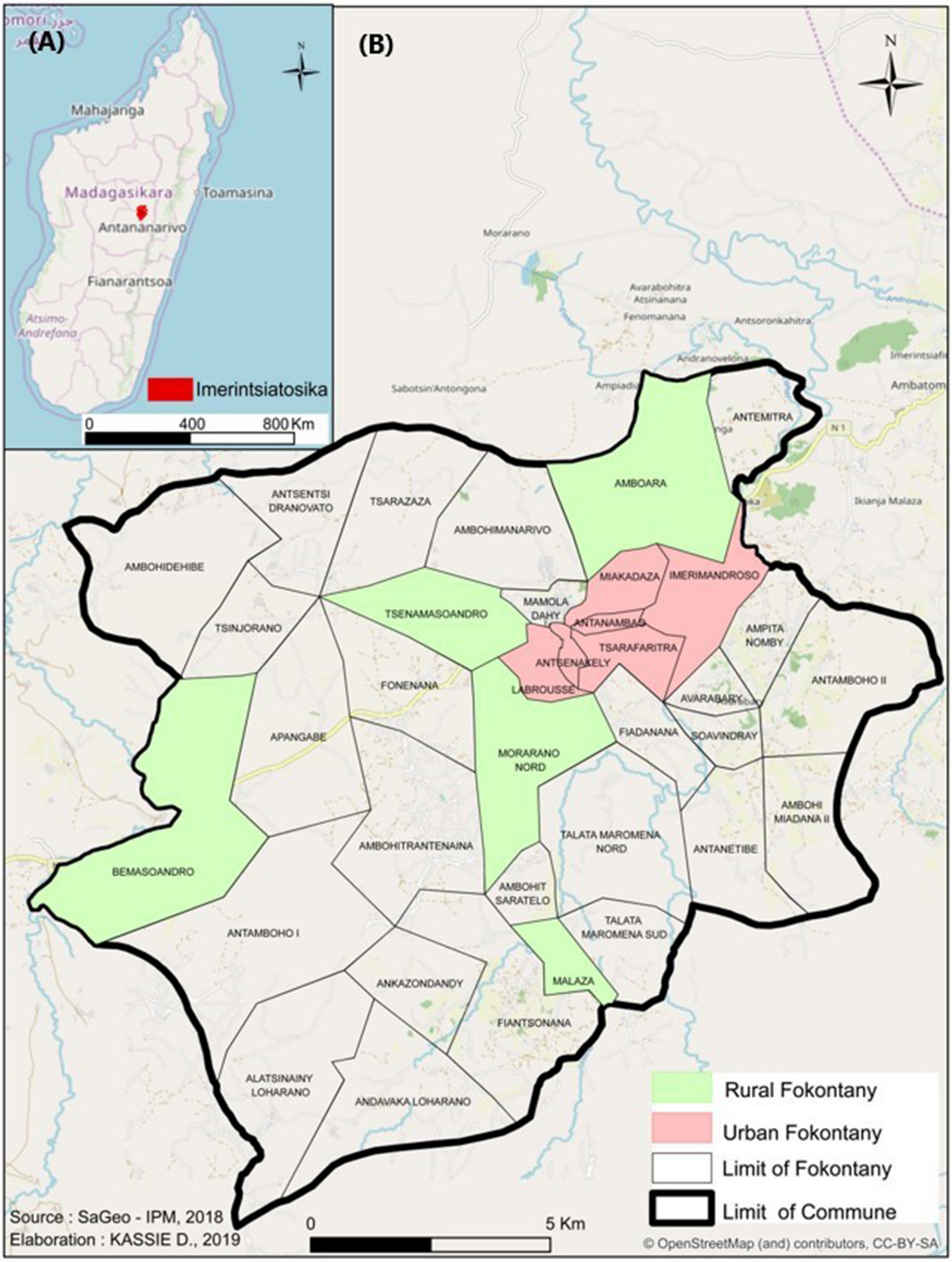

FIGURE 1 | Map of the study area in Madagascar **(A)** and Imerintsiatosika **(B)**. Red: urban studied fokontany; green: rural studied fokontany.

and Antananarivo) working with breeders in Imerintsiatosika were also included.

Q-Methodology

Q-methodology was used to explore the perception of breeders and drug vendors toward AMU. This semi-qualitative method studies the subjectivity of individuals regarding a complex and sensitive subject. Its main objective is to identify groups of individuals sharing the same point of view and to determine common and distinct opinions on a same subject by means of correlation (20). The precise methodology is described by Exel and Graaf (19).

Q methodology follows five steps: generation of the *concourse* (list of statements), construction of a set of statements (the *Q-set*), selection of the respondents (the *P-set*), ranking of the *Q-set* (the *Q-sorting*) and finally the analysis and interpretation of the factors (19).

Generation of the Concourse

The *concourse* is the raw material of the method, defined as "the flow of communicability surrounding any topics" (21). It consists of a list between 200 and 300 statements representatives of all the opinions and ideas about the subject (22).

In our study, the *concourse* was conceived firstly through a literature review of documents related to AMR and animal production (worldwide and in Madagascar), and then by implementing tools from participatory epidemiology (PE), in particular, direct observations and semi-structured interviews (SSI) of key informants (18). The literature review allowed us also to determine relevant information that needed to be include in the guide of interviews. The SSI were based on a check list including topics such as antibiotic use, antibiotic advice, relationships between farmers, veterinarians, and drug vendors, risk of antibiotic use for animals and humans, and knowledge about alternatives to antibiotics.

In order to get the maximum amount of information to help us to create the Q-set, we conducted the interviews with people working in different institutions as well as some breeders and sellers. As it is difficult to have the representativeness of all the types of actors intervening in the antibiotics sector, the interviews were therefore contained with some people with whom we were able to establish contacts and who are also key actors in Madagascar. The SSI were conducted in Antananarivo with 4 persons [2 employees from the direction of veterinary services, 1 from the National Research Center applied to rural development (FOFIFA) and 1 veterinary student] and, in Imerintsiatosika, with 8 persons (1 private veterinarian mandated by the veterinary services in charge of the commune, 3 drug vendors, and 4 breeders). At the end, the formulation of the statements include in the *concourse* was done from the literature review and the SSI of key informants.

Construction of the Q-Set

The Q-set is a list of statements built from the *concourse*. We first organized the information collected from the literature review and SSI into a list of statements around three main topics (use/advice on antibiotics, risk of using antibiotics, use of alternatives). The organization of the statements around the three main topics was done following an inductive approach. We started from a raw list of statements that we organized according to their similarities. The selection of the statements was done according to the relevance of the statements for the objectives of the study by the research team. Then, the statements were separated among our two study populations (drug vendors and breeders) and organized into sub-topics. To reduce the *concourse* to a manageable *Q-set* (between 30 and 60 statements), we removed statements with similar assertions. These were reviewed by three different researchers, who were familiar with the subject, to evaluate their relevance and understanding. They were then translated into Malagasy by the research assistant and reviewed by one veterinary student from Madagascar. We printed the statements on separate cards, which were randomly assigned a number. Finally, 2 drug vendors and 4 breeders were used to pilot the study protocol.

Selection of the P-Set

The *P-set* is the set of individuals interviewed, usually less than the number of statements. The goal is not to be representative of the population but to obtain a wide array of existing opinions (19). They are not chosen randomly but according to some socio-demographic characteristics considered to be relevant in the subject. Our respondents were identified with the help of the veterinarian in charge of food safety in the area, of his assistant and through a snowball sampling. We planned to include 30 breeders according to the species present in their farms (pigs, poultry, or both), their location (urban or rural) and their type of production (familial, semi-intensive, or intensive), and 30 drug vendors according to their type of activity (veterinarians, technicians, and sales representatives) and their link with the veterinarian in charge of this commune (independent, working with him, working for a company).

Statement Sorting and Ranking

The face-to-face interview was undertaken by the principal investigator and the research assistant, both of whom were trained in PE methodology. Throughout the presentation of the study, respondents were informed about the objective, the duration (around 1 h) and were provided with instructions to complete the tasks. Before the application of the method, a questionnaire on socio-demographic characteristics was completed by the respondent. For breeders, topics concerned age, gender, years of experience, education level (elementary school, middle school, high school, university), species (poultry, pigs or mixt), type (smallholding, semi-intensive, intensive), working status in the farms (owner or employee), and location (urban or rural fokontany). For drug vendors the topics were age, gender, years of experiences, jobs (veterinarians, technicians, or other salesmen), relationship with the veterinarian of the commune and training (presence or absence).

The respondents were then asked to rank the *Q-set* (meaning all of the cards) according to certain rules called *conditions of instruction* and to their own point of view. The first step was to place all the statements into three piles: "agree," "neutral," "disagree." Then they were asked to place each statement in a seven grade grid from +3: "totally agree" to −3 "totally disagree," 0 corresponding to "neutral," following a forced distribution (**Figure 2**). The cards were read out loud for people who were not able to read by themselves. During the interviews, they were free to move the cards as they wanted until they finally agreed with the position of all cards. Finally, a discussion was held on the extreme statements (+3 or −3) and sometimes certain other specific statements. At the end, we obtained a *Q-sort* for each participant. It is the result from the ranking of the *Q-set* by the respondent following the *conditions of instruction* (each statement have a grade between −3 and +3 allocated) and that represents an individual subjective pattern.

Data Analysis

Quantitative Analysis

Data analyses were run using R 3.4.1. software with "FactoMineR" and "qmethod" packages. The analytical process is described by Zabala (23). Data are presented in a matrix with statements in rows and *Q-sorts* in columns. First the inter-correlation matrix is calculated, it represents the correlation between each *Q-sorts*. Then, this matrix is reduced, and factors are extracted using Principal Component Analysis (PCA). Adversely to a classic PCA, *Q-sorts* are the variables and disposed in columns in the matrix. The number of principal components chosen for further analysis are based on the following criteria: the eigenvalue of the component should be greater than one, the total variance explained >40%, more than two *Q-sorts* should be loaded by factor and the factors should make sense once the analyses is completed.

The selected factors are then rotated with the Varimax mode to maximize the association between the variables, the *Q-sort* and the factors, and to obtain a clearer structure. To each *Q-sort* a factor loading is calculated and represent the relation between *Q-sorts* and factors. Then, the *Q-sorts* which define a factor are flagged. It belongs to a factor when it follows the two equations: $l > 1,96\sqrt{N}$ and $lj > \sum_{i=1}^{f} l^2 i - l^2 j$ where l is the factor loading, N the number of statements and j the considered factor ($p < 0.05$) (24). *Q-sorts* which do not respect this or that load to more than one factor are called confounding. For the next steps, only flagged *Q-sorts* are used in further calculations. Then the *z*-score is calculated. It represents the relationship between a statement and a factor. The factor score is the normalized weighted average statements scores (*z*-scores). It permits to have factors with different perspectives (a point of view or opinion). At the end, we obtain a factor score for each statement of each factor, that represent the score that an ideal respondent which loaded 100% with the factors will respond. The interpretation of the factors is based on these scores. When, for a statement the *z*-scores are statistically different between factors (more than a threshold based on the *SE* of differences between two factors multiplied by 1.96 for $p < 0.05$), it is called "distinguishing statement" (23). If there are no statistical differences between any pair of factors, it is considered as a "consensus statement" (the same opinion is shared by all factors).

Socio-Demographic Characteristic Analysis

To identify variables that could describe respondents within a same discourse, the socio-demographic characteristics from the questionnaire were analyzed with a Kruskal-Wallis test for non-parametric data on the R software.

Qualitative Analyses

Recorded interviews were transcribed and then translated into French or directly transcribed into French on WORD Microsoft Office 365 software version 2016. Where a recording device was not used, interviews were recorded in writing. The different factors were analyzed and interpreted using the ABC model of attitudes for sociological sciences (25). This model helps to study attitudes by describing them through three components: Affective, Behavioral, and Cognitive. Attitudes

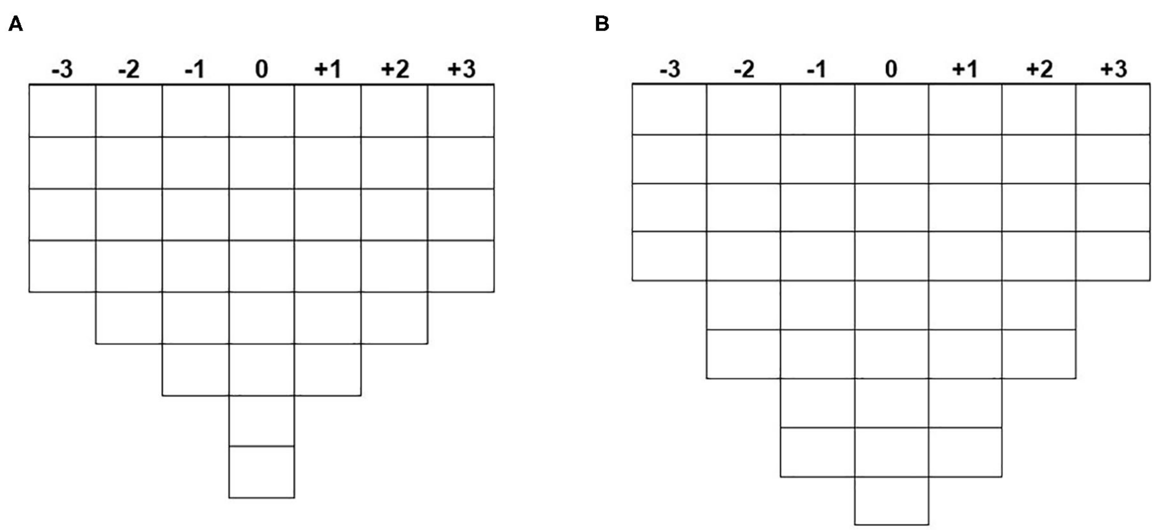

FIGURE 2 | Q-sorting. Breeders: 38 statements **(A)**; drug vendors: 45 statements **(B)**.

toward antibiotics were decomposed into three components: an affective component (feelings of breeders and drug vendors toward antibiotics, alternatives and relationships between the two categories of population), a behavioral component related to action (the AMU, advice and alternative usages) and a cognitive component (belief and knowledge about AMU, risks and alternatives).

RESULTS

The Q-Set

Two hundred and forty-five statements were formulated based on the literature review and the SSI. After categorization, reviewing and removal of duplicates, 55 statements for breeders and 47 for drug vendors were retained and translated into Malagasy. After the two field test sessions, the final *Q-set* was composed of 38 statements for breeders and 45 for drug vendors.

Breeders

Presentation of the P-Set

Thirty-one interviews were conducted in the area of Imerintsiatosika. Two farmers did not meet the inclusion criteria (no use of antibiotics and over 2,000 poultry). During data analysis, three *Q-sorts* (so three sets of answers from respondents) were found to be confounding and were removed from the analysis.

Out of the 26 respondents, the majority were men (17/26) and younger than 40 years of age (18/26). Participants were mainly educated (19/26 reached at least high school). Most breeders owned their farm (21/26), had at least one pig (21/26) and worked according to a semi-intensive model (16/26). The number of farms located in rural areas was quite similar to the number in urban areas (46 and 54%, respectively). Finally, the average number of years of experience was 10.38. Details of the socio-demographic characteristics are presented in **Table 1**.

Factor Analysis

Following the PCA, eight factors showed an eigenvalue above 1 and explained more than 50% of the total variance. After rotation, only three factors were extracted. These accounted for 57% of the total variance, loaded more than two *Q-sorts* and were the most meaningful. General factor characteristics, *Q-sorts* factor loadings and flagged *Q-sorts* (*Q-sorts* belonging to a factor) are presented in **Supplementary Material**.

The *Q-set*, *z*-scores and *Q-sort* values for each factor are presented in **Table 2**. The analysis of the factors was based on statements with extreme values (−3, −2 and +2, +3), the distinguishing statements and the content analysis of each individual interview. Following the analysis, the three discourses were named A "trust in antibiotics," B "belief in alternatives," and C "moderate use of antibiotics." The Kruskal Wallis test performed between the three discourses showed that the education level was statistically different between the three groups ($p < 0.01$) with group C having a lower level of education (**Supplementary Material**).

TABLE 1 | Socio-demographic variables and result of Kruskal-Wallis test for the whole population of breeders (a), people belonging to F1 (b), F2 (c), and F3 (d).

Variables		(a)	(b)		(c)		(d)	
		Population	F1	*P*-value	F2	*P*-value	F3	*P*-value
Number		26	13		7		6	
Gender	Woman	9	6	0.53	1	0.39	2	0.08
	Man	17	7		6		4	
Age	≤40	18	11	0.02*	4	0.059	3	0.33
	>40	8	2		3		3	
Experience	(years)	10.38	10.7	0.48	6.8	0.83	13.8	0.21
Education	Elementary sch.	4	1	0.07	0	0.009**	3	0.13
	Middle sch.	3	1		1		1	
	High sch.	10	7		1		2	
	University	9	4		5		0	
Status	Owner	21	10	0.67	7	0.008**	4	0.74
	Employee	5	3		0		2	
Specie	Pork	10	6	0.10	3	0.19	1	0.76
	Poultry	5	1		3		1	
	Mixt	11	6		1		4	
Type	Familial	5	3	0.89	2	0.49	0	0.85
	Semi-intensive	16	8		3		5	
	Intensive	5	2		2		1	
Farm localization	Urban	14	8	0.71	2	0.85	4	0.55
	Rural	12	5		5		2	

*$p < 0.05$; **$p < 0.01$.

TABLE 2 | *Q-set*, rank and z-scores for the P-set breeders.

		Factor					
		F1		F2		F3	
N°	Statements	Rank	*z*-score	Rank	*z*-score	Rank	*z*-score
1	When a neighboring farm has sick animals, it is necessary to treat immediately with antibiotics	1	0.79	−1†	−0.41	1	0.98
2	Breeders can treat an animal with any dose of antibiotics	−3	−1.93	−3	−1.75	−3	−1.37
3	If breeders use too much antibiotics on animals, we will not be able to treat some human diseases	0	0.08	1†	0.63	0	−0.06
4	**We must always ask advice to drug vendors before using antibiotics**	**3**	1.41	**2**	0.96	**2**	1.08
5	**We must always respect the withdrawal time of the antibiotics before slaughtering an animal**	**3**	1.27	**2**	1.01	**2**	0.98
6	Antibiotics use on animals can be dangerous for human health	−2	−1.09	0†	−0.09	−1	−0.73
7	The respect of the withdrawal time of the antibiotics protect consumers health	2	0.94	1	0.82	1†	0.28
8	*If breeders always use the same antibiotic to treat their animals, the antibiotic will not be efficient anymore in their farms*	*0*	0.41	*3*	1.30	*0*	−0.40
9	Everybody can enter in farms	−3	−1.67	−3	−1.85	−3	−2.26
10	Preventing diseases by antibiotics can lead to inefficient antibiotics	0	−0.18	2†	1.18	0	−0.15
11	*Vaccination can reduce antibiotics use in a farm*	*1*	0.76	*3*	1.29	*−1*	−0.67
12	**Antibiotics use in farms are always efficient**	**−1**	−0.56	**−1**	−0.55	**−1**	−0.51
13	Giving antibiotics is the cheaper way to prevent disease	1†	0.52	−2	−1.11	−2	−0.81
14	*We can stop antibiotics treatment when the animal is getting better*	*0*	−0.17	*−1*	−0.78	*1*	0.62
15	*Other methods exist to prevent diseases*	*1*	0.59	*2*	1.24	*−1*	−0.51
16	To prevent diseases, breeders should always use antibiotics on imported chicken	2†	0.89	0	−0.23	0	0.18
17	*Breeders use antibiotics to accelerate animal growth*	*2*	0.84	*−3*	−1.67	*−2*	−0.82
18	**Requiring prescription to buy antibiotics represent a loss of time and money**	**−2**	−0.84	**−1**	−0.51	**−2**	−1.00
19	Breeders must follow treatments advice from other breeders	−2	−0.61	−2	−0.81	0†	−0.02
20	The veterinarian or the technician always explain to the breeders which antibiotic he is using when he treats an animal	1	0.42	1	0.50	2†	1.04
21	Respecting the withdrawal time is a waste of money so breeders don't respect it each time	−1	−0.50	−1	−0.55	0†	0.20
22	**If prescription by veterinarians was mandatory to buy drugs, breeders would use less antibiotics**	**0**	0.04	**0**	−0.12	**0**	−0.27
23	Drug vendors should inform breeders about risks related to antibiotics use	0	0.01	0	0.35	2†	1.02
24	*We can breed without using antibiotics*	*−3*	−1.84	*0*	0.00	*−1*	−0.76
25	Expensive antibiotics are more efficient	−1	−0.40	0	−0.24	1†	0.54
26	Antibiotics can be used to treat any kind of infections	−1	−0.40	−1	−0.67	3†	1.26
27	Whenever an animal is sick, breeders can always use the same antibiotics	−1	−0.45	−2	−1.30	−2	−0.87
28	Breeders treat themselves with antibiotics because veterinarians and technicians are often busy	0	0.19	1†	0.49	−1	−0.51
29	If breeders separate sick animals from healthy one, we can prevent spreading disease	2	1.08	3	1.54	3	1.48
30	**Breeders should often clean the farm to have less disease**	**3**	1.89	**3**	1.87	**3**	1.82
31	The place where we buy antibiotics doesn't matter	−2	−1.21	−2	−0.99	0†	0.22
32	Breeders use antibiotics only when animals are sick	−2†	−1.48	2	1.16	1	0.86
33	**Antibiotics residues can be found in soil and rivers**	**0**	0.18	**0**	0.37	**1**	0.35
34	*When an animal is sick, breeders must always call the veterinarian*	*3*	1.77	*1*	0.49	*2*	1.22
35	*The veterinarian is expensive that's why breeders don't call him every time*	*1*	0.66	*0*	0.14	*−3*	−1.12
36	If the antibiotic is expensive, we need to reduce dosage	−3	−1.57	−3	−1.55	−3	−2.06
37	Eating meat (pigs or poultry) raise without antibiotics is better to human health	−1	−0.40	1†	0.64	−2	−0.83
38	*Using antibiotics is safe for animals*	*2*	0.95	*−2*	−0.79	*3*	1.62

†Statement distinguishing factor from the rest. In bold: consensus statements; in italic: distinguish statements.

Consensus Statements

Seven statements were consensus statements. When asked about the need for a prescription when buying AB, all the breeders agreed that it was not a waste of money or time (statement 18): the factor scores given by the breeders was −2 or −1 with no statistical difference within the two values (stat. 18: −2, −1). Indeed, they all believed advice from vendors to be necessary when using drugs (stat. 4: +3, +2), in particular regarding dosage (an overdose would lead to severe illness or mortality and an underdose would be ineffective). They did not have a strong opinion regarding the fact that prescriptions decrease the amount of AB used by farmers (stat. 22: 0), suggesting that they did not perceive the need for a prescription as a barrier to AB usage. They considered that cleaning the farm is a good way to reduce disease and consequently AB usage (stat. 30: +3), as *"property is a source of health"* E28/R25 (corresponding to answer 25 of breeder number 28). They did not believe that AB are always efficient (stat. 12: −1) saying that it depended on the disease and administration method. Concerning residues, they all believed that is was mandatory to respect the withdrawal time (stat. 5: +3, +2), but they had no understanding of residues in the environment (stat. 33: 0, +1).

Discourse 1A "Trust in Antibiotics"

This point of view was shared by 13 breeders and represents 23% of total variance. This discourse was influenced by the age of respondents, with statistically more people under the age of 40 (11 respondents were under 40 and 2 were over 40) ($p = 0.02$) (**Table 1**). This group was characterized by a positive opinion of AB and weak AMU practices, bad practices related to AMU misuse and overuse of AB. They strongly disagreed with the possibility of farming animals without using AB (stat. 24: −3), considering this to be unprofessional. AB were not used only when an animal was sick (stat. 32: −2) but also to prevent diseases and stress, particularly in imported chickens that were considered to be less resistant than local breeds (stat. 16: +2) *"I take an example, if today it's really warm and that the next day it's cold, we must use AB [...] and also when the animal moves on to a finisher feed after the growth feed, meaning that there is a dietary transition, we should use AB as it helps avoid animal stress. It's the instructor who taught us to use AB as prevention [...] and it works!"* E27/R13. AB were used as growth promoters (stat. 17: +2). This was consistent with the rest of their discourse concerning the safety of these products. As in group 1C, AB were considered to be safe for animals (stat. 38: +2) as well as for humans (stat 6: −2). But the prescription must be respected (made by the manufacturer that is a trusted professional) and AB should be bought in a specific place (stat. 31: −2), as agreed in group 1B. In accordance with this, it was considered important for them to call the vet when an animal is sick (stat. 34: +3), as they are trained, and therefore the best person to advise them. Meanwhile, they also treated by themselves when they were familiar with the disease, as breeders also have effective knowledge and experience, and the veterinarian is sometimes busy or considered to be too expensive. Finally, they did not have a clear opinion regarding the existence of other disease prevention methods (stat. 15: +1) or of the ability of vaccination to reduce AMU (stat. 11: +1). Thus, they did not consider these alternatives as a good means to reduce AB.

Discourse 1B "Belief in Alternatives"

The second discourse included seven breeders and explained 18% of total variance. This discourse was statistically influenced by two variables: farm owners ($p < 0.01$) and more educated people (5 university, 1 high school, 1 middle school, 0 elementary school, $p < 0.01$) (**Table 1**). This discourse was characterized by a more critical opinion of excessive AMU. Unlike the other groups, using AB was not considered to be safe for animals (stat. 38: −2). Excessive use leads to AB resistance and, therefore, they cannot be used as growth promoters (stat. 17: −3) or for disease prevention (stat. 10: +2) *"AB are not made to prevent diseases but to treat them [. . .] when a disease appears, no antibiotics will be efficient; and it becomes, it becomes, microbes become resistant to drugs"* E31/R30. This was coherent with the rest of their discourse even if it was not statistically specific to this group: they used AB, but only as a treatment (stat. 32: +2). Moreover, the consistent use of the same AB was linked to a loss of effectiveness (stat. 8: +3). This group also trusted alternatives (stat. 15: +2). Vaccination was considered as the best strategy to prevent disease and reduce AMU (stat. 11: +3).

Discourse 1C "Moderate Approach to Antibiotic Use"

This group included six breeders, representing 14% of total variance. It was an heterogenous group as there were no significant differences between variables (**Table 1**). Contrary to the other groups, which differed in their strong opinion about AMU (one group is really in favor of AMU whereas the other promote a more prudent use), they did not have a clear and specific point of view regarding AMU (stat. 24: −1), AMR (stat. 8: 0) and alternatives (stat. 15: −1). For factor 1A, they believed that AB was safe for animals (stat. 38: +3) and for humans as it protects meat from contamination by bacteria (stat. 37: −2). But they seemed to have a moderate use of antibiotics because they were never used as growth promoters (stat. 17: −2). They also thought that AB could be used to treat any kind of infection (stat. 26: +2).

By contrast to the two other factors, the relationship between breeders and veterinarians was more present. They trusted advice given by veterinarians and technicians who always explain the treatment (stat. 20, +2). So, they need to call them when an animal is sick (stat. 34, +3) regardless of economic considerations (stat. 35, −3). They also considered veterinarians and technicians to be the best persons to explain risks to them (stat. 23, +2).

Drug Vendors

Presentation of P-Set

Twenty-four people were interviewed in Imerintsiatosika, Ambatomirahava, and Antananarivo. One person was excluded because of an incoherent discourse. Four *Q-sorts* were confounding and excluded from further analysis. This population was mainly composed of men (12/19), of <40 years old (14/19). Technicians represented more than half of the total population (10/19) followed by sales reps (7/19) and veterinarians (2/19). Twenty-six-point three percent worked for chicken production company that was authorized to sell drugs. Most of the drug vendors received training (13/19) and the average number of years of experience was 12.9. Details on socio-demographic characteristics are presented in **Table 3**.

Factor Analysis

After the PCA, six components had an eigenvalue of more than 1 and explained more than 50% of the total variance. Three main factors were retained, accounting for 60% of the total variance (**Supplementary Material**). The main ideas of each discourse, like those of breeders, led to the same group name and flagged *Q-sorts* which are presented in **Supplementary Material**. Analysis and interpretation of discourses was based on **Table 4**.

Consensus Statements

Six statements were consensus statements. For drug vendors, knowledge seemed to be important in AMU as they considered it mandatory to receive training to sell drugs (stat. 31: −3). Moreover, they thought that it is important to be informed about the risks of using AB (stat. 27: +2, +3). But it seems that they did not have a clear opinion about the source of resistance in livestock and particularly the impact of misuse or overuse of AB (stat. 28: +1). Also, they did not have a clear opinion on the way to use narrow or broad-spectrum AB and their impact on resistance (stat. 37: −1), revealing a knowledge gap regarding AB specificity. For them, conditions of storage were essential because the molecules that constitute the AB should be stored at a proper temperature and protected from the light stat. 39: −3). They said that despite the information given to farmers on storage conditions, these were not always complied with. As for breeders, they considered that keeping the farm clean was a good alternative to antibiotics (stat. 40: +1, +2) as this reduces disease transmission.

Discourse 2A "Trust in Antibiotics"

Six people shared this factor and represented 22% of total variance. This group was influenced by the "training" variable, with a majority lacking in training ($p < 0.05$). For these 3 technicians and 3 other salesmen, it seemed impossible to breed animals without antibiotics (stat. 9: −2). They felt that AB in prevention were essential to overcome stressful conditions like weather change or weaning (stat. 1: +2) and they did not see any link with this practice and manifestations of resistance (stat. 16: −2). They considered that technicians and veterinarians played an essential role for breeders. It was important to inform them about dosage and length of treatment (stat. 5: +2) and to write it down (stat. 11: +3) to be sure that they would complete the treatment even if animals were getting better. It was necessary to examine the animals before administering treatment (stat 2: +3) to choose the appropriate AB. In coherence with this group, 2B also believed that it was important to inform breeders of the kind of AB used, the reason (stat. 30: −2) and the withdrawal time (stat. 43: +3).

Discourse 2B "Belief in Alternatives"

This discourse was shared by 7 people, representing 20% of the total variance. The two veterinarians were part of this group, but no variables were significantly different. Contrary to the previous discourse, antibiotics were not essential in preventing disease (stat. 1: −2). They linked such practices with reduced effectiveness (stat. 20: −3). As such, and similarly to group 2C, people in this group believed it necessary to change AB (stat. 32: −2; stat. 33: −2) and to not always give the breeders what they want (stat. 35: −3). But, similarly to the others, they believed that prescriptions made by a veterinarian should be mandatory to buy AB (stat. 42: +2) and that it was necessary to raise awareness of breeders about the risks (stat. 15: −2). Moreover, they knew that AB residues can be found in the environment (stat. 36: +2).

TABLE 3 | Socio-demographic variables and result of Kruskal-Wallis test for the whole population of drug vendors (a), people belonging to F1 (b), F2 (c), and F3 (d).

Variables		(a)	(b)		(c)		(d)	
		Population	F1	*P*-value	F2	*P*-value	F3	*P*-value
Number		19	6		7		6	
Gender	Woman	7	2	0.24	3	0.83	2	0.97
	Man	12	4		4		4	
Age	≤40	14	4	0.75	6	0.10	4	0.68
	>40	5	2		1		2	
Experience	(Years)	12.9	12	0.50	7.7	0.73	20.17	0.39
Job	Other salesman	7	3	0.23	1	0.06	3	0.11
	Technician	10	3		4		3	
	Veterinarian	2	0		2		0	
Relation with	Company	4	0	0.38	3	0.14	1	0.58
	Independant	8	3		2		3	
	Veterinarian	7	3		2		2	
Training	Yes	13	2	0.01*	5	0.46	6	0.33
	No	6	4		2		0	

*$p < 0.05$.

TABLE 4 | *Q-set*, rank and z-scores for the P-set drug vendors.

N°	Statements	Factor					
		F1		F2		F3	
		Rank	*z*-Score	Rank	*z*-Score	Rank	*z*-score
1	*Antibiotics to prevent disease are essential to the functioning of the farm*	*2*	1.30	*−2*	−0.94	*−1*	−0.31
2	Veterinarians or technicians should move to the farm when animals are sick	3	1.51	1	0.79	2	1.14
3	*Wholesalers have enough choice of antibiotics*	*1*	0.40	*−1*	−0.68	*2*	1.38
4	Eating meat (pigs or poultry) raise without antibiotics is better for human health	1†	0.95	0	0.02	−1	−0.47
5	It is necessary to inform breeders about dosage and length of treatment	2†	1.36	0	0.29	1	0.35
6	In first intention, we must use the most efficient antibiotics	1	0.31	1	0.51	0	−0.04
7	Some drug vendors sell fraudulent drugs	−1	−0.49	0	−0.14	2†	1.14
8	*There is no risk to use antibiotics If we respect the utilization advice*	*1*	1.06	*0*	0.24	*3*	1.65
9	Pigs or poultry can be raised without using antibiotics	−2	−1.44	1†	0.55	−1	−0.91
10	If an antibiotic is no longer efficient on an animal, it will also not be efficient on the other animals	−2	−0.71	−1	−0.86	−3†	−1.47
11	Dosage and length of treatment must always be written for the breeders	3†	1.59	1	0.65	1	0.49
12	If we always give the same antibiotics to breeders, it will become inefficient	1	0.31	1	0.53	−1†	−0.26
13	We must always ask questions on clinical signs or examine the animals before using an antibiotic	3	1.67	2†	0.80	3	1.87
14	Antibiotics use on animals is harmful for human health	−1	−0.39	0†	0.33	−1	−0.85
15	It is useless to talk about antibiotic's risks to breeders	0	−0.37	−2†	−1.40	0	−0.13
16	*Using antibiotics as preventive methods can lead them to become inefficient*	*−2*	−0.82	*1*	0.50	*0*	−0.21
17	Antibiotic choice depends of animal's symptoms	2	1.24	2	1.25	3†	1.86
18	If we misuse or overuse antibiotics on animal, untreatable human diseases can appear	0	−0.35	0†	0.47	0	−0.21
19	Vaccination reduce antibiotics use in livestock production	0	0.16	3†	1.71	0	0.03
20	*An antibiotic is always efficient on a bacterial infection*	*−1*	−0.71	*−3*	−1.68	*1*	0.84
21	To have the possibility to realize lab analysis will reduce antibiotics use	0	−0.13	3†	1.40	0	−0.16
22	Breeders always follow drug-seller advices	−1	−0.38	−1	−0.79	1†	0.86
23	We can trust in all drugs wholesaler supplier	−2	−1.03	−1	−0.72	1†	0.64
24	Antibiotics as preventive measure should not be use anymore	−2	−0.96	0†	0.28	−2	−1.26
25	*A better application of the law could reduce antibiotics use in livestock production*	*0*	−0.14	*0*	0.44	*−1*	−0.97
26	*It is better to use an antibiotic with a narrow spectrum than a large spectrum*	*0*	−0.25	*0*	0.32	*−2*	−1.03
27	**It is important to be formed about antibiotic's risks**	**2**	1.07	**3**	1.49	**2**	1.05
28	**If we misuse or overuse antibiotics, they can become inefficient on animals**	**1**	0.47	**1**	0.80	**1**	0.70
29	It is not a problem to give a less efficient antibiotic if it is less expensive for the breeder	−3†	−1.86	−2	−1.19	−2	−1.06
30	It is useless to inform breeders on the kind of antibiotic use and the reasons of their administration	−2	−0.82	−1	−0.77	0†	−0.23
31	**Everybody can sell drugs without having specific training**	**−3**	−1.73	**−3**	−1.82	**−3**	−2.04
32	When a product is efficient we have always to use the same	1†	0.64	−2	−1.07	−1	−0.54
33	Having only three or four different antibiotics is enough	0†	−0.37	−2	−1.19	−2	−1.14
34	Preventing diseases by vaccinate or cleaning the farms is less expense than using antibiotics	0†	0.29	2	1.13	3	1.53
35	*We must always give to the breeders what he wants*	*1*	0.55	*−3*	−1.91	*−3*	−1.37
36	*Antibiotics residues can be found in the soil or rivers*	*−1*	−0.51	*2*	0.80	*−2*	−1.12
37	**Using narrow spectrum antibiotics lead to inefficient antibiotics**	**−1**	−0.45	**−1**	−0.37	**−1**	−0.38
38	If more official controls were done, drug vendors will sell less antibiotics and win less money	−1	−0.70	−1	−0.32	−2	−1.01
39	**Conditions of storage of antibiotics are not important**	**−3**	−1.81	**−3**	−1.83	**−3**	−1.32

(Continued)

TABLE 4 | Continued

		Factor					
		F1		F2		F3	
N°	Statements	Rank	*z*-Score	Rank	*z*-Score	Rank	*z*-score
40	**If breeders take good care of their farm (cleaning, food, water, ...) the antibiotics use will reduce**	**2**	1.11	**2**	0.80	**2**	1.05
41	Antibiotics should be change if the animals don't cure with the first treatment	2	1.42	1†	0.64	2	1.18
42	Prescription to buy drugs should become mandatory	0	−0.52	2†	0.82	0	−0.02
43	Information about withdrawal time must be given to breeders	3	1.52	3	1.70	1†	0.28
44	*More an antibiotic is expensive more efficient it is*	*−3*	−1.59	*−2*	−0.95	*1*	0.52
45	Antibiotic choice is independent of the specie to treat	−1	−0.64	−1	−0.65	0†	−0.07

†*Statement distinguishing factor from the rest.*
In bold: consensus statements; in italic: distinguish statements.

So, they were aware of the AMR problem and expressed the need to reduce AMU. They also supported alternatives: they were confident that vaccination could decrease AMU in the farm (stat. 19: +3, stat. 34: +2). Furthermore, they were the only group that wanted to carry out more laboratory analyses to reduce their AB consumption and to choose the right AB (sat. 21: +3), even though this was not yet achievable in practice.

Discourse 2C "Moderate Approach to Antibiotic Use"

Six drug vendors, representing 17% of total variance, belonged to this group which was heterogenous (no significant variable, **Table 3**). This group did not have a specific point of view regarding the topics investigated. The participants underlined the link between wholesalers and drug vendors. They stated they were satisfied with the number of drugs available from wholesalers (stat. 3: +3). Moreover, they agreed that some people sold fraudulent drugs that could be out-of-date or diluted (stat. 7: +2). We noticed that they preferred to use a broad-spectrum AB (stat. 26: −2). They did not believe there was any risk in using AB if one respected the utilization guidance (stat. 8: +3). They did not think that resistance could be transmitted between animals (stat. 10: −3) and that residues could be found in the environment (stat. 36: −2).

DISCUSSION

The aim of this study was to identify patterns of opinions, among breeders and drug vendors from Imerintsiatosika, regarding antibiotic usage. A semi-qualitative method, the Q methodology, was used to this end. The subjectivity of individuals was evaluated through face-to-face interviews in a preliminary approach to the problem of AMR and AMU in this province. Three groups of opinion were identified among both the breeder and the drug vendors populations, with high level of similarities between the two populations. In fact, even if they don't have the same statements, they were ultimately classified in three groups with similar perceptions. Indeed, although these two populations have different professions, they seem to have a comparable structure in terms of opinion. The group A had a positive opinion of AB and a low risk perception, contrary to group B that was aware of the risk of AMR and ready to rely more on alternative options. Group C was fuzzier, with less consistency in the discourse. *This could enable tailoring messages around AMU without multiplying their number too much although reaching different professionals.*

Shared Opinions About AMU

Farmers and drug vendors were in favor of good management practices and biosecurity measures (stat. 30 for breeders and stat. 40 for drug vendors). Respondents considered that cleanliness, or good husbandry and management practices were factors of good health *"as living beings, humans or animals, we always need cleanliness. When we are clean, we are always in good health"* E8/R25. Protective measures to avoid people entering the farms were also commonly implemented by breeders (stat. 9), as stealing or poisoning pigs are common practices in Madagascar (personal source). But also because people were aware of the possibilities of pathogen transmission between humans and animals *"because diseases spread really fast, and we don't know from where a person comes from but if they enter the farm they can contaminate it"* E7/14, *"the person manipulates diseased pork meat and will come to my farm and touch the animals"* E10/R44. These biosecurity measures could be explained by the endemic presence of African Swine Fever in Madagascar. At the start of the epidemic, in 1996, half of the pig population of the country died (26). Meanwhile, breeders were afraid of disease transmission and reduced their movements between farms. As no national plan was implemented, nor resources allocated, these biosecurity measures were progressively reduced by breeders. However, farmers still keep in mind the danger of this epidemic and the benefit of biosecurity to control diseases. This represents an interesting finding to reduce AMU. Indeed, it has been shown that farms with a high level of biosecurity have fewer diseases (27) which lead to less treatment and that the evaluation of internal biosecurity (measures to reduce the spread of pathogens inside the herd) is inversely correlated to the use of AB for prophylaxis. which in turn leads to a reduction of antimicrobial use (28). As some people are already aware about the benefit of biosecurity, it will be easier to advocate the development of such measures to reduce AMU. Another common opinion among breeders was compliance with the withdrawal time (stat. 5) because *"we must wait for the drugs to be completely eliminated before slaughtering the animal otherwise it will transmit to disease to humans"* E15/R27. However, the national prevalence of antibiotic residues in pork carcasses was estimated at 28.3% in 2013 (29). The difference between our findings and this study can be explained by a number of reasons. It could be due to a misunderstanding of our statements. Indeed, qualitative data revealed that some breeders confused withdrawal time with treatment dosage. A lack of knowledge was also pointed out by a previous study in which 87% of farmers were not aware of the withdrawal times (12). Another explanation could be the gap between what farmers think should be done and what they actually do *"we suppose that the withdrawal time of the AB is 5 days and that the animal needs to be sold regardless, if breeders wait it will take 3 or 2 days, and they lose money"* E3/R1.

Breeders shared the opinion that they needed to ask for advice from drug vendors before buying AB (stat. 4). They were mainly interested in the AB dosage to avoid an *"overdose and kill the animal"* E26/R29 and because the veterinarian *"received training on the treatment of the animals"* E17/R31. However, direct observations, open-ended interviews and secondary data in Madagascar (12, 30) showed that self-medication was quite a common practice in breeders. Most of them considered that they had enough experience to avoid calling the veterinarian *"I called the vet when I started to breed, then I learnt the treatment that he was doing, so I don't call him now"* E15/R82. Moreover, self-medication was facilitated by easy access to drugs (sold in veterinary practices, drug depots and also in markets) and because a prescription was not always required. They also considered that the veterinarian was too expensive and too busy to come to the farm each time *"vets are lacking, no one will go to the countryside, to a remote place"* E15/R19.

Differences in Discourses

In both study populations, two main points of view relating to AMU, AMR and alternatives were present. The main differences regarding AMU between groups A and B, in drug vendors and breeders, concerned the need to use AB in animal breeding (stat. 24, stat. 9), especially for prophylactic measures (stat. 32, stat. 1). These recommendations were provided by all kinds of drug vendors including those hired by companies which offer guidelines on good husbandry practices (vaccination programs, deworming, and prevention measures). *"We use it (AB) as soon as an animal is introduced in a farm, against stress, for example. Many breeders use vitamin AB in piglets during the first 3 days of their life because during this period they are sensitive to cold"* DS7/R43; *"I mix vitamins and AB in the pig's food when they are not yet sick and when they have diarrhea, I use another AB as a cure"* DS18/R25. "Anti-stress" medication was an AB and vitamin mix commonly used in Madagascar. The use of AB as a prophylactic measure was linked to the desire to increase productivity for most breeders *"because our vet advises us [to use AB as preventive measure] (...) [it] improves animal health (...) and I notice that it helps, and it is what led me to do systematic monthly treatments with the antiparasitic and the 20% [meaning Oxytetracycline 20%]"* E7/R15. This is approach was greater in imported chicken that were more productive but less resistant than *akoho gasy,* the local breed. However, people from group B did not believe that this was a good means of preventing disease because *"AB doesn't prevent the disease but cures it, it fights against the disease"* DS11/R18 and it could lead to their reduced efficiency *"if we give the AB while the animal is not sick, and we use the same when the disease breaks out, it will lead to AMR"* DS20/R31. One veterinarian belonging to group B said that this was outdated advice provided by some drug vendors. Attitudes toward alternatives differed between discourses. Vaccination was an interesting alternative for group B *"the first [alternative] will be the mandatory vaccination of the chicken, this is the most important, because if they are vaccinated, there will be less disease and so we will use less AB"* E9/R38 and because *"vaccination is for prevention, it is used before AB"* DS22/R6. In an European study, vaccination was perceived as the most feasible alternative to reduce AMU in 19 alternatives given to pig health experts, and the fifth in terms of perceived effectiveness which is consistent with our findings (31). However, to be considered as an effective alternative to AB in Madagascar, they need to be accessible by farmers. In pig and poultry production vaccines are not mandatory. So, the choice to vaccinate belongs to the farmers. But, this choice also depends on the access to vaccines, the presence of veterinarians and the skills of farmers. As it is in deficit in remote area, some projects provide training of vaccination with villagers (32).

People from group B also had a different perception of AMU risk than group A. Group B was aware of the AMR issue and its possible impact on human welfare. Moreover, respondents of this group did not use AB as a preventive tool, as they believed that AMU can be linked to resistance and they trusted alternatives. Whereas, group A did not notice any side effect of AMU, they had a positive opinion of AB and a low perception of risk. In this study, knowledge about AMR was related to lower AMU. So, we can hypothesize that raising awareness or knowledge around AMR will reduce AMU among the breeder and drug vendor populations. Similar results were found in previous studies looking at pig production in European countries where higher risk perception was related to lower AMU (5, 7, 33).

Discussion on the Methodology

The Q methodology represents an interesting sociological approach to studying people's perceptions. Having a forced distribution helped people to prioritize their opinion and to identify the most important statements. The method is cheap, as little material is needed and it requires only a small number of participants (34); it is therefore well-adapted to low- and middle-income countries. However, the main limit of this method is that it is time-consuming for both participants and the research team (34).

Indeed, to be efficient, the Q methodology requires clear and comprehensible statements. It also calls for a maximum amount of information on the subject. To achieve these objectives, SSI and focus groups were run with different kinds of participants in order to collect a diversity of opinions to build the *concourse*. Moreover, two pilot studies were done to test our statements. If literature review enabled us to get design first interview guideline, PE and in particular SSI allowed us to modify some statements. For example, asking prescription and withdrawal time which are key for stakeholders in science and policy making but hard to understand by participants helped us to understand the local knowledge which demonstrate the usefulness of the method. This could not have been achieved solely by the literature review which is not country specific and may sometimes be outdated. However, as sometimes noticed during interviews, some participants still had trouble to understand certain statements. In particular, some words included in the statements that were hardly translated or exchangeable using a synonymous. For future studies, this problem could be limited by doing more SSI and pilot studies.

To guarantee the survey's objectivity, both investigators were trained in PE methodology and most of the participants (except the veterinarian from the city and one technician) were not aware of the survey's objectives. The data were also triangulated by open-ended interviews in order to check the right ranking of the respondents and to ensure a good comprehension of the statements. However, despite the triangulation, some erroneous ranking may have remained as coherence was only checked for a few statements (statements with extreme values). Furthermore, as the majority of respondents were poorly educated and sometimes illiterate, the duration of the interviews was generally longer than 1 h and half, leading to shortened open-end questions and potentially to a drop in respondents' concentration. Moreover, even if this bias was limited by the training of the interviewers, they can also influence the choice of the respondents in their decision-making process. Similarly, even if we followed a described methodology for the choice of the statements and the factors for the analysis, there is still a part of subjectivity as the final decision was done after a discussion within the research team. This subjectivity is inherent in qualitative research (35).

The main goal of the method was to maximize the diversity of opinions of the whole population (20). However, some farms were located in remote places and were difficult to access. Moreover, some of our respondents were included in the study because of their direct relationship with other participants, introducing some redundancies in the answer, as strongly related people can have the same opinion. In order to compensate for this lack and to obtain a wide array of perceptions, people were selected according to socio-demographic criteria.

It should be noted that this study was done in a restricted area and that, according to the Q Method, our respondents were not selected by random sampling (19). Despite this, the method does not allow a pattern of practices to be generalized to the entire country and no statistics regarding the number of people belonging to each group can be established. Nevertheless, it does form an interesting preliminary step to the development of further studies.

Recommendations

AMU control seems weak in Madagascar (36) *"there is no control of milk, meat or eggs, there is not even a structure"* DS24/R4. Even though prescriptions are a legal requirement, over-the-counter sales are frequent, as is often the case in LMICs (37). This can lead to the misuse of AB with improper treatment and failure to comply with doses or withdrawal time. Another consequence of weak national regulations is the presence of an informal market. As for human medicines (38), drugs can be purchased from specific places that are well-known to the local population. No studies have been carried out on the informal veterinary market in Madagascar, although its existence was underlined by group C, among drug vendor population. This market leads to the availability of counterfeit, diluted or out-of-date drugs that can be a contributing factor to the development of resistance. It would be necessary to enforce regulations related to AMU and to monitor AMR (39). But the attitude of participants toward regulation is close to a neutral opinion, meaning that people in our study do not seem to be favorable toward regulations that aim to decrease AMR, or are not aware of them. Farmers and drug vendors must be involved in designing policy regulation to raise acceptance (7). This could be more easily achieved as these two groups have similarities in their opinion. The profession doesn't seem to have an important impact on the perception of individuals which can enable tailoring messages around AMU without multiplying their number too much.

Another issue is the low number of veterinarians in Madagascar. To compensate for this lack, technicians (with varying backgrounds) may provide treatment under the supervision of the veterinarian in charge of the area. In isolated places where there are no veterinarians or technicians, self-proclaimed professionals give advice and sells drugs without adequate knowledge (personal source). Selling drugs in these conditions could have consequences on AMU. Specific communication strategies around AMR should also target these populations.

Our study points to the fact that a proportion of the breeders and drug vendors interviewed were not aware of AMR and displayed excessive and improper AMU. When we compare the three groups, the variable education was significantly lower for group 1C, we may therefore hypothesize that the difficulty of forming an opinion was related to poor knowledge of AMU and AMR. In previous studies, knowledge seems to be correlated to a lower AMU (7) and greater awareness of AMR (40). As in our study, AMR awareness might be related to a more prudent use of AMU and to a greater confidence in alternatives. However, it could be possible that the socio-economic level of the respondents can be a confounding factor. Indeed, higher education can be related to a higher income (or the opposite) and better access to alternatives because they are more likely to leave near important cities. Nothing in the study or in the literature can help us to confirm this hypothesis. Breeders and drug vendors belonging to group A and C must therefore be informed about AMU risks. An increasing awareness of risk has already been underlined in many studies in Europe (2, 5, 33, 41). In Madagascar, this may be achieved thanks to "champions," who are people with good AMU practices belonging to group B. People from the 2B groups could act as the promoters of good AMU practices by raising awareness of people around AMU guidelines and by explaining its possible impact on human health, as was proposed by one veterinarian of this group. Moreover, interviews seemed to indicate that there is a significant amount of communication among breeders. As the reduction of AMR requires a change in habits, group 1B farmers could act as "models," using their farm to showcase other possible and efficient methods for farming animals. These breeders and drug vendors could also promote alternatives such as vaccination and biosecurity. People are already aware of certain good practices (e.g., biosecurity, withdrawal time) and this should help the message to be better understood and accepted. However, to develop this strategy is only possible if the access of alternatives is reachable (in term of cost and availability) to farmers.

CONCLUSION

This study has underlined the need to educate breeders and drug vendors in Madagascar around better AMU practices and to promote awareness of AMR among the different stakeholders. By understanding the underlying factors that shape the perception of AB users, a more effective communication strategy could be developed to achieve accepted changes. A prudent use of AB and the development of alternatives could be advocated by "champions," such as farmers and drug vendors, who show exemplary behavior. Raising awareness as to the public health risk of AMR could ultimately reduce AMU in the general population. However, future studies are required at the scale of the territory to generalize our findings.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The study was approved by the Ethical Committee of Biomedical Research of Madagascar, with the authorization n° 037-MSANP/CERBM. Authorization of recording and written consent were obtained for each respondent before the interview.

AUTHOR CONTRIBUTIONS

CB, DK, and FG contributed of the conception and design of the study. CB and DR performed the data collection and analysis. DK, FG, AW, and LB reviewed the results. CB and FG wrote the first draft of the manuscript. DK, DR, AW, and LB reviewed the draft of the manuscript and wrote sections of it. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2020.00490/full#supplementary-material

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The Governance of UK Dairy Antibiotic Use: Industry-Led Policy in Action

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This article analyses the progress made in the UK with regard to tackling antibiotic "misuse and overuse" in food-producing animals. Moving beyond statistical realities, the paper examines how the UK's industry-led policy approach is shaping practice. Using a multi-sited ethnography situated in Actor Network Theory and Callon's sociology of markets, the UK dairy supply chain policies and practices were studied. Findings reveal that dairy industry policies only partially address the complex network of people, animals, and the environment in which dairy antibiotics circulate. Antibiotic "misuse and overuse" in agriculture is far from a behavioural matter, with solely farmers and veterinarians to blame. Instead, antibiotic use in food animals is embedded in complex economic networks that constrain radical changes in dairy husbandry management and antibiotic use on farms. More attention toward the *needs* of the dairy supply chain actors and wider environmental considerations is essential to reduce the dairy sector's dependency on antibiotics and support transition toward responsible farming in the UK.

Keywords: agriculture, antimicrobial resistance, governance, antibiotic policies and practices, matters of concern, actor-network theory

INTRODUCTION

Antimicrobial resistance (AMR) is one of the most complex public health challenges of the twenty first century. As a consequence, human, and animal antibiotic (AB) use has been internationally problematised with urgent areas for action identified (1). The central issue, with regard to both humans and animals, is *how* to reduce AB-use. Since ABs are used by farmers and veterinary surgeons, international and national policy narratives documents have focussed on the "misuse and overuse" of ABs by these particular actors (1–4). By framing the use of AB-use in food producing animals as "excessive," the problem has become calculable and amenable to intervention (2). As a result, the quantification of AB sales and use has become central to national and international discussions: metrics are used by policymakers to inform policies and evaluate the impact of these policies.

In the UK, responsible AB-use in its food supply chains is industry-led. In this governance model, the UK government has set AB reduction targets but has made the agricultural industry responsible to design and implement AB policies that will help to achieve those targets. Embedded within the UK's industry-led policy models is a belief that technocratic interventions (AB surveillance systems, AB guidelines, knowledge transfer instruments) promote responsible AB-use and can drive farmer and veterinary behaviour (4, 5). Statistical evidence on antibiotic resistance and sales in reduction data in the UK is annually produced by the Veterinary Medicine Directorate (VMD) in the UK Veterinary Antibiotic Resistance and Sales Surveillance (6) reports. The UK-VARSS reports have become important surveillance tools used by policymakers and livestock industry stakeholders to assess and evaluate responsible use activities across the livestock sectors. The numerical "facts" in these reports are used to order problems, settle uncertainties, and govern the social (7). The latest UK-VARSS report of 2018 states there has been a significant reduction in AB-use across and within livestock sectors in the UK. From 2014 onwards, the UK has achieved a 49% reduction in veterinary AB sales (sold by pharmaceutical companies to veterinary practices) see **Figure 1**.

Problematically, different metrics and frameworks across and within countries have been advanced to help govern AB-use and AMR, which results in a lack of analytical frameworks to systematically understand AB-use and AMR reduction opportunities and targets (8). At the same time, Leach and Dry (9) reject the objectivity of scientific data models and observe a close interplay between science and politics that influence the processes of modelling. The politicisation of a problem, why it matters and to whom and what should be done about it co-constructs the development and preservation of these models (9). Equally, Barry (10, p. 270) argues how the authority of numerical evidence suppresses "potential places for contestation," enabling debates to settle. Models and calculation become more than information; they serve as "anti-political" instruments to steer debates and settle concerns [(11), p. 208]. Moreover, some elements of an issue at stake are difficult to calculate and escape the metrological gaze: "calculative realities" are "thin" descriptions of reality [(12), p. 58]. Standardised procedures of models are not able to represent the complexity of the object and its practices in action [(10), p. 275]. As a result, AB surveillance models only partially represent reality as some aspects of AB behaviour are difficult to calculate and standardise and standardised procedures rarely accommodate the complexity of practices in action (10). This then ignores wider questions, such as how farmers and veterinarians are actually changing day-to-day antibiotic practices in response to policies.

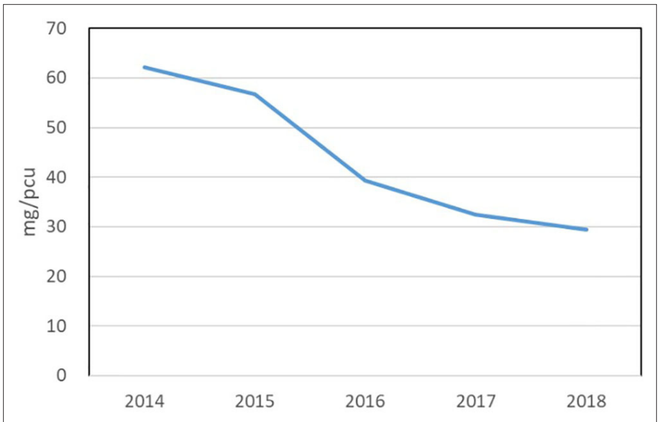

FIGURE 1 | The UK's veterinary antimicrobial sales in mg/PUC 2014–2018 (UK-VARSS 2019).

In this article, we argue that there is a gap in the understanding of the design and workings of the UK's industry-led policy approach in practice. Taking the dairy industry as our main focus, we turn our gaze away from statistical evidence in favour of examining how responsible AB-use is executed from within the inner workings of the UK dairy industry. Using conceptual insights from Actor-Network Theory (ANT) (13) and the Sociology of Markets (14, 15), the aim is to understand how dairy supply chain actors make decisions about livestock AB-governance as a matter of concern according to *their* agricultural networks and how this translates into *doing* responsible use in a market environment. We argue that the UK dairy supply chain actor networks do not act in a vacuum when responding to their AB-use responsibilities as food supply chains; there are economic opportunities attached to the evidencing of responsible AB-use activities. This means there are limitations if we only assess antibiotic policies from *within* the existing UK policy framework. Although dairy supply chain actors produce the data required by the UK's industry-led policy frame, such as AB sales measured against reduction targets, this article will discuss how they tailor dairy AB policies and practices as well to interests *outside* these very same policy frames, with unintended consequences.

In what follows, we begin by explaining how antibiotic use in food animals is governed in the UK and introduce dairy supply responsibilities in the wider context of dairy supply-led milk safety and milk quality procedures. Next, we introduce ANT and the sociology of markets and explain our methodological approach to set the scene for our empirical data. Using fieldwork data, we discuss how UK dairy supply chains translate their responsibilities in policies and practices of these policies. We trace what is at stake in dairy supply chain AB policies and how this shapes dairy supply chain-led antibiotic policies. The paper ends with a discussion in which we express the need to move beyond behavioural regulatory frameworks and focus instead on structural needs of the UK dairy industry.

MATERIALS AND METHODS

Setting the Scene: The UK's Industry-Led Policy Approach on Paper

The problematisation of antimicrobial use in food animals in the UK started in the late 1960's and it has remained an issue of concern ever since (16, 17). What has changed in the latest governance negotiations in the UK between policymakers, experts and industry makers is that livestock sectors and their food supply chains have been made responsible for governing the issue (3, 4, 18, 19). The role of the UK Government is to monitor these responsible use activities through a national antibiotic sales surveillance system. The UK Veterinary Medicine Directorate (VMD) publishes the annual UK-VARSS reports to fulfil reporting requirements of the European Union / European Medicine Agency (20). These figures are also used to update the UK policymakers on antibiotic resistance and sales. The key targets of the UK's industry-led governance approach are presented in **Figure 2** (4). In the context of the UK dairy industry, EU directives require that farms and processing plants undertake general hygiene measures related to the microbiological, physical, and chemical hazards of raw milk (21, 22). Through additional standards in terms of animal welfare, disease status, husbandry, and environmental footprints, private farm assurance schemes, milk processors, and retailers can add quality value to dairy products in highly competitive national and international milk markets (23). We will explain next how in the UK dairy supply chains, milk medicine residue management actors, the Dairy Red Tractor Farm Assurance Scheme, and milk processor and retailer milk contracts play a central role in definitions, expectations and practices of milk safety, quality and with it, antimicrobial practices.

One requirement in the EU directives is that animal products in the food supply chains are safe from medicine residues. When medicines are used in food animals, they can leave residues in animal food products (e.g., meat, milk, eggs) that could pose potential harm to consumers. To protect human health against AB residues in animal food products, AB withdrawal periods have been established for each AB product. The AB withdrawal period is the statutory minimum period that should elapse between the last day of AB treatment and the point at which the food-producing animal or its products enter into the food supply chain (24). Inside this statutory withdrawal period, food-producing animals, or their products cannot be used for human consumption. To limit residues in food animal products, supranational regulatory authorities have established "Maximum Residue Limits" (MRLs). The MRL is an official EU standard and is designed to protect the health of the European consumer by ensuring that food animal products are not placed in markets if they contain residues that their MRL (24). MRL thresholds of ABs are meant to separate AB "safe" from AB "unsafe" animal products. Although the VMD has a residue control program in place (25), the main responsibility for antibiotic residue management in dairy lies with the *milk processors* (and is, as such, industry-led).

To unify transparency across farm assurance schemes, in 2000 the British food industry introduced the "British Farm Standard," known as Red Tractor. Established as a not for profit company. Red Tractor is owned, funded and run by the food industry and has become Britain's biggest voluntary private farm assurance scheme across livestock species. This form of third party certification, alongside official regulation, has been established at the European level as a mechanism to guarantee food safety from "farm to fork" (23, 26). The Red Tractor standards are species- or product-specific and stand for production standards covering the harmonisation of animal welfare, food safety, traceability, and environmental protection across food producers (27). During fieldwork in 2017; Dairy Red Tractor's AB quality standards were under revision, resulting in several new antibiotic standards (28–30). Importantly, establishment of the scheme creates the impression that ABs in dairy farms are being used in a responsible manner (23).

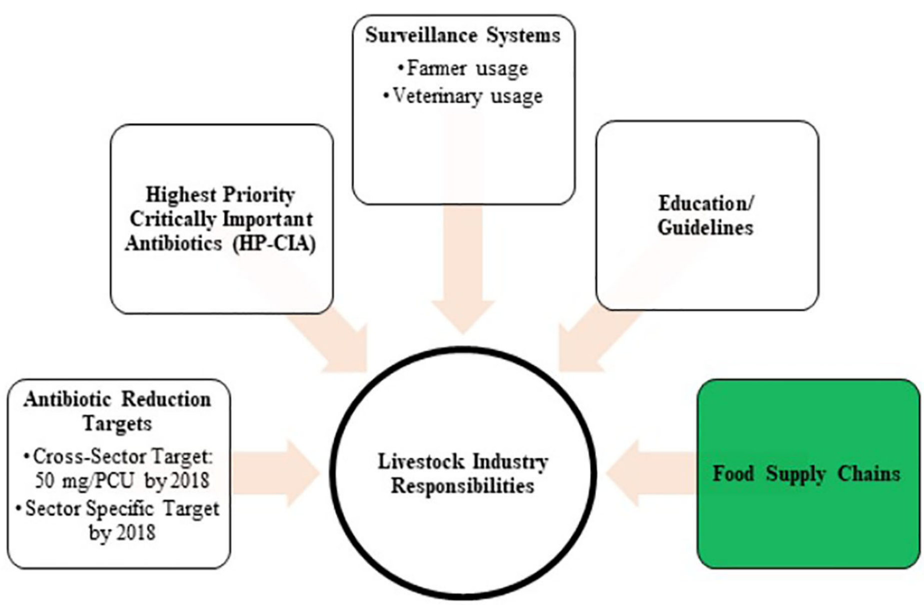

FIGURE 2 | The UK's Industry-led approach to govern responsible use across livestock sectors (Department of Health 2016).

On top of the Dairy Red Tractor Scheme, UK milk processors and retailers use milk contracts with farmers as assurance systems which define the safety and/or quality conditions of milk production. Milk processors set standards in the milk contracts in relation to milk quality/composition (somatic cell count, milk solids such as fat-protein-lactose and mastitis bacterial pathogens such as *E. coli*, staphylococcus spp.) and milk safety (residue control). Farmers receive a milk price in accordance with the quality/composition of the milk produced, as specified in their milk contract. The price a farmer receives for milk depends upon the nature of the contract. In addition to these milk contracts with processors, some British retailers (Tesco, Waitrose, Sainsbury, M&S) contract directly with farmers. This usually means that farmers need to meet a set of retailer standards (including antibiotic standards) as well as those of the milk processors. The farmer will still receive a fixed milk price from the retailer. These "dedicated supply chains" allow retailers to increase their profit by selling milk under their own-label tailored to meet the needs of their consumers (31). Retailers may require higher standards of animal welfare, disease screening, husbandry and environmental footprints, which enable value to be added to their dairy products in a highly competitive milk market.

As will become clear in the results section, economic interests attached to milk residue management, red tractor standards and milk contracts shape the content, implementation and practices of antibiotic policies in the UK dairy supply chains.

Theory and Methods: Theoretical Framework: Actor-Network Theory and the Social Studies of Markets

The UK food supply chains have been made largely responsible for the governance of responsible AB-use, in which metrics and knowledge transfer policies are used to govern and evaluate AB policies. As we argued, there are limitations attached in trusting scientific methods and their evidence to govern responsible AB-use in agriculture. Rather than accepting established risk frames, regulatory responsibilities, and granting scientific methods analytical privilege, we chose to examine multiple knowledges, conflicts, and interests attached to antibiotics in the UK's dairy supply chain's and how this co-constructed the practices of "responsible use" in the UK dairy sector. The latter is important, as it means that dairy antibiotic governance by dairy actors cannot be approached as an individual, rational act., but as a *collective* performance by networks of human (retailers, milk processors, farmers, etc.) and non-human actors (milk residues, Red Tractor Farm assurance Standards, Milk contracts, etc.).

The relations we build with human and non-human actors, which Latour (13, 32) refers to as actor networks in his Actor Network Theory (ANT), shape how we produce knowledge, and how this knowledge in turn, shapes the configuration of the actor-networks (33). Conceptually, ANT first of all bridges the nature/culture divide, by bringing non-human actors in their analytical frameworks, such as animals, technologies, literature, microbes, chemicals, institutions, laws, markets, and many more [(34–36)]. Secondly, taking scientific objects or technologies as objects of study rather than human behaviour, ANT scholars study the formulation of knowledge practices within and across sites of interests, in which the object circulates (in this case antibiotics) (13, 35). How knowledge is produced upon ABs depends what concerns (in terms of other actors) are attached to the ABs. For a farmer, ABs represents healthy cows and economic security, for vets ABs deliver farmer animal health/welfare and financial income, for retailers and milk processors, ABs pose a risk as milk residues, to consumer trust and unstable markets. As will be explained, different *matters of concern* circulate about ABs, depending upon the agricultural network they belong to.

Building on ANT, Çalişkan and Callon (14, 15) have studied markets as a socio-technical arrangement between human and non-human actors. Technologies exert an active role in this conceptualisation of markets. Through a process of "economization" (14), interests around technologies translate in new social, material, technical, and institutional arrangements between human and non-human actors as the market around the technology emerges. The work of Buller and Roe (37) on the process of economization around the issue of animal welfare in free range layer chickens is of particular interest here. The authors show that a rise in consumer agency has pushed retailers to incorporate consumer demands into their food market strategies. Evidence of "doing animal welfare" from "farm to fork" by food chain actors is represented by a range of "procedures, technologies, and performances" that "add" welfare standards to the chicken body [(37), p. 142]. In this way, the food chains' interpretation of consumer concerns shapes new markets and increases the power of the food supply chain over the bodies of animals (37). Using these ideas, we wanted to understand how dairy supply chains as economic actors conceptualise responsible use and how this results in new antimicrobial standards, protocols, descriptions, and technical devices.

Importantly, market actions inevitably contain a process of "framing," with not only intended but also unintended effects or "overflows" of actions on other agents (38–40). The concept of framing/overflowing is important in our analysis, as it will not only help us to examine what "matters of concern" drive policy action, but also how this results in unintended effects or "overflows." As Callon et al. [(39), p. 236] argue, "markets, when calculating interest, profits, and return on investments, draw a strict dividing line between that which is taken into account and that which is not." To study the "matters of concern" and how this is translated in the dairy supply chain governance of responsible use, emerging markets and its overflows, we asked the following questions: What actors make up the matters-of-concern involved with responsible use across dairy supply chain actor? What new dairy markets emerge as a result of new socio-technical arrangements around responsible use governance in dairy supply chains? What are the unintended effects or "overflows" of the UK dairy supply chain governance of AMR?

METHODOLOGY

ANT researchers use an ethnographic approach to study knowledge production and practices across sites of interest (35, 36, 41). Traditional ethnographies use observational methods to study people's actions and accounts in everyday contexts instead of experimental settings (42). They are most often single-sited ethnographies, demarcated in advance to study the situated human experience for a certain period of time in a setting of interest. Doing ethnography in ANT involves a different methodological approach than classical ethnographies. Their research tends to be multi-sited, examining the variety of knowledges across sites and actors instead of being limited to scientific experts in their laboratory settings (42). As our ethnographic interests were situated in AB knowledge practices (35), the handling (politically, economically, or physically) of livestock/dairy ABs could be expected to differ between sites. We traced livestock/dairy ABs to the sites where *they* brought us, including both human and non-human actors, ranging from retailer-farmer meetings, to farms, to people, livestock organizations, policy documents and more. The research did not involve finding truth, but instead describe how truth upon ABs is "enacted" or "performed" (35, p. 33).

Ethnographers often employ a variety of qualitative methods, tailored to the demands of the research site(s). This strategy is sometimes referred to as triangulation, in which more than one method of data collection is used (43). The methods usually involve observation (participant or non-participant) as the main method (covert or open), complemented with other methods such as in-depth interviews, focus groups, the study of material (documents) and may include quantitative approaches such as questionnaires (44). In this study, triangulation was used in a flexible manner in accordance with the sites of a multi-sited ethnography. This meant that in some sites we requested documents, interviews, participant-observations in veterinary clinics and on farms, focus groups or a combination of any of these. In order to get access to dairy stakeholders, we initially used social network of the University of Liverpool to recruit dairy supply chain actors, farmers, and veterinarians. We than opted for a snowballing or referral technique, where we recruited future participants from the social networks of the participants we interviewed. A recruitment advertisement was moreover published in a popular veterinary magazine to invite veterinarians to participate, but this resulted in only one positive response. We also encountered difficulties to get access to the big dairy companies, which resulted in a small sample of milk processor and retailer representatives (for a full oversight see **Appendix 2**: list of ethnographic fieldwork).

During the period of the ethnographic fieldwork between January 2017 and December 2018, 10 retailer-farmer meetings across the UK were observed. Next, 4 weeks of participant observation were undertaken at two veterinary clinics. This involved work shadowing of vets during their daily activities in the veterinary clinic and accompanying them during farm visits. A research diary was used to make notes of observations and discussions with veterinarians and farmers. Semi-structured interviews were furthermore undertaken throughout the course of the fieldwork with 4 key agricultural/dairy organisations;4 dairy supply chain actors; 2 veterinary consultants working for dairy supply chains as well as 21 veterinarians not directly connected with the supply chain and 3 farmers. Two focus groups were also conducted with retailers and farmers (see **Appendix 2** list of ethnographic fieldwork). Interviews focused on dairy supply chain's understanding of responsible use, AB concerns, the policy process, and responsible AB-use practices (see **Appendix 2**: interview guide). The interview material and transcribing records were kept on a secured hard drive space only accessible through passwords.

Data analysis evolved around the generation of data from the fieldwork material instead of using pre-determined models. This inductive approach allowed us to generate patterns, codes, and themes by the language and/or topics discussed by the respondents or from the observational data. The first step of data analysis was transcription of data in textual record (45). In order to situate actor-networks that were emerging throughout the fieldwork, we transcribed interviews as close to the time they were undertaken as possible. For the data analysis, we used N-Vivo as coding tool and performed a thematic analysis, which involved the identification of recurrent themes in the data that organized our topics of interest. Data was "reduced" in labels or codes which helped to start comparing transcripts and enabled us to bring in STS theories and concepts that supported the data. In what follows, we will represent the results of data analysis.

Results: The Practices of AMR Governance in the UK Dairy Supply Chains

Milk Processor Concerns: Milk Residue Governance

We identified that an important element of milk processors' responsibility to deliver milk safety is through medicine residue management. From a food safety perspective, the EU MRL legislation requires that products testing MRL positive at *individual cow level* should be recalled and destroyed (46). Importantly, it is the farmer who is responsible for ensuring that the raw milk of the *individual* cow is safe before it enters into the bulk milk tank (46). Milk processors rely on these responsible AB-use practices by farmers to reduce the risk of AB residues entering the milk supply chain. However, when the milk in the tanker travels from farm to farm before reaching the milk processor plant, it becomes diluted with milk from other cows on other farms. Similarly, milk residues get diluted when travelling from milk tanker to large milk tanks at processor plants. Milk processors refer to this process as "natural dilution," which occurs as a result of operational procedures (Interview milk processor 2). In this way, raw milk that exceeded MRL levels at individual cow level can test below MRLs at processor level because of this "natural dilution" process. Regardless of whether the milk can be considered safe, technically the farmers and milk processors are officially in breach of the EU MRL law if the MRL levels are exceeded at individual cow or farm bulk milk tank level.

"So natural dilution, it is not deliberate dilution but it is an operational consequence. We can't dilute out residues deliberately, it will be illegal to do that" (Interview milk processor 2).

To protect dairy supply chains, the FSA has previously tolerated the "dilution-effect" of milk residues by turning "a blind eye to it" (Interview veterinary surgeon 21). The recent international politicisation of the public health risks of AB-use in food animals has, however, renewed attention on how the UK dairy industry manages AB residues (Interview milk processor 2). According to some dairy industry stakeholders, the FSA has now begun to exert pressure on milk processors to increase their milk residue controls (Interview veterinary surgeon 21, respondent livestock organisation 4). This has turned milk residues into a matter of concern for some of the UK milk buyers, not only from a milk safety perspective, but also financially. Milk processors incur considerable expenditure to investigate milk failures (Interview milk processor 2). For milk processors, responsible AB-use by farmers can reduce the risk of AB residues entering the milk supply chain (Interview milk processor 1 and 2). Farmers are, in this case, identified as "key actors" who need to be educated so they can take up their individual responsibility for managing the risk of milk residues.

"Our main drive is to ensure that we don't have any antibiotic contamination in our milk. So we work very hard with our farmers to ensure that if they use antibiotics, they actually make sure they test their own milk before that milk goes into the milk factory for collection by ourselves" (Interview milk processor 1).

"What we are seeking to do is reducing the number of occasion where testing reveals the presence of antibiotics, so we are trying to develop a strategy that will help farmers to improve their performance in that respect" (Interview respondent livestock organisation 4).

Milk processors identify two important antibiotic practices by farmers that can result in milk residues entering in the dairy supply chain: "dry cow therapy" and farmers' "off label use" of antibiotics. Some milk processors (Interview milk processor 1) believe half of the antibiotic use on dairy farms occurs during the drying off period. The dry cow period is the part of that cow's lactation cycle during which the cow's milk production is stopped for at least 40 days until the next parturition (47). Previous guidelines recommended the blanket treatment of cows with ABs in the dry period, and it has since become the biggest source of prophylactic AB-use. An alternative strategy is Selective Dry Cow Therapy (SDCT), in which cows with a low probability of infection are given a teat sealant to prevent pathogens entering the cow's body (48). This strategy significantly lowers the use of antibiotics. As such, some of the UK milk processors see SDCT as the most important strategy to reduce AB usage of their farmers and with it, the risk of milk residue failures (Interview milk processor 1 and 2).

"If you can influence the strategy that farmers use in drying off, that is the way you can have the biggest impact on antibiotic usage" (Interview milk processor 1).

"There has been a real push for selected dry cow therapy from the local dairies" (Interview veterinary surgeon 5).

Farmers' off-label use of ABs is another major concern to milk processors. Going off label means using medicines outside the terms of the licence, which can affect the milk withdrawal period. One vet suggested that some farmers do not understand these off label mechanisms or misuse, which increases the risks of raw milk residues entering the milk supply chain (Interview veterinary surgeon 21). Farmers often prolong AB treatments or give an "extra shot" which prolongs official withdrawal times of original treatments (topping up effect).

"They don't necessarily know what going off-label is, because they might have never actually read what the on- label treatment is. And they also don't always realise that by going off-label, they are increasing the risk of residues because of the topping-up effect" (Interview veterinary surgeon 21).

From an ANT perspective, milk residues as a "matter of concern" to milk processors and its related practices such as dry cow therapy and farmers off-label use shape how milk processors respond to antibiotic governance. Milk processors not only produce political evidence of antibiotic governance, but also build new economic relations with retailers by addressing milk residues as economic risk to dairy supply chains. In their AB strategies, milk processors have made farmers accountable and foregrounded farmers individual responsibility to deliver safe milk. Policy instruments of behaviour change, such as SDCT protocols and workshops, milk residue stewardship programs, milk price penalties, and AB test kits are implemented to bring AB practises into line with established protocols. The antibiotic policies are supposed to reduce the risk of milk residues entering dairy supply chains. In practice, science and its methods are not transferred through a linear process. A clash can often be observed between the evidence-based theory of protocols/guidelines/standards and the reality of the professional decision making processes [(49), p. 1083; (50)]. Following Hamilton (51, p. 4), who is equally critical of evidence-based approaches that aim to bridge the theory-practice divide in vet-farmer communities, we will discuss how knowledge is not a product requiring discovery, communication and uptake. The adoption of knowledge tools emerges from a negotiation with local cultures and environments (52). In the next section, we will show how knowledge gets tweaked and tinkered with in accordance with matters of concern in farmer's agricultural networks.

Farmers Practices of Milk Processor Antibiotic Policies

Farmers identified the differences between artificial workshop settings and farm realities. While artificial classroom settings fostered communication and knowledge exchange between farmers it did not reflect the realities of working on a farm. As one farmer argued "you need to get mud on the boots and get out there" when learning new farming practices. Moreover, farmers argued that the act of SDCT is a process, entangled with conditions on the farm (Interview farmer 1). The milk processor SDCT protocols/workshops fail to address these complexities as they reduce the act of SDCT into a technical performance. Equally, veterinarians argued that knowledge transfer tools such as protocols, training, and videos were not always adopted by farmers in the ways that industry policymakers anticipated. Pre-existing values and reluctant attitudes toward technocratic interventions resulted in resistance toward milk processor antibiotic policies.

"The nature of farmers as well is you are dealing with people that have been doing things for a long time but don't always think what they are doing is wrong. So trying to take people, farmers, who see that they have a problem in the first place, seeing where that

problem might be coming from, seeing what they could do about that problem and then actually doing something about it is a. . . you have farmers on many different stages in that process" (Interview veterinary surgeon 5).

"Sometimes people are just very, very busy. Like it is hard to change your protocol and policies [. . .] that is why we have always done it cause dad did it. But it is hard to change that because it takes time and effort and thought and if you are already working at full capacity. . . it is really difficult to change that. And some of them just don't have the money" (Interview veterinary surgeon 2).

An unintended effect of AB self-tests is that farmers are becoming more knowledgeable about antibiotics and use them strategically to avoid positive milk residue tests, as farmers get penalised in case of a positive case. Instead of implementing appropriate AB-use behaviours, the policy develops a culture of what farmers can get away with. They use the tests as a "fruit machine game," to find the earliest data when the milk can be put back in the bulk milk tank (Interview veterinary surgeon 21). The penalising systems and control systems of milk processors produce reactive responses of farmers instead of systemic changes in their AB practice. But farmers should not be blamed for their policy responses, as they are constrained by the dynamics of their own agricultural networks. AB policies focusing on "behavioural" change rather than addressing structural problems in agricultural communities will therefore fail to change AB practices on farms. The use of on-farm milk residue tests has moreover resulted in farmers disposing of more waste milk into the environment than before (Interview milk processor 1). Until recently, this waste milk was usually fed to calves. However, under Red Tractor guidelines waste milk should no longer be fed to calves to avoid the risk of AB residues surfacing in another part of the food supply chain (28).

The truth is, they are probably disposing more milk than they have ever before. If they have an accident, it is much more beneficial for them to just get rid of the milk, as opposed to be charged 10p if they are found to be in breach"(Interview milk processor 2).

With waste milk ending up in agricultural lands or in slurries, this potentially creates a new uncontrollable pathway of milk residues. In this way, creating a system focussing solely on protecting the food supply chain from milk residues, "co-produces" a potential unintended environmental cost.

Finally, during our fieldwork various respondents (farmers, vets, consultants, and milk processors) were keen to emphasise some of the limitations of the Red Tractor farm assurance scheme. They raised questions about whether the Red Tractor Standards actually deliver what they promise on paper.

Although Red Tractor is meant to stimulate best farming practices, not all farmers saw the value of the assurance system. Respondents suggested that the Red Tractor scheme allows farmers to approach their Red Tractor obligations as a "tick box" exercise rather than as a tool that supports innovation.

"That is one of the problems with farm assurance, you know, a lot is a tick box exercise [. . .]. And if farmers do it by tick boxing they are probably not doing it for the right reasons. And we have people like that, of course we have that. It's hopefully at the time it will be less and less of them" (Interview milk processor 2).

"When you do your Red Tractor assessment they don't measure any barrier space or cubicle space. They don't count your cows or your cubicles. They have all recommendations of what should be but nothing is actually controlled. It is a paperwork exercise, tick a box, as long as you meet the major compliances. It is not good. Red Tractor is not good. It is the basic standard. Which a lot of farmers would say 'well yeah, but don't burn yourself with cost'. That is a fair comment, because cost drives down profit" (Interview farmer 2).

We found that resistance toward paperwork resulted in some of the farmers falsifying their records.

"What really struck me was, this farm was filthy. The house was filthy, the bathrooms, everything was absolutely filthy, he was filthy. This record book was immaculate, absolutely immaculate, not a spillage, nothing on it. Same pen and that was really good. I said about this when I went back in. So he showed me the calving issues, it was on the computer and I looked at it and he had written it out in the wrong month. So he had obviously written it before we came, done all the right cows and everything else, all the treatments but done all the records in the wrong month. So he transcribed it wrong. So that was the end of that. It was falsified records" (Interview milk processor 2).

For some farmers, the Red Tractor scheme and milk processor standards produce a "paper reality," in which there is a difference between what farmers *record* on paper and what they *do* in practice. Escobar and Demeritt (53) have found similar issues around audit, assurance, and animal welfare regulation on livestock farming, in which the materiality of paperwork produced resistance of farmers, resulting in failure of compliance. As such, rather than constructing farmers as "naïve" adopters [(54), p. 1776], we need to understand how farmers respond to and integrate milk quality and milk safety standards of private assurance schemes into their local values, customs, and practices.

Retailer Concerns: Consumer Profiles

From 2010 onwards, extensive media attention and consumer concerns have pushed some of the major retailers to implement AB policies, with these policies mainly focusing on recording AB usage (Interview retailer 2, veterinary surgeon 2). The publication of the O'Neill report in 2015 and the media concerns that came with it refocused retailer's attention on the issue (55). Retailers feared media messages could threaten consumer trust in food supply chains. From 2016 onwards, to avoid negative publicity, most UK retailers have implemented antimicrobial policies across their food supply chain. The dairy industry is considered as a particular risk to retailers, as the industry lacks oversight on how dairy farmers operate (Interview retailer 2).

"Retailers feel they have a far more vulnerable relationship with their dairy supply chain than they do with their beef and chicken supply chain for example [. . .] There is a massive range of dairy farmers. You've got some really good operators, and you've got some shit operators. So that makes them feel vulnerable. So, retailers want to be able to show they are doing something, working with their farmer suppliers to reduce the routine use of antibiotics" (Interview veterinary surgeon 21).

What matters to retailers is that they implement antibiotic standards that result in "evidence" of responsible antibiotic use activities. Metrics on AB reduction numbers are of particular interest to retailers, as this is visible evidence and provides accountability to consumers that responsible AB-use is being performed by farmers.

"From a retail public facing point of view is that, the public is only interested whether you use antibiotics or you don't. I think in dairy that is a challenge, but what we are doing now is restricting it and having the evidence that we actually have restricted it you know, so you always have it in your toolbox" (Interview retailer 1).

However, at the time of this fieldwork, retailers with customer *quality* sensitive profiles defined antibiotic standards and herd health standards that exceeded milk processor and Dairy Red Tractor Scheme standards. These retailers had their own teams of experts who translated consumer expectations into milk contract expectations. Additional policies and knowledge transfer tools on HP-CIA and SDCT, on top of milk processor and Dairy Red Tractor Scheme standards, were implemented at the time this research was performed. Some of these retailers used "interactive" sessions across the country to relay the new policy to farmers and vets. It was believed that these interactive meetings would foster farmers' adoption of the HP-CIA policy (retailer 2).

What we have done in January is that we focused on the mind of farmers, we don't believe that we have moved far enough yet and therefore we should encourage farmers to make further steps to improve [. . .] even though the farmers have been aware of it the last 6 years, there hasn't been a massive swing away from CIAs, that we could show in our results. So the feeling was we needed to communicate back and re-focus our efforts in trying to encourage farmers before there was legislation" (Interview retailer 2).

Some retailers increasingly push farmers to record herd health and welfare activities on their farms. The herd health performativity of farms is used to identify areas of improvement. Retailers can use this information to promote good husbandry practices in their food supply chains to consumers. Importantly, herd health performativity has become increasingly linked with AB performance on farms by retailers.

"I make sure that it is a benefit to farmers to record the information around health and welfare and recording the use of antibiotics, and other medicines, and recognize health as a responsibility, but also as a benefit to the farm, so they can benchmark themselves [. . .], that information is stored within our database and number crunched, that gives us a score of each farm. We can than benchmark each farm one against another, and use that information to develop strategies for those farmers who we believe and we can identify using far more antibiotics than the average or good dairy farms" (Interview retailer 2).

Herd health performativity standards moreover enable new commercial platforms to emerge for those retailers who are chasing differentiation in milk quality with their contracted farmers.

"Retailers are given a competitive marketplace and they are all seeking to find whether there is an opportunity for commercial advantage, so retailers and processors have their own policies and strategies on this" (Interview respondent livestock organisation 4).

"They want their own schemes, they want their own control, they want their points of differentiation. and I think, to a certain extent, that will be true, er, you know, of antimicrobial usage policy" (Interview veterinary surgeon 20).

Other retailers with customer *price* sensitive profiles may not have a "dedicated" milk pool. This means they are not directly involved with the production standards under which farmers produce. In this case, it is the milk processors and Dairy Red Tractor Scheme which sets the quality assurance of milk production and defines how dairy products take shape from farm to fork.

The previous fieldwork data shows how consumer concerns shape retailer responses on the governance of responsible AB-use. A process of "economization" takes place in which antibiotic standards potentially become part of commercial retailer strategies to position themselves on dairy markets. As a result, antibiotic policy strategies such as knowledge transfer strategies, SDCT and HP-CIA standards and herd health expectations differentiate rather than unite antibiotic practices by farmer and veterinarians. Rather than collectively addressing responsible use, retailers have their own expert teams, strategies, and priorities attached to responsible use.

Some researchers have questioned the neoliberal form of food safety governance by food supply chains. Higgins et al. [(54), p. 1778] have argued that this type of governance in food supply can "reinforce the profit-making logic of capital" instead of being translated in hegemonic practices. Bailey and Garforth (23) have also discussed how private industry led standards are used by food supply chains to gain marketing advantage and brand promotion. Nevertheless, from *within* the UK's industry-led framework and inside market boundaries, retailers are able to provide metrics and anecdotal evidence of success. However, we will show how the antibiotic policies represent only a thin reality of what happens *outside* the realm of the UK's policy framework and markets, with unintended effects.

Farmer Practices of Retailer Antibiotic Policies

During fieldwork and interviews, it became clear that the metrics around responsible use activities only provides a snapshot of reality. Some of the farmers contracted by retailers with customer quality sensitive profiles tried to circumvent contractual obligations.

"The farmer says that farmers are not filling in the files correctly. Some farmers complete online retailer quality assurance forms as the best performers but in the meantime, they use different billing systems for their antibiotic registration or use their secret stocks" (Fieldnotes veterinary practice 3).

"I had this case a farmer said to me that he was going to Ireland to buy in a lot of marbocyl" (Interview veterinarian 14, fieldnotes veterinary practice 3).

"The farmer may give penicillin as it is the first dose and he may complete the course brilliant. But another farmer may think well I know that the cephalosporin works better, in his mind, and he will give the penicillin, and at the same time give the cephalosporin. So on paper, it looks like they have done it wright, but in reality. . . they

have given 2 drugs at the same time for no apparent reason" (Interview veterinarian 17).

At the same time, farmers saw attendance as an obligation associated with their milk contract. Farmers are evaluated on whether they attended retailer meetings and workshops and therefore make an effort to show up at meetings, but instead of engaging with the knowledge-transfer, some farmers saw the retailer farmer meetings as a nuisance that disrupts their day. Although retailers may believe on the basis of attendance that they have successfully transferred their policies through interactive sessions, farmers will still continue with their daily routine practices as is expressed in the following quote:

"At the moment we seem to have series of workshops where we go to a nice hotel and we have a nice lunch and we have four speakers who talk to us about varying things. And we all fill a form in after, and we all go home and carry on and do what we were doing before. It was described to me the other day as: "Are you confident in what you're doing?" This was another farmer. He said, "Are you confident in what you're doing?" He laughed as he said it. I said, "Well, yes." He said, "Well, do what I do." I said, "What's that?" He said, "Let it wash over you, tick the box, move on" (Interview farmer 2, recorded in fieldnotes at retailer farmer meeting 9).

Participatory policy making as strategy to develop AB policy has been recently studied by van Dijk et al. (56). The process involved collaboration and dialogue between producers, veterinarians, industry, and researchers. Farmers and veterinarians in this case were seen as active partners in collaborative decision-making (56). Although the retailer we work shadowed during retailer farmer meetings used participatory policy making as approach, some of the farmers and vets argued that they did not felt enough included in the policy process, resulting in reluctance toward the retailer policy approach.

"Their policies involve a lot of tick boxing, but nobody actually reads the documents. We don't feel understood, included in the program. I feel it is us against them" (Discussion with farmer, recorded in fieldnotes at veterinary practice 3).

"I think as vets in practice we have not necessarily kept in the loop beforehand, so farmers have been going to retailer meetings and we have not necessarily found out about some of these things until after fact so we have not been able to take the initiatives as much as we've liked [...] and it means that if farmers hear from the supermarkets in their contracts that 'oh right we have to start doing selective dry cow therapy or at least have a look at it' and they start doing that without adequate teat preparation and hygiene, well we had plenty of farmers that have lost cows as a result of that. Whereas if vets had been involved beforehand then perhaps we could have implemented some proper training" (Interview veterinary surgeon 5).

The different retailer contractual expectations on responsible AB-use resulted moreover in different antibiotic practices of veterinarians and farmers.

"We had a bad caesarion and normally we give marbocyl to bad operations, but now we give it synulox. However, this client was not contracted with retailer X and he wanted marbocyl. The thing is with marbocyl is that you see a very quick recovery and milking gets up quickly. Which is not the case often with other drugs. So in this case we put the cow on marbocyl, the calve lived and we had a good overall recovery of the animals and productivity. I think supermarket contracts do influence antibiotic choices as you need to justify your use. If you know the retailer contract and expectations, you adapt your choices" (Interview veterinarian 14, recorded in fieldnotes veterinary practice 3).

"They are still using Marbocyl, as they are not on a specific retailer milk contract that does not ask them to reduce use" (Interview veterinarian 13, recorded in fieldnotes veterinary practice 3).

The previous discussion illustrates how the different contractual obligations/expectations of retailer milk contracts segregates dairy farmers and vets in their AB practices rather than unifying them. An important message from the previous discussion is that farmers and vets respond to dairy supply chain AB policies in accordance with *their* actor-networks, rather than it being an individual act. More research is therefore needed to examine how local agricultural networks shape farmers and veterinary antibiotic practices, rather expecting the individual farmer and veterinarian to change behaviour.

DISCUSSION AND CONCLUSION

We have revealed how the formulation, implementation and adoption of responsible AB-use within the UK dairy industry is interactional and interpretative, located within and across dairy supply chain actor-networks and their concerns. Using the methodology of examining the dairy antibiotic policies and practices of the UK dairy sector, we demonstrated how different matters of concern regarding dairy ABs circulate, affecting antibiotic policies and their practices. By tracing ABs in their actor-networks, we found which dairy actors are of importance and how this steers AB decision-making: how milk residues drive milk processor policies; how customer profiles drive retailer policies; and how agricultural interests define Red Tractor farm assurance standards. To farmers, AB decision-making is situated in complex agricultural networks; milk prices, milk contracts, milk withdrawal times, and more. We argue that antibiotics have become integral to farmers' understandings and practices of animal health and animal performance. ABs are embedded in the daily practices of farmers, supported by a vast array of human and non-human actors that confirm their importance. Educational strategies, training programmes, and technologies that support antibiotic governance will have a limited impact in changing farmers' behaviour, as long as antibiotics remain accessible to farmers.

The understanding of actor-networks is crucial if we want to evaluate how UK dairy supply industries take up their responsibility in terms of AB governance. In fact, our findings emphasise that AB-use is an inherent dairy supply chain economic activity, instead of an individual *choice* of farmers. We showed how AB decision-making, in terms of policies and practices, is situated in market interests of the dairy supply chain actors. Moreover, through a process of economisation, antibiotic standards translate into dairy cows, metrics, farmer behaviours, and new market opportunities.

However, with these emerging markets strictly defining what to take into account and what to ignore in terms of responsible AB-use (to maintain maximum output in their economic actor-networks), they generate exclusions and overflows (39). We have demonstrated in this article that dairy supply chain AB policies are not only practiced in accordance with the economic interests of milk processors and retailers, but also in accordance with farmer realities, potentially "co-producing" new potential invisible environmental, foodborne and human routes of AMR. Consequently, by making livestock industries responsible for implementing AB policies, without taking into account what "matters of concern" drive their AB decision-making, AB policies and their practices will create unexpected pathways and outcomes.

Having exposed the complexity of dairy AB actor-networks and their overflows, it becomes difficult to believe we can transfer antimicrobial policy responsibilities solely to the UK dairy industry. Neither can we expect farmers and veterinarians to ignore their AB interests if there are no financial alternatives offered. We suggest that the problem is not AB-use in itself; the "misuse and overuse" is merely a symptom of a dairy sector in need of structural changes at multiple levels. In order to re-evaluate our policy frame and interventions, we need to engage with the complexity of dairy AB networks rather than wanting to reduce it. This involves examining "matters of concerns" at multiple levels, from veterinarians, farmers, food supply chains, governments to consumers, and how they "co-produce" each other. Interventions need to simultaneously address these multiple levels to reduce the risk of overflows. Moreover, we need to continuously work *with* overflows of interventions and tackle them rather than ignoring them.

One way to approach the limitations of today's approaches is to change how we problematise issues related to responsible antibiotic use. The way we formulate problems around the actor-networks that involve responsible use, whom we include in the responsible use research collective and how we disseminate and implement the results, requires different forms of knowledge organisation. Although farmers and vets are asked to give their feedback on the policies during retailer and milk processors, farmers, and vets are not included during the formulation of problems. But problems are not the monopoly of experts [(39), p. 77]. As Callon et al. argue [(39), p. 35], "what is at stake for the actors is not just giving their opinion or expressing oneself or exchanging ideas, or even making compromises; it is not only reacting, but constructing." For example, what structural changes do farmers need in order to become less dependent upon antibiotics? What are problems or phenomena on farms identified by farmers that inhibit innovation and change in antibiotic dependency? Rather than contrasting lay knowledge and expert knowledge by referring to terms like rationality and irrationality, objective knowledge and subjective beliefs [(39), p. 80], we need a collaboration between different types of antibiotic knowledges.

It also involves vision-building across sectors and disciplines to study AB-use as part of a bigger picture of animal welfare, environmental impact and sustainable food production. Moran (8) has for example proposed to design a common framework across clinical, agricultural, and environmental settings that prioritises AB interventions on the basis of their cost-competitiveness. It moreover requires an analysis that acknowledges and integrates the different dimensions, levels, and stakeholders' interests associated with the problem under review. At the same time, the role of the state in facilitating schemes or monitoring the industries self-regulation of responsible use should be an important question to consider. As Higgins et al. [(48), p. 1778] argue, "the intermingling of private and public forms of governing is perhaps inevitable in dealing with environmental externalities generated by competitive agriculture, where meeting the contradictory demands of the market and public pressures to tackle environmental problems poses intractable dilemmas." A limitation of this paper is that it focused on specific networks and policies at the time of research. As these networks and policies are changing, there it the risk that the empirical data does not reflect the dairy industry anymore at this present moment or in the future. Another limitation is the small sampling size of several stakeholder groups. Due to restrictions in time, our sampling data of each group was small, which means the voices we used to represent different stakeholder groups may not represent the wider view of each group reported on.

One topic we left unexplored in this article are the potential effects of the UK leaving the European Union. Being part of Europe means being part of their internal food market with food products produced against certain minimal standards. Although food standards come with overflows, leaving Europe means leaving a framework that tries to supports good husbandry practice, to the consumer, the animal and the environment. Brexit means entering new competitive agricultural markets with potential disruptions to the internal market. How will animal health and welfare, consumer expectations, and export positions be translated in food safety and quality? How can the UK compete with markets which have significant lower animal health and welfare standards? How will it set import and export tariffs without disrupting national markets? How will it patrol its borders to avoid the risks of importing non-native livestock diseases? These are just a few questions which will need to be addressed if the UK leaves the EU.

To conclude, we find that policy and science offer a reductionist way of seeing the world. Dairy AB-use gets boiled down to an issue of "overuse and misuse," which results in a self-fulfilling prophecy: if only we measure we can see how effective we are. Within this frame, overflows don't matter because the frame has been set only to examine the use/misuse in relation to veterinary and farmer practices. However, in order to be effective, we have to look at the whole dairy supply chain network. The question next becomes how we can study AB-use as part of a bigger picture of animal welfare, environmental impact, and sustainable food production. Further research projects should therefore address the complex economic relationships which underpin food production, explore environmental concerns, include public views, examine the overflows of responsible AB-use policies, compare country approaches, and more. But for now, with the uncertainty of Brexit and a UK dairy sector in need for support and security, it is important to work together across levels to drive changes in the UK dairy sector as a whole.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participant were reviewed and approved by the Veterinary Research Ethics Committee, Institute of Veterinary Science, Leahurst Campus, Neston, South Wirral, CH64 7TE. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SB: writing the article. FW, IV, RC, and EP revisioning content. RV: editorial input.

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SUPPLEMENTARY MATERIAL

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Transition Pathways Toward the Prudent Use of Antimicrobials: The Case of Free-Range Broiler Farmers in France

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Reducing antimicrobial use (AMU) on farms is key for controlling the rise of resistant bacteria that have the potential capacity to infect humans *via* direct animal contact or *via* the food chain or the environment. To reduce AMU, antimicrobials must be used in a prudent and rational manner. Extensive efforts have been made recently to identify the cognitive and behavioral barriers to the appropriate use of antimicrobials by various livestock sector stakeholders. However, most studies carried out thus far have only partly captured the dynamic and systemic dimension of the processes involved in changes of practices related to AMU on farms. To shed light on the transition pathways implemented to reduce AMU, a qualitative study was conducted in France based on 28 semi-structured interviews with farmers, technicians and veterinarians from the free-range broiler production sector. Based on the thematic analysis of verbatims, we identified technical improvements which are key contributors to reduced AMU. We also highlighted some gaps in knowledge regarding AMU and antimicrobial resistance. We found that, rather than individual motivations alone, the extent to which farmers are embedded in collective organizations is decisive for changes in practices, and downstream operators (distributors and slaughterers) play a key role in the beginning of AMU transition pathways. As a result, we show that change in AMU requires a global rethinking of the overall socio-technical system rather than modifications of a single element in a farming system. Our results also highlight that transition pathways toward reduced AMU cannot just rely on trigger events, but also involves medium or long-term processes, with actors' experiences and practices being modified on an incremental basis over time. Our study sheds light on the need for multi and trans-disciplinary research involving the social sciences to analyze interactions between stakeholders and the collective actions implemented to tackle the challenge of AMU reduction.

Keywords: antibiotics, poultry, behavioral change, farming practices, animal health, veterinary medicine, qualitative approach, social sciences

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INTRODUCTION

Antimicrobial use (AMU) on farms is contributing to the rise of resistant bacteria that have the potential capacity to infect humans *via* direct animal contact or *via* the food chain or the environment, representing a major threat to human health (1). Antimicrobial resistance (AMR) is an increasing problem and has limited the effective lifespan of newly developed antimicrobial compounds to only 10–20 years (2). The recent growing awareness of AMR as a global public health threat has catalyzed the implementation of regulatory and voluntary public policies aiming to curb AMU and ensure antimicrobial stewardship to slow down the erosion of susceptibility or even decrease resistance of bacteria to antimicrobials. The main objective of numerous action plans implemented recently has been to reduce AMU. It should be noted that these plans are part of a longer-term dynamic involving the development of guidelines and incentives to favor the rationale or prudent use and prescription of antibiotics that date back to the late 1960s (3). Efforts to reduce AMU in the food animal production sector are complicated, however, by the fact that in addition to treating diseases, farmers use antimicrobials to keep their herds healthy and highly productive while ensuring animal welfare and food safety objectives. Antibiotics have been used as growth promoters in livestock farming since the late 1940s, and although this kind of use has been banned in Europe since 2006, it is still a major issue worldwide (4, 5). Managing tradeoffs between massive restriction of AMU and maintenance of current and potentially non-sustainable consumption levels poses a huge challenge to public policies (1).

Significant change in AMU on farms has been observed in recent years following public policies implemented in various countries (6–10). In France, an important decrease in AMU was observed after the first EcoAntibio plan was launched in 2011. While the plan's objectives have been achieved, efforts are continuing, in particular for intensive breeding productions (11), and a second plan is now underway. Extensive research has been done recently to define appropriate standards for quantifying and monitoring AMU in livestock (12, 13). Epidemiological studies also have helped to successfully identify risk factors and drivers influencing actual AMU on cattle (14), swine (15), and poultry farms (16–18). However, the translation of research results into public policies which are able to induce change in the field remains an important challenge (19). Consequently, a series of studies were performed to analyze the cognitive and behavioral barriers to the appropriate use of antimicrobials by various stakeholders in the livestock sector. Previous studies highlighted farmers' lack of knowledge about antimicrobials and AMR (20, 21), showing that while farmers were fairly unconcerned about the risks associated with AMR, they perceived many benefits from their use (20, 22, 23). Other works have shed light on the thought processes of field actors while choosing whether or not to use antimicrobials. Previous studies have shown that such a decision emerges from a complex process in which individuals have to juggle many sociotechnical and socioeconomic elements, and that assuming actors are irrational does not provide a comprehensive framework to understand their practices and knowledge (24, 25). For example, when prescribing antimicrobials, veterinarians have to simultaneously balance animal welfare, public health and economic criteria for their clients and their own firms (26–31). These studies therefore show that we should not only analyze actors' behaviors in terms of compliance or non-compliance with standards and recommendations, but also try to understand the inner (and complex) logics framing their practices and knowledge regarding animal health and AMU. Previous studies that focused on individual behavior and decision-making processes contribute key insights highlighting the importance of empirical descriptions of stakeholders' practices and knowledge. These can be used to better tailor public policies with regard to promoting the prudent use of antimicrobials.

However, a recent article also stressed that although the intersectoral dimension of AMR has been widely acknowledged, solutions for AMR are often focused on individual behaviors, and health issues are reduced to questions of individual responsibility (32). To reconnect the individual/behavioral component of practice change with more structural elements, the analysis of AMU drivers could be deepened by exploring at least two other dimensions that have received scant attention in the literature. First, most previous studies were based on a survey design that aimed to provide an accurate picture of practices and behaviors, but which did not allow an analysis of AMU reduction as a dynamic process. In the context of changes triggered by public policies, more knowledge is needed on the temporal dimension through which actors do or do not modify the way they use antimicrobials. Previous research on the conversion of dairy cattle farmers to organic farming showed that change in AMU is a long-term, potentially reversible process (33, 34) which should be studied over time. The concept of "trajectory of change" was recently used to examine the determinants affecting the reduced use of antibiotics in swine production. Results show that actors assimilate, appropriate and implement new health practices through learning processes (35) which are progressively established over time. This theoretical framework was inspired by previous sociological and interdisciplinary research analyzing multi-level sociotechnical transition in agriculture (36). Examples involving pesticide reduction during a transition to organic farming or integrated crop production (37, 38) insist on both the dynamic and systemic aspects of change, meaning that a transition is neither the result of an individual motivation or awareness, nor of a technical innovation alone, but requires the long-term and gradual re-arrangement of several components involving social, economic, and technical aspects of farming systems. Second, literature on AMU in veterinary science has mostly focused on one stakeholder's perception and behavior, and has paid little attention to social interactions between stakeholders. Research on dairy cattle (39) and broiler chickens (40) has suggested, however, that rather than being an individual process, decision-making regarding AMU involves a complex interplay of relations between farmers, veterinarians, and farm advisors. Sociological studies on pesticide reduction and soil conservation agriculture also have highlighted the crucial role of professional networks in the success of transition pathways in farming (37). These studies in particular insist on the importance of social integration phenomena that are part of change dynamics. Indeed, farmers' practices are always anchored in social networks which form communities in which knowledge, techniques and tools are exchanged and circulate. Changes in practices are thus often paired with a change in the network which is providing farmers technical and advisory support (41).

To shed light on the transition pathways implemented in the livestock sector to reduce AMU, we conducted a qualitative study in the French free-range broiler production sector. Poultry and swine production have been identified as major drivers of antimicrobial use and subsequent development of antimicrobial resistance at a global scale (42). Surprisingly, there is a relative paucity of articles on the factors associated with AMU in poultry (43) compared to cattle and swine. In France, the free-range broiler production sector has engaged for many years in a voluntary process to reduce AMU to the minimum. This transition, which is taking place in response to quality standards and emerging societal expectations, provides a unique opportunity to simultaneously decipher the temporal and systemic dimensions associated with changes in AMU, and explore the role of close advisors, such as technicians and veterinarians, in farmers' changes in practices.

MATERIALS AND METHODS

Selection of Participants

Three Farmer Organizations (FOs) were selected to represent both the principal production areas in France and different modes of production. We thus chose one FO from each of the two main production basins in France (in the west and southwest of the country). One FO from central France also was selected to ensure that different types of organizations were included (both cooperatives and private companies). Each FO was asked to select four farmers to represent different profiles in terms of experience (e.g., one farmer who recently began working with them and one with many years of experience) and production volumes. This target was set to meet sampling recommendations for qualitative studies regarding data saturation. It is acknowledged that the saturation point, meaning the point above which no new information appears, is generally reached after 10–12 interviews per actor category (44). In addition, interviews were conducted with technicians and veterinarians to analyze social interactions over the farmers' professional network. In each FO, two technicians were selected according to their experience in poultry breeding and their relationships with the farmers interviewed. The referent veterinarian of each FO was also interviewed. In addition, two managers (production managers in charge of AMU and FO director, respectively) were identified and interviewed in each FO.

Data Collection

In-depth interviews were conducted face-to-face by the first author between March and April 2015. A semi-structured guide, tailored to each category of participant (farmer, technician, veterinarian, manager) was used to conduct the interviews and allow themes to emerge from the participants' narratives. The guide included open-ended questions covering the interviewee's personal and professional development, daily work (husbandry practices, relation to animals, technical, and economic performance), animal health and animal disease management, relations with other stakeholders regarding animal health (technicians, veterinarians, hatchery, feed mill, auditor/inspector, slaughter house, distributor, consumer, etc.), and use and perception of antimicrobials. To capture change over time in AMU practices, interviewees were asked to describe their personal trajectories regarding the use of antimicrobials over the past 10 years. They also were asked to identify in their life story any determining factors or triggering events related to AMU practices. We systematically put farmers' conceptions back in the frame of their work and in the context of interactions with their peers and advisors to examine interdependencies through a systemic approach.

The contents of the interviews were tape recorded, after having received each interviewee's oral agreement, and after specifying our ethical engagements of confidentiality and anonymity. The digital recordings were supplemented by written notes. Interviews lasted on average 2.15 h.

Data Analysis

All the interviews were fully manually transcribed, and compiled with field notes. All of the transcripts were first read through to gain a sense of the data set as a whole. A thematic analysis was then performed following the methods described elsewhere (45). The first step consisted in identifying themes, concepts, and ideas that appear to be connected in some way. Text fragments were recursively grouped into categories sharing common features. In a second step, these categories then were mapped to place them in context with each other and create themes. Once all of the data were coded, similarities and differences across categories and themes were scrutinized to establish relationships and patterns. Data were progressively interpreted by putting in perspective excerpts from the data with the research question. The analysis was conducted in a circular fashion, with repetitions of forward and backward movements from text fragments, attribution of codes, and interpretation (46).

RESULTS

Interviewees' Characteristics

The sample encompassed 12 farmers who represented diverse situations; for example, the poultry unit was a secondary activity for some while others were specialized in poultry farming, some produced chickens under an "antiobiotic-free" label, etc. (**Table 1**). The sample also included six production technicians (2 for each FO), 6 managers (2 for each FO), and four veterinarians (1 for FO "A" and FO "B," and 2 for FO "C").

Perception of Antimicrobials and Antimicrobial Resistance

General knowledge about antimicrobials and AMR was found to vary greatly among the farmers interviewed. The first difficulty when addressing the subject of antimicrobials was for farmers to properly identify the pharmaceutical class of the drugs used.

TABLE 1 | Main characteristics of the farmers interviewed.

Interview ID	Age group	Gender	FO*	Type of buildings or huts	Year of installation	Productions on the farm	Description of farmer
Farmer 1	50–55	M	A	Huts	1978	Poultry (main production) and vineyard	Took over family farm. Initial training in agriculture but not aviculture.
Farmer 2	30–35	F	A	Hut and 400 m²	2013	Poultry (main production) Suckler cattle Crops	Works on husband's farm (took over family farm). Converted to farming (no initial training in agriculture).
Farmer 3	50–55	F	A	Huts and 400 m²	1989	Poultry (main production) and crops	Took over family farm. Initial training in agriculture but not aviculture. Conversion of the wife to farming.
Farmer 4	45–50	M	A	Standard buildings + 400 m²	1997	Poultry (main production) and crops	Took over family farm. Initial training in agriculture but not aviculture.
Farmer 5	45–50	F	B	400 m² standard buildings	1998	Poultry (main production) and crops	Works on husband's farm (took over family farm). Converted to farming (training in agriculture but not aviculture).
Farmer 6	65–70	M	B	400 m²	1974	Poultry	Took over family farm. Initial training in agriculture but not aviculture. Retired.
Farmer 7	45–50	F	B	400 m²	2002	Poultry and suckler cattle (equal parts) and crops	Works on husband's farm (took over family farm). Converted to farming (training in agriculture but not aviculture).
Farmer 8	30–35	M	B	400 m²	2013	Poultry	Took over family farm. Initial training in agriculture but not aviculture.
Farmer 9	40–45	M	C	200 m² and 400 m²	1999	Poultry (secondary production), dairy cattle and crops	Does not work on the family farm. Initial training in agriculture.
Farmer 10	35–40	F	C	400 m²	2014	Poultry (secondary production), dairy cattle and crops	Took over family farm. Converted to farming (training in agriculture but not aviculture).
Farmer 11	60–65	M	C	400 m²	1977	Poultry	Took over family farm with training in agriculture and aviculture.
Farmer 12	45–50	F	C	400 m²	1989	Poultry and suckler cattle (equal parts) and crops	Works on husband's farm (took over family farm). Converted to farming (no initial training in agriculture).

**FO, farmer organization.*

Some were unsure which of the drugs that they used were actually antimicrobials. With one exception, the farmers interviewed could not provide an accurate definition of AMR; they often described it as the result of the human body becoming habituated to antimicrobials. Confusion about drug residues in meat was also observed.

> *"The danger? There are residues in the meat, and the human body probably absorbs a little bit at a time. And then when you need to take an antibiotic, because everyone can get sick, the antibiotic no longer has any effect (..) Basically, the antimicrobials persist in your system, and then you cannot get cured because the human body is saturated with antibiotics."* [Farmer 11]

Despite this confusion and inaccuracies, the main direct consequence of AMR on human health was clear for most of the farmers interviewed. They understood that AMR complicates treatments for human infections.

> *"- Why do you think AMR is dangerous?*
> *- We cannot be cured anymore. That's what I understand. It upsets me too."* [Farmer 5]

Even though the majority of farmers were aware of AMR, it did not appear in the interviews as a major concern in their daily work or a threat to their health.

The farmers' main sources of information on AMR were vets and medias. FOs often offer training sessions on technical topics for their members, but none of the farmers interviewed had participated in a session dedicated to AMR. What they knew about AMR often came from unofficial talks.

> *"- Has your farmer organization or the technicians provided you with some training about AMR?*
> *- No, we just talked about it in passing, and sometimes on other occasions, even in relation to people. There are enough ads as it is on TV."* [Farmer 6]

Farmers thought they had never used many antimicrobials, but acknowledged that they had used comparatively more antimicrobials in the past. Several years ago, antimicrobials may have been used even when they were not necessary from a sanitary perspective. In some cases, they were systematically administered to chicks upon arrival on the farm. Interviewees explained these misuses by the fact that free-range broiler farming in the past was not as professional as it is today, and knowledge and experience were lacking. The sanitary conditions also were different.

> *"Of course there were more treatments, maybe because we had more health issues. And we were probably not as attuned to the antimicrobials question as we are today. We didn't have an all-in-all-out system and we didn't follow biosecurity measures."* [Farmer 11]

In contrast, interviewees considered that they now are using few antimicrobials, and only when necessary. This may explain why AMU in free-range broiler farming did not seem to be an issue or a frequent conversation topic for farmers. Nevertheless, the farmers interviewed clearly perceived a trend, or a dynamic of change, in the way antimicrobials were used in poultry farming; however, this evolution was not necessarily related to a growing concern about AMR but rather to a gradual shift in their farming practices.

> *"For me, antimicrobial use is not a big issue, not on my farm. Maybe other farmers have trouble. I don't know."* [Farmer 4]

Their conviction that their AMU was low is based on the comparison with what they perceived not only of their past consumption, but also the AMU of other farmers. In particular, they assessed their AMU levels by comparing themselves with two other types of broiler production, conventional, and organic, which they used as positive and negative references, respectively. They thought they used less antimicrobials than conventional broiler farmers. They also though their AMU to be very similar to organic broiler productions because they considered their farming practices were very comparable.

> *"Conventional broiler farming, it's not at all my thing. I mean, to see broilers squished together, well not squished, but enclosed in a poultry house, no. I wanted a quality product. I hesitated between organic and Label Rouge* (a French quality scheme). *I've been told that between organic and Label Rouge there was not really much difference."* [Farmer 8]

This quote also points to the importance placed by farmers on the quality of their products. They judged they had good farming practices, ones which were sustainable and ethical for the animals, the environment and the consumer. Using as few antimicrobials as possible thus made sense for farmers, because it is part of a wider engagement to produce quality broilers. Clearly, reducing AMU has become a component of their definition of "good farming" and, therefore, of their professional identity.

> *"Then, it's maybe in my philosophy; I'm not prone to taking antimicrobials. (...) I'm in favor of breeding broilers as naturally as possible."* [Farmer 7]

Showing low AMU was also a way for farmers to convey a greener image of farming, on a topic that is usually a source of social criticism. Farmers were paying close attention to the expectations of consumers and society.

> *"The request to decrease the use of antimicrobials comes from the government, but actually society is asking us to reduce it, so we have to consider this request."* [Farmer 1]

Reducing AMU also brought economic advantages for farmers who spent less money on health issues. Some farmer organizations have started to produce broilers to market them as "raised without antibiotics." Farmers who agreed to produce antibiotic-free broilers received extra payments for those flocks.

> *"Some expenses unfortunately cannot change, I'm thinking of gas, (...) there are things on which we barely have any impact. Consumption of veterinary products, there's an impact, you chose to administer them or not. And believe me it slows lots of farmers down." [Technician 6]*

Although financial incentives play a role in practice changes regarding AMU, some farmers also highlighted that personal beliefs and conceptions also are crucial determinants.

> *"It works. It's not just something I think, it's that I know it works. (...) The wallet works. When financial compensation is not involved, there are financial penalties (...) It's a shame but hey, we are not all made the same! But I think, I am sure, that there are better results with people who are really convinced than with those who become convinced because they get some money. Money is a means but it is not the best." [Farmer 9]*

Technical Factors Involved in AMU Reduction

Analysis of the interviews also sheds light on the way farmers managed to reduce their AMU. First of all, farmers associated better health and reduced AMU with improvements in chicks and feed quality.

> *"Because now, you have to admit it, hatcheries are delivering perfect goods. Whereas before, what could you do when you received a flock of sick chicks? It was neither the farmer's fault nor the feed's fault." [Farmer 6]*

Farmers also explained that AMU reduction was made possible by the adoption of new practices such as the acidification of water. This is propelled by discussions with professionals from the poultry sector (sales agents, technicians or vets), but also by recommendations from other farmers or after a farmer had experimented with it on other livestock. One farmer explained he first learnt how to use the acidifier on his duck production unit, and then extended it to all of his poultry production units as he judged that he used fewer antimicrobials since adopting this technique.

Probiotics and herbal drugs were other examples of products recently adopted by farmers. Most herbal drugs are currently classified as a dietary supplement in France. That implies that farmers have free access to these products, and can quickly react to a health issue. These products were recommended by some FOs to be used as a prophylaxis, but technicians also used herbal drugs as an alternative to antimicrobials to manage some health issues. Interviewees highlighted that the adoption of new practices such as herbal drugs relied on the ability of technicians and veterinarians to show the proof of their efficacy.

> *"It's true that once they have seen that herbal drugs work, they tend to continue with herbal* drugs, rather than go back to chemical drugs." [Technician 4]

Farmers carried out multiple experiments, mainly with alternative medicines. Experiments can be initiated on the request of the FOs, which recruit farmers to carry them out. One farmer also explained how he developed his own experiments on the management of water quality, without any collaboration with the FO's technical staff. After having successfully decreased the occurrence of digestive disorders in chickens (and in turn reduced antimicrobial use), he showed his neighbors how to lower the pH of water. This example shows how learning progressively passes from one farmer to another.

Farmers progressively have been adopting more preventive approaches to manage their farms. Most of the practices mentioned by farmers as levers for reducing AMU were actually not innovative by themselves (cleaning and disinfection, prophylaxis, etc.). What farmers emphasized is that the changes that occurred did not involve the adoption of new tools or practices as much as improving how they implemented some existing practices. In a nutshell, it was less what they did than how they did it. They mentioned, for instance, the improvement in cleaning and disinfection operations, and in the respect of a strict downtime between two flocks.

> *"Now we have a more preventive approach. I think we've been taught to decontaminate water pipes." [Farmer 11]*

Technical advisors also highlighted the critical role of biosecurity as a lever for AMU reduction. The main difficulty relies in their effective implementation of good practices in the field, and the maintenance of farmers' compliance over time. In this regard, the recent epidemics of highly pathogenic avian influenza in France have brought to the fore the crucial role of well-known biosecurity measures, and offered technical advisors opportunities to insist on biosecurity compliance. These episodes were used by technical advisors as an opportunity to prompt change in biosecurity practices.

> *"We've been fighting for biosecurity every day, ever since 2006 (...) and now we are finally succeeding. Basically, the regulations and the current situation in France are a huge help (. . .), it has been an opportunity clearly answer the question: what is biosecurity?(. . .) When someone says, "Why do I have to change, I don't understand, my chickens, they go outside, you are full of nonsense." (...), now I can respond: "You are doing biosecurity today for influenza", but it is actually for all diseases." [Manager 3]*

Farmers also stated that they have progressively modified their reaction when facing a syndrome, including a mortality episode, in the flock. Farmers described how, instead of treating with antimicrobials as soon as the problem starts, they were now waiting to see how it evolves. Sometimes clinical signs ceased quickly by themselves; waiting and watching the flock closely enabled farmers to avoid AMU. This is actually an example of collective learning within the professional network, because technicians and veterinarians also had to modify the way they react when a farmer calls to notify mortality.

> *"I wouldn't have agreed to wait and see without treating because I was young, inexperienced. I didn't know it was useless. But today when some of my animals are coughing, I don't rush to the vets. Because I know it's going to stop in a few days." [Farmer 7]*

Role of Interpersonal Relationships in AMU Reduction

All of the stakeholders mentioned that the technical support provided to help farmers solve health issues in their flocks would not be effective without well-established confidence relationships between farmers, technicians, and veterinarians. According to actors, this confidence relationship was also absolutely necessary for farmers to accept the risk of waiting before treating in situations with a case of mortality.

Interviewees highlighted that trusting relationships are formed progressively, and that the degree to which actors invested time in these relationships was critical.

> *"Concretely, we have to pass a lot of time with them [the technicians], they have to trust us, and we have to talk to them about lots of things other than poultry. You have to create a relationship (...) You can talk about their work, or about plenty of other things, and then they gain confidence, and they listen. But it takes time. It's a relationship." [Veterinary 2]*

Actors highlighted that three main mutual commitments were necessary for establishing this relationship of confidence. First, veterinarians, technicians and farmers shared a responsibility because any inappropriate practice could damage the whole production organization. Second, they had to remain humble and question themselves when facing a problem. Third, actors also had to stick together and help one another. Farmers were not alone; technicians and veterinarians committed themselves to being reachable on weekends and bank holidays.

"I tell farmers, 'When you have sick animals, call your technicians so we can decide what to do together, what level of risk we should take'. It's true that Friday always is a challenge, and farmers say: 'Wait, how are we going to spend the weekend!'. (...) I give them my number, so we take stock together. (...) We've got to make farmers feel that we are with them, we have their backs. If you leave them to struggle with their own fears, they are going to take the easy way (...). So you have to stay by their side, etc. they shouldn't be alone. When a farmer has done this with you once, (...) he no longer needs this positive feedback precisely because he has made his own paradigm. He says to himself, 'If it is possible, we can do it, I have already succeeded once.'" [Manager 3]

The trusting relationships established by farmers, veterinarians and technicians have even made it possible to share the decision-making process regarding the use of antimicrobials. To a certain degree, the choice of a given intervention, while theoretically the sole domain of veterinarians according to the French Public Health Code, integrates the expertise of both the farmer and the technician who first intervenes when there is a problem on a farm.

"When animals fall ill, the technician is called. He goes there and does an autopsy. If he identifies what the problem is, he manages things himself. If he's not sure, he usually calls us, and then we discuss it. In some ways, he is like our eyes. We do a lot over the telephone because the technicians have already done the legwork. So you definitely must have a relationship of trust. One has to be absolutely sure that they're not going to tell us a load of rubbish. But normally, it's true that legally, it's not supposed to happen like that." [Veterinary 2]

Gradually, the close relationship formed between a technician and a farmer allows personalized adjustments. The technician draws from his or her personal knowledge of the farmer to encourage good practices, using whatever argument s/he deems to be the most persuasive under the circumstances [economic (cost of treatment), fear of being audited, or benchmarking with peers].

Role of Collective Actions in AMU Reduction

Our results highlight the key role of downstream operators (distributors and slaughterers) in the beginning of AMU transition pathways. Regular audits prompted by the request of downstream operators do not simply verify conformity with specification standards. They are used as an opportunity to initiate change in an FO's practices.

"It was really with this audit that we said OK, we have to do something because next year he [the auditor] will ask us to do it anyway, so we might as well go ahead and develop something for the technicians to make it more efficient." [Manager 1]

Downstream operators clearly asked FOs to put in place monitoring tools that allowed AMU to be evaluated in a quantitative manner. The development and adoption of such tools by the FOs had a positive impact, making it possible to become aware—based on factual data—of AMU practices on farms. Once AMU was closely monitored, FOs started developing "antibiotic-free" labeling strategies for positive market differentiation. Farmers and managers emphasized that the use of these tools was even more effective than the financial bonus associated with "antibiotic-free" production to reduce AMU. The tools made it possible to quantify and visualize use, enabling farmers to compare their performance with that of others, and a dynamic of emulating good practices was established and further rewarded by labeling.

"Antibiotic-free chickens was something that definitely helped us reduce antibiotic use. It is clear, because I think that we all ended up being very invested in this, the technicians, vets, farmers, and the group of farmers who adhered. Sure, the bonus had an effect, which surely also made it possible to do a certain number of things. But I think that gradually it even became like a kind of challenge to say: We are getting there so we should no longer use antibiotics." [Manager 2]

In addition to quantitative tools, downstream operators also have the power to ask for qualitative changes in practices, with reduction of the use of critical antibiotics.

"We made a progress plan together with this client, who is a client with whom we have a really close partnership. Once we had the plan, the client wanted us to move forward on it. He said that he didn't want, and wasn't expecting, zero-treatment chickens, but rather a positive dynamic, meaning better management of antibiotics." [Manager 6]

To reduce AMU, FOs have progressively developed various mechanisms which aim to engage farmers in a transition pathway that is shared at a collective level. To encourage farmers to spontaneously join collective actions to reduce AMU, FOs have been mobilizing levers such as the shared identity of farmers, their pride in being a farmer and a sense of belonging to a community. One FO clearly stated that the objectives of its strategy were to create a new social standard that farmers would want to comply with by joining a specific action. This action was based on the establishment of a multicriteria performance score which aggregated various indicators and could penalize treatments of increasing severity (with, for example, an antibiotic treatment associated with a higher penalty than a treatment based on herbal medicine). The expected result, from the FO's point of view, was that farmers would voluntary enroll in the process, and their "culture" would progressively be modified through the embrace of this new approach. Ultimately, farmers would change their practices simply by embracing a collective challenge. Rather than pushing them to change their practices, the FO was asking them to change their "state of mind."

"Once again, the point of this project is to get the employees and the members on board in a process whose ultimate goal is to improve performance and reduce antibiotic use because we will lower antibiotic use through everything in the project. I mean there is no one factor that will alone reduce use, there is the state of mind (...). By being part of the process, farmers are going to start asking themselves the question. I am hoping that

by creating the dynamic, farmers will say to themselves: 'Damn, I have to use an antibiotic, that bothers me.' Whereas before, the reaction was:' The birds are sick, let's get out the antibiotics', you see what I mean?" [Manager 4]

The goal was to induce farmers to enroll in a comprehensive approach that had multiple objectives. Most of the time, reducing antimicrobials was not the sole focus, but rather one component in a combination of changes that aimed to increase overall performance (which was not only assessed in terms of productivity or profitability, but also of complying with certain values and professional identity). Reduction in antimicrobial use as it was addressed by the FOs was therefore complex and not an objective in itself, but served in fact several purposes. With the exception of one FO, most of the tools mobilized were not developed specifically to reduce AMU. Rather, they were items designed for another strategic function that were later applied to reduce AMU (e.g., a smartphone application first developed to manage internal controls and salmonella tests). As a result, the management of actions related to AMU is often assigned to several different actors for whom AMU is an added duty on the fringe of their main mission. This reflects the fact that the FOs do not yet have a clear vision of the economic impact of changes in AMU, and have therefore decided to divide tasks between existing staff rather than creating a position dedicated only to AMU reduction.

The three FOs finally reached the conclusion that reducing AMU was a "management" issue that needed to be spearheaded and coordinated at the FO level rather than left to the initiative of individual farmers. They highlighted the importance of a collective strategy piloted by a lead actor who, convinced of the importance of the subject and with a vision for his or her company, decides to set up actions such as appointing an AMU coordinator and putting in place an elaborate framework for a transition pathway toward AMU reduction.

"In the end, not that many people are orchestrating this. (...) The main obstacle, as we mentioned earlier, is linked to systems—both the education system and the industrial operating system—which compartmentalize. Therefore, what is perhaps the most exhausting part is to explain to people that it is necessary to decompartmentalize, that it is necessary to train to become like a pilot (...). We need to bridge the gap between advice and practice. (...) Ultimately, if we want to define actions and measure them, a coordinator must be someone who is not busy with something else, we need to afford the luxury of having someone with health skills who gets paid to do nothing but that." [Manager 2]

DISCUSSION

Debates about appropriate methodologies for studying public health problems have long been polarized by the opposition made between quantitative and qualitative approaches (47). Epidemiological approaches have been widely used to hierarchize the respective role of risk factors and analyze the causal link between farming practices and AMU on farms. On the other hand, sociological research and qualitative methodologies aim to gain an inside view of the context and intentions underlying professional practices and knowledge, and to document interactions and power relations between the various stakeholders. This article rather leans on this second body of work and uses it to discuss interdisciplinary approaches which have been developed these last years in the field of animal health, and AMU in particular.

However, we should first of all expose some limitations of the study. The sampling strategy and the theoretical models we used certainly limit results generalization to very specific production sectors. Although the selection criteria used in the sampling and the data saturation which occurred in the analysis allowed us to document a wide range of practices regarding antimicrobials use in free-range broilers in France, our results may not be applicable to all animal production systems. Indeed, since organizational characteristics of the value-chain and of the labor division within FOs have been proved to be a decisive factor of AMU decision-making process, our conclusions could be only applicable to animal production systems sharing similar characteristics, such as the pig and poultry industry which are known for more integrated socio-economic structures. We also acknowledge that some AMU practices may have changed since the time of the study. However, it is likely that those changes are limited as (i) interviews suggested that major changes in AMU (e.g., reduction of metaphylactic use) had already occurred before that time, and (ii) AMU was already low at the time of the study (16). Moreover, as the objective of this article is not to provide a quantitative assessment of AMU but to analyze the drivers of AMU practices and knowledge (stakeholders' interactions, labor division, organizational characteristic of the FOs, etc.) which shape long-term farmers' trajectories, our conclusions should thus remain valid for other studies. Consequently, the present work, based on a case study of the free-range broiler sector in France, brings new insights on the transition pathways toward an optimized and prudent use of antimicrobials.

First, farmers identified that technical improvements are a key success for reduced AMU, in particular the quality of inputs (feed, chicks), use of alternative medicines and biosecurity. These results are in line with previous studies. The quality of feed and chicks has been found to be decisive for chicks' health (48) and associated with variations in AMU in broiler production (18). In addition to these well-known technical factors, farmers also emphasized the role of alternatives to antimicrobials. The efficiency of alternatives such as herbal drugs has not yet been demonstrated, and experimental proof is obviously lacking. However, a recent epidemiological study carried out on the same study population (16) showed that the use of herbal drugs was associated with a decreased probability of AMU in the field. As farmers and health advisors are increasingly interested in the use of alternative prevention strategies (including vaccines, prebiotics, probiotics, and herbal drugs), further studies are needed to assess their effect in relation with AMU reduction. Results highlight that the adoption of these new technical tools (acidification of water, use of herbal drugs) is a progressive process, in which on-farm experiments have a key role. The implementation of such experiments depends on farmers' motivations, the appeal of novelty, and the advice farmers may receive from technical advisors (technicians, veterinarians). Once actors perceive that a form of "proof" has been established, the practice can spread through informal exchanges that occur between farmers, or be incorporated into a formal transfer program such as training activities set up by FOs. The positive impact of joint learning has already been studied in intervention studies in the context of Danish Stable School (49). All of the stakeholders (farmers, technicians, veterinarians, managers) also identified biosecurity as a crucial lever for managing AMU on farms. In France, recent episodes of highly pathogenic avian influenza that seriously impacted the poultry sector (50) obviously put the spotlight back on this "well-known" tool for disease control. The relationship between biosecurity measures and AMU on farms is, however, complex; thus far it has mainly been investigated in the pig sector. Results from a study carried out in German farrow-to-finish farms found that the level of biosecurity of herds was associated with the amount of antimicrobials used (51). Similar observations were made in a multi-site cross-sectional study conducted on pig herds from Belgium, France, Germany and Sweden (52). In contrast, no clear association was found between biosecurity and antimicrobial consumption in the context of Danish pig farming, which presents generally high biosecurity and many years of official restrictions regarding antimicrobial use (53).

Second, results highlighted gaps in knowledge regarding AMU and AMR. As a previous study demonstrated that the level of farmers' knowledge was significantly and inversely related to AMU at the farm level, whatever the species considered, efforts need to be pursued to heavily target knowledge of AMU and AMR in communications with veterinarians and through educational campaigns for farmers (54, 55). Regarding farmers' perceptions, one of the main drivers identified in the present study for antimicrobial reduction was alignment with farmer professional identity and sense of good farming. Implementing a new practice that contradicts farming identity complicates and even prevents its adoption by farmers who happen to be very sensitive to what their peers are doing, and often compare their practices (56). In a previous work examining the social factors that influence the length of the antimicrobial treatment administered to dairy cows for mastitis (54), the authors showed that giving an antimicrobial treatment over an extended period despite the injunction to reduce AMU enabled farmers to comply with the social norm of "being a good farmer" that was conveyed by their peers, vets and advisors. Our study suggests something slightly different. Indeed, even though professional networks are a key component of farmers' decision-making process, there was clearly no identity break associated with decreasing AMU. On the contrary, French traditional free-range broiler farmers have built a conception of their work that values AMU reduction. It was in particular expressed through the fact that they attached importance to consumers' opinion and were eager to prove that they produce quality products. All in all, farmers' knowledge and practices, among which their attitudes toward AMU, are associated with farming subjectivities which are equipping farmers with a certain sense of good farming, that is to say attributing positive values to a certain type of farming (56). Of course, these subjectivities are also the product of larger social structures which in our case mostly relate to the professional network and the FO, but in some cases can be more directly connected to national agricultural policies (57). For instance, farmers' identity has been used as a driver for change by one of the FO analyzed, which clearly stated an objective of changing the "culture" or "state-of-mind" of farmers to accompany them toward a reduction of AMU.

Third, our results showed that farmers' embeddedness in collective organizations is decisive for farmers to accept and change their practices. Analyzing AMU reduction should not rely on a conception of change made from an individualistic or behavioral point of view, but should rather try to understand how the structure of the sociotechnical and socioeconomic networks in which farmers are embedded favors change or not (or what kind of change it favors). Results of our study showed that the FOs act like a professional network for farmers, providing technical advice, inputs supply and products commercialization. Farmers and technicians know each other, and technicians know which incentive can motivate farmers to implement some practices, and thus deliver advice that is personally adjusted to farmers (40). The confidence relationship between farmers and their advisors underpins the moral support that technicians and veterinarians provide to farmers. Palmer, Sully et al. (58) have for example shown the importance of a trusting relationship for the implementation of biosecurity measures in livestock farms. In our case, this moral support provided by farm advisors was decisive to help farmers considering making any change and accepting to take a risk, such as mortality. As showed by Fortané et al. (35), farmers have to operate a cognitive change by modifying their perception of risk while learning to wait before treating in case of mortality. The farmers we met learnt that in some cases treating the flock with antimicrobials may enable puny broilers to be saved, but the latter will always have a lower weight than the other birds and ultimately penalize the flock. Accepting a certain level of mortality during a short period of time in the flock is a way to accept natural sorting among birds. This change in the attitude toward risks and antimicrobial treatment was of course related to a change of their conception of what a good farmer is to someone who does not necessarily have to act as quickly as possible to stop mortality and disease in his or her flock. Lamine et al. (37) observed a similar change in farmers who had converted to integrated crop protection, and who changed the hierarchy of the accepted risks. They delayed their seeding in order to avoid diseases and decrease crops treatments, but on the other hand, they had to accept the higher risk of rain. By accepting a risk which they did not accept before conversion, they also changed their conception of what "beautiful wheat" is. It is also noteworthy that economic incentives did not appear in our study as a major driver for change in AMU compared to technical and cognitive factors, with the exception of a financial bonus for breeding antimicrobial-free broilers. This finding is in line with previous work that showed that financial incentives and penalties are inefficient if farmers do not intend to change (59).

All of these elements shed lights on different aspects of agricultural transitions and practice changes (36). First, transitions are always systemic, which means that it is not enough to simply withdraw a sole element (for example, antimicrobials). This withdrawal implies a global (though not necessarily radical) rethinking of the system. In the present study, farmers experimented with alternative medicines of different natures, they also implemented new biosecurity measures and tried different strategies, mostly preventative, to manage animal health. These systemic elements are not just technical or economic. It is important not to forget the social, cultural, and cognitive components of farming systems since transitions also encompass phenomena such as professional relationships, a sense of good farming and perception of risks. Second, transitions are dynamic, which means they have to be understood as a mid or long-term process and often from an incremental perspective. They cannot just be related to motivations or trigger events inducing radical changes, as even though these aspects matter in many cases (60), including in AMU reduction (35), they should not necessarily be considered as a starting point of a trajectory of change. Analysis of verbatims showed that for the free-range poultry farmers we interviewed, the decision to reduce AMU was not triggered by a specific event, but was part of a broader dynamic of change that was fostering this transition toward more sustainable farming. Reducing AMU was part of this change, but was not the alpha and omega of it and more importantly, these changes occurred progressively. Previous works on transitional pathways in organic crop farming have shown that a farmer's experience is essentially built and adjusted through experimentation related to the introduction of a new technique (61). Our results show that adoption of new preventive practices (such as acidification of water, or use of alternatives to antimicrobials) was a progressive process in which farmers' experiences and relationship with risk were gradually recomposed over time. The farmers did not mention brutal changes, but a change in continuity (62), even for technical improvements which are often made on an incremental basis. This finding supports those from a previous study, suggesting that a change of practices related to AMU on pig farms was shaped over a relatively long period of time (35).

In addition to technical factors, our results also highlight the importance of time in the establishment of trusting relationships between actors, which are a crucial prerequisite for farmers' acceptance of the risks associated with AMU reduction. This is linked to the point that the transition pathways we observed in our case-study did not involve a withdrawal from the sociotechnical networks in which the farmers were embedded. On the contrary, these networks (materialized by the professional relationships with vets and advisors, as well as the technical and economic support of the FO) actually enabled changes and transitions in farming practices. This result is quite distinct from other cases described in the literature, for example for transitions toward soil conservation agriculture or pesticide reduction, where the strong ties of the traditional sociotechnical network had to be broken in favor of weaker ties that could then be strengthened with more alternative networks (37, 41). This could be interpreted as a consequence of the specificity of our fieldwork. We studied three relatively small FOs in a quality sector where the relationships between farmers, technicians and veterinarians are close. Furthermore, the farmers we interviewed had strong confidence in their FO to help them work in a way that fulfilled their professional identity, and so they trusted the strategy offered by their advisors to reduce antimicrobials. Perhaps more importantly, we studied a quality label sector that was already providing forms and senses of sustainability to farmers, who did not feel that reducing AMU was a massive change in their way of farming and of being (good) farmers, so that the transitions in which they engaged felt like a "natural" continuity in their career and the trajectory of their businesses. All in all, our study sheds lights on the diversity of agricultural transitions.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because sharing publicly full excerpts would compromise the agreement to which the participants consented. Requests to access the datasets should be directed to MP, mathilde.paul@envt.fr.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors contributed conception and design of the study. CA collected the data, performed the thematic analysis, and wrote the first draft of the manuscript. NF and MP wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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Veterinary Diagnostic Practice and the Use of Rapid Tests in Antimicrobial Stewardship on UK Livestock Farms

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In this paper we consider the shifting role, practice and context of veterinary diagnosis in addressing concerns over what is, in the context of the growing threat of antimicrobial resistance, considered unnecessary or excessive antimicrobial medicine use in UK livestock farms. With increasing policy and regulatory interest in diagnostic practices and technologies, coupled with an expanding focus on the development and deployment of new rapid and point-of-care on-farm diagnostic testing, this paper investigates current diagnostic practices amongst veterinarians working on dairy, pig and poultry farms in Great Britain (England, Wales, and Scotland) and, more specifically, veterinarians' use and perceptions of new and emerging rapid and point-of-care diagnostic tests. Drawing on a series of 30 semi-structured interviews with farm animal veterinary professionals across the three sectors, this paper examines the manner in which such tests are both used and anticipated in clinical farm animal veterinary practice and the possible impact rapid test technologies might have on broader farm animal health management and disease control. Analysis of the transcribed interviews reveals a number of complexities around the use of rapid and point-of-care diagnostic tests. The relative rapidity and simplification of such tests, facilitating immediate treatment responses, is held in balance against both the accuracy and the more detailed and documented procedures of established laboratory testing routes. In situations of multifaceted on-farm etiologies, respondents maintained that rapid tests may offer restricted diagnostic capabilities, though in other situations they were found to offer ready confirmation of disease presence. A third complexity arising from the growth of rapid and point-of-care testing and revealed in this study relates to the shifting distribution of responsibilities in animal health care within contemporary food chains. The growing availability of rapid and point-of-care tests effectively diversifies the range of diagnostic actors with consequences for the flow of diagnostic and disease information. The veterinarians in this study identified areas where new rapid and point-of-care tests would be of particular value to them in their clinical practice particularly in addressing concerns over inappropriate antimicrobial use in animal treatment. However, despite the considerable policy advocacy on rapid and point-of-care tests as key tools in shifting diagnostic practice and reducing unnecessary antimicrobial use, veterinarians in this study, while recognizing the potential future role of such tools and technologies, nonetheless viewed diagnostic practice as a far more complex process for which rapid tests might constitute only a part.

Keywords: antimicrobial use, livestock farms, veterinarians, rapid diagnostic tests, diagnostic practice

INTRODUCTION

In 2015, the UK's Review of Antimicrobial Resistance, originally commissioned in 2014 to investigate the emerging issue of antimicrobial resistance and propose workable solutions, released two reports. The first of these, published in October of that year, looked specifically at the role of rapid or point-of-care diagnostics in human medicine in reducing unnecessary antimicrobial use (1). The second, appearing two months later and entitled "Antimicrobials in Agriculture and the Environment" (2), sought to identify means to reduce the use of antimicrobials in livestock systems. Building on the earlier document, this second report also highlighted the potential role that rapid and point-of-care diagnostic tools might also play in reducing antimicrobial use in animal treatment. These two documents, followed by the Review's final report (3)–also known as the O'Neill report after the Review's Chairman–have since become key statements in informing subsequent responses of Government (4), NGOs (5), and industry (6) to the need to reduce antimicrobial use in agriculture and to the potential role of rapid and point-of-care diagnostic tests (which we define, for both terms, following Abuelo and Alves-Nores [(7), p. 293], as diagnostic tests "performed at or near the site of care," producing a result in a short period of time on the farm thereby allowing a faster decision to be made about treatment) in that reduction. The UK Government, under its current Five-Year Action Plan for Antimicrobial Resistance, thereby committed to:

> Explore, in collaboration with industry, options to develop rapid and reliable diagnostic tools to inform veterinarians' prescribing decisions; and promote the uptake of these tools (4).

The emphasis placed here on new, rapid and point-of-care veterinary diagnostic procedures and practices comes at a critical time within the development of both livestock agriculture and the veterinary profession. The former is becoming increasingly data-rich, through food chain monitoring, "smart" technologies and assurance processes leading to improved surveillance of animal health. The latter, meanwhile, with innovations in diagnostic and treatment technologies, is nevertheless adapting to different roles and structures as corporate veterinary practices become ever more present across the UK veterinary landscape (8–10) and as the responsibility of the farm animal veterinarian expands from the traditional role of animal "doctor" to include broader terrains of environmental and health planning as well as management within an increasingly vertically integrated agro-food sector (11–13). It is against this background that the role, the practice and the technologies of veterinary diagnosis are increasingly being discussed and debated both within the veterinary profession and beyond. In this paper, drawn from an ongoing social science-led research project (Diagnostic Innovation in Agriculture [DIAL], www.dialamr.com) into the broader function of diagnostics and diagnostic practice in farm animal treatment, we first consider the shifting place of veterinary diagnosis and stewardship with respect to antimicrobial use in livestock production. Taking insights and analysis from a recent qualitative study of diagnostic methods, tools and point-of-care technologies used by farm animal veterinarians in England, Scotland, and Wales, we then go on to investigate and report on how broader advocacy of rapid and point-of-care solutions becomes translated into current veterinary practices and the potential impact such diagnostic test technologies might have on farm health management and disease control. In doing so, this paper identifies a series of drivers and impacts of change which, we argue, have a potentially significant influence upon the role and place of farm animal veterinarians in contemporary agro-food systems.

DIAGNOSIS AND ANTIMICROBIAL USE

Diagnosis, which we might define as the process or activity of identifying the nature and cause of a disease or injury, is central to both human and veterinary medicine. Yet, while the techniques and procedures of diagnosis have long attracted the attention of instructors and scholars, social science and sociological investigations of the practice of diagnosis have remained relatively few and far between (14, 15). This is particularly the case for the procedures and practices of veterinary diagnosis (16). Yet, recent developments in the social sciences themselves—drawing particularly on "more-than-human" studies and the Sociology of Science and Technology (16, 17) and also in the social sciences' attention to veterinary practices (18)–have raised the profile of veterinary diagnosis, its evolving social and professional context and its relationship to emerging technologies. As Hobson-West and Jutel argue [(16), p. 397] diagnosis confirms "the scientific and professional power of veterinarians" both with respect to animal owners and other para-professionals in the animal care sector.

At one level, the rising global concern for antimicrobial resistance and the role that farm animal veterinarians play in antimicrobial prescription and use brings a new attention to the processes, practices, and technologies of clinical diagnosis. However, the rapid and increasing use of antimicrobials throughout the latter half of the last century and beyond has raised specific issues and challenges for the role and place of veterinary diagnosis.

The arrival of antimicrobials in livestock systems, first in the US in the 1940s and then elsewhere (19), impacted significantly upon the traditional role and place of veterinary diagnostic practice within agriculture in two important ways. First, until partially restrictive legislation was finally introduced, both in the UK and in the US, low doses [defined as between 50 and 200 grams per ton of feed; Graham et al. (20) of commercially available antimicrobial drugs could be purchased legally and given to animals directly by farmers without the need for veterinary diagnosis, prescription or administration (21). There were many economic reasons for this, not the least being the dramatic upscaling of intensive livestock agriculture and the production of cheap and faster-growing animals, particularly poultry (22). Low dose, growth-promoting antimicrobials rapidly became an integral part not only of entire animal production systems but also of the structure of the consumer market for animal products. As Puig de la Bellacasa points out, "productionism colonizes all other relations" [(23), p. 184]. However, this also meant that in practice a growing proportion of antimicrobial use decisions were being made increasingly by farmers themselves and commercial advisors with little, if any, recourse to professional veterinary diagnostics. As H.C. Swann, writing in the British Veterinary Journal in 1963 reiterated:

> When illness occurs in animals which a farmer suspects may be related to a certain system of feeding and possibly to the use of a particular foodstuff, he [the farmer] frequently seeks the free advice of the supplier's technical officer whose duty theoretically is to assess the situation in terms of the use of his firm's products, but it becomes increasingly difficult for him [the officer] to limit his advice to dietetics and husbandry. Consequently, free advice–not necessarily correct–is frequently given on disease problems by unqualified people (24).

Historically, farm animal veterinarians across the US (25), Germany (26), the UK (27, 28) and elsewhere in Europe (29) found themselves, albeit at different degrees, in an increasingly difficult position. With the expanding use of antimicrobials as growth promoters, easily obtained by farmers from feed suppliers and elsewhere and deployed without veterinary supervision (particularly in the rapidly intensifying poultry and later pig sectors), the capacity of veterinarians to control and manage antimicrobial use in agriculture was diminished. (30) argues that, in the 1950s and 1960s, many UK veterinarians and their organizations nevertheless became reconciled to the use of low dosage antimicrobials as growth promoters as a means of encouraging agricultural modernization, reducing animal feed costs and providing cheaper food to consumers, in the absence, at the time, of credible scientific evidence of the contribution of sub-therapeutic antimicrobial levels to both residuals and resistance transmission (25, 31, 32). Commenting on the relative failure of the 1969 Swann Report to address the issue of excessive antimicrobial use in agriculture, an editorial in the British Medical Journal in May 1980 claimed:

> "… over-enthusiastic representatives of pharmaceutical firms as well as black market operators may find farmers, including poultry producers, all too ready to sidetrack their veterinarians and to bid for any supplies of prescription-only antibiotics that may become available through irregular channels. Prosecutions may close that door if evidence is forthcoming, and farmers need to be educated out of attempting to diagnose and treat or prevent enteritis by using antibiotics without veterinary help" (33).

In his incisive analysis of the later debates around the UK's Swann Committee and subsequent regulatory moves, Kirchhelle (27) suggests that the British veterinary profession, whose members both prescribed and sold antibiotics, sought control over antimicrobials "not only to generate income but to secure their profession's primacy over competing nutritional and health experts," an observation that echoes (28) point that the UK veterinary profession's vision of the time was one that actively sought new areas of employment and income in response to a growing and intensifying livestock industry. Smith-Howard (34), writing on the US experience, has referred to this as a "leveling influence," across the professions of farmer and veterinarian, but, as she points out, many within the veterinary professions of both the US and the UK saw the growing availability of antimicrobials to farmers as a direct challenge to the veterinarians' specific area of diagnostic expertise.

The second impact of the rapid introduction of antimicrobial use into the infrastructure of contemporary livestock farming on veterinary diagnostic practices has been the growth of preventative prophylactic and metaphylactic treatment. With the expanding intensification of livestock agriculture, animals were increasingly being treated with broad spectrum or "shotgun" antimicrobials administered premixed into animal feed both to stimulate growth but also to prevent subclinical disease. Indeed, as Kirchhelle has said:

> "With antibiotic dosages in feeds increasing, the boundaries between growth promotion, prophylaxis and treatment soon blurred" (27).

Both in the UK and in the US, concern was being expressed as early as the 1960s that the "irrational" prophylactic prescription and use of antimicrobials to cure potential disease was making veterinary diagnosis irrelevant and largely redundant as a decision-making process across a range of endemic livestock diseases (24, 35). Within intensification regimes that were, to varying degrees, now established as the norm in many areas of livestock agriculture, antimicrobials were becoming not only, as Harrison called them in 1964 "a substitute for good husbandry," they were also becoming a substitute for good diagnosis.

Commentators have seen the growth in prophylactic use of antimicrobials in livestock farming, often without veterinary diagnosis and on healthy animals (36), as a somewhat inevitable compensatory response to the halting or reduction of growth promotion in countries where such policies have been enacted (37). In a large number of European countries, providing antimicrobial medicines in the feed and water of farmed animals either to prevent disease (prophylaxis) or to halt the spread of disease already affecting one or more members of a group or flock (metaphylaxis) accounts for a greater proportion of total antimicrobial use in farming than the treatment of sick animals, particularly where they are regularly used to prevent disease in young piglets, poultry chicks and dairy cows (38–40). As Broll et al. (41) point out with respect to the prophylactic use of tetracyclines in German pig farms, such practices often occur without precise diagnosis and without confirmed disease presence. Moreover, in a number of circumstances, the medicines used in prophylactic treatment are considered critically important in human medicine (1) and may be deployed at far higher concentrations than were being used for growth promotion. In the UK, decreasing the use of antimicrobials for the prophylactic treatment of animals has become a major target in the drive to achieve more responsible and sustainable antimicrobial use in livestock farming (5, 42). This is in line with recent EU guidelines stating that "routine prophylaxis must be avoided" and that "prophylaxis should be reserved for exceptional case-specific indications" (43).

We might sum all this up by suggesting that the initial period of massive antimicrobial use in livestock agriculture, both for growth promotion and later for prophylactic treatment, has offered a challenge to the role and importance of veterinary diagnostics across a number of livestock systems, ironically at a time when diagnostic technology was improving considerably as procedures developed essentially for human medicine (such as those based upon the diagnostic potential of technologies such as polymerase chain reaction) were being transferred to veterinary medicine (44, 45). Highly effective, broad-spectrum antimicrobials engendered a widespread acceptance that the treatment is the diagnosis. These various challenges to veterinary diagnostics, it is claimed, not only helped contribute to what some argue has been an excessive and inappropriate use of such medicines in livestock farming (46), but also gave rise to the contested possibility of the proliferation of resistance on farms (47, 48).

PRACTICING VETERINARY ANTIMICROBIAL STEWARDSHIP

As the antimicrobial resistance "crisis" deepens and as governments and professional bodies mobilize to address and reduce unnecessary antimicrobial use in both human and animal populations, there has been a renewed emphasis on the role of farm animal veterinarians as critical players in the advocacy of antimicrobial stewardship. A term initially devised for human health care, "antimicrobial stewardship" has become widely adopted as a "as a set of coordinated interventions, as a programme, as a philosophy, and as an ethic" (49) across both human and animal contexts. Drawing on Landecker (50), it is now the problem of antimicrobial resistance rather than the antimicrobial solution to infectious disease that comes to define more recent biopolitical action. "As with antibiotics, the task of managing vitality turns to the control of the substances that were the previous technologies of production," she writes (50).

Critically, the notion of antimicrobial stewardship combines, first, a more organizational and strategic path aimed at changing established practices, management contexts and long-term health care to allow for more sustainable and responsible antimicrobial use. As Page et al. (51) point out, this includes enhanced infection control, farm biosecurity, vaccination and on-farm health monitoring, all of which place the veterinary practitioner in a potentially different, more carefully negotiated, role with respect to farm clients, farm processes and farm technologies (52). A second path, informed by our survey and addressed below, is a more clinical and prescriptive path which includes the identification, selection, dosing, administration and duration of more specifically targeted and appropriate antimicrobial use for treating infection. In this second path, new practices and technologies of diagnostics and diagnostic testing become a key focus. Although both paths have arguably achieved a substantial reduction in antimicrobial use within the UK (53), the latter's emphasis on diagnosis, while, on the one hand, reaffirming the professional role and expertise of the veterinary clinician, raises, on the other hand, a number of issues within the context of antimicrobial stewardship and responsible medicine use, as we show below.

Looking in turn at these two paths, the first strategic component of antimicrobial stewardship clearly places specific responsibilities upon farm animal veterinarians. Here, the Swann Report of 1969, was prescient:

> "We should like to see more use made of the veterinary surgeon as adviser when the introduction of an intensive enterprise is contemplated by a farmer so that disease may in some measure be prevented" (54).

In his 2009 review of veterinary expertise, Lowe referred to a sense of growing "marginalization" amongst the food animal veterinary profession in the UK, despite their critical position "not only between animals and their keepers, but also between government and farmers, between agriculture and the food industry and between the livestock sector and consumers" (11). This sense of marginalization had not been helped by repeated hesitations by the British government over past decades with respect to the introduction of a more State-supported preventative approach to on-farm disease management (28). Neither has it been helped by the profession's own difficult acceptance of the neoliberal shift to a more clientelist relationship with animal famers (12, 55) often in situations of growing competition with an emerging para-professional sector in farm animal health-care. In response, Lowe (11) has argued that veterinarians should take on a greater variety of problem-solving roles within livestock agriculture, moving away from a regulatory and purely clinical approach to more market-driven preventative roles with respect to animal disease and the food sector, an argument also taken up by Gardiner et al.

> "The work of a dairy, poultry or pig specialist is not restricted (or even mainly focused) on consideration of the individual animal body; the "animal body" here is much more likely to be the whole herd or flock. The specialist role will incorporate a wide variety of management, preventive and agricultural economics issues, as well as attention to pressing public good issues such as animal welfare" (56).

This extended notion of the veterinarian's role is being increasingly adopted within the veterinary profession and recognized across a range of different political and professional cultures (57). The British Veterinary Association and the Royal College of Veterinary Surgeons joint publication "Vet Futures" (2015), for example, advocates greater involvement of the profession as a whole in wider issues of environmental sustainability, farm business planning, biosecurity and food health, alongside the more traditional fields of animal health and welfare. Furthermore, evidence from research confirms the growing importance of veterinarians as trusted suppliers of animal health, biosecurity and farm management advice and, in certain cases, the challenges they face in this new role (58–61).

Moreover, greater knowledge of resistance pathways on farms–derived from improved diagnostic testing along with closer pathogen and medicine monitoring–may allow veterinarians to prescribe antimicrobials not only to treat animal disease but, additionally, to reduce specific types of resistance across the entire farm through the notion of "cycling" antimicrobial treatments, an approach that puts veterinarians at the forefront of developing and extending better pharmacological understanding of both biosis and antibiosis (62).

This more holistic farm management approach to disease management offers considerable scope for innovative and interactive approaches to decision-making practices which foreground alternatives to more conventional mechanisms of external scientific expertise and regulatory authority. In dairy cattle, for instance, Morgans (63) argues that the relative success of both Danish and Dutch farmer groups in collaborating with veterinarians and scientists to achieve significantly reduced use of antimicrobials lies, in part, in the cooperative and facilitative nature of agricultural organization (64). In a recent paper, van Dijk et al. (65) report on the experimental establishment of a series of multi-actor participatory mechanisms enabling dairy farmers, veterinarians and food industry partners to collectively design and deliver practical on-farm changes to reduce antimicrobial use and maintain herd health and welfare. In both of these observations, we see not only shifts in both veterinary and husbandry practice but also part of a more fundamental reassessment of the ways in which herd health planning and disease management is addressed in livestock production. It is increasingly asserted that such responses are having an impact. Longer weaning times, better health management of groups of animals, vaccination, enriched housing, better ventilation and temperature control, the separation of ill animals from the herd/group, the use of slower growing breeds and lower stocking densities and many more all contribute to reducing the need for antimicrobial treatments (5, 66–68).

Annual audits confirm that the total volumes of antimicrobials used in livestock agriculture in the UK are falling (53, 69, 70). Between 2012 and 2018, the total amount of Critically Important Antimicrobials (CIA) purchased, prescribed and/or administered in a survey covering 90% of the UK broiler sector (including ducks and turkeys) fell by 82.6% (71). In the UK pig sector, recent data from the Veterinary Medicines Directorate reveals a 60% fall in antibiotic usage between 2015 and 2018 (53). While some commentators have suggested that these falls represent the 'low hanging fruit' of antimicrobial use reduction, they nonetheless demonstrate that significant achievements can already be attained through improved stewardship, and disease management.

RAPID AND POINT-OF-CARE DIAGNOSTICS

The emerging resistance "crisis" of the last ten or so years–largely in human medicine but also to a lesser extent in animal health–has considerably refocused debate on the second, more clinical, pathway of antimicrobial stewardship and, in particular, on the technologies and practices of diagnosis. Coupled with this has been the growing emphasis on "evidence-based" medical and veterinary practice, which in turn places renewed attention on diagnosis as well as on parameters such as the sensitivity and specificity of individual test procedures (72). Within the wider debate on diagnostic tools and tests, the last decade has also seen a considerable emphasis on rapid or point-of-care tests as having a particular contribution to make in reducing unnecessary antimicrobial use. Acknowledging that "diagnostics have had less impact on antimicrobial prescribing than might have been expected," the Wellcome Trust argued in 2016 that:

> "Rapid diagnostics are thought to have a vital role to play in the battle against drug- resistant infections. They have the potential to guide more rational use of antibiotics, by distinguishing between viral and bacterial infections, and by identifying specific pathogens and their antibiotic resistance characteristics" (73).

Returning to the final report of the O'Neill review of 2016, we find a similar emphasis on the use of diagnostics:

> "Fundamental change is required in the way that antibiotics are consumed and prescribed, to preserve the usefulness of existing products for longer and to reduce the urgency of discovering new ones. Rapid point-of-care diagnostic tests are a central part of the solution to this demand problem, which results currently in enormous unnecessary antibiotic use" (3).

The reasons for this new focus on diagnosis and diagnostic tests are essentially three-fold, based around issues of technological development, rapidity, and evidence. While significant advances in the technologies of diagnostic testing for many infectious diseases (74) have allowed testing technologies to become not only smaller and more portable (75), making them more accessible to individual and corporate veterinary practices, rapid and point-of-care tests are not available for all aspects of diagnosis relevant to antimicrobial selection. Conventional reliance on the traditional "pipeline" –where samples are sent to centralized laboratories and test results communicated to veterinarians—can be a hindrance to urgent treatment decision making. Newer diagnostic technologies could offer, it is claimed, more rapid results (76), accurately and at lower cost (77). Finally, as the drive toward more evidence-based veterinary medicine gains strength, and as concern grows over the inappropriate use of antimicrobials to treat animal disease, we note an increasing

TABLE 1 | Veterinarians interviewed with practice type, gender, and location.

Interviewee	Practice	Location
10 cattle veterinarians	6 from corporate practices 4 from independent practices 5 males and 5 females	The South West of England, East Midlands, and East Anglia
9 poultry veterinarians and 1 poultry welfare consultant	3 from corporate practices 5 from independent practices 2 consultant veterinarians 8 males and 2 females	Scotland, South West England, East Anglia, East Midlands, Yorks/Humber, South East England, and the North West
10 pig veterinarians	3 consultant veterinarians, 6 from independent practices 1 food company veterinarian 4 males and 6 females	Wales, South West England, East Anglia, Yorks/Humber, and Scotland

Source: Authors Survey, 2019.

attention being paid to diagnostic tests as critical legitimators of treatment decisions, particularly with respect to the use of antimicrobials. This can be seen in the expanding use by assurance and certification schemes of mandatory diagnostic tests for the deployment of critically important antimicrobials (78).

While recognizing the importance and potential of rapid and point-of-care diagnostics in contributing to reductions in antimicrobial use, many commentators–from science, policy, and industry–also acknowledge that significant economic, institutional, and practical barriers exist in bringing newly developed rapid tests to the marketplace (1, 79, 80). Various initiatives, such as the UK Longitude prize (awarded for the development of new point-of-care diagnostic tests in human medicine), are seeking to address these barriers through the offer of specific stimulus to new diagnostic development (Longitude.org, undated). Our concern in the remainder of this paper, however, is not what hinders the emergence of new rapid and point-of-care diagnostic tests but rather the manner in which such tests are both currently used and anticipated in clinical farm animal veterinary practice and the possible impact rapid test technologies might have on broader farm animal health management and disease control.

METHODS

A qualitative, semi-structured interview-based survey (81) was undertaken of 30 farm animal veterinarians currently working in farm animal clinical practice and drawing evenly across the poultry, dairy and pig sectors in England, Scotland, and Wales. The aim of the interviews–drawing in part on an earlier study (82)–was to explore veterinary roles in active antimicrobial stewardship, first, by investigating current diagnostic practices–particularly within the context of antimicrobial prescription and use–and, second, by exploring with veterinarians the current deployment and future impact of rapid and point-of-care diagnostic tests in contributing to more selective and reduced use of antimicrobials. The interviews were divided into four thematic foci addressing in turn: recent employment history; current diagnostic practices (employing "walk through" and narrative accounts); current experience with rapid and point-of-care diagnostic tests; and the relationship between diagnostic practice and antimicrobial prescription and use. Interviews were carried out across a variety of regions of Great Britain, ranging from South West England to Scotland and reflecting geographical concentrations of the three main production types (dairy, pigs, and poultry). The sample was generated initially through contacts with partner veterinary practices and later extended through snowballing techniques, personal contacts and, in the pig and poultry sectors where numbers of veterinarians are substantially smaller, through targeted solicitation. Further details on the interviewees are provided in **Table 1**. All interviews were carried out in 2019, the majority in the first three months of the year.

The veterinarians ranged in age and experience from recent graduates to veterinary practice directors with many years' experience. Of the interviewees, 13/30 were female. Most interviewees worked at independent veterinary practices (though many of these had multi-site offices) and a few were either employed by larger corporate veterinary companies or acted as independent veterinary consultants. The majority of the interviews were carried out face-to-face at the veterinary practice (23 of the 30, with seven being undertaken on "Skype") and were, in each case, undertaken by two interviewers drawing across the social and the veterinary sciences. Interviews lasted between one and two hours and were recorded, anonymized and transcribed. Ethical approval for the survey was granted by the University of Exeter Geography Ethics Committee, approval reference number eCLESGeo000069v.3.0.

Analysis of the interview transcripts was initially undertaken through standard systematic thematic coding techniques, allowing a series of common themes to emerge from the responses (83). A more detailed analysis of the three sets of interview transcripts (pig, poultry, and dairy cattle) was undertaken by the research team drawing on the Realistic Evaluation method, originally developed by Pawson and Tilly (84) and its emphasis on Context, Mechanisms, and Outcomes (85). For the purposes of this paper, the analysis focused more specifically upon interviewee responses to the third and fourth foci of the interviews: experience and use of rapid and point-of-care diagnostic tests and the relationship of diagnostic testing to antimicrobial stewardship. From that analysis, three particular inter-related themes emerged from the interview transcripts: first, how the use of rapid and point-of-care diagnostic tests challenges established practices and assumptions on the part of veterinarians; second, how rapid tests, while useful in many contexts (particularly within dairy farming) run up against the complex disease etiology of more intensively farmed species such as pigs and poultry and; third, how the growing commercial availability of rapid and point-of-care diagnostic tests is leading to a diversification of responsibilities and actions in disease monitoring, assessment and treatment, with implications both for the professional role of clinical veterinarians and for the responsible stewardship of antimicrobial use. Taken together, these three themes provide insight into how the future development and deployment of rapid and point-of-care diagnostics might articulate with the practices and concerns of clinical veterinarians working in different sectors of livestock production.

RESULTS AND DISCUSSION

As we have shown above, rapid and point-of-care diagnostic tests are widely seen within various policy and scientific communities as part of the "solution" to excessive antimicrobial use in both human and animal health care: "a step change in the way that technology is incorporated into the decision-making process around antibiotic use" (1). In their adoption by clinical veterinarians across different production sectors (here, dairy, pig, and poultry) and across different animal health conditions, rapid and point-of-care diagnostic practices introduce or expose new and different levels of complexity, be they in the test parameters and on-farm sampling environment, the animals themselves (their multiple biomes and their pre-existing conditions and treatments) or in the very divisions of labor that characterize the performance of diagnostic testing. Certainly, both the approach to, and general usage of, rapid and point-of care diagnostics varies significantly across the three production sectors as do the levels of complexity raised by that usage. The following section draws out those variations but is also attentive to the more common issues, across all three sectors, that are raised by rapid and point-of-care diagnostic tests, widely seen, as cited above, as a generic "solution" to inappropriate antimicrobial use in livestock farming.

The Practices of On-Farm Rapid Diagnostic Testing

Rapid and point-of-care diagnostic tests can be carried out on-farm with acceptable sensitivity and specificity, producing fast results that allow treatment decisions to be made quickly, accurately and at lower cost (77). Yet, at the present time, their availability is relatively limited within clinical farm animal veterinary practice and varies significantly across production sectors. In both the commercial (and highly integrated) poultry and pig sectors, where health management and treatment take place largely through regular vaccinations and feed or water-based medication, through an attentiveness to the microbiome of group housing and where staged interventions are generally at a group or flock level rather than at the level of individual animals, we found rapid and point-of-care diagnostic tests to be currently less common than in the dairy sector.

Poultry veterinarians interviewed in the course of this research stated that the most frequently used on-site diagnostic tests were conducted post-mortem, as its relative inexpensiveness rendered other diagnostic tests less valuable in the health management of individual fast-growing flocks with limited treatment opportunities. The poultry veterinarians nevertheless saw the potential for new rapid, on-farm testing to contribute to more specifically targeted antimicrobial use but recognized that the tests were simply not available at the current time. One possible technological development of interest to poultry veterinarians was portable PCR machines:

> "They've been looking at PCR-type tests that you can take onto farms that will tell you from your swab whether it was *E. coli* or whether it was *Pasteurella* or something like that. That would be very useful. Yes, we expect it to be *E. coli*. It would be even better if we could turn around and say, 'This *E. coli* that you've got in there is actually likely to be pathogenic, as opposed to just a post-mortem contaminant'" (DIAL Project: Poultry veterinarian P.03a.19).

Similarly, pig veterinarians, operating in a sector that is substantively different from either poultry or dairy, with disease management at group level characterized by a strong emphasis on broader epidemiological approaches and assessment of on-farm bacteriological and resistance histories, were interested in speeding up the testing results. In the words of one pig veterinarian: "I think the biggest problem we have is that rapidity is not there" (DIAL Project, Pig veterinarian 29/19). Pig veterinarians pointed to the benefits of a rapid test that would be able to differentiate specific pathogens and diseases such as *Streptococcus suis* meningitis and bowel edema in weaners caused by strains of *E. coli*, where post-mortem examinations yield insufficiently precise results. For some, the advantages of rapid tests were straightforward:

> "If you could plop a drop of scour [diarrhea] on a plate it says: Yes it's an *E. coli*. Yes it has virulence factors such like for you to be significant and this is its resistance profile, then that would allow you to institute treatment faster and more logically" (DIAL Project, Pig veterinarian Pg.03.19).

Dairy cattle veterinarians, however, given both the value and relative importance of individual animals as milk producers as well as the more diverse structure of the industry itself, used rapid and point-of-care diagnostic tests far more commonly than veterinarians in the pig and poultry sectors. A number of well-known and widely available commercial tests exist for dairy cattle veterinarians, though not all would necessary be deployed in the case of identifying the possible need for an antimicrobial treatment. Nevertheless, here too the more general adoption of rapid tests was nonetheless limited by a number of factors (86), including (1) concerns over the practical use on rapid tests in on-farm situations, (2) their limited range of disease applications and (3) by the fact that, for many cattle veterinarians, these tests rarely offer unequivocal confirmation of a specific pathogen on which to base the prescription of antimicrobials. Indeed, perceptions of the accuracy of rapid and point-of-care tests was a theme that emerged repeatedly in our survey with a number of veterinarians maintaining that manufacturers' sensitivity and specificity specifications were not always easy to ascertain for rapid tests. As one cattle veterinarian put it:

> "I'm not sure of the sensitivity of those things, so even in the absence of a bacterial positive, I'm not sure we'd always be brave enough to say we're not going to treat on that. I think the rapidity depends on the aspect of it. It can sensibly limit the benefit of those so if they don't have a sensitivity that's as good as the lab's, or nearly as good, then they're probably not going to be used then.

> The largest convenience factor is it's quite easy just to run that through there" (DIAL Project, Cattle veterinarian C.05.19).

In the balance between convenience and accuracy, veterinarians confirm that they sometimes intentionally privileged the former when it came to the use of rapid tests. The decision to use a rapid or point-of-care test was frequently driven by the need to provide the client with an immediate answer.

> "I've heard people say before that maybe it's less sensitive but if they could prove the sensitivity of it… To be honest I think a farmer would rather have an answer even if you say "Look, there's maybe like even 20% chance that this could be a false positive," I think they'd rather have that 80% chance that it is correct, if you see what I mean. I know with tests they've got to have the really high specificity and sensitivity but actually the farmer doesn't really care about that. As long as it's an overall majority he would rather take a hit at that than have nothing at all" (DIAL Project, Cattle veterinarian C.08.19).

Veterinarian concern for how notification of disease presence might be taken by the farmer seemed to implicitly raise the value, for some, of "scientific evidence," as justifying the necessity of treatment or confidence not to treat. Here, the act of scientific diagnosis and the exclusive role of veterinarians in performing diagnosis (and subsequently prescribing treatment) becomes a key component of professional legitimation.

> "There's no getting around the fact that if you can present someone with the scientific evidence like they've definitely got this disease and it's definitely a problem and it's definitely sensitive to this then you've got a far better case for treating it then being like, "Well, I think 70% sure it's got this but it will take me three weeks to confirm it so I've just guessed because I can't really…" like that's always going to be a weaker case for antibiotic use" (DIAL Project, Poultry veterinarian, P.03b.19).

Where sensitivity and specificity are important to the diagnostic decision, in the eyes of veterinarians across all three sectors, laboratories remain the standard reference even though the cost is often higher, the time taken to receive the results longer and any limitations to the test are identifiable. As another cattle veterinarian remarked:

> "I try and be as rigorous as possible and the labs now are very good–they always offer that element, certainly when it comes to testing for infectious diseases on antibody levels, now the labs will always put the specificity, sensitivity of the test at the bottom of your results, so that is extremely helpful and very good practice. I think it's just a very good reminder that there are limitations to the test" (DIAL Project, Cattle veterinarian C.03a.19).

Although veterinarians across the three sectors maintained that there remained a gap in the market for rapid and point-of-care diagnostic tests, it is significant that many saw the future of such devices not in specifically reducing unnecessary antimicrobial use but as part of an extended diagnostic pathway that might begin with a simple "rule-in" or "rule out" and then lead to a more investigative testing or treatment: "A positive result, it's easy isn't it? It's the negative that is difficult" (DIAL Project, Cattle veterinarian); "Pen side tests are great but […] it just then prompts you to investigate a bit further" (DIAL Project, Pig veterinarian). When compared with laboratory tests–which frequently include a range of test parameters as well as predictive values, sensitivity and specificity information and which are getting faster in their delivery–rapid tests, in the words of one interviewed pig veterinarian: "will not give you enough information to treat well". Veterinarians interviewed in the course of this research stated that what would be most useful to them would be a simple test that distinguished a bacterial from a viral infection while accepting that this would only ever be a diagnostic starting point. What remains abundantly clear, however, is that rapid or point-of-care tests are not seen by UK livestock veterinarians, at least at the current time, as the critical panacea for antimicrobial use reduction.

Animal Complexities

The relative simplifications inherent in rapid and point-of-care diagnostic tests, though seen as a considerable advantage in speed and potential pathogen or disease targeting, also came up against the complexity of on-farm biotic environments and the multispecies "messmates" (87) that co-constitute farmed animal bodies. Acknowledging the complex biome of pig production units and the difficulties of pinpointing the precise cause of an illness, pig veterinarians expressed certain reservations over the possibility of widescale adoption of current rapid and point-of-care diagnostic tests as definitive mechanisms for identifying pathogens and disease:

> "Pneumonias and things like that, you do get outbreaks of and cause problems. I don't know if they'd be more difficult to do as a rapid test because I suppose you do them more on the nasal swabs and things like that because your … serology on your respiratory ones are a little bit less reliable in terms of it's not showing that's what's causing the problem and you probably have various things involved and it's a bit more—yes I'm not sure how well you could rely on that test. […] There's a bit of this but they are positive for that antibody-wise but is there something else involved as well" (DIAL Project: Pig veterinarian Pg.02.19).

Other veterinarians pointed to the difficulties of securing a relevant test result in the face of pre-existing treatments:

> "We've used the vaccine, we create the test so then we can make a diagnosis, but with difficulty. Now we've got easy tests to use we can't make the diagnosis because we've got too much vaccine" (DIAL Project: Poultry veterinarian P.03a.19).

The focus—or reliance–upon the presence or absence of particular markers, on changing strips of color or on positive or negative read-outs is a perhaps a necessary but nonetheless problematic simplification. Farms are complex microbial spaces with every farm displaying a unique mix of pathogens, many of which might be endemic and/or subclinical but nonetheless present.

There's a lot of diseases that we have problems with [...] that cause a lot of sub-clinical disease that we do diagnose but because we vaccinate with live vaccines snap tests aren't massively useful for that and that could trigger off quite a few diseases, like we vaccinate but our vaccines can only do so much so we quite often get sub-clinical disease (DIAL project, poultry veterinarian P.03b.19).

Infections with some pathogens may be, to some extent, obscured by other infections–viral or otherwise–leading to complex disease etiologies. Individual animals, herds, or flocks may exhibit temporary microbial imbalances or dysbiosis, particularly within the confined and complicated microbiome of the contemporary industrial farm. The very diversity and ubiquity of microbes within larger organisms–such as farmed animals–and their groups, challenges the notion of simple disease presence or absence and suggests that diseases emerge from highly complex and, in many cases, potentially beneficial "pathobiomes" (88), themselves highly contingent upon the material spaces, the microbial histories and the contemporary management practices of farms. It is in the ability to distinguish and select amongst this complex environment that the broader "empirical" diagnostic practice reveals its greater value. This perhaps suggests that any simplification of diagnostic processes may well have a localized impact on reducing some erroneous prescription and treatment decisions but may do little, if anything, to manage the wider biotic complexity of the contemporary farm.

Diversifying Animal Health Responsibilities

The role and place of diagnostic testing in farm animal clinical veterinary practice is changing. In part, this is in recognition of concerns over the inappropriate and excessive use of antimicrobials in livestock production systems (82, 89–91)]. Many former practices of herd- or flock-level prophylactic or metaphylactic treatment with critically important antimicrobials are disappearing, certainly in the UK.

"It used to be terrible. Don't get me wrong, we used to put chlortetracycline in feed for every crop of broilers, we didn't care, we'd do three days of enrofloxacin at the start of crop just in case there were any issues" (DIAL Project: Poultry veterinarian P.03b.19).

However, it is far from clear from this research the extent to which, after the O'Neill report, rapid and point-of care technologies will contribute specifically to further reductions in antimicrobial prescription and use. Ironically perhaps, the singular results of rapid and point-of-care tests often require greater interpretation and judgement on the part of the skilled veterinarian than more complex multi-parameter lab-based testing from which a more informed picture of disease etiology can be built. This too raises issues of consistency in both the interpretation of rapid test results and subsequent treatment decisions.

One particular consequence of the growth of rapid and point-of-care diagnostic tests that we draw from the current research is the impact upon the extension and diversification of responsibilities for animal health. The move from purpose-built laboratories to veterinary practice labs as a location of testing and now potentially to rapid on-farm diagnostics alters the accessibility of these different technologies. Many rapid diagnostic tests can be purchased commercially in farm service outlets and are increasingly being used by farmers themselves, generally (but not always) under veterinary supervision, not only to monitor animal health but also as the basis for subsequent treatment decisions. This has implications, not only for the traditional authority and role of the veterinarian, but also for the nature of the treatment decisions that follow. As one cattle veterinarian put it:

"There's a fear with *[named on-farm culture test]* on the farms I work with, [farmers] are under a lot of pressure to become a technician, become involved in making the decisions. [...] However, I think within a few weeks I'd be cut out the loop and he [the farmer] would be the diagnoser and the treatment instigator and making bad decisions and all that" (DIAL Project, Cattle veterinarian C.02a.19).

For many farm animal veterinarians, this diversification of roles and responsibilities is welcome and many practices have developed (frequently laminated) protocols for client farmers to follow in sampling, in testing, in interpreting the results and in making subsequent treatment decisions, usually in accordance with a pre-determined health plan; for example, the use of culture plates in mastitis management.

"We would go out and train them in what to do and then we'd get them to do it. Then the question is three weeks later when they're doing it on their own, are they still doing it properly or have they forgotten or cut corners, or did they forget to switch the incubator on or whatever? All the things that can go wrong, and some farmers obviously are very much better at following protocols than others and some farmers just have this desire to just do their own thing all the time" (DIAL Project, Cattle veterinarian C.02b.19).

Regular animal health monitoring by farmers and farm staff can also build up a more complete picture of herd and flock health, an obvious advantage when veterinary interventions are required. Some veterinarians, however, expressed discontent about the risks associated with such role diversification and diagnostic simplification. These included contamination of samples, poor maintenance of the test environment, misinterpretation of the results and, as a consequence of any of these, unnecessary or inappropriate medicine use. The use of the formalized and pre-determined "protocol" thus becomes critical in the legitimation of veterinary authority when tests are being used by farmers.

"It makes me nervous ... because at the end of the day I am responsible for prescribing on that farm. If they're doing a test and they're making a choice about what they use, I stopped being relevant to that decision-making process. Whereas if we had a set protocol–this is what you do–I've kind of okayed it, they know the parameters within which they can operate, and we know what it needs" (DIAL Project, Cattle veterinarian C.03a.19).

As the technologies of animal health monitoring and surveillance become more portable, faster and easier to operate, this diversification of roles may stretch beyond the farmer to include even broader food chain actors. Farms, particularly those firmly integrated into vertical chains, are increasingly monitored through rapid technologies, whether by milk companies, food processors, assurance, and certification schemes or food retailers. This clearly has implications for the veterinarian's clinical role as the following three comments from interviewed veterinarians demonstrate:

> "I must say that it seems to me that in this country because there are other bodies that are very heavily involved with monitoring milk by different aspects it's actually not easy to get a grip of what goes on when it comes to not just milk quality but also very much the bacteriological aspect of milk. There seems to be a little bit of a dichotomy to be honest and vets seem to be a little bit… you really need to be proactive otherwise nobody really offers [the monitoring data]" (DIAL Project, Cattle veterinarian C.03b.19).

> "Tests [as opposed to diagnostics] are increasing ordered by food chain actors—vets not involved; animals are being slaughtered or treated unnecessarily" (DIAL Project, Cattle veterinarian C.02b.19).

> "I think our whole business model is changing and has got to change. If we take, for example, the poultry sector, the vet is an advisor, at the end of the day; they will be doing some tests on the farm, all the farm post-mortems or whatever. They're capturing data that's fed back up the chain and becomes relevant to management decisions up there" (DIAL Project: cattle veterinarian C.03a.19).

Unsurprisingly perhaps in the face of this growing diversification of roles, a counter tendency is observable that seeks to reinforce and strengthen the very specific legitimation and conventionalization of veterinary authority. Under the UK Veterinary Surgeons Act (1966), diagnosis can only legally be carried out by veterinarians. This unique authority is specifically and newly mobilized in the insistence–first by the Red Tractor Assurance scheme and now followed by others–that critically important antimicrobials can only be used on assured farms when preceded by a diagnostic test undertaken by a veterinarian (78). However, as non-veterinary practitioner sources of advice, data and services relating to animal health and disease management continue to multiply (60), the boundaries of what constitutes a diagnosis are becoming less and less clearly defined, and veterinarians can no longer rely solely on such traditional Aesculapian authority awarded uniquely to those who heal (92).

CONCLUSION

Diagnosis, as a practice, as a form of specific expertise, as both a scientific and a social process lies at the very center of medical and veterinary activity and professional legitimacy. Yet diagnostic practice is changing.

> Diagnoses are […] contested, socially created, framed and/or enacted. And while diagnosis of disease is "central to the practice of medicine" as Blaxter put it [2009] and as the context of the practice of medicine has changed, so too has the play of social, political, technological, cultural, and economic forces which impinge upon diagnostic categories and diagnostic processes [(93), p. 793].

In this paper, we have demonstrated how, in their responses to the requirements of antimicrobial stewardship and, in particular, to the growing policy emphasis being placed upon rapid and point-of-care diagnostic test technologies, farm animal veterinarians interrogate and respond to the shifting context of diagnostic testing, revealing what is today a complex and by no means singular landscape of practice. While veterinarians share concerns around the diagnostic power and potential of currently available and developing rapid and point-of-care tests compared with laboratory test procedures–especially when antimicrobial prescriptions might follow—expediency and rapidity within the context of veterinarian/client relations emerges as a strong driver for the expanding use of these technologies, particularly, but not exclusively, within the dairy sector. Increasingly common calls from veterinarians for a simplified, cheap and accessible method to differentiate viral from bacterial infections on-farm are, to a degree, mitigated by veterinary experience that disease interactions are often highly intricate, multiple, and inter-related. In such instances, rapid and point-of care tests might offer, in certain conditions, what might be considered a problematic simplification of diagnostic practice.

The diversification and potential multiplication of test practices and health monitoring mechanisms that do not require a veterinarian and are becoming widely facilitated by rapid and point-of-care technologies emerge from this study as something of a double-edged sword. While veterinarians might welcome the additional data and information that testing undertaken by farm staff and other food chain actors might bring (as long as it is made available to them and can be used holistically), veterinarians also express concern over the conditions, accuracy and interpretation of the test results by non-clinicians which inevitably complicates the veterinarian's traditional responsibility and authority for diagnosis and animal treatment. What nevertheless remains clear is that rapid or point-of-care tests are not seen by UK farm animal veterinarians, at least at the current time, as the critical panacea for antimicrobial use reduction across all production sectors.

DATA AVAILABILITY STATEMENT

The datasets generated for this article are not readily available because the data set will be deposited in UKRI depository at termination of contracted research. Requests to access the datasets should be directed to https://www.dialamr.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Exeter, Geography

Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HB, KR, ABr, and SH led the conception and design of the study with contributions from KC, LM, ABa, KA, and GR. The data collection was carried out by KC, LM, GR, and KA. Analysis of the data was undertaken by HB, KC, and SH with contributions from KR, GR, LM, ABa, ABr, and KA. HB wrote the first draft of the manuscript. KR, KC, SH, ABr, ABa, GR, LM, HB, and KA contributed to the manuscript revision and interpretation of the data and all authors have read the paper.

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REVIEW
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Veterinary Herd Health Consultancy and Antimicrobial Use in Dairy Herds

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The globally increasing level of antimicrobial resistance affects both human and animal health, why it is necessary to identify ways to change our current use of antimicrobials. The veterinary herd health collaboration between veterinarians and dairy farmers provides a useful setting for changing antimicrobial use in livestock. However, farmers and veterinarians work in a complex agricultural setting influenced by socio-economic factors, which complicates their choices regarding antimicrobial usage. It is therefore necessary to be aware of the range of potential influencing factors and to integrate this knowledge in the relevant local settings. This manuscript presents a literature review of relevant factors relating to antimicrobial use within the veterinary herd health consultancy setting, including knowledge gaps of relevance for changing the use of antimicrobials. An enriched version of the framework of the Theory of Planned Behaviour was used to organise the literature review. We identified diverging attitudes on correct treatment practices and perceptions of antimicrobial resistance among veterinarians and farmers, influenced by individual risk perception as well as social norms. Furthermore, disagreements in terms of goal setting and in the frequency of herd visits in relation to herd health consultancy can negatively influence the collaboration and the intention to change antimicrobial use. Farmers and veterinarians emphasise the importance of legislation and the role of the dairy industry in changing antimicrobial use, but the relevance of specific factors depends on the country-specific context. Overall, farmers and veterinarians must communicate better to understand each other's perspectives and establish common goals within the collaboration if they are to work efficiently to reduce antimicrobial use. Farmers and veterinarians both requested changes in individual behaviour; however, they also called for national and structural solutions in terms of balanced legislation and the availability of better diagnostics to facilitate a change in antimicrobial use practices. These various paths to achieving the desired changes in antimicrobial use illustrate the need to bridge methodological research approaches of veterinary science and social sciences for a better understanding of our potential to change antimicrobial use within the dairy farm animal sector.

Keywords: antimicrobial use, antimicrobial resistance, veterinarians, farmers, veterinary herd health consultancy, decision-making, social factors, dairy cattle

INTRODUCTION

Antimicrobial use (AMU) is important to consider as antimicrobial resistance (AMR) is increasing globally, affecting both human, and animal health (1, 2). Within the farm animal sector, veterinarians are responsible for the use of antimicrobials in collaboration with the farmer. This specific interaction should therefore be taken into account when promoting "rational AMU," which here is defined as a limitation in inappropriate use, as well as a reduction in the need for antimicrobials. This definition has been adapted from the European Commission, which characterises inappropriate use as "use in an untargeted manner, at sub-therapeutic doses, repeatedly, or for inappropriate periods of time" (3). With this in mind, the veterinary herd health consultancy (VHHC), which frames the collaborative work between the veterinarian and the farmer at dairy farms around the world, comprises an interesting study case with regard to promoting rational AMU. The majority of antimicrobials currently used in dairy cattle are used to treat and control mastitis [(4), p. 22–3] and pneumonia in calves [(5), p. 5–6], and these diseases are therefore central topics in the work on rational AMU.

Over time, veterinary tasks in dairy herds have changed character. Previously, the focus was primarily on the treatment and prescription of medicine, but there has more recently been a shift towards disease prevention [(6, 7), p. 11–6]. With the introduction of epidemiology into veterinary science, the collection and analysis of quantitative data in veterinary practices has led to an acknowledgement that production diseases are multifactorial and connected with housing, nutrition, genetics, and other diseases. The concept of herd health management (HHM) was introduced and characterised as "an integrated, holistic, proactive, data-based, and economically framed approach to prevention of disease and enhancement of performance" by LeBlanc et al. [(8), p. 1267]. The HHM approach and research within the area have inspired practitioners globally to introduce, advise on and apply preventive measures related to herd-level health and production, often through data- and knowledge-driven engagement on farms (9–11). The HHM approach ideally implies a continuous collaboration between the farmer and the veterinarian, as the same veterinarian will often be affiliated with a farm over long periods of time. This close collaboration, in combination with a focus on herd health and production, provides a suitable setting for working explicitly towards rational AMU. The specific HHM approach differs from country to country (6, 10, 12, 13), but the type of VHHC in focus in this review article is defined by a continuous collaboration between a farmer and the same veterinarian, with regular herd visits and a focus on herd health and production.

Research shows that the traditional focus on quantitative data analysis and economics embedded within the HHM approach does not motivate all farmers to change their behaviour (14–17), and factors relating to farmers' and veterinarians' decision-making processes in particular need further investigation (18, 19). Farmers and veterinarians act in a complex agricultural context characterised by legislation on AMU, changing incomes due to fluctuating milk prices, the physical condition of the farm, farm and veterinary businesses aiming to make a profit, and social norms to which farmers and veterinarians try to adhere. All of these factors could potentially affect the choice to use antimicrobials rationally, implying the need to understand and take such "qualitative" factors into consideration as a part of the VHHC when working to change behaviour.

We argue that the choices made by farmers and/or veterinarians either individually or in collaboration, for example whether or not to prescribe or treat an animal, are the starting point for working towards rational AMU in dairy cattle. Our focus is therefore on the factors that influence behaviour in terms of rational AMU within farmers' and veterinarians' collaborative framework. Possible influencing factors affecting individual and/or collaborative AMU choices must be identified and considered from an overall sociological perspective. The VHHC could then not only be expanded to include quantitative data on health, production and economics as part of a motivation for change but it could also be broadened to take farmer- and veterinarian-specific motivational factors into consideration.

However, not all factors are equally important to every farmer and veterinarian. Each farmer is a unique individual, and a personal approach should be taken within a specific-herd context [(20), p. 3330, (16), p. 13]. Furthermore, the local agricultural setting differs from country to country, which is why identified factors might not all be of equal importance across all countries. It is therefore necessary to relate every identified factor to the country of interest, with its national context-specific barriers and opportunities [(21), p. 160–1].

The overall objective of this study was to improve the understanding of relevant factors for achieving rational AMU within the collaborative context of VHHC in dairy cattle herds. The first sub-objective was to review, summarise and discuss the factors of relevance for VHHC and rational AMU in dairy herds. Furthermore, the findings are discussed from a socio-economic perspective to broaden the understanding of their meaning. The second sub-objective was to identify knowledge gaps of relevance for changing AMU practices within the VHHC setting, as well as challenges and opportunities for future research.

The initial inclusion criterion for the literature search was studies on dairy cattle and AMU (other types of medication were excluded). Secondly, studies had to be conducted in an intensive production context characterised by high milk production and relation to a global market, as we argue that there are different AMU-related factors at play in intensive and extensive farming. Finally, studies had to place an emphasis on the farmer–veterinarian relationship. The review began with a systematic literature search across seven databases, and 39 out of 122 articles were used in this review after screening for relevance. We also included additional articles conducted within the social science research field to discuss and elaborate on the multifaceted area of AMR research.

OVERVIEW OF FACTORS AFFECTING THE INTENTION TO MOVE TOWARDS RATIONAL ANTIMICROBIAL USE: A SOCIO-ECOLOGICAL MODEL

Numerous factors influencing the intention to change AMU were identified in the literature search. We used a model developed and previously used in the disease prevention and control context as a structural framework to organise these factors and to give a better overview [(22), p. 278]. Their model was originally built upon a study by Panter-Brick et al. [(23), p. 2813] and was developed to illustrate barriers to the control of zoonotic diseases. Controlling zoonotic diseases is complex and unpredictable aspects must be taken into consideration, such as future consequences that can be difficult to comprehend and react on in the present, as is the case with AMR. The model was chosen due to its more holistic approach, taking into account the agricultural setting.

The model proposes that a person's intention to perform a certain behaviour can be explained by three factors: (1) the person's attitude, (2) the person's subjective norm and (3) the person's perceived behavioural control [(24), p. 179–82]. The original model builds on the Theory of Planned Behaviour, but has been further developed here in order to take extrinsic (e.g., national, regional, and herd-specific) factors more directly into account [(23), p. 2811–2]. Panter-Brick et al. (23) argued that intention to change is not driven solely by intrinsic factors, making the model socio-ecological and combining social and physical aspects of the individual. In our case, the relationship between two groups of individuals (farmers and veterinarians) and their cooperation within VHHC in the agricultural context is important. Therefore, we further developed the model to contain and organise the intrinsic and extrinsic factors while allowing for the factors to be either specific to one group or common to both.

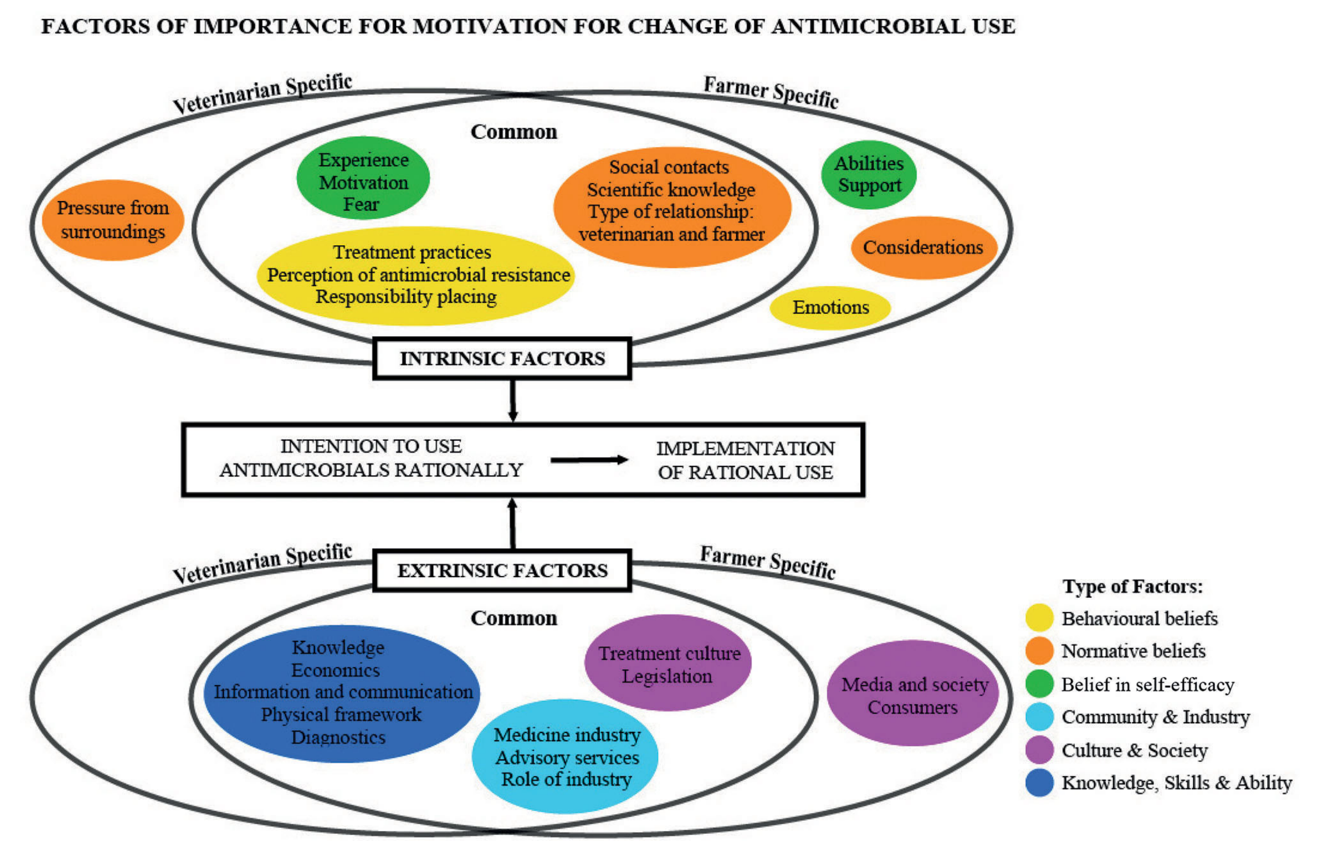

FIGURE 1 | Factors influencing AMU. Some factors have been identified as common to both veterinarians and farmers, whereas others are only identified for the one or the other. The model was inspired by Ellis-Iversen et al. (22).

The original Theory of Planned Behaviour and its focus on individual behaviour has been criticised on a number of occasions, especially in relation to its behaviourist foundation [(25), p. 5–10, (26), p. 3, (27), p. 1–3]. In this context, we do not use the model as an argument for behaviourism but as a framework for structuring the research of different empirical aspects and contexts where the farmer–veterinarian interaction can influence the use of antimicrobials. The model helps us present an overview of areas and situations that influence AMU, both at individual and farm level, but also from a broader societal perspective. This is in line with research within the social sciences, where the structural dimensions related to AMU (e.g., social, economic, and biological factors) are investigated [(25), p. 8–10; (28), p. 2].

The intrinsic factors in the model consist of three groups: (1) Behavioural beliefs representing a person's attitudes, which are often defined by core values; (2) Normative beliefs defined by social norms and how the individual perceives these; (3) Belief in self-efficacy, which is closely related to a person's trust in their own ability to carry out the change.

The extrinsic factors also consist of three groups: (1) Community & Industry, including influence from the agricultural industry, and trade partners as well as the rural community; (2) Culture & Society, including national legislation and guidelines as well as influence from consumers; (3) Knowledge, Skills & Ability, relating to the overall availability of important resources, finances, knowledge, and tools for possible change (22).

Figure 1 shows how the findings from the reviewed papers have been embedded in the model. The identified factors appear as headlines placed within the appropriate section of the model, e.g., concerning either one of the groups within the intrinsic or extrinsic factors, and relevant to either the farmer, the veterinarian or both. For each headline, e.g., "Responsibility placing," several studies may have contributed findings to support the importance of this factor. In the next section, the identified factors and the related literature are presented according to the structure of the model, starting with the intrinsic factors and ending with the extrinsic factors. It is important to note that only factors that were identified in the literature are summarised and discussed.

INTRINSIC FACTORS AFFECTING THE INTENTION TO MOVE TOWARDS RATIONAL ANTIMICROBIAL USE

Research on intrinsic factors related to an individual's attitudes, core values, perception of social norms and belief in their own ability to change will be presented in the following sections.

Differences in Veterinarian and Farmer Attitudes on Antimicrobial Use

The first of the intrinsic factors are behavioural belief-based factors, concerning personal attitudes. The first point to be presented here, "Treatment practices" (**Figure 1**, intrinsic, common factor), appeared to be an important point for both veterinarians and farmers, with a range of attitudes on how to approach treatment. Several studies suggest that veterinarians and farmers both agree that sick animals need treatment [(29), 44–5, (30), p. 86, (31), p. 4, (32), p. 7], yet motives seem to differ between the two groups. According to Speksnijder et al. [(29), p. 44], veterinarians regard diseased animals from a professional and ethical point of view, with treatment primarily related to their perceived obligation as a veterinarian to ensure animal health and welfare. For farmers, treatment appears to be driven by a focus on animal welfare and an urge to stop individual animal suffering [(33), p. 112–3]. However, the threshold for treatment can change, e.g., alleviating suffering among diseased animals can be addressed by intense follow-up instead of immediate treatment [(34), p. 1845–7]. Both studies identified practical farmer-specific issues related to having sick animals: it is time-consuming and interrupts the daily routine, and it can be economically challenging [(33), p. 114, (34), p. 1845–8]. Having sick animals is therefore a complex issue for both farmers and veterinarians, but it complicates different aspects for the two groups. For veterinarians, it is mostly about ethical and professional standards, whereas for farmers, the challenges are primarily related to practical issues and emotional frustration.

Other perceptions about "Treatment practices" have also been identified in the literature (**Figure 1**, intrinsic, common factor). Several studies found that both veterinarians and farmers believe that vaccination plays a key role in reducing AMU [(32), p. 11, (31), p. 7, (35), p. 5–7, (36), p. 3232–7]. However, vaccination was perceived as ineffective among farmers in Washington State [(36), p. 3234]. Differences in prescribing behaviour and AMU patterns have also been described. Misuse and illegal over-the-border purchases of antimicrobials have been identified among farmers [(36), p. 3233–4, (37), p. 56, (38), p. 3496, (39), p. 9–10], and veterinarians from France, the UK and Switzerland expressed their frustration with veterinary prescribing behaviour, either directed at themselves or their colleagues [(40), p. 67, (32), p. 9–12, (39), p. 8–10]. Alternative treatment methods were perceived by farmers as being too time-consuming [(33), p. 114–6, (34), p. 1845], and a distrust in their effect was also identified [(33), p. 115]. The attitudes behind or reasons for some of these treatment practices cannot always be elaborated upon due to the study design that is traditionally used within veterinary research, e.g., surveys and questionnaires. For example, the position on vaccination among farmers in Washington State was identified based on a questionnaire study (36), and this type of study rarely provides the reason behind an answer, as would be possible in an interview, for instance.

Looking into the social science literature from human medicine might provide some possible explanations for the identified treatment practices among veterinarians and farmers. For example, Broom et al. [(41), p. 1995] found a ritualised AMU among doctors. Specific treatments repeatedly resulting in positive outcomes might lead to both farmers and veterinarians believing that this treatment is more effective and therefore preferred. For the farmer, this might result in a request for specific antimicrobials, which he or she perceives as most effective. This could cause potential conflicts between veterinarians and farmers due to disagreements over drug preferences. Similarly, veterinary drug choices may be ritualised.

Responsibility for the rational use of antimicrobials and where this responsibility should be placed has also been studied (**Figure 1**, intrinsic, common factor, "Responsibility placing"). There is evidence in the literature that both farmers and veterinarians might perform "other-blaming" behaviour when placing responsibility for the rational use of antimicrobials. "Other-blaming" can be understood as viewing other people as responsible for causing an issue, while the individual's own behaviour is perceived as unproblematic. One study from the UK found that frustrations among farmers and veterinarians due to the physical framework of the livestock industry as well as a lack of stewardship among doctors contributed to other-blaming [(32), p. 7–12]. The same finding was reported in the Netherlands, where the misuse of antimicrobials by doctors and international traffic were seen as the primary causes of AMR by some interviewed veterinarians [(29), p. 45]. Dairy farmers interviewed in Tennessee believed that there was no connection between AMU in agriculture and public health risks. Instead, this risk was perceived as being linked to AMU in the human sector [(31), p. 7]. Renunciation of responsibility by both veterinarians and farmers can therefore act as a barrier to changing AMU.

In connection with this attitude and "Perception of AMR" (**Figure 1**, intrinsic, common factor), some literature suggests that farmers and veterinarians perceive their own AMU as an insignificant contributor to global AMR [(30), p. 87, (29), p. 44–5]. However, the opposite opinion was also identified [(42), p. 4, (29), p. 44, (36), p. 3235], as well as an experience-dependant factor as more experienced veterinarians seem to be less aware of the potential risks related to antimicrobial overuse [(43), p. 367]. A survey completed by veterinarians from New Zealand found that younger veterinarians were more likely than older ones to perceive AMR as a risk [(30), p. 88]. An ethnographic study conducted at a dairy farm in the UK concluded that the perception of AMR as a risk is related to knowledge. The study argues that knowledge of AMR within agriculture is based to a large extent on practical experiences in specific farm contexts. Due to microbial culturing not being used at farm level, other factors will often outweigh resistance as plausible explanations for treatment failure [(44), p. 1–9]. To elaborate on the risk perception of AMR experienced by farmers and veterinarians, inspiration can be found in research conducted within human medicine. Doctors must balance the acute risk of losing a patient in need of antimicrobial treatment and the global, long-term risk of AMR [(45), p. 828–30]. Similarly, this could be an underlying mechanism explaining why farmers and veterinarians do not see their own AMU as a significant contributor to AMR globally; perhaps the acute risk of losing an animal takes priority over the long-term perspective of AMR, thus "forcing" the farmer or veterinarian to ignore the risk of resistance. In a similar way to the renunciation of responsibility mentioned earlier, the perception of own AMU as an insignificant contributor to global AMR can lower the intention to change AMU [(44), p. 1–9].

Literature suggests that "Emotions" can shape farmers' attitudes (**Figure 1**, intrinsic, farmer factor). Fischer et al. [(46), p. 2729] found that farmers felt frustrated when they had sick animals, and Vaarst et al. [(33), p. 113] found that "favourite cows" could receive treatment even when the prognosis was poor. This point about emotions was not found for veterinarians in the literature. Research on the prescribing behaviour of doctors identified the need to "just do something" when patients were close to dying [(41), p. 1999]. This feeling of at least trying to do something might be similar to the one experienced by farmers—and is potentially also evident for veterinarians.

As illustrated by the behavioural belief-based factors identified in the literature, farmers and veterinarians have different opinions regarding AMU and AMR. They differ in their understanding of AMR and the responsibility associated with it. Working collaboratively within a VHHC situation, potential challenges might occur due to disagreements or a lack of understanding of other people's perspectives. Having different core values regarding the motives for treatment might result in different treatment thresholds among farmers and veterinarians, with potential differences in the decision-making process and preferred solutions. Reasons for this have been discussed in the literature [(7), p. 14–6], and economic models propose that people choose to act based on the maximum expected utility. However, this is not always the case as there is evidence that farmers do not always decide whether to treat an animal based on economic reasoning (17).

It has also been suggested that decision-making is affected by the context, as well as ways of perceiving risk [(47), p. 159–99]. A difference in perception of risk among farmers and veterinarians has been proposed [(15), p. 2–4]. Sorge et al. [(48), p. 1497–9] suggested that this difference may be due to the lack of knowledge among farmers affecting their risk perception, in this case relating to Johne's disease. In the case of AMR, it could be that farmers do not perceive AMR as a risk due to a lack of knowledge of local, global and future consequences. The knowledge deficit model describes how a poor understanding of the scientific reasoning behind any given advice is why lay people may not follow the advice. In other words, the reason for the difference in risk perception and decision-making between the veterinarian (the expert) and the farmer (the lay person) is due to the farmer's lack of knowledge [(49), p. 112]. However, critics of the knowledge deficit model argue that risk assessment is complex and individual, and related to more than just a lack of knowledge [(15), p. 3–6, (49)]. Differences in risk perception due to a lack of knowledge is therefore not likely to be the sole explanation for the differences in attitudes between veterinarians and farmers. Instead, to avoid major disagreements jeopardising the collaboration within VHHC, farmer-specific VHHC have been proposed, where the individual farmer's risk perception and attitudes are explored through dialogue and taken into account [(15), p. 3–6].

In conclusion, the behavioural belief-based factors identified in this section highlight the importance of trying to understand the other party's perspectives and contextual framework, e.g., emotions, individual risk perception and attitudes, to avoid major disagreements that could jeopardise the ability to change AMU behaviour in collaborations between the farmer and the consulting veterinarian.

Social Norms Affecting the Veterinary Herd Health Consultancy Relationship

Personal beliefs and attitudes contribute to a person's actions related to changing AMU, but these factors are also influenced by other people. The opinions and behaviour of others can influence and modulate a person's response by building "social norms," which are created as informal guidelines for behaviour within a group. Social norms are enforced through social sanctions, whereby people feel uncomfortable violating norms due to public disapproval possibly causing shame or embarrassment. Alternatively, following social norms can result in reputational benefit and improve one's self-concept [(50), p. 914–25, (51), p. 3–5]. The literature suggests that the relationship with and opinions of other people are important to both farmers and veterinarians in terms of how their social norms are formed over time [(52), p. 2375–9, (32), p. 8–9]. Some social associations are more relevant to veterinarians, some are more relevant to farmers and some are relevant to both. The identified factors related to social norms affecting herd health management and AMU will be summarised according to this division and discussed in the following sections.

Social Norms of the Veterinarian

"Social contacts" (**Figure 1**, intrinsic, common factor) is a factor common to both farmers and veterinarians, but has a different meaning to each group (see below). For veterinarians, colleagues' opinions were identified as particularly important. A lack of support from colleagues over their choice of prescription could lead veterinarians to prescribe against their own judgement [(32), p. 9]. Swiss veterinarians attending peer study groups emphasised the importance of sharing their experience with their peers to gain new knowledge, compare themselves with others and receive new stimuli [(39), p. 12]. It can be argued that veterinarians compare themselves with their peers and follow e.g., practice policies and their colleagues' prescribing choices to stay in line with social norms.

Another point from the figure with specific relevance to the social norms of the veterinarian is "Pressure from surroundings" (**Figure 1**, intrinsic, veterinarian factor). One aspect of this will be described here, the other in section Social Norms of the Farmer-Veterinarian Interaction as it concerns the farmer–veterinarian relationship directly. As is apparent from the literature, colleagues' opinions are not always perceived positively but rather as a pressure to prescribe in a specific way. A practice policy for AMU was found to be an important factor for prescribing among veterinarians in New Zealand, next after their own training and costs/benefits for the farmer [(30), p. 88]. This may imply that veterinarians do not want to go against or question an existing practice policy in some situations, so they choose to prescribe according to the policy and perhaps against their own judgement. A certain "prescribing etiquette" has been identified within human medicine, i.e., a set of cultural rules defining AMU. These rules are derived from a hospital culture where the autonomous and experience-based prescribing behaviour of senior doctors affects junior doctors. Furthermore, a culture of "non-interference" in colleagues' prescribing choices also exists [(53), p. 190–4]. Another study within human medicine identified certain "rules of the game" for AMU at hospitals. These rules arise due to the prescribing norms and working conditions at hospitals [(54), p. 83–7]. A prescribing etiquette and cultural rules for AMU might also apply to veterinarians. Despite veterinarians working more independently compared with doctors in a hospital setting, AMU choices might still be influenced by colleagues' opinions, as evident from the literature.

Social Norms of the Farmer

In relation to farmers, "Social contacts" (**Figure 1**, intrinsic, common factor) including opinions from a perceived positive reference group—namely other farmers—were identified as important [(52), p. 2375–9]. The concept of being "a good farmer" was introduced in connection with this, meaning the importance of living up to other farmers' perceptions of "good farming" (46, 52). The role of being "a good farmer" encompasses multiple social norms, each of them dictating appropriate behaviour [(55), p. 207–10, (56)]. As identified in the literature, being "a good farmer" can imply achieving high production levels [(46), p. 2729] as well as using extended therapy for mastitis, i.e., treating for more days than recommended by the veterinarian to achieve the best possible treatment outcomes [(52), p. 2374]. Several studies have illustrated that "the good farmer" can have multiple meanings according to the local "rules of the game" [(56, 57), 589–99].

A local understanding of "the good farmer" could be established through communication with other farmers and through opinions from trusted sources, e.g., the veterinarian [(52), p. 2376–7]. In relation to this, it seems relevant to present the concept of "roadside farming." According to Burton [(55), p. 201–6], "Roadside farming" is characterised by the exchange of social information by farmers. This happens either by presenting their own farm as well as possible by the roadside or by evaluating other farms. Therefore, a local understanding of "the good farmer" might also be established through non-verbal communication, e.g., through "roadside farming." In conclusion, it is important for farmers to live up to their social contacts' perception of "good farming." The social norms related to this concept are created through communication (both verbal and non-verbal) with the outside world, and farmers probably choose to live up to the social norms due to an expected reputational benefit.

A second point specific to farmers is "Considerations" (**Figure 1**, intrinsic, farmer factor). The literature suggests that farmers perceive expectations from the dairy industry regarding rational AMU positively and as something they want to live up to [(58), p. 34–7] [(59), p. 477]. From a normative perspective, this could be explained as an aspect of being "a good farmer." Furthermore, farmers might be motivated to live up to expectations from the dairy industry if they expect to achieve a reputational benefit from doing so.

Social Norms of the Farmer–Veterinarian Interaction

One of the factors related to the farmer–veterinarian relationship is actually specific to veterinarians, but also directly relevant to the interaction between the two (**Figure 1**, intrinsic, veterinarian factor, "Pressure from surroundings"). The aspect related to colleagues has been described in section Social Norms of the Veterinarian, but the aspect related to the farmer will be described here. The literature suggests that veterinarians experience pressure from their clients, and one of the reasons behind this has been identified as an actual or perceived client demand for antimicrobials [(60), p. 2, (29), p. 44, (43), p. 367, (61), p. 82–3, (42), p. 4]. Another reason for this pressure to prescribe antimicrobials is due to economic considerations for the farmers. Some broad-spectrum antimicrobials are economically attractive to farmers due to the short withdrawal periods, resulting in veterinarians experiencing pressure to prescribe in a less responsible manner—for example the cheapest treatment solution instead of the most suitable product [(32), p. 8, (30), p. 86–7]. Social norms might also explain why veterinarians feel a pressure to prescribe; they may experience social sanctions (e.g., a bad reputation) from the farmer if they refuse to prescribe cheap broad-spectrum antimicrobials. Research within human medicine has shown that local norms for prescribing practices and interpersonal pressure from patients and their relatives, together with the risk of patients relapsing when not treated, influenced AMU at hospitals [(45), p. s. 830–4]. Similar social and cultural influences might be at play in the veterinarian–farmer collaboration, perhaps encouraging the veterinarian to prescribe out of consideration for the continued relationship with the farmer, the risk for the animal or an urge to comply with social norms. There seems to be a disparity between what veterinarians and farmers perceive as the "correct" choice of antimicrobials and the parameters that this choice should be based on. This disparity could cause complications in the VHHC collaboration, and a mutual understanding should therefore be sought and choices related to AMU should preferably be based on scientifically valid general or local evidence (62).

"Scientific knowledge" has been identified as an important guide of both veterinarians' and farmers' behaviour (**Figure 1**, intrinsic, common factor). However, there is a difference in the perception of "scientific knowledge": farmers primarily view the veterinarian as a representative of scientific knowledge [(63), p. 147], whereas published literature from veterinary experts is the epitome of "scientific knowledge" for veterinarians themselves [(64), p. 3, (42), p. 4–5, (37), p. 60]. This difference in perception could also affect the veterinarian–farmer collaboration in relation to HHM. Farmers might not appreciate veterinary recommendations based on published literature, as they may find the advice incompatible with the reality on their farm and expect the veterinarian to adjust the advice accordingly [(7), p. 15].

Regarding the "Type of relationship" between the veterinarian and the farmer within a VHHC setting (**Figure 1**, intrinsic, common factor), the literature suggests that both groups agree on the importance of a good collaboration when working with AMR [(32), p. 11]. A stable school project in Denmark showed that a mutual trust and openness among the participants had a significant influence on the results obtained [(65), p. 2548–50]. A study from the UK also highlighted the importance of established trust between the veterinarian and the farmer in terms of the veterinarian knowing the actual AMU on the farm [(37), p. 58]. A lack of commitment or understanding of the individual farmer's way of farming (e.g., organic farming) was found to negatively influence the relationship from the farmer's perspective [(33), p. 113–4, (66), p. 19–20]. Conversely, veterinarians in France felt that they were stuck in a role as "firefighters" at organic farms and faced difficulties changing this role due to a lack of regular farm visits and farmers' lack of appreciation for advisory services [(67), p. 12–8]. Furthermore, some Flemish veterinarians believed that the farmers' mentality when it came to using antimicrobials led to high AMU, thus discouraging the collaborative effort [(42), p. 2–3]. The influence of farmers' mentality, behaviour, age and knowledge on veterinary prescribing behaviour was mentioned by Swiss veterinarians [(39), p. 8–9]. Furthermore, veterinarians emphasise the importance of regular visits to work preventively to tackle disease instead of focusing on treatments [(35), p. 3–4, (29), p. 42].

The perceived importance of the mutual relationship between both veterinarians and farmers might be explained by the concept of trust [(12), p. 89]. Möllering [(68), p. 4] gave definitions of trust in the following statement: "Trust can be defined, first of all, as a state of favourable expectation regarding other people's actions and intentions. As such it is seen as the basis for individual risk-taking behaviour, co-operation, reduced social complexity, order, social capital, and so on." Reduced social complexity implies that social interactions can proceed without the constant evaluation of potential actions by those involved [(69), p. 5–35]. By establishing trust within the relationship, veterinarians and farmers can reduce the complexity of their social interaction and need not discuss or evaluate every single outcome of a certain decision.

According to Luhmann [(69), p. 21–6], we are more trusting of a familiar person than a stranger, and establishing a relationship takes time, which may explain why some interviewed veterinarians from Ireland and the Netherlands emphasised the importance of regular herd visits. Luhmann [(69), p. 21–6] also mentions how trust is less likely to be broken within a persistent relationship, such as the relationship between a veterinarian and a farmer, who will most likely have to continue their collaboration over an undefined period of time. When farmers experience a lack of understanding and commitment from their veterinarian, they may also experience a lack of trust. According to Luhmann [(69), p. 21–6], no one wants to take too many risks when initially building up trust within a relationship. This could explain the farmers' mentality negatively affecting the collaboration, as experienced by the Flemish veterinarians surveyed. Another example of these mechanisms can be found in a social science study concerned with VHHC from European countries and the USA, which identified a tendency for veterinarians to prefer farms with intensive farming due to the regular visits and the potential to build up a close relationship with the farmer. In contrast, relationships with farmers from extensive farms were more distant as they had diverging views on the need for consultancy and less regular herd visits, possibly implying a relationship built on less trust, commitment and understanding [(7), p. 15].

In conclusion, both farmers and veterinarians care about other's opinions and these can influence their own opinions and behaviour. Within collaborations such as a VHHC agreement, both parties should be aware of the influence they have on each other. A better understanding of each other's perspectives, wishes and drivers can result in a more purposeful VHHC towards a local and practical rational AMU. In relation to this, building a mutual relationship through dialogue based on trust could reduce social complexity. A theoretical understanding of the mechanisms behind social norms and their impact on individual behaviour is also of importance.

Social Norms Shaping Attitudes and Behaviour

Some of the factors placed within the behavioural belief-based factors might also be explained by social norms. Different treatment practices might be a result of social norms developed within the local society of the farmer and the veterinary clinic. The concept of being "a good veterinarian" might be equally as relevant as "the good farmer," and also shaped by social norms. For example, social norms might explain why veterinarians see it as their duty to alleviate the suffering of animals, since years of education have taught them to do so. It has been proposed that norms are based on beliefs about facts. If new knowledge emerges and changes what is understood as correct, new norms might be created. However, these changes are often delayed due to the difficulties people face when changing norms and admitting the mistakes of former beliefs [(50), p. 931]. The pressure to prescribe experienced by veterinarians might be complicated further due to a potential delay when changing norms that leads to a disparity in beliefs and knowledge on rational AMU among both veterinarians and farmers.

For farmers, the misuse of antimicrobials identified by Raymond et al. [(36), p. 3233–4] and Buller et al. [(37), p. 56] in the previous section on behavioural belief-based factors can also be discussed from a social norm perspective. It has been proposed that some people simply like to violate social norms, also known as "flouting convention," which could explain the misuse of antimicrobials by farmers. Another perspective on the misuse of antimicrobials might be a disapproval of norms due to reflective judgement [(50), p. 918]. The surveyed farmers in the study by Raymond et al. (36) might be dissatisfied with the legislation related to AMU and want to contribute to a new way of thinking and new social norms. In connection with this, the theory of psychological reactance might also offer an explanation about the farmers' behaviour. If a person's perceived free behaviour is restrained, for example if a farmer is forced to use certain antimicrobials and these must always be prescribed by a veterinarian due to legislation, they may feel motivated to regain their freedom and use the antimicrobials illegally, ignoring the social influence from others (70). It is possible that similar tendencies could be identified for veterinarians, e.g., a delayed response to regulations on the use of critical antimicrobials, we have, however, not found published literature describing such behaviour.

Summarising normative belief-based factors underlines the influence of social norms in the everyday work of veterinarians and farmers—both individually and in their collaboration. In addition, awareness of how social norms can influence and explain attitudes and decisions may help to improve mutual understanding within a VHHC setting.

Using the Positive Feedback Loop of Self-Efficacy

This section concerns the third of the intrinsic factors, the belief in self-efficacy-based factors. Belief in self-efficacy is a person's trust in their own ability to do something. Without this trust in oneself, it can be difficult to change behaviour. "Experience" seems to be an important aspect in achieving self-efficacy for both farmers and veterinarians (**Figure 1**, intrinsic, common factor). The literature suggests that for veterinarians, a lack of work experience can affect their trust in their own decisions [(43), p. 367]. Personal experience with specific drugs or treatments also affects veterinarians' decisions [(42), p. 4, (60), p. 2, (30), p. 86, (38), p. 3497–8, (39), p. 11]. Similarly, personal experience also guides the drug choices doctors make at hospitals, where the clinical situation determines the use of antimicrobials independent of formal policy recommendations [(53), p. 193]. The literature suggests similar aspects among farmers, and several studies have identified a large amount of trust in their own treatment experiences [(71), p. 371–2]—sometimes they will trust this even more than the veterinarian's advice [(31), p. 6, (33), p. 113–4, (34), p. 1848–9, (65), p. 2549, (30), p. 86]. Some studies have identified the use of antimicrobials without any input from the veterinarian, which perhaps implies the same thing [(58), p. 33–4, (63), p. 144]. The opposite situation where the veterinarian works as a trusted source of information for the farmer and possibly contributes to an improved belief in self-efficacy has also been identified, as previously mentioned [(30), p. 86, (46), p. 2732] (**Figure 1**, intrinsic, farmer factor, "Support").

Besides experience, "Fear" also affects the self-efficacy of both farmers and veterinarians (**Figure 1**, intrinsic, common factor). The fear of a negative implication on animal welfare if AMU is reduced further was identified for both groups [(37), p. 55–6, (42), p. 4, (32), p. 7, (58), p. 34]. Some farmers also feared a decline in production, as identified in the survey by Jones et al. [(58), p. 34] and the interview study by Golding et al. [(32), p. 7], as well as economic losses in general. Furthermore, the literature suggests that some farmers are scared to change or halt their AMU due to the risk of relapse in their animals [(40), p. 64, (52), p. 2373], indicating that emotions act as a barrier.

Fischer et al. [(46), p. 2731] identified a lack of ability among farm workers to identify sick animals (**Figure 1**, intrinsic, farmer factor, "Abilities"). The study also identified a sense of apathy among farmers due to external factors present on their farm, e.g., time and economic constraints, sometimes making it difficult to deal with sick animals. A lack of ability and an apathetic attitude can further affect the self-efficacy of farmers.

There is uncertainty surrounding "Motivation" (**Figure 1**, intrinsic, common factor) for both farmers and veterinarians and how this affects their belief in self-efficacy. For example, the reason for farmers from the UK not wanting to change AMU on their farms after participating in workshops with a focus on the same is unknown [(59), p. 480–3]. However, as identified in a stable school project in Denmark, sharing good examples or solutions increased the motivation for change among farmers, probably because changing one's own practices seems more achievable when others have succeeded in making similar changes [(65), p. 2549]. The importance of seeing a positive effect of measures taken to improve AMU was identified among farmers. Seeing the results of successfully implemented measures increases the motivation to continue, possibly due to a higher level of trust in self-efficacy [(34), p. 1844]. The literature suggests that veterinarians' motivation is influenced by their clients' motivation [(43), p. 368–71, (32), p. 8], e.g., in a positive feedback. Again, there is an element of uncertainty involved—could a lack of motivation for veterinarians be due to a lack of belief in their own ability to affect the farmers' motivation?

According to Bandura [(72), p. 27–32], self-efficacy is an individual's belief that their effort will produce desired effects, affecting their motivation to act. If people truly believe that they have the ability to change something, they are more likely to try to do so. Bandura also highlights the effect of fulfilling valued goals, which results in self-satisfaction and increased motivation. This might explain why farmers' and veterinarians' motivation can be driven by a belief in self-efficacy via positive feedback. The identified fears of a negative impact on animal welfare and a decline in production might be connected to doubts about their ability to act according to their own core values within a restricted AMU setting. By being aware of the different barriers or opportunities for improving an individual's self-efficacy, veterinarians and farmers can better assist each other in increasing the motivation to act.

The following section will describe extrinsic factors that may have an effect on the intention to move towards a more rational AMU, as well as hinder or promote its implementation.

EXTRINSIC FACTORS AFFECTING THE INTENTION TO MOVE TOWARDS RATIONAL ANTIMICROBIAL USE

Extrinsic factors relating to the external framework surrounding the farmer and the veterinarian will be presented in the following sections. The extrinsic factors include three groups: Community & Industry; Culture & Society; Knowledge, Skills & Ability.

Agricultural Industry and Community Influencing Antimicrobial Use on Farms

Literature suggests that the rural industry (**Figure 1**, extrinsic, common factor, "Role of industry") plays an important role in the development of improved AMU for both farmers and veterinarians [(35), p. 3–4, (73), p. 7–8, (74), p. 6, (37), p. 60–1, (46), p. 2732–3]. According to Golding et al. [(32), p. 10], interviewed farmers expressed a need for the industries and the government to lead the development by supporting research, providing specific guidelines and ensuring better prices for farmers' products. However, which partner should take responsibility differs depending on the respondent, with retailers, food companies, national, and international authorities, farm associations, the dairy industry and veterinary organisations all being mentioned [(35), p. 3–4, (32), p. 10, (73), p. 7–8, (37), p. 60–1].

The "Medicine industry" (**Figure 1**, extrinsic, common factor) represents an important factor in the agriculture industry, and the literature suggests that both farmers and veterinarians are concerned about it in terms of changing AMU. However, ease of administration has primarily been identified as a consideration for veterinarians, whereas farmers are more focused on the price of medicines. For example, surveys completed by veterinarians from Ireland, the Netherlands, Flanders and other European countries indicated that veterinarians consider the ease of administration for both themselves and the farmer when choosing an antimicrobial drug [(64), p. 3, (60), p. 2–3, (42), p. 4], while farmers complain about medicine prices and choose antimicrobial drugs based on withdrawal times [(40), p. 65, (58), p. 33–4, (31), p. 5–6]. In addition, some veterinarians from France requested more knowledge regarding alternative medicines [(40), p. 67], and farmers in a focus group study suggested improved labelling of drugs so that correct dosages, withdrawal times and the appropriate disease indication would appear clearly on the original label [(31), p. 9].

Another aspect of the rural community that both veterinarians and farmers believe influences their intention to change AMU is the "Advisory services" (**Figure 1**, extrinsic, common factor), which we will discuss in the context of HHM contracts between the two groups. The literature suggests that veterinarians focus on retaining clients, e.g., to ensure income [(29), p. 42, (39), p. 11]. Some veterinarians in the UK do so by making adjustments according to the farmer's economic situation or by compromising their own opinions to avoid conflicts and thereby maintaining client relationships [(32), p. 8–9]. Ohio veterinarians emphasised the importance of advisory services to reduce the need for antimicrobials [(38), p. 3497]. From the farmers' perspective, some have expressed their frustration regarding prices for veterinary assistance and advice [(33), p. 113–4, (36), p. 3237, (31), p. 6, (32), p. 9]. Other farmers believed consultancy was of limited benefit due to different goal setting or perspectives between themselves and the veterinarian [(33), p. 113–4, (65), p. 2549, (34), p. 1848, (67), p. 12–8, (66), p. 19–20]. Some farmers requested more frequent herd health consultancy from their veterinarian [(33), p. 113], and a survey from the UK identified an association between a positive opinion of herd health plans and a high level of knowledge of AMR among farmers [(75), p. 6].

As indicated by the summarised factors of importance relating to "Community & Industry," veterinarians and farmers are concerned with the same issues, e.g., the role of industry, the medicine industry and veterinary advisory services. However, their perspectives are not always aligned. The collaboration within VHHC can be complicated due to different interests, e.g., intervals between visits. Communication is needed to align expectations for the collaboration and to avoid veterinarians compromising to retain clients. Furthermore, communication could also result in a mutual understanding of what is important to each group, e.g., medicines that are cheaper or easier to administer, or industry- or government-led initiatives to reduce AMR. Not all of these needs should or could be fulfilled within the VHHC collaboration, but working towards a mutual understanding and establishing a common goal within the collaboration could create a sense of unity, which could subsequently promote positive feelings towards the collaboration in general.

The identified factors relating to the role of the industry, the medicine industry and advisory services will vary from country to country. It is relevant to consider different factors depending on the country's history regarding the introduction, development and role of advisory services, the medicinal products available on the national market and the usual role played by the industry. Therefore, the factors must be carefully considered in relation to the context in question.

Legislation, Consumers, and Culture Influencing Antimicrobial Use on Farms

In terms of "Culture & Society"–based factors, "Legislation" is an important factor for both farmers and veterinarians (**Figure 1**, extrinsic, common factor). In line with the role of the industry mentioned in the previous section, government initiatives to enforce rational AMU are called for in the international literature. Experts consulted in a study by Carmo et al. [(74), p. 6] agreed that mandatory interventions have a high potential to reduce AMU. Several studies have identified a need for more legislation in the area of AMU [(35), p. 3, (40), p. 69, (46), p. 2732–3, (39), p. 10, (29), p. 44–5, (42), p. 6], but the opposite opinion was also identified in the literature [(63), p. 144–5, (42), p. 6]. Interviewed farmers from the UK expressed concerns about the administrative work and "tick-box" conformity following legislative initiatives [(37), p. 61]. In addition, some of the interviewed farmers felt that legislative restrictions on AMU challenged their economic situation and disrupted their business [(32), p. 9–10]. Swiss farmers and veterinarians stated that no penalty should be given to farmers with high AMU [(73), p. 7]. The different attitudes towards legislation and the role of the government might depend on the country in which the study was conducted. As illustrated by Postma et al. (42), the surveyed veterinarians from the Netherlands and Flanders had differing opinions on governmental restrictions on AMU. This might be due to the different legislative history of the two countries. At the time of the study, the Netherlands had already experienced legislative restrictions on their AMU and had managed to reduce their AMU without compromising animal welfare, resulting in a more positive attitude towards governmental restrictions. In contrast, Flanders had not yet gone through these changes, possibly explaining their more sceptical attitude towards the possibility of reducing their AMU. A similar tendency was found in the study by Swinkels et al. (52), who found that the interviewed dairy farmers from Germany and the Netherlands also had different opinions on governmental restrictions depending on their country's history and their production structure.

Two farmer-specific points were identified in the literature, namely "Consumers" and "Media and society" (**Figure 1**, extrinsic, farmer factor). Farmers perceive society as a negative reference group due to a lack of support and understanding of the dairy production process. Interviewed farmers from Sweden, Germany and the Netherlands expressed their frustrations about society due to a simplified and judgemental view of AMU in livestock production and a lack of appreciation of their work in food production in general [(52), p. 2377–8, (46), p. 2732–3]. The media is not perceived as a trusted source of information regarding AMR, and some farmers felt that it assisted in creating a skewed view of agriculture [(32), p. 7, (46), p. 2732–3]. Swedish farmers were also frustrated with the double standards among consumers regarding animal health and environmental issues [(46), p. 2732], and some farmers from Tennessee mentioned a lack of knowledge among consumers, causing misunderstandings about milk marketing [(31), p. 7–9]. However, farmers from the UK also acknowledged the potential for consumers to drive an improvement in AMU by demanding certain product standards [(32), p. 9–10]. To our knowledge, concerns regarding consumers, media and society have not been identified for veterinarians within the literature. This might be due to the less direct effect on their profession, as opposed to the livestock industry, which instantly feels the economic consequences of a downturn in demand.

Within "Culture & Society," different treatment cultures were also identified in the literature (**Figure 1**, extrinsic, common factor). The factor "Treatment culture" is defined as treatment options that have been shaped by the respective country. This is exemplified by the questionnaire study by Espetvedt et al. [(61), p. 86], where Norwegian, Swedish, Finnish and Danish veterinarians were asked about their treatment thresholds for mild clinical mastitis. Differences in treatment thresholds across the four countries were identified and reasons behind this hypothesised, e.g., due to differences in pathogens, herd size and farming systems, distance between herds and country geography in general, as well as differences in penalties, herd health programmes and legislation. Treatment culture is not only valid for veterinarians, farmers too are affected by the situation in their specific country. For example, surveyed farmers from Tennessee requested treatment protocols to guide their AMU [(31), p. 10]. Farmers from other areas of the USA also stated a need for protocols, but few actually used them [(36), p. 3231, (71), p. 373]. The lack of treatment protocols or a reluctance to follow them as a part of farming culture could lead to unnecessary use of antimicrobials, thereby creating a country-specific treatment culture.

Looking into the VHHC collaboration, communication between the veterinarian and the farmer is important for achieving a mutual understanding of things that are perceived as important by each side, as seen with the "Community & Industry"–based factors. In terms of "Culture & Society"–based factors, this includes attitudes towards legislative restrictions and—specifically for the farmers—how consumers, media and society are perceived. Again, a mutual understanding and a common goal could create a sense of unity, which could give rise to a positive attitude towards the collaboration in general.

When comparing different countries in relation to AMU and factors of importance for changing AMU, it is important to be aware of the agricultural framework of the countries of interest. As previously stated in this section, treatment cultures seem to be dependent on the country in question, as well as legislation and the role of consumers and society in general. Therefore, it is important to contextualise for national conditions.

Availability of Resources Influencing Antimicrobial Use on Farms

This section concerns the last of the extrinsic factors, the "Knowledge, Skills & Ability"–based factors. According to the literature, veterinarians and farmers agree on the overall importance of "Knowledge," "Economics," "Information and communication," "Physical framework" and "Diagnostics" when addressing the resources available to support a change in AMU.

In terms of "Knowledge" (**Figure 1**, extrinsic, common factor), both groups are focused on further education as a key factor in changing AMU [(35), p. 4–5, (74), p. 3–11, (38), p. 3496–7, (64), p. 5, (60), p. 4, (31), p. 7–11, (71), p. 373, (63), p. 144–7]. Several studies have identified a lack of knowledge of AMR among farmers [(31), p. 7, (37), p. 50–2, (75), p. 6, (40), p. 67, (44), p. 1–9], and younger veterinarians have been identified as being more knowledgeable about AMR compared with their older colleagues [(38), p. 3497]. Furthermore, veterinarians focus on the need for research on AMR [(64), p. 5–6, (35), p. 6].

Besides a lack of knowledge, the economic situation of the veterinary practice can influence the intention to change AMU for veterinarians (**Figure 1**, extrinsic, common factor, "Economics"), but this depends on the country-specific legislation and economic structure relevant to the veterinary practice. Veterinarians across all Nordic countries are only allowed to profit marginally from the sale of antimicrobials (61). If a larger proportion of veterinary income could be derived from the sale of antimicrobials, this may lead to more frequent prescribing [(60), p. 2–4]. There was an association between years of work experience and an expressed need to retain the right to sell and earn money on antimicrobials among Dutch veterinarians [(43), p. 367]. However, in another Dutch study, interviewed veterinarians declared that pharmacy incomes did not drive antimicrobial prescription [(29), p. 45]. In France, the veterinary profession has been accused of contributing to the increasing AMR due to their professional conflict of interest as medicine sales make up a large proportion of their income. This led to them redefining the veterinary position in the public debate on AMR [(76), p. 3–7]. Another aspect of "Economics" is the farmer's economic situation, which is often regarded as a limitation to changing AMU by both veterinarians and farmers [(32), p. 8, (71), p. 373, (35), p. 3, (46), p. 2731, (43), p. 368–71, (29), (42), p. 2].

In line with the economic situation, the "Physical framework" of the farm often challenges change (**Figure 1**, extrinsic, common factor). The importance of good management [(31), p. 7, (34), p. 1844–8, (59), p. 481–2, (37), p. 57], climate and housing conditions [(43), p. 370, (42), p. 2–3, (32), p. 11], quality of feed [(43), p. 368, (42), p. 3] and biosecurity [(35), p. 5, (36), p. 3234, (42), p. 2–3, (74), p. 6–7] are all emphasised by both farmers and veterinarians. An ethnographic study conducted in East Africa concluded that antimicrobials often became a "quick fix" for a lack of hygiene among citizens [(28), p. 3–4]. A similar tendency for antimicrobial misuse could be a consequence of poor hygiene at dairy farms. The literature suggests an apathetic attitude among farmers and veterinarians towards the physical framework at farms and the challenges this causes. This could imply a shifting focus from changing individual behaviour to an institutional focus as a prerequisite for change. Instead of farmers taking responsibility by renovating and improving their farm facilities and management, conditions for farming in general could be improved at a national level. Continuing to describe the factor "Physical framework," time constraints faced by farmers could challenge changes in AMU for both the farmers themselves and their affiliated veterinarian [(43), p. 368, (32), p. 9, (71), p. 373, (46), p. 2731, (40), p. 64]. Furthermore, some veterinarians agree on the importance of reliable and accurate farm data on AMU and herd performance in evaluating farm-specific AMU and identifying areas for improvement [(29), p. 42, (35), p. 4, (74), p. 11]; however, we did not identify the same focus from farmers within the included literature.

Literature suggests a mutual focus on the importance of communication skills when addressing AMU and AMR (**Figure 1**, extrinsic, common factor, "Information and communication"). A lack of communication skills [(32), p. 14] and communication on the topic in general was highlighted by both veterinarians and farmers [(71), p. 370, (60), p. 4, (38), p. 3496]. Relevant stakeholders in Ireland have requested more information on AMR and for this to be communicated in an effective way [(35), p. 5].

Lastly, "Diagnostics" (**Figure 1**, extrinsic, common factor), including availability, prices and usefulness, leads to frustrations among both veterinarians and farmers. Interviewed farmers from New Zealand were not convinced of the usefulness of bacterial culture since their veterinarian's prescriptions were not affected by the results [(30), p. 86]. Several studies identified limitations in the diagnostics available, e.g., due to costs, sampling difficulties, the time required, the variable and multiple pathogenic results, and the veterinarians' own experience conflicting with the results [(29), p. 43, (64), p. 3, (32), p. 8, (74), p. 4, (44), p. 6]. However, the literature suggests that both veterinarians and farmers agree that valid diagnostics are important and should be implemented further [(35), p. 4–5, (31), p. 9, (36), p. 3236, (64), p. 4, (32), p. 8, (74), p. 8–9].

Several "Knowledge, Skills & Ability"–based factors are therefore important when looking at the resources required to assist a change in AMU according to veterinarians and farmers, and both groups seem to be concerned about the same factors. However, communication remains important as the individual farmer or veterinarian might have different needs [(77), p. 1303–4]. One could imagine a newly educated veterinarian being employed as the herd consultant at a farm with no history of using diagnostics in mastitis treatment. In this case, the veterinarian might not need knowledge of AMR. However, the veterinarian might perceive that the farmer lacks knowledge about both mastitis diagnostics and AMR. Only through communication and by striving to understand each other's perspectives can they agree on a plan that both parties accept.

As with the other identified factors, not all the "Knowledge, Skills & Ability"–based factors are of equal relevance across all countries. It is possible to imagine that there are different traditions in the use of diagnostics, physical frameworks of farming and the level of knowledge about AMR across different countries. Therefore, it is important to contextualise according to national conditions.

CHANGES IN ANTIMICROBIAL USE FROM INDIVIDUAL VS. SOCIETAL PERSPECTIVES AND FUTURE PROSPECTS

This review of relevant factors in the journey towards rational AMU in dairy cattle herds within a VHHC setting has shown that veterinarians and farmers emphasise more national-oriented solutions as well as those related to the local collaboration. Examples include the request for support from the dairy industry and sector organisations, as well as a revised VHHC framework. In addition, there was a call for balanced legislation on AMU that will not compromise animal welfare or herd finances, and a new discourse on AMU in media and among consumers. These are all examples of areas in which national or structural solutions are demanded by farmers and/or veterinarians.

As mentioned in the introduction to the methodology used in this article (section Overview of Factors Affecting the Intention to Move Towards Rational Antimicrobial Use: A Socio-Ecological Model), the focus on individual behavioural change as a way to reduce AMU, as embedded in the Theory of Planned Behaviour, has been criticised. Instead, there is an emphasis on the need to understand the structural dimensions related to AMU. However, the literature on which this review is based has illustrated that farmers and veterinarians call for both approaches. Due to the type of research, e.g., interview studies that take the individual farmer or veterinarian and their perspectives as a starting point, much of the included literature tends to focus on conclusions at the individual level. These individual solutions will be relevant in an everyday situation, as well as being the continual focus of the local VHHC. However, the factors mentioned by farmers and veterinarians in the included literature, which lie beyond the framework for individual action and in their opinion call for national and international solutions, underlines the need to elaborate the farmer–veterinarian collaboration and include and understand the relevant context. To study these elements, there is a need for a change in research methodology.

Researchers within the field of social sciences have used other methodological approaches to understand the field or the context surrounding AMU. They often take a societal starting point as opposed to an individual one by mapping e.g., the discourse (25), actors and stakeholders (76), social and biological processes (78), infrastructure (28) and networks (54) relevant to AMU.

The approach in this article is reminiscent of a societal approach. We used a model that originally built on the Theory of Planned Behaviour as a structural framework to map all the relevant factors for farmers and veterinarians, and to outline the differences and potential challenges these differences can cause in the VHHC collaboration. However, it is clear from social science research within the area that the context includes more than just national differences in e.g., legislation, the economic model and daily tasks of veterinary practices, available diagnostics and medicines. It is also about discourse and connections between historical, economical and farming structure developments and social and biological processes (25, 27, 78, 79). These structures and developments all become entangled in the individual veterinarian's or farmer's lifeworld, as well as in their mutual collaboration.

The literature that met the inclusion criteria of this review was primarily conducted within the veterinary research area. It investigates farmers' and veterinarians' perception of AMU and their possibility to change it within the VHHC setting. Analysis of the literature has clarified that there is more at play in the farmer–veterinarian collaboration than just economic and rational considerations. Social and cultural norms in the form of specific "rules of the game," a ritualised AMU, different perceptions of risk, a "prescribing etiquette," "the good farmer," "the good veterinarian," "treatment culture" and emotions such as frustration and fear could potentially shape the collaboration and the possibility to change AMU. The modified Theory of Planned Behaviour used in this article has not directly exposed nor explained any of these mechanisms, rather it has thematised the factors of importance. These factors have been explained and elaborated further through theoretical concepts to better understand the context surrounding the farmer–veterinarian collaboration when working with AMU.

As a result, there is a need for more studies with a focus on both individual actions and the structures surrounding them. The individual actions are those relevant to the daily life of a veterinarian and a farmer working together and making individual and collaborative decisions on AMU. However, the structures surrounding them are just as important as they permeate and affect their local realities. We have limited knowledge on the effect of changes in social and biological processes on farmers' and veterinarians' motivation and AMU levels over time. Therefore, studies conducted in the intersection of qualitative and quantitative research to investigate the actual level of AMU and the motivation to change this over time within the HHM setting are needed.

Furthermore, there is a need to combine the methodological approaches of veterinary and social science literature. A more holistic approach, intertwining the theoretical perspectives of the two research areas, will work synergistically to address the required change in AMU in dairy cattle. The research should acknowledge the fact that everyday decisions and actions related to AMU lie in the collaboration between farmers and veterinarians. However, this must be combined with reflections on the effect of the outside world, which surrounds and defines the farmers' and veterinarians' local mode of action.

CONCLUSION

We have summarised the available international literature on factors that influence farmers' and veterinarians' intention to use antimicrobials rationally. This has made it easier to interpret this knowledge in relation to VHHC, which comprises one of the primary settings for working with rational AMU in the production animal sector. Awareness of the identified factors within VHHC can improve the effort to reduce AMU. New perspectives have nuanced the understanding of why and how many of the identified factors are at play within this collaborative context. Important topics have been identified, such as social norms including pressure from social networks, diverging risk perceptions and the importance of trust in the working collaboration. This highlights the importance of communication in improving the understanding of other people's perspectives as well as common goal setting within VHHC. We have identified that not all factors are of equal interest across countries, e.g., legislation and types of advisory services. Moreover, the economic models for veterinary practices differ from country to country, affecting the specific meaning and importance of a given factor.

The included literature and research, which was conducted primarily within the field of veterinary research, focuses on the individual farmer and/or veterinarian and their perspectives on AMU and potential for change within the VHHC setting. However, the review study has identified a request from both farmers and veterinarians for national or international solutions to the AMR problem, for example support from the industry and a new discourse among consumers and media. These solutions go beyond an individual's frame of action. Within the field of social sciences, there has been a focus on the structural dimensions related to AMU, supporting the need for and investigating these national and international perspectives. We argue that future research would benefit from a combined focus on the individual and collaborative actions of farmers and veterinarians within the VHHC setting that frames the everyday choices of AMU in intensive dairy farming. However, the overall structural framework (historical, biological, economical, etc.) surrounding and defining the actions of farmers and veterinarians must also be considered. We have therefore identified a need for studies that bridge the theoretical perspectives of veterinary research and social sciences to understand the potential to change AMU within VHHC in dairy cattle farming.

AUTHOR CONTRIBUTIONS

NS, DL, and LN contributed to the design and conception of the review study. The literature search was conducted by NS. Analysis and discussions of the included literature were performed by NS, DL, CJ, and LN. NS produced the first draft of the article, which was redrafted, and edited by DL, CJ, and LN. All authors contributed to the article and approved the submitted version.

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Alternative Medicines on the Farm: A Study of Dairy Farmers' Experiences in France

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Despite being of debatable efficacy, alternative medicines are in regular use on both organic and conventional dairy farms as part of a strategy for limiting the on-farm use of antibiotics. The study presented here examined French dairy farmers' understanding of and experiences with these medicines, focusing on homeopathy, aromatherapy and phytotherapy. Adopting an interdisciplinary approach combining animal science and sociology, we considered how dairy farmers' use of alternative medicines fits into a holistic approach to herd health management, on the one hand, and into farmers' networks of professional relationships, on the other. Our findings show that farmers are interested in alternative medicines for reasons that are at once technical, ethical, and economic. In the absence of local veterinarians specializing in homeopathy and aromatherapy, farmers enroll in short-term training courses to learn how to use these medicines. Alternative medicines are not a substitute for conventional medicine for these farmers; rather, they constitute one part of a holistic approach to herd health that combines preventive measures with a variety of curative treatments, and which is grounded in close attention to the animals' state of health. Farmers make use of guidelines for observing livestock that are central to the veterinary alternative medicine approach. Interestingly, women farmers appear to play an important role in introducing these practices into the management of the farm operation. Finally, farmers' interest in alternative medicines is indicative of their broader expectations for advice and support in moving toward the integrated management of livestock health, a key element of the agroecological transition. Recognizing these expectations offers useful insights for rethinking the role of veterinarians in dairy farming.

Keywords: homeopathy, essential oils, holistic approach, animal health management, comprehensive investigation

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INTRODUCTION

Stricter regulations for the use of antibiotics in livestock production were introduced in Europe in 2015 to help limit the spread of antimicrobial resistance (AMR) and preserve key antimicrobials for use in human medicine. The objective is to move toward a more prudent use of antibiotics for animal health on farm. In the bovine dairy sector, researches have shown that there is still inappropriate use of antibiotics, especially for udder health management (1, 2). Better adherence to treatment doses and durations, treatment thresholds or less systematic use of antibiotic therapy, especially for the drying up of dairy cows, are ways to reduce the amount of antibiotics used (3).

Some scientific studies focused on the behavior of farmers with regard of antimicrobial use (AMU) in order to understand the reasons why they do not follow the general recommendations even when they are aware of them. These studies highlight the importance of local standards amongst farmers (4), as well as the economic and working time constraints that farmers face (5). AMU on farm is also directly influenced by attitudes of advisors, especially veterinarians, and regulations (6). In general, veterinarians, who are the main prescribers of antibiotics in animal husbandry, are considered key stakeholders in accompanying farmers to move toward prudent use of antibiotics (7, 8). Various studies suggest ways to improve collaboration between farmers and veterinarians on the issue of AMR (9, 10).

Another strategy to reduce AMU that is suggested by public policies is the promotion and the development of alternatives treatments. However, the notion of "alternative" is poorly defined and remains vague. In the French action plans that have been implemented to fight against AMR, the term "alternative" covers a wide variety of products and methods: preventive products such as vaccines, food supplements (probiotics), treatment products other than antibiotics such as macrophages or herbal products (phyto- and aroma-therapy) (11, 12)[1]. The use of "alternatives" is also considered by agricultural stakeholders as a way to limit AMU for animal health management. Studies conducted on farms engaged in AMU reduction trajectories show that the farmers commonly use phytotherapy and aromatherapy, but also homeopathy (3, 13). Although no general statistics on the subject exist, a variety of local surveys point to the importance of this phenomenon. In France, for example, according to Le Guénic (14), 19% of conventional livestock farmers and 72% of organic livestock farmers in the region of Brittany were using homeopathy and/or aromatherapy. According to a recent European study, homeopathy is regularly used on organic farms in Germany, Switzerland, Norway, and Greece (15). As these figures suggest, it is in the organic farming sector that alternative medicines are most widely used. Indeed, alternative medicines are cited in organic certification regulations as preferable to antibiotics, provided their efficacy has been shown (Council Regulation (EC) n°837/2007).

The question of the effectiveness of alternative medicines has been a focus of intense debate, however, both in the scientific community and among professional veterinarians. Veterinary homeopathy[2] is among the most controversial areas, since clinical research trials have so far failed to definitively establish its effectiveness. For some, this is proof of homeopathy's lack of value (16); others argue that more research should be done (17).

The terms of the debate are different for phytotherapy and aromatherapy,[3] both of which are based on traditional knowledge. Ethnobotanical studies have inventoried the different types of plants used by farmers to treat their livestock (18, 19). Here too, however, more research is needed, since the therapeutic properties of many plant species have not been determined scientifically. Questions have also been raised concerning the potential toxicity of some plant-based medicines, both for the animals being treated and for the human consumers of livestock products (20).

Given the lack of scientific information as to the risks and benefits of alternative forms of veterinary medicine, how can we understand farmers' interest in these practices? Why and how do farmers adopt these treatment methods, despite the fact that such methods are rarely recommended by veterinarians (21)? Do such treatments really constitute viable alternatives to antibiotic use, or do they in fact have no effect on animal health? Although some research (22, 23) has found that the use of alternative medicines does not add to farmers' management costs, this is not enough to conclude that they are effective.

The research described here sought to examine dairy farmers' uses of alternative medicines as a way of better understanding their interest in these treatment methods. We focused on homeopathy, aromatherapy, and herbal medicine, since these are the types of alternative medicine most widely used in France.[4]

Our goal was to move beyond an exclusive focus on farmers' motivations—an approach that has previously been explored [(23, 24)]—and toward a more detailed understanding of the livestock management practices associated with the use of alternative medicines to treat animals on the farm. To do so, we needed to reposition these practices within farmers' socio-technical and socio-professional systems. We thus adopted an interdisciplinary approach, combining a livestock farming systems perspective (25) with a sociological framework (26) to examine how the use of alternative medicines fits into farmers' overall management of herd health, on the one hand, and into their networks of professional relationships, on the other.

MATERIALS AND METHODS

This article is based on three distinct datasets from three different field studies conducted in different parts of France (Franche-Comté, Normandy and the Grand Ouest), within the framework of separate research projects. The methods of data gathering and analysis were qualitative: the goal of this article is not to provide a quantitative account of the phenomenon under investigation,

[1]The French action plans implemented since 2012 to fight against AMR in veterinary medicine are presented on the website of the French ministry of agriculture (https://agriculture.gouv.fr).

[2]Homeopathy is a therapeutic method developed by Samuel Hahnemann from the end of the eighteenth century. It is based on the so-called "doctrine of similars"– the idea that any disease may be treated with dilute preparations of substances that would ordinarily (in healthy individuals, in undiluted form) produce symptoms similar to those associated with the disease. Most homeopathic remedies are based on plant extracts, although some are made from animal products. Homeopathic medicines are typically administered in the form of granules or liquids.

[3]Phytotherapy seeks to treat or prevent diseases using medicinal plants (whole plants or plant parts, dried or fresh). Aromatherapy is based on the use of plant extracts in the form of essential oils.

[4]Most phytotherapy and aromatherapy products are not considered medicines under French law and are thus not authorized for use for therapeutic purposes. They are usually marketed as dietary supplements by the companies that make and sell them. Homeopathy occupies a more ambiguous position under French law: homeopathic remedies may be sold as medicines but are not regulated for veterinary use. Livestock farmers in France typically purchase homeopathic remedies from pharmacies; most veterinary practices offer few if any homeopathic products for sale.

but instead to assess its variations (27). Compiling data gathered within the context of three distinct research projects in different regions enabled us to review a wide range of uses of alternative medicines by dairy farmers in France.

The first two datasets come from ethnographic research conducted in Franche-Comté in 2016 (COPPECS project) and in Normandy in 2017 (Normandy region project) (In the remainder of this article, we will refer to these as Study FC and Study N, respectively). Our methods consisted of comprehensive interviews with farmers and with the instructors of farmer-training courses, in addition to phases of participant observation. Our objective was to study how breeders use alternative approaches of animal health on their own herd.[5]

For Study FC, we conducted eight comprehensive interviews: six with individual dairy farmers in Franche-Comté who had completed one or more training courses in animal health; one with a facilitator at an agricultural training center; and one with a veterinarian who offers homeopathy trainings. We identified interviewees with the help of intermediary organizations (not specific to organic farming) that offer short courses for farmers in animal health. We selected the farmers to be interviewed from the lists of participants in these training courses. This strategy enabled us to identify dairy farmers who regularly use homeopathy and/or herbal medicine and aromatherapy to treat their animals. We also participated in a group discussion day for dairy farmers on the topic of herd health management. Study N was conducted in collaboration with an agency providing technical advice and support for farmers that was seeking to improve its services relating to animal health. Over the course of one year, we followed a group of six dairy farmers (men and women) who were meeting regularly with an advisor to discuss holistic approaches to herd health. Having originally met through training courses in aromatherapy, these farmers wanted to learn more about other alternative methods for livestock health and to engage in peer-to-peer discussions about herd health management. We attended three meetings of the group during the year and conducted individual interviews with two of the farmers.

In these two geographic study areas, the interviews we conducted with the farmers were sociotechnical in nature; that is, we were interested both in the farms' herd health practices and in the farmers' understandings and descriptions of animal health. The interviews also included a section on the farmers' connections with their socio-professional environment.

We constructed an interview guide listing the different topics to be covered in our interviews with the farmers. Questions were open-ended, giving the farmer the opportunity to speak at greater length on the subjects he or she felt were important as well as to raise new topics we had not initially asked about.[6] These interviews were recorded, transcribed in full, and then subjected to a content analysis using the Grounded Theory method (28), with the goal of understanding the farmers' perspectives on their experience. Following an inductive process, and using the farmers' practices and points of view as a starting point, we constructed an analytical grid highlighting the key themes that emerged from the interviews.

The analytical grid was developed in several steps. First, we defined broad themes based on the elements we had sought to examine; for each theme, we identified the relevant sections of the interviews. Next, within each broad theme, we identified a number of sub-themes based on the interview material. Here we followed an iterative process, going back and forth between the interview material and the analytical grid, eventually arriving at a stabilization of how the themes and sub-themes were designated. For example, in the initial grid we designated homeopathic practices, aromatherapy practices, and phytotherapy practices as three broad themes. In re-reading the interviews, however, we observed similarities in the approaches to livestock health management associated with these different types of medicines, including the central importance given to observation of the animals. We therefore decided to designate a broad theme relating to animal observation and then to distinguish sub-themes for the types of medicine in order to identify the variations in observational techniques associated with homeopathy, aromatherapy, and phytotherapy.

In the Grounded Theory method, the process of data interpretation is achieved through the construction of the analytical grid. The research results presented in the following section are therefore organized according to the themes and sub-themes defined in the final phase of the analysis. Studies FC and N enabled us to analyze how farmers access these forms of alternative medicine through training opportunities, and how they then implement the techniques they have learned on their farms. The interviews conducted with the other actors (group leader, veterinarian) and the observations of group situations enabled us to better understand the social context within which familiarity with alternative medicines is acquired by dairy farmers.

This analytical grid was then put to the test of analyzing the data from the third set of interviews, conducted in 2015 in the Grand Ouest[7] (Brittany and the Pays de la Loire) as part of a study of the use of homeopathy on organic dairy farms (European project IMPRO). We will call this Study GO.

Study GO included 15 interviews with bovine dairy farmers who had converted to organic production and who were using or had used homeopathy to treat their herds. Interviews were conducted either with or without the farmers' veterinarian present. Interviewees were identified with the help of agricultural advisors and technicians specializing in organic farming, or through rural veterinarians. These interviews sought to examine farmers' practices in veterinary homeopathy and their views

[5]The first and second authors on this paper completed the field work in Franche-Comté as a team; the first author alone conducted the field work in Normandy.

[6]For example, some dairy farmers who were using homeopathy sought to explain to us in detail their methods for observing sick animals, showing us the kinds of notes they make and giving specific examples.

[7]The third author on this paper conducted the interviews in the Grand Ouest with the assistance of a homeopathic veterinarian. The idea for writing this article emerged from an informal discussion among the three authors: the first and second authors proposed to the third the idea of pooling and comparing the three datasets, applying the analytical grid developed in the first two studies to the data from the third.

about this type of medicine more broadly. The first part of the interview took the form of a questionnaire[8]; the remainder was more open-ended, inviting the farmer to express why he or she became interested in homeopathy and the role homeopathy plays in the farm's overall management of herd health. The presence of the veterinarians did not constitute an impediment to free expression on the part of the farmers. On the contrary, we observed that the farmers did not hesitate to speak openly about their practices with regard to homeopathy, even when the veterinarians considered those practices out of line with their recommendations. In addition, the farmers defended their views with regard to the advantages and disadvantages of homeopathy, notably in situations where they disagreed with the veterinarians.

The semi-directive portions of the interviews were recorded and transcribed in full. These sections were then analyzed using the analytical grid developed for the first two datasets. The analytical grid proved to be robust: the themes and sub-themes did not need to be modified. We were thus able to enrich and refine the results by adding these interviews with organic dairy farmers, whose experiences with veterinary homeopathy is notably different from that of non-organic dairy farmers. Data saturation was achieved by combining and comparing the results of these three studies.

The analytical grid that emerged from this work featured the following themes:

- Why the farmers became interested in alternative medicines; and what steps they took to learn more about these different approaches and treatments
- The most important herd health issues on the farm; methods used to address these issues; any recent changes in this regard
- The different alternative medicines used on the herd; for which kinds of health problems; and the advantages and limitations of these methods
- Any other management changes made on the farm to address herd health
- Use of local veterinarians and/or other advisors on livestock health

In addition, we gathered factual data on the basic characteristics of the farms and their production systems, including herd size, number of employees, and participation in various quality schemes (organic, geographical indications, etc.).

RESULTS

Study Sample

The combined study sample (made up of data from Studies FC, N and GO) consisted of 23 farms specializing in milk production, the large majority of which (21) were certified organic. Four farms were producing milk for Comté, a cheese that enjoys PDO (protected designation of origin) status and is subject to specific production requirements and quality specifications. One farm was both organic and a milk producer for Comté. Only two farms, both located in Normandy, were not enrolled in a quality-assurance certification program.

Herd size ranged from 37 to 130 milking cows (average herd size in France is 59 milking cows). Breeds of cows varied considerably: only two farmers, both of them organic and both located in the Grand Ouest, had herds made up exclusively of the breed known as Prim-Holstein (the French sub-type of the Holstein breed), the leading dairy breed in France. The farmers in Franche-Comté and in Normandy were all milking the breeds specific to their respective regions, Montbéliarde in Franche-Comté and Normande in Normandy. The remainder of the organic dairy farmers interviewed had herds made up of various breeds, including mixed-breed animals in some cases.

The number of employees per farm ranged from one to four man-work units (MWU)[9] with an average of 2.35 MWU (the French national average for dairy operations was 2.18 MWU in 2016) (29). Eleven farms employed two people, usually a husband and wife owning and operating their farm together.

The individual(s) we met with at each farm were the person or persons primarily responsible for herd health. Eight interviews were conducted with a female farmer only (three in Franche-Comté, two in Normandy, and two in the Grand Ouest); ten with one or more male farmers (three in Franche-Comté and seven in the Grand Ouest); and five with a couple working together on the farm. We can see from these numbers that women farmers play a significant role in the management of herd health.

A Different Approach to Care

The farmers we interviewed explained that their interest in alternative medicines emerged from a desire to take a different approach to livestock health—specifically, one that would be less reliant on antibiotics. For the organic farmers, certification rules require that they use antibiotics more sparingly; but both organic and non-organic farmers emphasized economic motivations for their interest in alternative medicines. Antibiotics and conventional veterinary medicine in general were described as very expensive. When antibiotics are administered to a milking cow, moreover, its milk has to be dumped for a period of several days, resulting in a loss of revenue. Farmers also underscored the high veterinary bills associated with a herd that is not in good overall health. One female farmer expressed the fear that some antibiotics currently used on dairy farms may be prohibited in the future.

In addition to these economic motivations, the farmers we interviewed emphasized concerns relating to their animals' welfare. Many said that they don't like administering injections. Adopting a different approach to veterinary care thus also meant choosing medicines that were less painful for the animals. Farmers' explanations frequently interwove economic

[8]The questionnaire included detailed questions relating to herd management (preventive measures such as hygiene and careful monitoring of the herd, choice of allopathic and homeopathic treatments for the most common herd health issues) followed by a series of statements relating to the risks of antibiotic resistance and the value of homeopathy for addressing these risks (farmers were asked to indicate if they were more or less in agreement with these statements). Data from this portion of the third study are not addressed in this article since we had no analogous data from the other two studies.

[9]MWU is a measurement of work hours in agriculture: one MWU corresponds to one person working full-time on the farm operation.

motivations with ethical motivations, as is evident in the following exchange:

Researcher: What made you want to take these types of training courses?

Farmer: Well, in the first place because it is less expensive. And then also because I'm convinced there are other ways to take care of the animals than… just giving them shots. We don't use any vaccines for our animals either. I don't believe in giving the animals injections all the time. There's no need for it.

(Interview with a female farmer in the Jura, February 2016)

Farmers' interest in alternative medicine is thus inscribed within a larger questioning of how dairy animals should be cared for. For the farmers we interviewed, the goal was not simply to substitute one type of medicine for another, but rather to change their approach to animal health: placing more emphasis on limiting risks to animal health, interpreting those risks differently, thinking more about prevention. In Franche-Comté, the farmers we interviewed had taken a number of different training courses relating to animal health, including alternative methods (acupuncture, osteopathy) and preventive methods (feeding programs, ways of managing calves, etc.). In Normandy, the women farmers we met with had begun by taking courses in aromatherapy, but at the time of our study had also become interested in other alternative methods.

We also observed that this questioning of dairy management practices tended to emerge at a particular moment in a farmer's career—a point at which inherited or previously established farming practices could be reconsidered. Thus, for seven of the farmers we interviewed (five women and two men), pursuing training courses in alternative methods coincided with starting a farm, taking over the farm from a relative, returning to the farm after a period away, or otherwise making a new investment in a farm operation. In the interview excerpt below, for example, the (female) farmer started farming with her husband when her father-in-law retired. She decided to focus on animal health in part because she wanted to change the way her father-in-law had managed the calves:

Researcher: So, you had what you needed to start farming. Did you have to do some new training?

Farmer: No, no, these were courses for a PPE.[10] *You do that for 5 years, it's required, but I found it interesting. And then I did a training course on calves because I realized I missed that, since my father-in-law was in charge of them before. When I arrived, he said to me: here, you take the baby (laughs). but the way he managed the calves'health… it didn't fit to me, I felt it was too abrupt, I had to find solutions to manage it differently*

(Interview with a farmer in the Jura, February 2016)

[10] A PPE (*plan prévisionnel d'exploitation*, or future farm plan) is established when a farmer receives from federal subsidies to begin farming. The PPE can specify various obligations on the part of the farmer, including taking additional training courses.

For some of the organic farmers we met with, a desire to change their approach to herd health helped prompt their decision to transition to organic, while for others, it emerged as a consequence of their shift to organic. For one part of organic farmers we interviewed, participation in training courses on alternative approaches to herd health predated by several years their decision to convert to organic: for them, organic agriculture was the realization of a longer-term commitment to changing their livestock management practices and in some cases their crop management practices as well.

Farmer: In any case, when I started practicing homeopathy–it was long before we went organic, and there were no regulations then.… It was more an issue of animal health that got me into homeopathy… and animal welfare, more than anything else.

(Interview with a dairy farmer in Ille-et-Vilaine, December 2014)

Other organic farmers first learned about alternative medicines during the transition period—often through participating in training courses and discussion groups with other organic dairy farmers, or other farmers transitioning to organic. Indeed, one of the major concerns for farmers converting to organic is finding therapeutic alternatives to the use of antibiotics, with the objective of complying with the requirements of the organic farming specifications.

Farmer-Training Programs as an Entry Point for the Use of Alternative Medicines

Training courses relating to animal health, generally offered through agricultural organizations and agencies, were the principal route by which farmers learn how to use alternative medicines. Usually these take the form of short training courses, from one to several days in length, scheduled in the winter when farmers' workloads are relatively light. The farmers we met with in Franche-Comté all learned how to use alternative medicines for the management of herd health thanks to courses offered through the regional adult agricultural education agency. In Normandy, one of the women farmers we interviewed first learned about veterinary aromatherapy from an article in a professional agricultural journal. She tried using the techniques on her own, but without success. Then she saw a notice in the local agricultural newspaper that an alternative agriculture technical organization in her region was offering courses in veterinary aromatherapy. The other female farmer we interviewed in Normandy learned about these courses from a neighboring organic dairy farmer who had participated in the trainings previously. Of all the farmers in Study GO, only two did not receive any short training on alternative medicine. All the others famers interviewed in the Grand Ouest had learned about alternative medicine via training courses offered through professional organic dairy organizations. For the most part, the instructors for these courses are veterinarians specializing in homeopathy or phytotherapy who travel throughout France to teach courses of this type. Other professionals are sometimes also involved, including a psychologist trained in naturopathy who has developed his own approach to the use of aromatherapy to treat farm animals. As we saw when we participated in the training days, the instructors for these courses emphasize a holistic approach to animal health—their presentations are not limited to the use of alternative treatments based on homeopathic granules and essential oils. They also address broader topics such as how to properly observe an individual animal's condition, how to detect early signs of health problems, and how to use preventive methods to minimize health issues.

The central role of short training courses as an introduction to the use of alternative medicines stands in contrast with the weakness of other forms of advisory services and technical support for alternative veterinary medicines in the regions where we conducted our research. The farmers we interviewed typically only called their local veterinarians in emergencies or for the most serious health problems. They said they didn't speak to these vets about the alternative medicines they were using; or if so, only rarely. One farmer in the Grand Ouest, for example, lamented the lack of interest in alternative medicines among the veterinarians belonging to his local practice:

> *Researcher: Can you call a veterinarian to treat an animal using homeopathy?*
>
> *Farmer: No, unfortunately. Here, we have no one.… That's it; I can't look to my local vets for help! It's not even worth trying.*
>
> *(Interview with a farmer in Ille-et-Vilaine, December 2014)*

A few farmers were able to call on the services of a homeopathic veterinarian located near their farms. This was the case for two male organic farmers in the Ouest and for one female farmer in Franche-Comté. The other farmers we met with had no access to a homeopathic vet in the rural veterinary practices in their area. For aromatherapy, no local advice was available for any of the farmers we interviewed.

Thus, as there is very little individual service offer in alternative medicine, short training courses are the main way for farmers to access to alternative medicine. Following the trainings courses, important connections can be forged between farmers and course instructors. Some farmers had taken several courses with the same instructor. Two levels of veterinary homeopathy, "introductory" and "advanced," are typically offered for farmers. Among the aromatherapy group we followed in Normandy, the farmers met once a year with the instructor or with another individual trained in the instructor's approach. They used this time to review treatments that had worked for them, specific challenges they had encountered, or health issues they were contending with more generally. The instructor would ask the farmer about the symptoms they had observed, and could thus restate the key points to be observed in assessing an animal's health. The instructor could also review hygiene practices and dietary strategies to minimize health problems.

Another type of connection can also develop between famers and course instructors through the use of remote advisory services. Following training courses in veterinary homeopathy, one organic dairy farmer in the Grand Ouest and one dairy farmer in Franche-Comté stayed in touch with the veterinarian-instructor for individual advice. In the case of the Franche-Comté dairy farmer, these advice sessions were conducted with the veterinarian in person, on an annual visit to the farm—together, the farmer and the vet would review the herd's health and discuss additional preventive measures to put in place. For the two Grand Ouest dairy farmers, further advice from this veterinarian took the form of telephone conversations concerning a specific health issue with sick animals.

Farmer-to-farmer discussion groups are another means by which the connections established in training courses can be extended. We identified one such group in Franche-Comté (to which three of the female dairy farmers we interviewed belonged), focused on the topic of homeopathy. A male dairy farmer we met with in Maine-et-Loire belonged to another group focused on various aspects of herd health management, including homeopathy. The goal of these groups was to share successes and failures in herd health management, to improve farmers' observational skills with their animals, and to extend their knowledge of different homeopathic remedies. In these groups, farmers try to follow the "unicist" principle of homeopathy, according to which the remedy is determined by the animal's individual characteristics and the manner in which the disorder presents itself, not simply by the disorder itself or the underlying disease agent. The farmers keep notes on each animal they have treated using homeopathy, so as to have detailed, individualized account of herd health problems. These notes support in-depth discussion about famers' use of homeopathy. Generally speaking, however, the content of these farmer-to-farmer exchanges related to all aspects of herd health, not just the use of alternative treatments.

In this way, the training courses are the starting point for new relationships between breeders, and new collaborations between breeders and specialists in alternative medicine. These training courses are also a place of information on suppliers of herbal or homeopathic products. Most farmers buy the products that have been advised to them in training. Sales technicians that sell ready-to-use products made from dried plants or aromatic extracts can also advise farmers on their use. Some of the farmers we interviewed said they consult these individuals and purchase their products to address specific risks to herd health.

Farmers' Uses of Alternative Medicines Are Diverse

We observed a wide variety of ways in which alternative medicines are used by dairy farmers to manage herd health. This diversity of practices is manifested first of all in differences in the level of understanding of these medicines: some farmers always used the same remedies for the same problems, while others sought to tailor each treatment to each case by closely studying the animal's condition.

These differences in approach in turn depended on the farmer's level of personal investment in learning about the techniques. Some farmers used the training courses to acquire a handful of "recipes" or simply purchase ready-made products: these might be mixtures of essential oils or homeopathic "compounds." In the following interview passage, for example, the farmer explains how he uses several products containing essential oils to treat udder problems:

Researcher: And then you use herbal remedies… say for mastitis?

Farmer: For mastitis. During the lactation.

Researcher: And the product is… ?

Farmer: There are two products… I mix them and then I put them down the cow's throat… It's from APA, it's an anti-infective… it's [the brand name] Gentiana.

Researcher: So, it's an phytotherapy, is that right?

Farmer: Yes, and then the other one is… Arobactole? Let me look, I can't remember! Here, it's Symbiopole, I mix these two products and…

Researcher: Ok. And so you do that as soon as you notice… ?

Farmer: As soon as there is mastitis…

(Interview with a male farmer in Haute-Saône, February 2016)

Other dairy farmers take steps to further advance their expertise in alternative medicines. As we have seen, acquiring expertise in alternative medicines is a long process, typically involving multiple short training courses and, in many cases, participation in a discussion group.

The diversity of uses of alternative medicines is also manifested in the ways farmers combine different alternative medicines together and with conventional medicine. All of the farmers we interviewed used a variety of therapeutic approaches, either in parallel, for different types of health issues, or for a single type of health problem in the herd. All also continued to use antibiotics, although they reserved them for the most serious cases: antibiotics were either administered immediately for animals with the most serious symptoms, or kept as a backup strategy if a homeopathic or aromatherapy treatment proved ineffective. Some farmers also combined different types of alternative medicines. Among the 15 organic dairy farmers interviewed with respect to their use of homeopathy, for example, two also used aromatherapy, either at the same time as homeopathy, or for different types of problems among the herd.

For example, in the interview selection just cited, the farmer said he uses two herbal products to treat mastitis. He went on to say that about half the time, he also has to use an antibiotic:

Researcher: APA and Arobactole. The two together?

(…) Farmer: 50 ml of APA and then 75, 70… yes, about 70… of the other.

Researcher: Ok, got it. In the infected quarter?
Farmer: No, no: for that, you grab them and put it down their throat. That one is an oral solution. You use the gun … And then if that doesn't work, then we go to Mastijet… we go to the antibiotic.

Researcher: Ok. And does that happen often, that you have to use Mastijet?

Farmer: We have very, very few…. that is, now we have almost no … It's the related factors: we have lower cell counts, so for mastitis, we probably have… maybe not even 20 per year.

Researcher: Cases of mastitis where you use essential oils?

Farmer: Cases where we use a treatment, yes. There are not even 20 per year… So you can put that there are 50%, I think that… for about 50% of the cows, it will work. For 50% we go to antibiotics.

(Interview with a male organic farmer in Haute-Saône, February 2016)

In Franche-Comté, where the dairy farmers we met with regularly participated in short training courses on animal health, one farmer said he would call an osteopath for animals showing signs of lameness, or to check on a cow and calf following a difficult birth. One female farmer we met with practiced acupuncture in addition to using homeopathy, herbal remedies, and aromatherapy. In the passage given below, the researcher is asking the farmer about the treatments she uses for different health problems. She uses aromatherapy for mastitis, homeopathy for metritis, and in some cases both homeopathy and osteopathy for lameness:

Researcher: For example, for mastitis, is there a type of mastitis where you would normally use homeopathy and another type where you would do something else?

Farmer: No. For any case of mastitis, I always use aromatherapy. For now, it works. But I don't have many, either… Once I had to bring in [the veterinarian] for a mastitis caused by a pathogenic E. coli and the animal was really in a bad way and at the time… Well, it was really at the beginning for me [using homeopathy] and I thought, I'm not going to tackle this on my own because she might not recover. So that was the one time where… she was lying down and… not doing well at all.

Researcher: Metritis, in general, can that be treated with homeopathy?

Farmer: Yes.

Researcher: And lameness, do you have cases of lameness where you call the vet?

Farmer: The osteopath.

Researcher: Oh, the osteopath.

Farmer: Yes. Because for lameness, I begin with… Well, in the first place, I don't always know if it is a paronychia, or if it's… So I always start with Pyrogenium. Right away, I see if that has an effect or not. Then there can also be lameness after calving, so then I would give Hypericum, or things that are more… you know, if I think there is a problem. I use Arnica after almost every calving.

And then, well, you know, afterwards, if that hasn't worked, if I don't see that the hoof is swollen, all that, I call the osteopath. Yes. In fact we never have the vet come for lameness, really.

(Interview with a female farmer in Mayenne, January 2015)

The use of different therapeutic approaches to animal care thus involves choosing among different types of possible assistance, corresponding to different methods: the local veterinarian is called in for emergencies and the most serious cases; specialists such as the osteopath may be called in for some specific types of problems; some farmers remain in contact with the veterinarian/course instructor for telephone consultations or occasional farm visits; while the farmer him- or herself administers some treatments, including alternative medicines, after having taken a few courses.

Alternative Medicines in the Overall Management of the Dairy Operation and Herd Health

For many of the farmers we interviewed, animal health was a central preoccupation; alternative medicines were simply one tool among others within a holistic approach to herd health. Indeed, when we reposition the use of alternative medicines within overall herd management, we can see that dairy farmers use a variety of different measures to reduce health risks. Particular attention is paid to managing the cows' diet so as to limit health problems, especially metabolic disorders linked to milk production (acidosis, metabolic problems associated with calving, etc.). More broadly, we see that the overall improvement of herd health is linked to preventive measures that correspond to changes in livestock management: better management of feeding, particularly by adjusting the nutritional balance of the ration using the Obsalim® method[11]; and changes in housing to improve the animals' comfort and minimize unhealthy conditions.

At the same time, the farmers we interviewed emphasized that learning about alternative medicine had taught them how to observe their animals more closely and more precisely, and to identify signs of health problems they were unaware of before:

Male farmer: In fact, I have learned… even if I am not… anyhow, I'm not going to brag about my skills in homeopathy! But… but still. I will say that for me the big advantage of the homeopathic approach is that I have learned to observe my cows. That's the most important thing for me! That's what homeopathy has done for me. At first, it's that… it's that.

(Interview with a farmer in Maine et Loire, December 2014)

Female farmer: What I've gotten from homeopathy, I often say, is how to make a diagnosis. That for me is… absolutely the most important thing! It's… for me you don't get that from other approaches, in other alternative medicines or other… even in allopathic medicine. You don't have that… I often say, making a good diagnosis, for me it's not a simple thing. Or, I want to say… it's taken me years to get to the point where I can figure that out a bit… But even now, I sometimes call the vet to get a diagnosis. Not necessarily for the treatment. And I find that the approach to diagnosis using homeopathy, for me, is incredibly important. And incredibly valuable, too… even more than all the remedies, really.

(Interview with a farmer in the Manche, January 2015)

This was also the case with two female farmers in Normandy who practiced aromatherapy exclusively. One of them emphasized how she observes her animals more since she received training in this approach:

[The farmer is describing what she learned in the courses on aromatherapy:]

Well, I would say, it gave us… the different things to observe when looking at the animal. (…) The eyes… the discharge from the nose, the chest… really everything you can observe but…. And then from there, it's like you apply it differently. And then, because of that, you are much more aware. So you observe much more.

(Interview with a farmer in Normandy, March 2017)

This shift in how the farmer observes his or her animals leads in turn to a change in the farmers' relationship with their animals, how they work with the cows, bringing to the fore the sensory aspects of their daily work. Gaining these new observational skills so as to be able to detect health problems early thus emerges as a new element enabling the farmers to improve their overall management of herd health. Importantly, it is also a skill that allows them to access advisory services remotely, as we have seen: during a telephone consultation to help determine a homeopathic remedy, for example, the farmer can precisely describe the sick animal's condition and any changes in its behavior.

DISCUSSION

Reflections on the Study Methodology and Characteristics of the Farmers Interviewed

Our study sample is not representative of French dairy farmers overall because our research was not designed to elucidate the opinions held by French dairy farmers in general with respect to the use of alternative veterinary medicines. Rather, our objective was to understand the perspective and experience of farmers already using homeopathy, phytotherapy and aromatherapy on their farms. Our key criterion in selecting farmers for the sample was to access a diverse range of uses of alternative medicines. For each field study area, the first step was to identify a group of farmers making regular or occasional use of homeopathy, phytotherapy or aromatherapy to treat herd health issues. To do so, we approached a number of actors connected to the local dairy sector, including advisory services, training organizations, and (in the case of Grand Ouest) veterinary practitioners. Given this approach, most of the farmers we interviewed had participated

[11] Developed by Dr. Bruno Giboudeau in the early 2000s, the OBSALIM® method seeks to detect dietary imbalances using specific criteria for the observation of individual animals and/or the whole herd. These criteria are directly inspired by the observational approach used in homeopathy (30).

in activities associated with these organizations. This could be considered as a bias of our study, and represents one limitation of this type of qualitative approach, which necessarily involves using intermediaries to identify potential interviewees. To minimize this bias, we have drawn on different types of intermediaries, with the use of veterinarians in the Grand Ouest. Another potential strategy would have been to contact a company manufacturing and selling products typically used in veterinary phytotherapy, aromatherapy, or homeopathy (assuming the company would be willing and able to share their customers' information).

So this study does not enable us to describe the typical profile(s) of farmers, or farm operations, making use of alternative medicines. Nevertheless, there are elements of these farms' characteristics that stand out from our research. First, we found that the use of alternative medicines is not limited to the organic dairy sector. Second, for conventional farmers as for organic farmers, interest in these medicines goes hand in hand with a desire to reduce AMU and move toward a more holistic approach to herd health. Third, we identified a clear gender aspect to usage of alternative medicines, which we explore in the next section.

Reducing Antibiotic Use on Dairy Farms: the Role of Women Farmers

A second feature that appears in the study sample is the role of women in the adoption of alternative medicines. A substantial number of women farmers were interviewed, either alone or together with their partners. Indeed, on the farms of our study sample it was frequently the women who had sought training in alternative medicines and/or had acquired the most expertise.

Research on the role of women in European agriculture has frequently emphasized the ways in which women are subject to forms of domination: although women have always played an active role in the work of agricultural production, their contributions have often been minimized, for instance by being lumped together with domestic chores (31). Women have thus been slow to gain official recognition of their professional work as farmers. The most frequently studied forms of emancipation for women in agriculture are (1) holding an off-farm job (32), and (2) the development of complementary on-farm enterprises, such as agri-tourism, direct sales of farm products, or small production enterprises (33, 34). Nevertheless, these activities of women farmers are often implicitly analyzed as external or peripheral to the farm's primary economic focus, thus confining women to a position of supporting their husband's work (35). These forms of women's entrepreneurial activity also receive weaker public policy support than those typically developed by men (34).

At a larger level, the increased specialization of farm operations and the ongoing professionalization of farming has coincided with a withdrawal of women from activities directly linked to the agricultural production of the farm. These trends are reinforced by mechanization, which has often entailed a replacement of women's work by machines (36). The role of women in agriculture thus appears to lie either outside of or on the periphery of the farm's primary production activities, or be limited to domestic tasks. By contrast, our study shows that women can occupy key positions within the farm's primary agricultural enterprise, including initiating new practices for livestock management. The domain of care, historically and culturally considered as belonging to women (37), is the domain where changes are first introduced—changes that then spread outward to other aspects of herd management. This observation calls for further research more specifically focused on women's role in the technical aspects of dairy management and in the adoption of new practices.

Development of Observational Skills as a Strategy for Reducing On-Farm Antimicrobial Use

Several studies on the on-farm use of alternative medicines highlight farmers' "incorrect" use of these medicines. With respect to homeopathy, in particular, farmers are said not to perform a sufficiently thorough diagnosis of the animal's state of health, and to have a tendency to simplify the homeopathic approach by linking a given remedy with a given illness (38, 39). The "unicist" homeopathic approach—the prevailing approach in the world of veterinary practice—holds that every sick individual is affected in a unique way by a given disease, and thus requires a specific, unique treatment. In our interviews, farmers expressed their challenges in adhering to the unicist principle, which they found complicated and requiring many years of study. Nevertheless, they found the use of homeopathic medicine to have practical value for their farms, enabling them to better care for their animals.

How can we understand the fact that farmers find these medicines effective, while some authors argue that they don't use them correctly? Our results make it possible to move beyond this apparent dilemma, showing how the use of alternative medicines fits into overall dairy farm management and supports a holistic approach to herd health. Science and the veterinary profession see an opposition between conventional medicine and alternative medicine; but dairy farmers use both in a practical fashion, simultaneously or sequentially, with the underlying goal of better managing risks to herd health. Hektoen (24) found similar results in a study of Norwegian dairy farmers, who likewise view homeopathy as a new tool, among other tools, to be used in caring for their cows. As noted previously, moreover, the instructors of these training courses in alternative medicines present close observation of the animals as a central topic. In the training course we attended, the instructor in aromatherapy repeatedly emphasized the importance of closely and regularly observing the animals' condition, offering a series of charts for use in assessing specific health problems—charts we later observed farmers making use of. Similarly, close, careful observation of the animal is central to the homeopathic approach to veterinary care. Clinical diagnosis in homeopathy is based on a large number of precise visual indicators relating to the condition of the animal's body, specific aspects of its behavior, and characteristics of its excreta. To perceive changes in the behavior of a given animal, one must be in the habit of regularly and closely observing the herd. All of this suggests that the efficacy farmers experienced in alternative medicines is related to the larger effect of the whole approach to care they adopt when they use these medicines, including closer attention to the herd.

Acquiring skills in the direct observation of livestock requires changing how one works with the herd, making it possible to reprioritize the sensory dimension of the farmer's relationship with his or her animals. Observational skills are not ordinarily taught in agricultural schools, however. They are generally considered to be innate, or as a form of practical knowledge passed from father to son, or from employer to student during farm apprenticeships (40, 41). Nevertheless, our results show this type of practical know-how, based on sensory elements, can be effectively formalized and in this way taught to farmers. The training courses offered to farmers in connection with alternative medicines thus constitute one pathway, among others,[12] for developing farmers' observational skills.

In scientific literature, farmers training are considered as a main driver for AMU reduction (6, 43). The challenge is to improve farmers knowledge regarding use of antibiotics and prevention methods. Our results show light on another category of skills: the observational skills, that are of importance when farmers aim at improving animal health management.

Alternative Medicines Suggest New Ways for Veterinarians to Work With Farmers

Our results also have relevance for ongoing discussions with regard to the changing role of veterinarians on dairy farms. The fight against AMR—and more generally the increased demand among citizens and consumers for better management of livestock health and a greater respect for farm animal welfare—hold consequences for the veterinary profession: often regarded simply as providers of urgent care or as intermediaries for the delivery of veterinary pharmaceuticals, veterinarians are now being asked to place more emphasis on advisory services and preventive medicine (8, 44). As Fortané et al. (45) have shown for the pig farming sector, reducing on-farm antibiotic use requires changing the nature of the relationship between the farmer and his or her professional network, of which veterinarians are an important part.

The farmers we interviewed have invested time and money in improving their animal health management practices. These farmers have turned to short training courses offered by agriculture-related organizations in part because of the lack of specialists in alternative medicines in their local professional milieus. Most rural veterinarians have little interest in seeking training in forms of medicine whose efficacy has not scientifically established (21, 46). As we have seen, however, demand for alternative medicines exists not only among organic dairy farmers but also among dairy farmers more generally. What is more, this demand is indicative of broader changes in farmers' needs and expectations with respect to managing the health of their animals: a desire to focus more prevention, a desire to adopt a more holistic approach (47, 48). A better understanding of farmers' interest in homeopathy, aromatherapy, and phytotherapy—and more importantly, an understanding of the broader needs and expectations underlying that interest—can provide veterinarians with useful information for rethinking their professional interactions with farmers.

In the scientific literature to date, the primary avenues that have been explored with regard to the future role of veterinarians involve the creation of HACCP-style management systems such as Veterinary Herd Health Management (VHHM) (9) and Animal Health and Welfare Planning (AHWP) (49). With VHHM and AHWP, the veterinarian develops a herd health management plan based on explicit objectives defined in consultation with the farmer, and then conducts regular assessments to see how the farm is doing with respect to the plan (49, 50). A variety of challenges can emerge with this type of initiative, however: objectives are not always clearly established; and it can be difficult to measure the extent to which the farmer has followed the veterinarian's advice, or the effects of specific recommendations on herd health (51). More fundamentally, some farmers are reluctant to participate in such initiatives. Jansen et al. (52), after conducting a study to identify the causes of this reluctance, emphasized the manner in which the veterinarian communicates with the farmer: the former must tailor his or her language to fit the latter's way of thinking about herd health management. To work effectively as advisors, veterinarians also need to improve their listening skills, seeking to understand the farmer's perspective—the logic underlying his or her practical decision-making (53). For Duval et al. (21), too, veterinarians must be proactive, making the most of their conversations with farmers to suggest improvements in herd health management.

Finally, developing an advisory role for veterinarians implies rethinking the economic model of the veterinary profession since in many countries, veterinarians both prescribe and sell veterinary pharmaceuticals. For example, in France, nearly 70% of rural veterinarians' income comes from the sale of medicines (54). Restrictions on the sale of antibiotics by veterinarians is seen as a way to reduce AMU, but could lead to a significant reduction in revenue for rural veterinary practices (8, 54) and thus contribute to the loss in numbers of rural veterinary services (44). Our study, however, has identified potential strategies for how the advisory services of veterinarians could be remunerated. Furthermore, we identified different types of professional connections between farmers and alternative medicine specialists, corresponding to different types of paid services: short training courses for farmers; periodic phone consultations; annual farm visits to conduct an overall review of herd health management practices. To this may be added the farmer-to-farmer discussion groups organized by some homeopathic veterinarians (55, 56). These groups are similar to the "stable schools" organized in Denmark (57), in which a group of livestock farmers meet at one of their homes, defining problems to be discussed in advance and sharing their experiences of specific treatment failures and successes. Skilled facilitators are essential to the smooth functioning of such groups (58).

[12]Training courses in the Cows Signal® approach, based exclusively on animal observation, are also offered in many European countries (42).

A study of organic dairy farmers' advisory networks for animal health issues (59) showed different forms of annual contracts established between farmers and veterinarians. Some are proposed specifically to farmers converting to organic, to help them during the conversion period. In sparsely populated areas with few practicing veterinarians, groups of farmers have created a system of annual contracts with one or more veterinarians to ensure that veterinary services remain available. In this case, the contracts can cover a variety of services, including farm visits, telephone consultations, trainings, and the facilitation of farmer-to-farmer discussion groups. Like VHHM and AHWP, these annual contracts are based on the idea of regular monitoring of the herd by the veterinarian, but they are more flexible because it is the farmer who determines the frequency of the consultations, according to his or her needs. In addition, these kinds of activities require different skills on the part of the veterinarian, including a different approach to interacting with farmers. Service contracts with farmers thus appear to be a useful strategy by which veterinarians can be remunerated for advisory services, albeit one that places them in direct competition with other dairy services professionals.

CONCLUSION

Although their effectiveness is controversial, alternative medicines are currently considered to be one strategy among others for reducing antibiotic use in livestock agriculture. Alternative medicines are also in regular and widespread use by both organic and conventional dairy farmers. In this article, we sought to take dairy farmers' interest in homeopathy, aromatherapy, and phytotherapy seriously, studying in detail their use of these therapies for herd health management. We found that alternative medicines are not understood by farmers as a substitute for conventional medicine; rather, these medicines play a role in a holistic approach to herd health that includes both preventive measures and a variety of curative treatments, grounded in careful and continuous observation of the animals' state of health. Farmers employ criteria for the observation and interpretation of animals' condition that are fundamental to veterinary homeopathy and aromatherapy. Although short training courses are the primary avenue by which farmers learn about alternative medicines, individual advisory relationships with alternative medicine specialists can follow on from these courses. Farmers' interest in alternative medicines thus suggests larger expectations and needs for advisory services and assistance with respect to the integrated management of animal health. Understanding these needs and expectations offers useful avenues for rethinking the place of veterinarians on dairy farms: to move beyond the role of "prescriber of medicines" and more toward that of a farming advisor. This involves more than simply educating farmers as to good practices for antibiotic use and disease prevention; it should also mean helping farmers develop their skills for monitoring herd health and appropriately treating animal health issues.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: Interviews with farmers are confidential data. Requests to access these datasets should be directed to florence.hellec@inrae.frandlt.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

FH, CM, and MJ participated directly in the collection and analysis of the empirical data. FH and CM jointly conducted the field survey in Franche-Comté and developed the analytical grid for the data collected in Franche-Comté and Normandy. FH conducted the field survey in Normandy. MJ made the field survey in Grand Ouest. FH and MJ used this grid to analyse data collected in Grand Ouest. FH wrote an initial version of this article. CM and MJ read and commented this version. All authors approved the final version of this article.

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CONCEPTUAL ANALYSIS
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Reducing Antimicrobial Use and Dependence in Livestock Production Systems: A Social and Economic Sciences Perspective on an Interdisciplinary Approach

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Objective: In livestock production, antimicrobial resistance (AMR) is considered an externality as it is the undesired result of preventive and curative antimicrobial use. To address this biosocial issue, our objective is to present an approach based on interdisciplinary research to develop strategies and policies that aim to contain AMR.

Method: To do so, we addressed three fundamental questions on which control policies and strategies for agricultural pollution problems are centered in the light of AMR. To ensure the technical, economic, behavioral and political feasibility of the developed measures, we demonstrated the usefulness of systemic approaches to define who, what and how to target by considering the complexity in which the ultimate decision-maker is embedded. We then define how voluntary or compulsory behavioral change can be achieved via five routes, introducing a clear taxonomy for AMR Interventions. Finally, we present three criteria for ex-ante analysis and ex-post evaluation of policies and strategies.

Conclusion: Interdisciplinary systemic approaches enable the development of AMR policies and strategies that are technically, politically, economically and, last but not least, behaviorally feasible by allowing the identification of (a) all actors influencing AMU in livestock production, (b) power relations between these actors, (c) adequate regulatory and intervention bases, (d) what behavioral change strategy to use, (e) whom should implement this, as well as the cost-effective assessment of combinations of interventions. Unfortunately, AMR policies and strategies are often investigated within different disciplines and not in a holistic and systemic way, which is why we advocate for more interdisciplinary work and discuss opportunities for further research.

Keywords: antimicrobial resistance, antimicrobial use, livestock production, systems thinking, behavioral change, interdisciplinary research

INTRODUCTION

For the two past decades, concerns regarding antimicrobial use in farm animals grew considerably due to the growing prevalence of antimicrobial resistance (AMR) and the way this affects human health. AMR is a natural process that results from the ability of microorganisms to quickly adapt to changing conditions. Indeed, the appearance of rare and advantageous mutations that neutralize the effects of antimicrobials is inevitable in large and dense microbial communities and the rapid generation times allow these mutations to quickly become prevalent in growing communities (1). Additionally, bacteria have the capacity to exchange mobile genetic elements, including resistance genes, via horizontal gene transfer within and between bacterial species, further enhancing their ability to adapt (1).

But while AMR is a natural phenomenon, its increasing prevalence is most certainly not. In fact, it is fueled by anthropogenic factors such as the intensive clinical and agricultural use of antimicrobials worldwide, the growth of the world's human population, changes in human lifestyle (e.g., increased urbanization, migration and travel), and misconceptions and malpractices regarding antimicrobial use (AMU) (1). Over time, this increasing prevalence is predicted to have a significant impact on global health and wealth by potentially causing up to 10 million deaths each year, at a cumulative cost of $100 trillion to global economic output by 2050 (2). To further contextualize this, the World Bank Group estimated that reductions in annual global GDP due to AMR (ranging between 1.1 and 3.8%) may be comparable to the losses caused by the 2008–2009 financial crisis, with the difference that the economic damage would continue for decades and would mostly affect low-income countries (3).

To contain this serious threat to global health and wealth, the 194 member states of the World Health Organization (WHO) endorsed a global action plan (GAP) in 2015 and committed to establishing national action plans (NAPs) based on the "One Health" approach, which recognizes the interaction between human health, animal health and the environment (4). By 2018, 60% of Member States declared having a NAP in place and 33% reported that they were in the process of developing one (5). This global attempt to contain AMR with a One Health approach seems timely, since it was estimated that by 2030, antimicrobial consumption, which has now been repeatedly associated with AMR (6, 7), would increase by 67% in livestock (8), by 33% in aquaculture (9) and by 15, 32 or 202% in humans, depending on the scenario (10).

In the European Union, this political will to contain AMR has led to a European strengthening of the response to AMR with the development of an EU One Health action plan against AMR and new EU regulations on veterinary medicines [Regulation (EU) 2019/6] and medicated feed [Regulation (EU) 2019/4] (11). In practice, the Member States' efforts to reduce AMU in veterinary medicine, and mainly in animal husbandry, resulted in a 32,5% decrease in sales of veterinary antimicrobial medicinal products between 2011 and 2017 (12). While this seems to be a good start to achieve a more sustainable use of antimicrobials in European livestock production, there are still challenges ahead. Further efforts will be needed to reach the European Commission's target of a 50% reduction of antimicrobial sales for farmed animals and aquaculture by 2030, as set out in the recently adopted "Farm to fork" strategy. The degree of effort required to achieve this target is also likely to differ between Member States, given that large variations in AMU trends have been observed between European countries, with some using 136 times as many antimicrobials for the rearing of food-producing animals (12). Finally, in addition to significant differences in national AMU trends, monitoring at farm level also revealed variations between farms, species, and production cycles (13, 14), further complicating the picture.

To address the challenges posed by antimicrobial resistance, countries have been advised to invest in AMR containment (3) through AMR surveillance and by curbing the prevalence of antimicrobial resistance via optimal antimicrobial prescription and use in both human and veterinary medicine. Regarding the latter, the institutionalization of AMU as well as the reduction of antimicrobial dependence is necessary in order to achieve a sustainable use of antimicrobials. In livestock production, antibiotics play a crucial role since they are not only a therapeutic but also an economic asset. The preventive use of antimicrobials to treat at-risk herds or animals (prophylaxis) as well as clinically healthy animals sharing premises with symptomatic animals (metaphylaxis) allows the limitation of economic risks and labor costs (15, 16). Outside of Europe and the USA, antimicrobials are also used as feed additives, which are thought to improve animal growth, feed conversion and yield and allow farmers to keep pace with the demand for meat while lowering the prices (17). To reduce this reliance on antimicrobials, the focus is often on information and technological innovations as vaccination and alternatives to antimicrobials. But while investments in (therapeutic) innovations are foreseen in the GAP, and presumably the NAPs based thereon, the promise of new technologies might not be enough. In fact, therapeutic alternatives to antimicrobials are currently not sufficiently developed in order to effectively replace antimicrobials (18). Considerable investment in research and development will be needed, which means that these options will not be widely available in the coming years. Moreover, it is very likely that such options will offer short-term solutions since we are engaged in an infectious arm's race with microbes that always find a way to accommodate to new therapeutics. In this regard, Smith (19, 20) esteems that the vision for AMR control is currently focused on technological and biomedical innovations, the benefits of which could be short-lived if our society remains heavily dependent on antibiotics. In addition, there is no guarantee that alternatives will be immediately adopted by farmers, as it was the case for the live oral Lawsonia vaccine in pigs, that was not widely used despite positive results (18). Studies cut across many disciplines have shown that the adoption of new technologies by farmers can be influenced by numerous factors, e.g., environmental factors such as land use (21) and land characteristics (22); personal features such as age, human capital or risk preferences (23); economic attributes such as market intervention by regulators (24) and costs of acquiring the technology (25); extension services (22) as well as cultural and social factors including social identity (26), social networks

(27, 28) and peer group influence (29). It is therefore clear that farmers' behavior is embedded in both biophysical and social landscapes (30) and that decision-making processes are complex and context dependent. In addition to this, other actors in the social landscape may also indirectly influence farmers' behavior by voluntarily or involuntarily creating physical (e.g., land appropriation) or social structures (e.g., norms) that restrict, or enlarge, farmers' opportunity space (30). To better understand farmers' behavior while considering the systemic complexity in which it is embedded, several frameworks and systemic approaches have been developed (30–32) with the hope that this would help design research that represents farmer's behavior more realistically and that it would lead to the development of more effective sustainable agriculture policies.

In this respect, our objective is to add to an interdisciplinary research agenda by providing a perspective on strategies for reducing the dependence on AMU and the threat of AMR from a social science and economic point of view. This perspective was inspired by how social scientists and economists contributed to environmental policies (33). We discuss how knowledge about farmers' behavior and the system in which they operate can contribute to answering three central questions for the development of policies and strategies and can provide a clear taxonomy of AMR interventions in livestock production. To better illustrate this, we also provide examples of existing policies and strategies to address antimicrobial use and dependence. Next, we present three criteria for ex-ante analysis and ex-post evaluation of these policies and strategies and, finally, we discuss the importance of an interdisciplinary approach to get insights in farmers' behavior and the system they are embedded in upon introducing research opportunities.

THREE FUNDAMENTAL QUESTIONS FOR DEFINING POLICIES AND STRATEGIES TO MITIGATE AMR IN LIVESTOCK

Since AMR in livestock and agricultural pollution are both externalities, the design of policies and control strategies for the latter might also be useful for the former. We therefore used three fundamental questions on which the design of policies and control strategies for agricultural environmental pollution is centered (34) to develop an approach to design new policies and strategies to mitigate AMR in livestock. The first fundamental question is: *who* among those who play a role in the production of an externality should be targeted. The second question aims to determine the basis for measuring effectiveness or, in other words, *what* variable(s) control policies and strategies wish to change. Finally, the third question is *how* to target, i.e., by what mechanism(s) the intended actors and bases should be targeted.

Identifying Key Actors in Antimicrobial Decision Systems

To reduce antimicrobial use and dependence in livestock production, it is necessary that farmers, as ultimate users, and veterinarians, as antibiotics prescriber, change their behavior. It is thus only logical that policies and strategies target them. This is the case in Denmark, where veterinarians do not have the right to sell veterinary drugs (35) and pig farmers need to remain under set antimicrobial use thresholds if, according to the yellow card initiative, they do not want to face legislative implications, including a reduction of the stocking density of animals (36).

However, the solution to the question "who to target" does not need to be limited to the actual users of the antimicrobials. Indeed, when dealing with externalities, it has been suggested that, in addition to the actual source, others could be targeted (34). This idea has been reinforced by systemic approaches that suggest that there are many more actors who have an influence on how food is being produced and that often, farmers are end-of-pipe decision makers largely influenced by the practices and demands of other actors in the system (30, 37). In this regard, value chain approaches for the analysis of animal health systems grew in popularity as they allow for the analysis of the different actors involved, their roles, and the interactions between the actors as well as how this influences practices (38). Since value chains are in turn embedded in a bigger biological, social, economic, and regulatory context, analytical frameworks have been developed to study such big and complex systems. For example, Lamprinopoulou et al. (39) developed a framework to analyze Agricultural Innovation Systems (AIS), which consists of innovation processes that encompass all type of knowledge that all actors in an agricultural system demand and provide, as well as the interaction between these actors. The framework allows to define the functions and structures, i.e., identification and classification of actors, of an AIS and to assess how, at a micro level, systemic failures may affect the contribution of actors to the fulfillment of the functions of the AIS. Moreover, the functioning of the entire system is also explored by investigating if basic structural components and functions are sufficiently coordinated, aligned and harmonized. This approach was further used by Rojo Gimeno et al. (37) to comprehensively depict swine health systems by identifying key actors and their functions as well as merits and failures at micro and macro level that impact functions. A shortcoming of such approaches might be that the natural environment is not taken into account. To fill this gap, Hagedorn et al. (40, 41) developed and an analytical framework to analyze nature-related transactions, which has later been applied to agricultural soil conservation by Prager (31). Here, the interdependencies between ecological and social systems are taken into account by considering the biophysical characteristics of soil and the related farming practices that contribute to soil degradation, as well as all the actors, policies, institutions, instruments, and governances structures that may influence these.

To take a systemic look at antimicrobial use in livestock production, **Figure 1** presents a simple representation of a value chain integrated in a bigger societal system and environment. Consistent with the literature on value chain analyses, the links of the chain have been divided into 4 categories: inputs, production, processing and distribution, and marketing (42, 43). In the context of livestock production, inputs refer to all the goods and services that are needed to raise livestock such as veterinary services, veterinary medicinal products, and feed. Production refers to the farming of the animals and can, depending on the production system, include several stages. For example, weaner

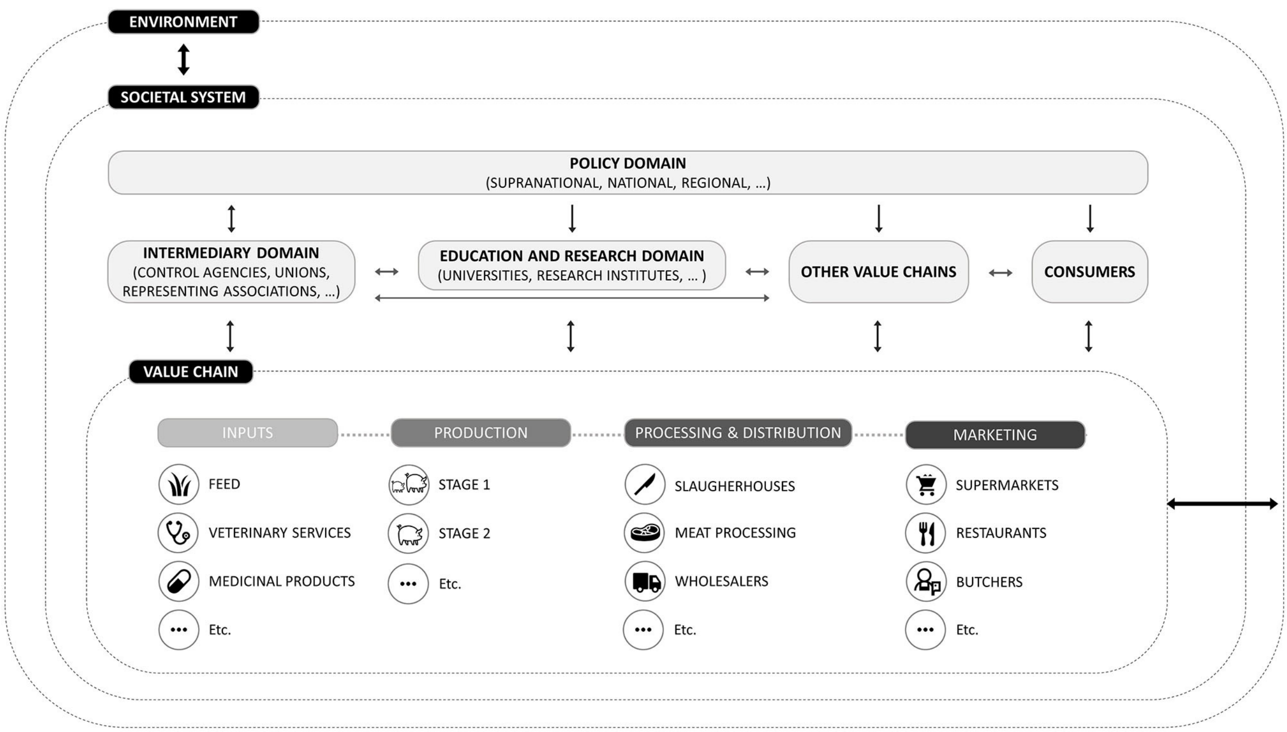

FIGURE 1 | Interactions between value chains, societal systems and the environment.

producers can be specialized in breeding piglets, which will subsequently be sold to a fattening farm where the pig production cycle will be finalized. The processing and distribution category involves the slaughtering of the animals as well as the further processing of the meat. Finally, distributors such as retail, food suppliers, restaurants and exports are labeled as distribution and marketing.

When considering the value chain, it becomes more clear that besides farmers and veterinarians, other actors of the value chain could be targeted. In the upstream part of the value chain, input suppliers such as feed mills could be subject to policies, e.g., by banning or further regulating the production of certain inputs like non-medicated feed to avoid cross-contamination with antimicrobial residues (44, 45). Targetable actors can also be found in the downstream part of the chain, as, for example, the knowledge of truck drivers regarding the health of animals for transportation could be regulated (46) and the compliance of transportation companies to strict rules regarding the cleaning and disinfection of lorries could be controlled (47). Lately, labeling systems have also been set up to provide information about the antimicrobial use during the production of animal products (48).

When looking at the societal system in which a value chain is integrated, the actors it comprises may also influence actors and practices in the value chain. In **Figure 1**, these actors external to the value chain were divided into four categories from which the first three were based on Rojo Gimeno et al.'s (37) framework to characterize animal health: a policy domain, an intermediary domain, an education and research domain, and consumers. The policy domain comprises several levels such as (supra)national and regional governments. The intermediary domains refers to actors that, on the one hand, advise governments and may perform governmental activities and, on the other hand, may influence the value chain as well as the research and education domain via collaborations and the development of awareness campaigns. Finally, the research and education domain comprises schools, research institutions and universities developing and providing knowledge for the other actors as well as private and public extension organizations.

Such external actors could also be targeted by policies by for example subsidizing control agencies or farmers' organizations to develop communication campaigns to raise awareness. Universities could be expected to improve courses on AMR in the curriculum of veterinarians or farmers (49) or could be compensated for it. Educational campaigns about AMR, antimicrobial stewardship or biosafety could be promoted for farmers (50), veterinarians (51) and also advisors (from, e.g., feed mills or companies that work on farm equipment) (52). Such campaigns can also be supported by industries, such as pharmaceutical companies (53). Investment in R&D could allow the development of new tools. Alternatively, Giubilini et al. (54) suggest taxing meat, allowing consumers to compensate society for the AMR they contribute to by consuming meat that was produced with the use of antibiotics.

Defining a Basis for Policies and Strategies

In this section, we will explore different options that may provide an optimal basis for measuring impact, or in other words, a variable that policies and strategies are intended to change. To serve as an optimal base to formulate a regulation or strategy and to measure compliance with that regulation/strategy, any elements in the input/technology-production and AMR relationship can be used as long as they are (a) correlated with AMR; (b) enforceable; and (c) targetable in space and time (33).

To identify several bases that could be used, we systemically analyzed the production segment of a livestock value chain. This exercise may of course be expanded to other segments of a value chain or layers of a system, as done by the UK government who produced AMR systems map to provide an overview of the factors influencing the development of antimicrobial resistance and the interactions between them in a one health context (55). The decision to restrict the analysis on actors and pathways regarding AMR in this paper relies on our aim to illustrate how systemic approaches may contribute to the identification of compliance bases rather than providing an extended overview of the ways in which a system may contribute to AMR. To this end, **Figure 2** pictures the potential contribution of four farms (A, B, C, D) to AMR. For every farm, livestock production is presented as a result of inputs and technologies. Inputs refer to the goods and services necessary for production. Technology, refers to the production system or methods used for animal production and can determine the choice of inputs, as some technologies require more inputs of one type and fewer inputs of another. An example is antibiotic free vs. conventional production, where disease prevention through enhanced biosecurity and vaccination is preferred to treatment with antimicrobial substances. Different combinations of inputs and technology are therefore leading to varying levels of livestock production (output) and AMR, which will also be influenced by natural variability due to favorable mutations in microorganisms, horizontal gene transfer, chance and others. When considering technology or production practices as a compliance base, biosecurity factors (56) or organic production (57) make good candidates as correlations with AMR have been demonstrated. There have been clear links shown between the quantity of AMU on the one hand, and AMR on the other.

It is important to note that, since a production cycle can be composed of several stages, inputs can also refer to animals, which can also influence AMR levels. This is represented in **Figure 2**, where the output of farm A is sold and transported to farm B, where it is considered an input. In case, the animals carry resistant microorganisms (pathogens or commensals that carry resistance genes), AMR can be introduced on farm B through the input and influence the prevalence of AMR. Such transfers of AMR between farms are also prone to natural variability and have been documented for, i.e., methicillin-resistant *Staphylococcus aureus* (MRSA) in pig farms in Norway (58) and for ceftiofur resistant *Escherichia coli* in Belgian broilers, where the hatchery of origin proved to be an important risk factor (59). Moreover, it is suggested that animals can be infected with resistant microorganisms in transport trucks (60). In Denmark, the Specific Pathogen Free system (SPF system), developed by the pig sector in collaboration with universities, aims to avoid the introduction of new pathogens into pig herds via strict biosecurity rules, health control and transportation of pigs between herds. The system comprises 75% of the pigs born in Denmark and herd held statuses are publicly available (17).

Besides animals, the use of inputs such as antimicrobials have been proven to influence AMR levels on farms (7) and are therefore a good base to formulate a regulation. In, for instance, Denmark, the Netherlands and Belgium, antimicrobial consumption is monitored at farm level for several species, which allows the benchmarking of farmers and/or veterinarians (61). But even if the farmer is responsible for the chosen inputs, some aspects may be beyond control, such as the cross-contamination of non-medicated feed with residues of antimicrobials in feed mills or transport trucks (45). In 2016, Filippitzi et al. (45) estimated that 5.5% of the total feed produced in a year could be cross-contaminated with different levels of antimicrobials when antimicrobial medicated feed represented 2% of the total annual feed produced in a country.

In addition to inputs, outputs may also be targeted. Targetable outputs may include the type of animals that are produced (e.g., species and age) since different animal species metabolize drugs differently or the amount of output as consuming less animals could also reduce the use of antimicrobials (62). However, the correlation with AMR is less straightforward for these options than for input or technology based ones, which might therefore be preferred.

Finally, we should keep in mind that AMR can also be introduced in a farm through interactions with the environment or the 'outside world'. Examples of such interactions include mutual use of farm workers or veterinary practitioners that can introduce resistant microorganisms (58), delivery trucks that travel from one farm to another (63), pests like rats (64), insects (65), or antimicrobial residues in the environment (66). When considering the One Health approach, antimicrobial residues from human wastes may end up in the environment (66) and subsequently influence AMR levels on farms. The level of interaction with the outside world is also influenced by technology, as, for example, free-range animals interact more with the environment than intensively produced animals that remain in stables.

With regard to interactions between farms and the 'outside world', it might be more complicated to find compliance bases. In such cases, AMR proxies such as monitored AMR trends could be used. Such options have a higher correlation with AMR but are less attributable to a producer than input/technology and production bases. Moreover, the surveillance of AMR trends in the European animal production is currently limited and results are published with a 2-year delay. To compensate, national surveillance systems have been put in place, each with their own sampling, testing and reporting modalities, yielding results that cannot be compared (67).

Taxonomy of AMR Interventions: Five Routes to Behavioral Change

Once it is defined who and what should be targeted, the next step is to determine the mechanisms through which the intended actor(s) and variable(s) can be targeted. This entails the choice for a policy instrument, an advisory approach, a

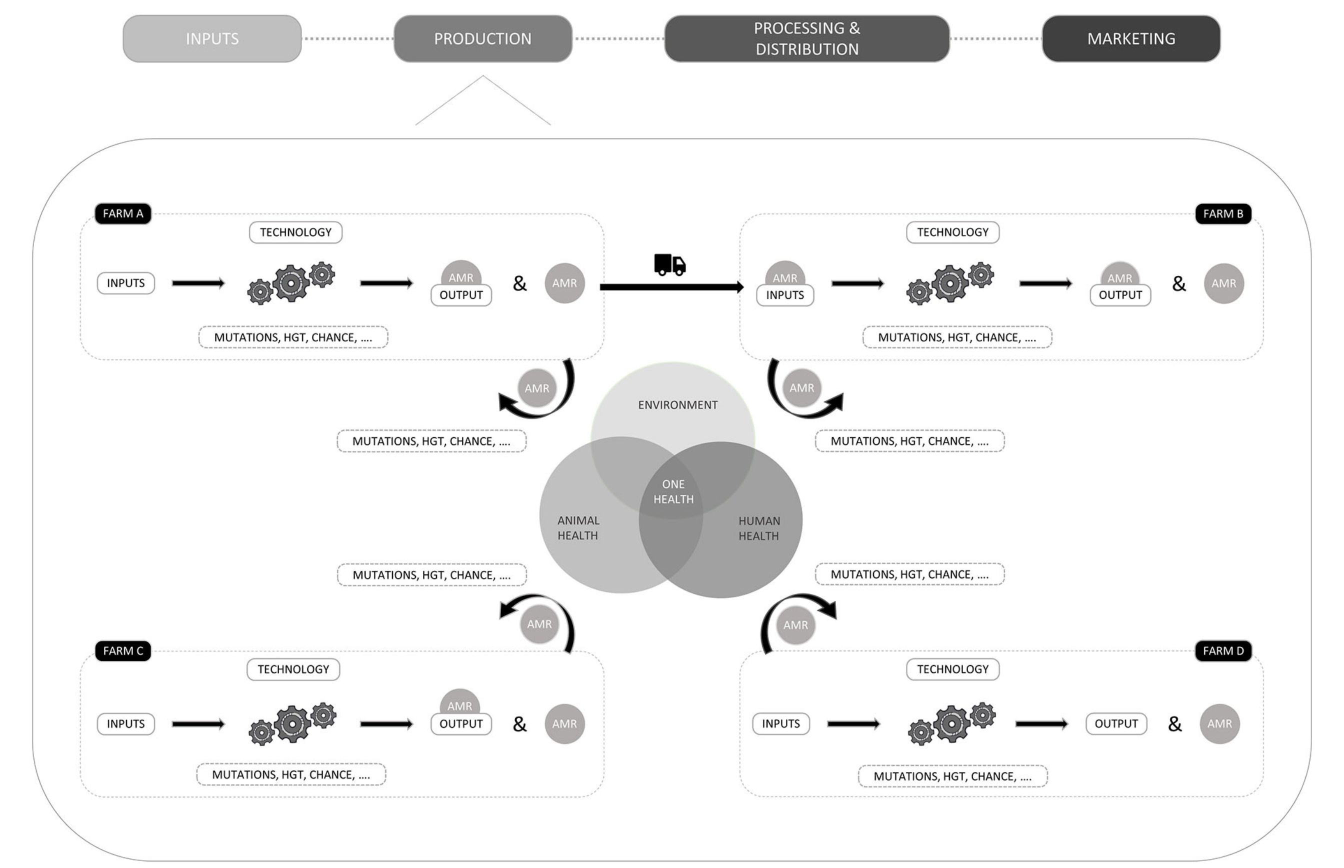

FIGURE 2 | Graphical representation of the potential interaction of farms within a value chain with their environment and with each other. The potential contribution of four farms to AMR and the interactions with their environments is provided.

structural intervention and other types of options. To change behavior, several intervention frameworks have been developed for different contexts such as policy making and retail (68). While the used vocabulary or level of detail regarding the categorization of the intervention type may differ, most of these frameworks consider regulation and coercion, norms, social influence and networks, knowledge, incentivization and enablement as factors that may influence one's behavior (68). Our choice was for Van Woerkum's exhaustive classification of interventions into five possible routes (69) (**Figure 3**) since it has recently been adapted and applied in veterinary sciences (70, 71).

According to Van Woerkum's framework, a first way to achieve behavioral change involves regulation (69). This route differs from the others in that it attempts to make change compulsory, in contrast to the others that strive to induce voluntary change. Therefore, "bad" behavior is made illegal while "good" behavior is made mandatory. The best known regulations on antibiotics are the ban on the use of antimicrobials as growth promoters in the EU. and the yellow card policy in Danish pig farming (36). Moreover, regulations can also be organized at sector level as part of quality systems, as was the case for Dutch veal calves, broilers and pigs (72).

To induce a voluntary change, the second route includes provisions and tools, which are instruments that are implemented to change the external material circumstances so that people become motivated to change their behavior. In some cases, the provisions can be restrictive (by making the 'bad' behavior less straightforward) and behavioral change is then coerced. However, in the case of AMR and AMU, most provisions and tools are rather enabling and give the intended person external motivation to voluntarily change by making it easier and more achievable to reduce and improve the use of antimicrobials. Examples of tools include coaching sessions to develop and implement farm health plans (73) and alternatives treatments such as bacteriophage therapy (74).

Another way to change external circumstances involves the use of economic and financial incentives. Here, the attempt is to create external circumstances that change the financial conditions in such a way that behavioral change is favored. Typical examples include subsidies for the 'good' behavior or taxes (fines) for the "bad" behavior. In the European Union, several countries have levied a tax on the sale of antibiotics (75, 76). Private companies can also use this approach by paying a price premium for products that are produced in 'good'

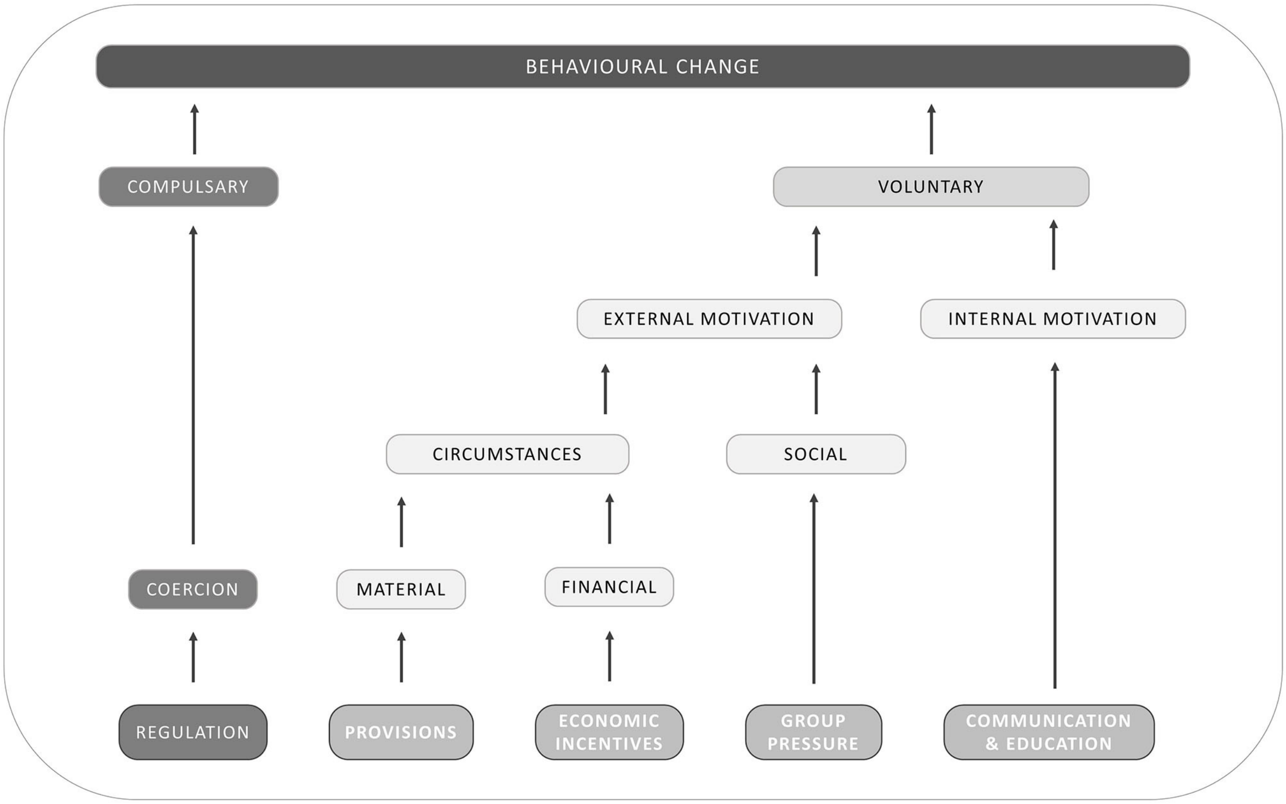

FIGURE 3 | Possible routes to induce behavioral change [adapted from Van Woerkum, published in Leeuwis (69)].

production systems through labeling of products as produced without the use of antibiotics (77).

In addition, a third and more direct method to change external motivation of decision makers relates to group pressure and social norms. This mechanism attempts to induce behavioral change by making use of the typical desire of people to comply with the group norm. It is the attempt to use existing social norms, and make people aware of these norms. In some cases, new social norms need to be formed prior to this, if the social norms within the target group does not support the intended behavioral change. An example for the use of group pressure is the benchmarking of farmers and/or veterinarians based on AMU in Belgium, Denmark and the Netherlands (61).

Finally, the last route to voluntary behavioral change goes through communication and education. Through these mechanisms, change agents attempt to change the internal motivation of decision makers so that they become convinced that behavioral change is the best decision. Newly developed tools or economic studies that demonstrate the cost-effectiveness of measure to reduces AMU, such as improved management strategies (i.e., biosecurity strategies) (78) can be used as incentives. Within this category, typical extension instruments such as articles in agricultural magazines, demonstration farms, leaflets, study days, digital apps, and others are found. This is arguably one of the most used and investigated routes, mainly in the field of social veterinary epidemiology, which is the study of human behavior that affects the causes, spread, prevention and control of animal diseases and health problems (79), and related disciplines (80–82).

DESIGN AND EVALUATION OF POLICIES AND STRATEGIES: EVALUATION CRITERIA

The design of policies and strategies to reduce antimicrobials resistance is essentially guided by three criteria, being effectiveness, efficiency, and fairness (equity). These criteria should be used when evaluating, both ex-ante and ex-post, the performance of policies and strategies. Effectiveness refers to the question whether the implemented policy or strategy achieves its goal, i.e., a reduction in AMR. Policies or strategies that are not effective should not be further considered. In a world with unlimited resources, effectiveness would in fact be the only criterion of importance. However, this is not the case, especially for financial resources and time.

All policies and strategies within each of the five behavioral routes involve the allocation of resources. At farm level, policies and strategies usually aim to change AMU, biosecurity and production practices in general and/or to stimulate the adoption of alternative disease management measures. All this involves costs and benefits of which the end result may be negative or positive. Producers of antimicrobials may incur financial losses if the use of antimicrobials is drastically reduced. Policies and strategies such as the use of social norms, communication and education require the investment of financial resources and time by extension agents, researchers and other organizations. As resources are limited, the allocation of resources to one type of policy or strategy may come at the expense of another. Hence, resource allocation of animal health control in general and the reduction of antimicrobial resistance in particular, has to be informed by structured analyses (83, 84). Two criteria to evaluate these considerations are efficiency and fairness.

The economic efficiency of a policy intervention is the greatest when the social benefits net of social costs are maximized, regardless of how these may be distributed (85). The two most common approaches to evaluate economic efficiency in animal health are cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) (84). The former assesses monetary values to costs and outcomes to compare the net benefits of different courses of actions. Whereas it is the preferred approach by economists, it has a number of difficulties, particularly the problem of assigning monetary values to impacts such as improved human health or reduced AMR. This problem is circumvented in CEA by comparing costs in monetary units to outcomes expressed in more technical units, e.g., reduction in AMR or percentage reduction in average AMU. Through CEA, the effectiveness of different policies and strategies can be compared according to their costs. Whereas it is not always feasible to formally apply a CEA framework in quantitative terms, due to, amongst others, data scarcity and uncertainty, the use of estimates and sensitivity analysis to accommodate for uncertainty in a more broadly defined cost-effectiveness way of thinking, can aid in setting and prioritizing policies and strategies (84, 86, 87). Currently, economic tools and even economic thinking is insufficiently represented in the animal health domain and is often applied to individual farm decision support, but not to programs aimed at improving animal husbandry with regard to the reduction of externalities (88). This can lead to inefficient policies and strategies and low value for (public) money.

One shortcoming of cost-effectiveness analysis or CBA is that they do not consider the distribution of costs and benefits across all actors involved. Important criteria related to this are equity and fairness. While both concepts are related, they are not identical. Equity refers to the mere distribution of costs and benefits of different policies and strategies. Typically, these are not equally distributed over society, especially with an issue like AMR. Whereas the benefits are usually for society at large, through a decreased human health burden, costs often accrue to one or more specific groups, such as farmers, veterinarians or pharmaceutical companies. Nonetheless, the distribution of costs and/or benefits between different regions or groups may be a considerable measure when choosing between different policy options. Likewise, unequal distribution of costs and benefit can give rise to substantial opposition against new policies or strategies and may be the source of considerable lobby group efforts to weaken more severe regulation.

A problem is that equity considerations have been very resistant to rigorous analytical treatment. One of the reasons is the many competing notions of equity, which makes that the concept is analytically slippery. This becomes more clear when the notion of equity is replaced by the related concept of fairness. Whereas equity considers the mere distribution of costs and benefits across society, the concept of fairness refers to whether that distribution is socially just and acceptable. Fairness is a concept with which analysts are not comfortable, because it is open to subjective evaluation. One principle to overcome some of this difficulty is the Polluter Pays Principle (PPP), an environmental policy principle which requires that the costs of pollution be borne by those who cause it. In its original emergence, the PPP determined that the costs of pollution prevention and control must be allocated to the polluter. Its immediate goal is that of internalizing the environmental externalities of economic activities, so that the prices of goods and services fully reflect the costs of production (89).

Another concept related to this is the political feasibility of options if dealing with options that have to be decided upon and set by the government, such as public standards and taxes (90). Even if an instrument is theoretically effective and efficient, it can never be effective in practice if it is shot down in the political decision process. A proposed method to improve the political feasibility of policies and strategies is participatory design, i.e., the involvement of actors and stakeholders in the setting and prioritization of policies and strategies. Above the fact that such approaches might lead to more relevant, effective, and technically feasible measures, they have the advantage that participation of all involved and affected stakeholders in the design of the measures could lead to higher acceptability and thus higher political feasibility, which in turn leads to higher effectiveness.

DISCUSSION

In our introduction, we discussed the global political will to contain AMR through surveillance and optimal antimicrobial use and prescription. For the latter two, strategies are focused on reducing use and dependence, often without taking the behavioral character of AMU and AMR into consideration. To better visualize the interconnection between human decisions concerning AMU and AMR in livestock production, we looked at it from a systems perspective and adapted "the fix that fails" system archetype to represent the relationship between AMR and AMU. System archetypes are causal loop diagrams—or visual representations of balancing (B) and reinforcing (R) processes in a system—that seem to recur in many different life settings. The "fixes that fail" archetype involves the quick implementation of a solution to alleviate symptoms (91). The relief is however of short duration since unintended consequences arise from the solution over a long period of time or as an accumulated consequence of repeatedly applying the solution (91). In our system of interest, antimicrobials are used to treat animal morbidity, thus decreasing or balancing the latter (see B1 in **Figure 4**). Unfortunately, this repeated use leads to a delayed and unintended increase in AMR prevalence, which in turn reinforces animal morbidity (R1 in **Figure 4**). Along with antibiotics, alternatives to antibiotics such as phage therapy (B2 in **Figure 4**) and preventive measures/an improved animal health (B3 in **Figure 4**) can also balance animal morbidity. The first option will, however, suffer the same fate as antimicrobials since repeated use will result in resistance to these therapies (R2 in **Figure 4**). Only the improvement of animal health and disease prevention, which involves structural changes rather than quick solutions, is therefore expected to balance the prevalence of resistance in addition to animal morbidity.

This simple representation of the interrelationships between animal morbidity, solutions and consequences allows to easily visualize the imbalance that has been created by repeatedly reinforcing the same feedback loop as well as the unintended consequence that results from it. In order to solve this, global efforts are being made to contain AMR, mainly by institutionalizing AMU and by trying to reduce the dependence on AMU, the former acting on the first balancing loop (B1) in **Figure 4** and the latter on the two other balancing processes (B2 and B3). Since everything is interconnected, interventions in one feedback loop may also impact the others. For example, an improved animal health is expected to decrease animal morbidity, which, in turn, should result in a decreased need for antimicrobials and alternatives thereof, both of which have proven to be extremely valuable and indispensable assets for animal and human health. By juggling the use of both, the prevalence of corresponding resistances may be kept to levels that will not menace public and animal health, stabilizing their efficacy to decrease animal morbidity.

Addressing AMR in a sustainable manner is therefore based on the development of strategies and measures that aim to achieve an equilibrium where animal morbidity is reduced through solutions that enhance/preserve animal health, antimicrobials and their alternatives without compromising the effectiveness of the latter two. The effectiveness of these strategies and policies relies on whether these are technically, economically, behaviorally, and politically feasible in a certain temporal and spatial context.

In order to develop such strategies and policies, we addressed three fundamental questions on which control policies and strategies for agricultural pollution problems are centered in the light of AMR (34). We demonstrated the usefulness of systemic approaches to define who, what and how to target by considering the complexity in which the ultimate decision-maker is embedded. With regard to the third question, we explored five routes for behavioral change, being regulation, provisions, economic incentives, group pressure and communication and education. Whereas, this scheme has been developed in environmental sciences and economics to describe options to stimulate behavioral change regarding land use management and environmental sustainability, it has recently been popularized in veterinary sciences by Wessels et al. as the R.E.S.E.T. model (70) and was used by Lam et al. (71) to showcase interventions to change the antibiotics use behavior of Dutch dairy farmers with the suggestion that all the routes should be used in order to reach the entire sector. While this scheme was aimed at individuals, we also believe that it can be used to categorize AMR interventions at system level, in this case livestock production. A clear taxonomy moreover allows for the identification of gaps in current strategies, as this was done for antibiotic stewardship in human medicine (92). Moreover, we also believe that every way of targeting actors should not be used to the same extent in order to effectively manage AMR with limited resources. In this regard, we propose to guide the design of policies and strategies to contain antimicrobials resistance by considering their effectiveness, economic efficiency, and fairness (equity) and by defining cost-effective combinations of instruments within the different categories to target the relevant actors of a system. These criteria are seldom being used in the design of policies and strategies for AMR and even less so in a holistic and systemic sense, that is, taking into account the full breadth of potential actors and bases as well as the full breadth of potential policies and strategies across all five routes of behavioral change. This is exacerbated by the fact that policies and strategies within the five behavioral change routes are often investigated within different and distinct disciplines. Researchers in veterinary medicine and veterinary epidemiology mainly deal with technical measures that will result in a reduction in the use of antimicrobials, such as better biosecurity, vaccination and alternatives to antimicrobial, which are sometimes hard to adopt due to a lack of social science knowledge. More recently, the field of social veterinary epidemiology, which is composed of research from both veterinary epidemiology and social sciences, has boomed, resulting in an amplification of studies that aim to inform policies and strategies mainly from within the communication and education route. Finally, economists are often mainly dealing with economic incentives such as taxes and labels, and to a lesser extent with regulation, most often private standards.

These observations, in addition to the systemic approaches we are suggesting to use to define who and what to target, point to a need for more interdisciplinary research. The final decision of how and when to use antimicrobials has a non-linear, uncertain and unpredictable character that is shaped by various factors that are inherent to a system. Such a system is best understood when tools and methods from different disciplines are used. Such approaches, here referred to as interdisciplinary systemic approaches, have already been documented in relation with urban (93) and agricultural (30) sustainable solutions for climate change, and sustainable energy use in homes (94). They have also been advocated for in the context of antimicrobial resistance by Flowers (95), who considers that public health policies lack a systems perspective and highlights the added value of health psychology, that focuses on the individual, and its synergies with medical sociology, which focuses on the systems and organizations. In addition to crossing the boundaries of disciplines, we suggest to go a step further by advocating for the involvement of stakeholders in the development of solutions and strategies *via* participatory approaches, which could be considered by some as a shift from interdisciplinarity to transdisciplinarity (96). According to Stock and Burton (97), transdisciplinarity mainly differs from interdisciplinarity by aiming to synthesize new disciplines and theory. In the case of antimicrobial resistance, the One Health approach is often referred to as inter- and transdisciplinary, while the degree of integration in practice varies between, on the one hand,

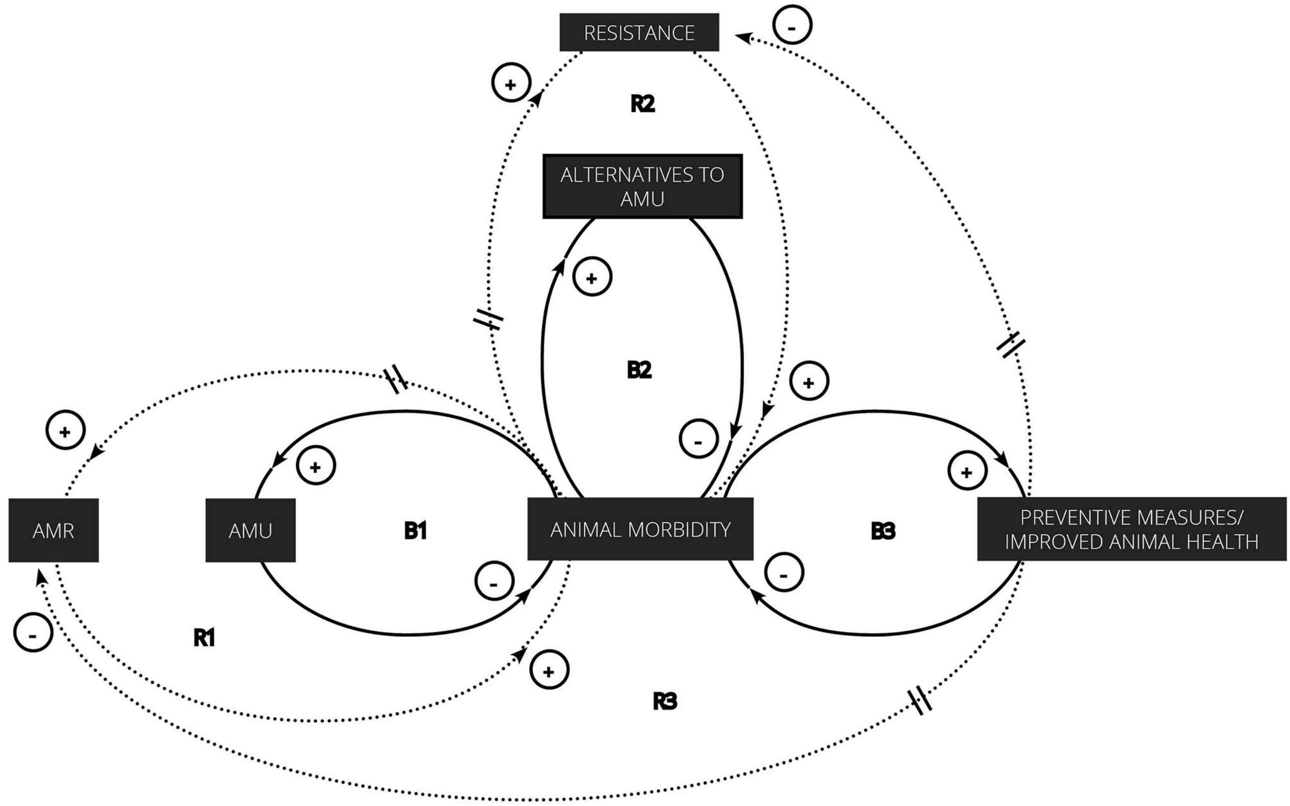

FIGURE 4 | "Fixes that fail" archetype adapted to represent the interconnection between AMU, therapeutic alternatives to antimicrobials, preventive measures/improved animal health, resistances, and animal morbidity in livestock production.

improving knowledge exchange and communication between environmental, animal health, and public health research and, on the other hand, truly viewing these domains as interconnected and therefore as one research area. However, the contributions of the different disciplines within One Health often remain very discrete, meaning that problems that are addressed in a One Health way, are addressed from the perspective of one discipline across the three research domains. For example, topics that are studied in both human and animal health are often approached from a biotechnological perspective, leaving out social and economic sciences. In contrast with this, our approach aims to promote a true holistic perspective based on goal-oriented interdisciplinary research. This relates to having a strong Agricultural Knowledge and Innovation System (AKIS) (98) and veterinary public health sector, with a critical mass of diverse stakeholders that collaborate in concerted efforts. The stakeholder mass should encompass both business and transdisciplinary actors (e.g., farmers, companies) and non-business actors such as organizations (e.g., farmers' organizations, federations of veterinarians) and public institutes and organizations. These stakeholders should collectively strive for such a goal-oriented interdisciplinary agenda. Moreover, the public institutes and organizations such as public animal and/or human health agencies could take the lead to facilitate this. For example, Living Labs could be set up as part of research and innovation projects (99) and knowledge centers funded by public-private partnerships could be created to steer this process.

In addition to obtaining a holistic view of a problem and identifying solutions, interdisciplinary systemic approaches can further allow to anticipate unexpected positive or negative side effects that the solutions may entail. For example, reducing AMU to solve AMR will also help reducing AMR pollution that could disturb ecosystems (66), but might have negative implications when it comes to animal welfare.

Finally, in addition to the defining who, what and how to target *via* interdisciplinary approaches, we identified a fourth question that relates to who will implement the regulation or strategy, i.e., by whom the party of interest will be targeted. Indeed, when considering policies or strategies, it is often considered that these will be implemented by the government. However, key actors in livestock production systems could be used to target the party of interest. For example, farmers' unions or farming schools could develop courses on biosecurity to incite farmers to improve this on their farms. Consumers could be sensitized to the problem *via* retailers by obtaining information about the use of antimicrobials during the production of the meat. In this regard, some companies are currently trying to provide their customers with information about the production and provenance of their products *via* the block chain technology in an attempt to enhance transparency regarding food supply chains (100).

CONCLUSION

Strategies and policies that focus on reducing use and dependence to antimicrobials often do not take the behavioral character of AMU and AMR into consideration. To address this, we have introduced an approach that relies on interdisciplinary systemic approaches to comprehensively characterize antimicrobial decision system, hence identifying all actors influencing AMU in livestock production, adequate regulatory and intervention bases, which behavioral change strategies to use and whom should implement this. In addition, we suggested to identify the best combinations of behavioral strategies through cost-effective analyses since economic and time resources are limited. To enable the development of policies and strategies *via* the suggested approach, several areas for further research arise:

a) Interdisciplinary systemic research to assess the behavioral aspect of AMR by characterizing antimicrobial decision systems in livestock production systems.
b) Interdisciplinary research allowing the development of solutions or interventions across several disciplines in order to enhance their overall feasibility.
c) The use of participatory design (or co-creation) approaches in order to develop solutions that are adapted to the context in which decision-makers are embedded.
d) Economic analyses in order to identify cost-effective combinations of interventions from different behavioral change routes at system level.

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The writing was mainly performed by FB and EW. All authors contributed equally to the conceptual thinking and editing of this paper.

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Access to Veterinary Drugs in Sub-Saharan Africa: Roadblocks and Current Solutions

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Background: Access to veterinary drugs for livestock has become a major issue over the last decade. Analysis has tended to focus on the demand for these products, while studies looking at the drivers behind their use generally focus on farmer behavior and interactions between veterinarians and farmers. However, the use of drugs also depends on structural factors that determine the functioning of the drug supply chain and farmers' access to the drugs. This article presents an overview of the factors that limit access to veterinary drugs in sub-Saharan Africa (SSA) as well as the international policy tools and arrangements that claim to improve it.

Methods: We have conducted a scoping review of the scientific and grey literature as well as the publicly-available data from both the animal health industry and international organizations. We aimed to gather information on the veterinary drugs market in SSA as well as on the international norms, recommendations, guidelines, and initiatives that impact SSA farmers' access to these drugs.

Findings: We highlight numerous barriers to veterinary drug access in SSA. The SSA market is highly dependent on imports, yet the region attracts little attention from the international companies capable of exporting to it. It suffers from a high level of fragmentation and weak distribution infrastructures and services, and is driven by the multiplication of private non-professional actors playing a growing role in the veterinary drug supply chain. The distribution system is increasingly dualized, with on the one hand the public sector (supported by development organizations) supplying small scale farmers in rural areas, but with limited and irregular means; and on the other side a private sector largely unregulated which supplies commercial and industrial farming systems. Different innovations have been developed at the international and regional levels to try to reduce barriers, such as homogenizing national legislations, donations, and vaccine banks. Alongside decades-old inter-state cooperation, many new forms of public-private partnerships and other hybrid forums continue to emerge, signaling the private sector's increasing influence in global governance.

Conclusions: Policies on animal health would be bolstered by a better understanding of the drivers behind and the components of access to veterinary drugs in different regional and national contexts. Inequalities in drug access need to be addressed and a market-driven approach adopted in order to strengthen our understanding of what determines veterinary drug use at the farm level. Policies should balance the interests

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of the various stakeholders, being careful not to reinforce bias toward certain diseases deemed "interesting" and neglect others that could prove to be highly important for veterinary public health.

Keywords: access to medicines (ATM), animal health, international pharmaceutical market, supply chain, Sub-Saharan Africa (SSA), veterinary drugs

INTRODUCTION

Over the last 30 years, integrative approaches have been adopted in health policies, placing interdependencies on a global scale and between species at the forefront with the Global Health and One Health paradigms. Global, cross-species interdependency has been pushed to the forefront of discussions through Global Health and One Health paradigms. This approach has been justified by the increasing prominence of emerging infectious disease risks, such as HIV/AIDS, Ebola virus disease, antimicrobial resistance (AMR), and Covid-19. Most of these risks emerged in developing countries due to increasing contact with reservoirs of pathogens in animals as well as flawed health systems.

Access to drugs is a core component of any health system or policy. In the last few years, multilateral organizations have pushed for the reinforcement of regulation of the trade and use of drugs within the context of the struggle against AMR. These efforts have highlighted the importance of tailoring policies to national contexts if they are to be effective (1). However, although access to drugs has been the subject of many academic works dedicated to human health, in particular within the context of developing countries (2–6), the animal health sector has received much less attention. Recent attention given to AMR in international and national policy has led to an increase in animal health studies (7–9).

The aim of this paper is to provide an initial general picture of the issues related to drug access in the context of livestock farming in SSA. We focus on SSA because it is the poorest region in the world and thus demonstrates the most salient issues regarding access to drugs, and most SSA countries bear a heavy burden when it comes to the economic and health impacts of animal diseases (10). Secondly, SSA is large enough to provide examples of a wide range of national situations.

When it comes to understanding the drivers of consumption of veterinary medicines, previous studies have tended to emphasize the role of demand—that is the "final" consumers, whether farmers or veterinarians. These studies are mainly published in veterinary journals not directly concerned with publishing social science research. The conditions under which drugs can be accessed and the importance of supply have been overlooked. Pioneering work on these issues in the social sciences has focused on Western countries (11–14). In SSA, a few studies have adopted a market-driven approach to veterinary drugs: this is partly the case for Bardosh et al. (15) in Uganda, Bessell et al. (16) in Tanzania, Kingsley (17) in Nigeria, and (18, 19) in Kenya. Available data on the veterinary drug supply chain have described the world market of veterinary drugs (20, 21), the regulation of this market (22–24), and the processes of harmonization of technical specifications at an international level (22, 25, 26), but they are to a certain extent outdated and only include brief references to SSA.

In studies on SSA specifically, more attention has been given to veterinary infrastructures, and their role in delivering services to low-income farmers in view of agricultural development (27–33). Some elements on access to drugs can be found indirectly in works focusing on specific animal health issues (e.g., bovine trypanosomiasis, tick-borne diseases, Newcastle disease, etc.) or products (vaccines, trypanocidal drugs). These studies describe the uses and misuses of drugs by farmers and animal health workers as a consequence of their knowledge and perceptions of diseases and drugs. They provide information on farmers' perceptions and self-assessment of veterinary drug-dispensing services [see for example Somda et al. (34) for Gambia; Enahoro et al. (33) for Ghana and Tanzania; Machila et al. (35, 37) and Higham et al. (36) for Kenya; Moffo et al. (8) for Cameroon; Soudre et al. (38) for Burkina Faso]. Many of these studies highlight farmers' lack of knowledge, awareness, or compliance (39, 40). Less common are studies that attest to the farmer's essential and positive role in animal disease management (41).

This paper is a scoping review based on the academic literature and publicly available grey literature. We aim to underline the main challenges sub-Saharan countries face in providing equitable access to veterinary drugs. We adopt here the definition of veterinary drugs proposed by the FAO (42), which includes: "drugs, insecticides, vaccines and biological products, used or presented as suitable for use, to prevent, treat, control or eradicate animal pests or diseases, or to be given to animals to establish a veterinary diagnosis, or to restore, correct or modify organic functions." In this paper, we focus on drugs used for livestock (excluding pets), and on modern drugs (excluding traditional or ethnoveterinary medicines). According to the WHO (43), drug access is defined by the availability of drugs, including issues of quantity, regularity, quality and diversity, and affordability (or economic accessibility).

We present the information we gathered according to a socio-economic framework of supply chains. We consider access to drugs as the result of activities carried out by various entities (public and private) from the conception of a product to its final use, including the issue of residues. These activities include research and development, production, distribution, prescription, and use of drugs. The stakeholders and activities involved can be referred to as the veterinary drugs supply chain, using a broad understanding of the notion of a supply chain, which also includes all of the actors that contribute indirectly to the organization and functioning of the circulation of drugs, from molecules to residues, through the drafting of norms, rules, and recommendations.

This approach makes it possible for us to highlight the variations and inequalities between and inside countries, and the structural factors that limit the choices available to low-income farmers while minimizing the role of individual attitudes and perceptions as social determinants of consumption patterns. It looks at supply as a driver of consumption, and at policies on access to drugs, and regulation of their use.

After describing how the material used for this study was selected (Section Materials and Methods), we present the main socio-economic barriers to drug access in SSA (section The Many Factors That Limit Access to Veterinary Drugs in SSA) before presenting an overview of the contemporary political arrangements that have emerged at the international and regional level (Section International and Regional Arrangements for Improving Access to Veterinary Drugs) as part of efforts to improve access to veterinary drugs in SSA.

MATERIALS AND METHODS

Data were collected through a scoping review (44) of academic work and grey literature containing empirical material. The main objective was to map existing knowledge and to identify gaps in knowledge on veterinary drug access in SSA.

For the academic work, a scoping review was conducted using the scientific database Web of Science. The search terms used to identify publications were: [(drug* OR medicin* OR pharma* OR access) AND (veterinary* OR animal OR zoo* OR husbandry OR livestock OR poultry OR sheep OR goat OR pork OR cattle) AND (trade OR use OR delivery OR service*) AND Africa AND (health OR disease OR epidemic OR epizoo*) NOT ethno]. These terms were searched in the topic (= title, abstract key word) and for the publication period 1975 to 2021, in all types of documents. From the 1,076 documents pre-selected, a first screening based on title and abstract and a second one based on the full texts, and 46 relevant documents were finally selected.

For the grey literature, we looked at the websites of different organizations involved in animal health in SSA and in some cases contacted them directly. This included the World Organization for Animal Health (OIE), Food and Agriculture Organization of the United Nations (FAO), AU-IBAR (the African Union – Interafrican Bureau for Animal Resources), ILRI (International Livestock Research Institute), World Trade Organization (WTO) as well as the Veterinary International Committee for Harmonization (VICH), GALVmed (The Global Alliance for Livestock Veterinary Medicines), HealthforAnimals (a non-profit, non-governmental organization representing companies and trade associations from developed and developing countries), pharmaceutical companies (Elanco Animal Health, Virbac, Zoetis, and MSD), and market research companies (Vetnosis, Mordor intelligence, Transparency market, Future Market insights). We collected data and technical reports describing the international veterinary drug market, veterinarian services, and drug distribution and use in SSA. Our material also includes recommendations, guidelines, norms, directives, and agreements related to veterinary drugs.

RESULTS AND DISCUSSION

We present and summarize here results concerning factors that limit access to veterinary drugs (understood in terms of quantity, diversity, adequacy, physical or geographic accessibility, affordability) by using a general framework of supply chains: overall market size, production, trade, and consumption. Subsequently, we present the contemporary repertoire of policy tools used to overcome these barriers.

The Many Factors That Limit Access to Veterinary Drugs in SSA

What little information there is on the veterinary drugs market in SSA is difficult to access. Market information is not freely or wholly shared by the economic actors involved; information transmitted by national bodies to international organizations such as the OIE is not always publicly accessible, e.g., the OIE reports assessing the performance of the national veterinary services (PVS) or the veterinary legislation (VLSP). Moreover, any statistics that are publicly available are likely to only partly document the circulation of veterinary drugs, due to the market share held by informal products. "Illegal drugs" represent 20–30% of the market, according to HealthforAnimals (45). Additionally, the categories used to describe this market vary according to the source. These variations relate to the types of drug (insecticides, vaccines, biologicals, pharmaceuticals, feed additives), types of animals (pets, farmed animals), and geographic groups.

Nevertheless, these sources give an overall picture of the veterinary drug market in SSA: a small share of the world market, indicators of low use in some production systems, a limited local production of drugs (exemplified by the vaccines sector), weak distribution infrastructures and services, a lack of professionalization in the supply chains, and serious quality issues.

Production and Imports

The production of veterinary drugs is limited in SSA. Only a few countries have private drug manufacturers (mainly tertiary manufacturers), such as Bupo Animal Health (formerly Bedson) in South Africa and Cooper-K in Kenya, or the capacity to even partly supply neighboring countries. The production of veterinary drugs is often underpinned by public veterinary structures that focus on easy-to-produce generic medicines to support veterinary public health activities for small-scale farmers through vaccination campaigns or parasite control.

Regarding the specific case of vaccines (see **Figure 1**), the information provided by the OIE Wahis database[1] for 19 countries in SSA suggests 500 million doses a year were produced in the region during the 2014–2018 period, covering around 20 different types of vaccines. Ethiopia represents a third of this production, the vast majority of which was vaccines for poultry. The most widely produced vaccines were for Newcastle disease and anthrax (produced in 14 of the 19 countries where data

[1]OIE-WAHIS (OIE World Animal Health Information System) is a database providing worldwide data on the animal health situation and animal health capacities https://wahis.oie.int/.

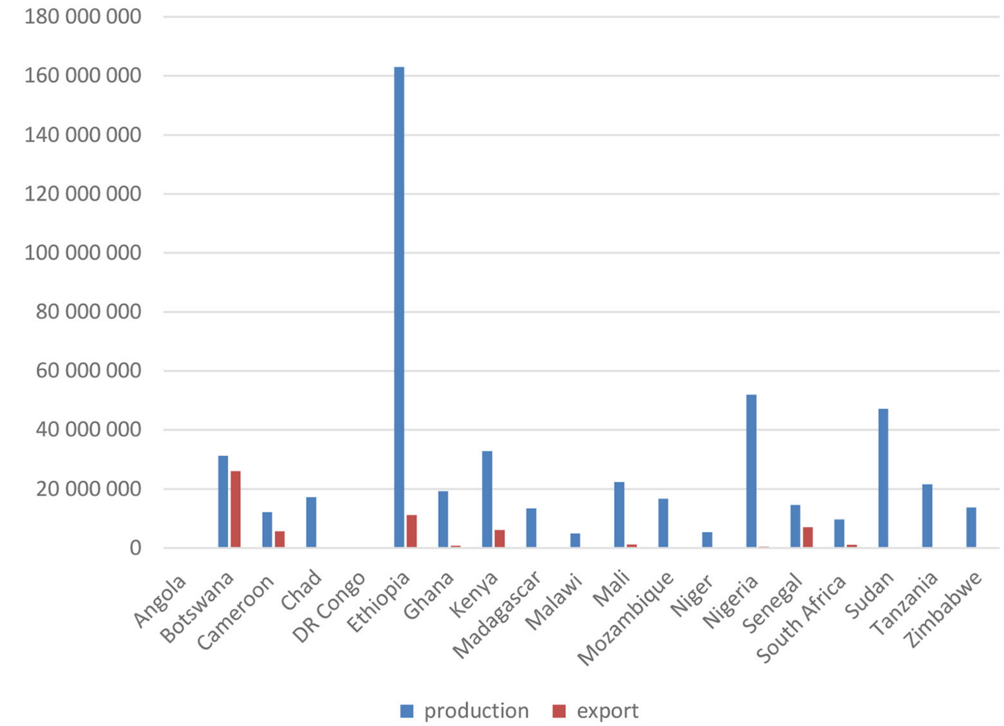

FIGURE 1 | Production and export of vaccines for animals in sub-Saharan African countries (based on OIE Wahis database, average number of doses for 2014–2018).

is available), followed by the vaccine against *Peste des Petits Ruminants* (PPR) produced in 9 of the considered countries. Production mainly responds to national needs. Few countries have the capacity to export: the most salient exception is Botswana, a country that exports around 80% of its production and represents 43% of all recorded exports in SSA. Regional cooperation exists, such as the Pan-African Veterinary Center of the African Union (AU-PANVAC) in Ethiopia, which produces biological reagents for animal disease diagnosis and also provides independent quality control of veterinary vaccines.

The veterinary drugs market in SSA is dependent on imports from Europe, the US, Brazil, and, increasingly, China and India, with a complex organization between primary, secondary, and tertiary manufacturers and export and re-export processes that still need to be clarified by further research. Most of these products are imported by national distributors. Among the larger pharmaceutical companies, only a few have established branch offices in SSA, according to their annual reports and websites. Elanco Animal Health, Virbac, Zoetis, and MSD Animal Health have all established branch offices (subsidiaries) in South Africa. The Elanco Animal Health group, which acquired Boehringer Ingelheim's veterinary branch in 2016 and Bayer's in 2019, has the most extensive presence on the continent, with subsidiaries also in Angola, Kenya, Mozambique, Zambia, and Zimbabwe. The lack of harmonization in SSA national regulation, in particular when it comes to drug registration processes, contributes to a market fragmentation that discourages importation (46).

Weak Distribution Infrastructures and Services in the Public Sector

Infrastructure and services are necessary for the adequate distribution of drugs to their final users. Various papers underline how limited access to veterinary services is a major problem for livestock producers in sub-Saharan countries: see the issues of the OIE review dedicated to *Veterinary institutions in the developing world: current status and future needs* with a special focus on SSA countries in 2004 and the issue *Good governance and financing of efficient veterinary services* in 2012; as well as the recent review of Abakar et al. (32) on the status of veterinary services in the Sahel over the last 20 years. Other studies focus on a specific country or group of countries such as Kenya and Uganda (47–50), Tanzania (51), Central Africa (52), South Africa (53, 54), or Tanzania, Uganda, and Ethiopia (55).

In most countries in SSA, access to veterinary drugs was provided in the past by a centralized public sector inherited from the colonial period (31), managed by the veterinary profession and based on a populational approach to animal health (56). However, in the 1980s, under pressure from the World Bank, most developing countries adopted structural adjustment programs (SAPs) taking a market approach as the preferred means of providing services whilst at the same time reducing state expenditure. Impacts of the SAPs have been extensively analyzed and discussed in several international forums and publications in the decades following the reform, analyzing the consequences of the subsequent drastic shift of responsibility from the public to the private sector, including in the veterinary drug deliveries and veterinary services (30, 48, 52).

For example, Smith (52) indicates that the SAPs "imposed drastic reforms aimed at restructuring the public veterinary service and at privatization"; this process has been top-down and at times chaotic with no attempts made to find appropriate solutions for the diversity of production systems. Smith concludes that only a handful of countries and a small proportion of producers have benefited from this privatization. A successful example is that of cattle breeders in the Central African Republic, whose access to trypanocides (for the control of trypanosomiasis) was greatly improved. This success is attributed to the powerful cattle breeders' association determinant in driving the reform (52).

Veterinarians and para veterinarians[2] are few and far between in SSA, see for example (57) in Ethiopia. Based on data from the OIE WAHIS database, we estimate that there are ∼7.4 animal health professionals for every 100,000 inhabitants in SSA (made up of two veterinarians and 5.4 para-veterinarians). By comparison, there are on average 49 and 53 animal health professionals for every 100,000 inhabitants in the UK and US, respectively. Moreover, public services suffer from inadequate and unpredictable budgetary allocations and drug supply and have limited capacity to visit farmers. Their role as drug suppliers is restricted to the delivery of parasiticides and to vaccination, particularly during outbreaks. Rates of absenteeism are high and opportunities for career progress are limited. Some of these veterinarians work in parallel for private clinics, selling drugs and delivering therapeutic individual care for pets and farmed animals. This partly makes up for the absence of the private sector but also contributes to the blurring of lines between public and private services (27).

The performance of the veterinary authorities in regulating the circulation and use of veterinary drugs is also described as limited in many SSA countries, according to the PVS evaluation tool developed by the OIE. This tool includes a section on the technical authority and capability in relation to veterinary medicines and biologicals. Grading ranges from one ("The veterinary services cannot regulate veterinary medicines and biologicals") to five ("The control systems for veterinary medicines and biologicals are regularly audited, tested and updated when necessary, including via an effective pharmacovigilance program"). In SSA, based on the currently available reports on the OIE website for 20 countries, two countries are graded level one (Guinea Bissau and Congo), 15 countries level two (Guinea, Ivory Coast, Benin, Mali, Mauritania, Namibia, Niger, RCA, Kenya, Seychelles, Rep of Sudan, South Africa, Togo, Chad, and Nigeria), two countries level three (Senegal and Swaziland), one country level four (Botswana), and none are graded level five.

This public sector weakness has a greater impact on low-income farmers, particularly in remote areas. It also limits the potential to face public health challenges requiring the intervention of public authorities, and regional or international coordination.

[2]According to the OIE terrestrial code, "Para-veterinarians", or "veterinary paraprofessionals" are professionals authorized by the veterinary status body, working under the direction and responsibility of veterinarians.

Challenges in the Development of Private Distribution of Veterinary Drugs

The number of public veterinary services has not been fully offset by the private sector, particularly with regards to the distribution of veterinary drugs in rural areas. These reductions have led to many failures in the supply of veterinary drugs and services (48, 49). Gehring et al. (58) indicate that in some villages in South Africa, the nearest accessible outlet for veterinary drugs was between 10 and 30 km. There is little incentive for private veterinarians and pharmacists to provide services in areas where the use of veterinary drugs per cattle head is low, purchasing power is limited, animals are widely dispersed, and transaction costs are high. Private veterinarians are more likely to commit to sectors where revenue is higher, such as the emerging market for pet health in cities or the burgeoning sector of intensive livestock farming in peri-urban areas (31, 52, 59, 60).

The privatization of veterinary services has contributed to the transformation of veterinary drugs and services from public goods to simple commodities. This privatization has an impact on drug availability: it favors the offer of drugs with high economic returns or those that respond to farmers' habits regardless of efficiency and adequacy. For example, Bardosh et al. (15) show that product availability in Uganda is dependent on what interests the animal health industry, which has led to higher sales in non-tsetse effective drugs.

Most studies on the provision of veterinary services conclude that there is a need for collaboration between the different stakeholders of veterinary services (public/private, donors) (32, 61), including farmers (41), as well as between human and animal health services (62, 63). More recently, to support veterinary drug delivery and services, new business models and institutional arrangements have emerged, such as cost recovery for public veterinary services, public/private partnerships, or contract farming. Experiences of contracted farming have been documented, for example, in the poultry and aquaculture sector in Burundi, Kenya, Rwanda, and Uganda (64).

The Multiplication of Non-professional Actors in Veterinary Drug Supply Chains

Gaps in delivery of veterinary services following the implementation of the SAPs have been partly filled by a variety of actors with basic knowledge or by other unqualified actors (65–69). Some studies, for example, that of Turkson (70) in Ghana, describe how shortages of practicing veterinarians see farmers taking the medication of their animals into their own hands.

Community animal health workers (CAHWs), sometimes referred to as the third sector (as opposed to the public or private sectors), have been trained to fill this gap, usually through the support of donors (49). They provide basic veterinary services to farmers in rural areas. Their formal knowledge consists of brief training from public veterinary services and NGOs (71). They are encouraged to develop a private veterinary drug supply system to finance their activities long term. Successful examples have been reported, for example in Kenya (18, 72). However, as public services, this CAHW-provided service also suffers from many constraints such as irregular supply, the low purchasing power of farmers, and transport difficulties (73, 74).

In various countries, the liberalization of veterinary drug distribution has also encouraged the emergence of alternative supply chains made up of a large number of middlemen (66, 69), mostly in peri-urban areas. In these areas, livestock farming is developing in conjunction with the increasing urban consumer demand for meat and a process of intensification supported by urban investors or by producer organizations (e.g., commercial poultry farmers' associations). The private markets for veterinary drugs have become concentrated in these areas. Private as well as public veterinarians (as part of a secondary activity) are involved in these private supply chains. Some of the individuals involved only have practical knowledge of drug use (e.g., commercial poultry farmers), while others do not have any knowledge at all but have capital they wish to invest in growing markets. Frequent failures observed in veterinary administration and regulation have left the private supply chains unregulated from imports to retail, and many drugs are sold without prescription. As a consequence, veterinary medicines can be found anywhere, anyhow (27). Gehring (75) describes a significant record of adverse reactions reported to the Veterinary pharmacovigilance center in South Africa due to inappropriate, extra-label uses of products by non-veterinarians.

Issues With Convenience and Quality of Available Drugs

The issue of veterinary drug accessibility also includes questions around convenience, suitability for local needs, and quality. As in the human health sector, (76), diseases endemic to Africa have received little attention from the pharmaceutical industry or research into disease epidemiology, which raises the issue of neglected animal diseases (77). The low level of training provided to CAHWs also limits both the convenience and diversity of available veterinary drugs. The role of CAHWs in delivering medicines is generally officially limited to drugs that represent the least potential for abuse, those with a broad-spectrum, and those that can be sold over the counter.

This lack of diversity, along with differences in price, may encourage the extra-label use of medicines, including use for other indications, methods of administration, species, age groups, and so on. This practice also includes the use of human medicines for animals, particularly when human medicines are more easily available and affordable, which can be the case when different countries adopt economic policies including low import taxes and grants aimed at improving access to human drugs. These uses give rise to inappropriate use of drugs, particularly in the absence of technical supervision and an effective regulatory framework. For example, veterinary services in Madagascar have reported injectable contraceptives intended for women (progestogens Confiance^{TM}, Pfizer), easily available at a low price, being used as an alternative for surgical castration of adult sows before culling (78). Misuse is also fostered by unsuitable packaging, for example, labels in foreign languages, or when small-scale farmers only have access to 1,000-dose packs Newcastle-disease vaccines, despite only having a relatively small number of animals.

Sub-standard and non-registered drugs are also an issue. The market for illegal drugs is estimated to be worth 400 million US dollars a year in SSA and North Africa and 1–2 billion US dollars worldwide (45, 79). Institutions for drug quality control are sorely lacking and only a few countries with significant production capacities (Botswana and Ethiopia) have properly equipped control laboratory facilities staffed by technically competent personnel, according to the aforementioned PVS tool. The lack of quality control and reliable certification of quality hinders farmers in their distinction between high- and low-quality drugs. Consequently, this deters sales of high-quality products, leading to an economic mechanism of adverse selection whereby bad products drive good products off the market (80).

Various issues with quality have been raised, from lower concentrations of active ingredients than that stated on labels to toxicity. According to a survey conducted in West Africa by the Interstate School of Veterinary Science and Medicine in Dakar and quoted by Le Minor (26), 67 and 69% of the veterinary drugs sampled in the formal and informal sectors, respectively, were of sub-standard quality. Of these sub-standard drugs, most were trypanocides and antibiotics (oxytetracycline). The sub-quality of trypanocides sold in SSA has been demonstrated by numerous studies. Bengaly et al. (81) provide an assessment of the quality of trypanocidal drugs sold in French-speaking countries in West Africa (Benin, Burkina Faso, Côte d'Ivoire, Mali, Niger, and Togo) in which "51.90% of the samples were non-compliant compared to the standards and were containing lower quantity [sic] of the active ingredient compared to the indications on the packaging." Another study conducted by Tchamdja et al. (82) revealed a high proportion of trypanocides of sub-standard quality on the Togolese market (40%) and an even higher proportion (53.57%) for the sample collected from unofficial markets. The same problem is described by Tekle et al. (83) in Ethiopia, with 28% of trypanocidal drugs tested failing to comply with quality requirements. Vougat Ngom et al. (40) analyzed the quality of veterinary drugs sold in the Far North Region of Cameroon and concluded more positively that general quality was good, with concentrations often different but similar to that which is labeled and with no differences between vendors. Furthermore, they concluded that some differences in concentrations were likely the result of poor storage rather than intentional dilution and said the main problem in the region was poor compliance with recommended treatments among farmers.

At Farm Level: Low Availability and Affordability

Overall, the use of veterinary drugs in SSA is low. The global veterinary drug market has been described by Crosia (21) as globalized and dominated by less than ten American and European pharmaceutical firms. Recent analyses by market research firms have described the dynamic nature of the global veterinary pharmaceutical market thanks to a growing pet sector in Western countries and an increasing number of farmed animals in emerging Asian countries (84). SSA's contribution to this dynamic is difficult to calculate since data are scarce, but the omission of SSA in such market reports is also telling. Annual reports of the major companies and most market studies on veterinary pharmaceuticals do not refer to Africa or SSA or do so only indirectly through the category "rest of the word" (21, 85) or jointly within the category Middle East (84, 86). South Africa is the only country in SSA sometimes highlighted in market analysis (87). This indicates a lack of corporate interest in the SSA market. Other rare studies give an overview of the situation in specific countries in SSA: Messomo Ndjana (88) in his veterinary thesis on the distribution and quality of veterinary drugs in Cameroon; and Grasswitz et al. (20) in a report for UA-IBAR on the veterinary pharmaceutical industry in three sub-Saharan countries (Kenya, Uganda, and South Africa).

Depending on the source, the SSA market, along with other countries in North Africa and the Middle East, represents 1.7–7% of the global market (20, 21, 84). While there is a lack of recent data, past calculations have indicated that more than half of this market is concentrated in South Africa (20). These figures can be compared with the livestock population in SSA: according to FAO (10), SSA accounts for 14% of livestock worldwide (and North Africa and the Middle East represent 3.3%). Therefore, the average level of consumption of veterinary drugs per livestock unit in SSA can be estimated as between 12% (1.7/14) and 50% (7/14) of the world average use level.

Although the overall availability and diversity of veterinary drugs are low, significant differences exist between countries, farming systems, and animal species. A study conducted by GALVmed (unpublished, personal communication) based on a survey administered to local veterinarians in seven countries in SSA (Burkina Faso, Ghana, Kenya, Uganda, Nigeria, Senegal, Tanzania), documents the variations in farmer's access to drugs. Backyard poultry is the least "medicated" species in all countries studied. More than half of the backyard poultry farmers in Senegal, Uganda, Tanzania, and Kenya do not have any access to veterinary drugs. In the low-input small ruminant sector, veterinarians declared that half of the farmers did not have any access to drugs in Nigeria, and only had access to one type of drug (dewormers or antibiotics) in Burkina, Uganda, Tanzania, and Kenya. Access was assessed by veterinarians as very limited in Uganda and Tanzania, compared to Senegal, Burkina Faso, and Ghana. In Nigeria, the situation differs between species, with better access to treatments for small ruminants compared to those for poultry and cattle. The most accessible drugs were vaccines against Newcastle disease, antibiotics and anticoccidials for poultry, and antibiotics and vaccines against PPR for small ruminants (goats and sheep). In Tanzania, access is described as limited for the majority of farmers, however, a few cattle owners have access to a relatively large diversity of drugs (21 different drugs, which was the highest level of diversity reported by this survey for any species). Interestingly, in Uganda, antibiotics for backyard poultry are said to be more accessible than vaccines; and in the commercial sector, more than half of farmers only have access to antibiotics. Similarly, for small ruminants in Kenya, Uganda, and Tanzania, antibiotics were reported as being more accessible than vaccines.

Similarly, high variations in access and use between and within countries in SSA are shown in data focusing on antibiotics. The *Fifth annual report on antimicrobial agents intended for use in animals* edited by the OIE (89) indicates for 2017 an average consumption of 117.48 mg/kg of adjusted animal biomass for the 102 reporting countries, compared with an average of 30.35 mg/kg for the 24 reporting African countries (sub-Saharan and north-African countries). The specific case of Cameroon described by Mouiche et al. (90) shows large differences between species, from 213.32 mg/kg for poultry to 0.47 mg/kg for goats.

Finally, accessibility also depends on affordability. Most farmers in SSA have low purchasing power. According to the International Livestock Research Institute (91), poverty is widespread among livestock owners in SSA. Modern drugs are therefore less affordable for these farmers and the market opportunities are limited for supply chain stakeholders. Moreover, compared to emerging Asian countries engaged in what is commonly described as the "livestock revolution" (92), low-input farming systems remain predominant in SSA. For example, in 2011, SSA represented 2.1% of the world-intensive poultry production compared to 38% for China (and 46.8% for the whole East Asia and Pacific Region) (93). Low-input livestock production (including inputs such as veterinary drugs) is the main approach for farmers in pastoral areas who have limited and uncertain access to markets and cash and are exposed to external threats such as climate-related risks (94).

International and Regional Arrangements for Improving Access to Veterinary Drugs

Different international- and regional-level institutional arrangements have emerged over time to help SSA countries improve drug access and coordinate and harmonize actions. This can directly improve access to veterinary drugs, promote the regulatory policies of international organizations, and mobilize pharmaceutical firms. Veterinary drug supply chains are framed by arrangements that have been promoted and institutionalized by international organizations such as the World Organization for Animal Health (OIE), the Food and Agriculture Organization (FAO) of the United Nations (UN), the Codex Alimentarius and the Veterinary International Conference on Harmonization (VICH), and the World Trade Organization (WTO) Sanitary and Phytosanitary Measures (SPS) Agreement (22–24). Standards set by the VICH and Codex Alimentarius also provide countries with a set of norms with which to regulate production, marketing authorizations, trade, and use of veterinary drugs (22, 24). Bilateral and regional agreements also contribute in the form of donations and vaccine banks. Aside from inter-state cooperation, we note a rapid increase in initiatives where the private sector plays a central role, in particular pharmaceutical companies. However, these arrangements rarely include Research and Development and are mainly focused on trade and veterinary advice rather than on the production side.

We focus here on the arrangements implemented at the international level, within a framework of international cooperation in which animal health is considered a global public good. Important efforts are also carried out at the national level, including, for instance, price subsidies, taxes, flexibilities in the Agreement on Trade-Related Aspects of Intellectual Property (TRIPS). However, they go beyond the scope of this paper.

Slow Harmonization of Regional and National Regulations

As mentioned above, many countries in SSA have very weak regulatory systems. For example, in Mozambique, there is no legislation addressing veterinary drugs, whilst in Angola, it appears that veterinary drugs are only superficially mentioned in legislation that mainly focuses on human medicines (95, 96). Moreover, regulations that are in place are not always effective, and the heterogeneity between countries restricts the opportunity for a regional market. To combat weaknesses in many national regulations—their lack of effectiveness and their heterogeneity inside the SSA—diverse initiatives have been implemented at the international or regional level. We present here the main international organizations participating in the regulation of drug access in SSA, as well as recently developed regional initiatives.

The Main International Institutions Regulating Veterinary Drugs

The OIE, established in 1924, is a major actor in this domain. It institutionalizes the sanitary norms for the international trade of animals and animal products, which member countries can use to prevent the introduction of diseases and pathogens without creating unjustified sanitary barriers (24, 97). For example, the Sanitary Code for Terrestrial Animals formalizes guidelines for the prudent and responsible use of antimicrobials. It also promotes the development of professional veterinary capacities and the involvement of veterinary services in the creation of regulations.

As with other commodities, the international trade of veterinary drugs is subject to norms set by the WTO. Through the SPS agreement, which came into force in 1995, the WTO seeks to reduce state use of non-tariff barriers that could be deemed unjustified and protectionist (98). The Codex Alimentarius, a joint program of the FAO and WHO established in 1963, focuses on food safety. It develops norms concerning the maximum residue limits of veterinary drugs in food, and by this means regulates the use of drugs in farming worldwide, throughout the supply chain (99, 100).

The VICH, the International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Medicinal Products, brings together regulatory authorities and the pharmaceutical industry in setting internationally recognized norms for veterinary drug registration and marketing authorizations (22–24). Established in the mid-1990s by industrialized countries (the EU, US, Japan), and inspired by the ICH (the International Council for Harmonization of Technical Requirements for Pharmaceuticals for Human Use), it is currently expanding its scope to become more global by including Nigeria, Uganda, Tanzania, and Zimbabwe. It aims to achieve greater international harmonization of registration requirements for veterinary drugs, to ease their circulation, and support their access (101).

The Regional Harmonization Initiatives From WAEMU, SADC and EAC

The African Union, through the AU-IBAR, is leading the harmonization of veterinary laws and regulations across various regional communities in Africa. This process is combined with harmonization in the domain of human health. GALVmed plays an important role in supporting this process. GALVmed is a non-profit NGO, with charity status, set up in the early 2000s by the UK's Department for International Development (DFID) and funded by the Gates Foundation. GALVmed takes inspiration from GAVI, the Vaccine Alliance, which works in the human health sector. It has been working since 2011 to promote drug access for small-scale livestock farmers in SSA (102). In particular, GALVmed is supporting the initiative "Harmonization of Registration Requirements for Veterinary Immunologicals and Development of a Mutual Recognition Procedure in East Africa Community (EAC)" which is funded by the Gates Foundation (46).

Other examples of ongoing initiatives aimed at homogenizing market authorization processes and quality control are given by the centralized system set up by the West African Economic and Monetary Union (WAEMU) in 2007 with the support of ANSES (the French Agency for Food, Environmental and Occupational Health & Safety) (103), and also by the adoption of the "Regional Guidelines for the Regulation of Veterinary Drugs in the Southern Africa" in 2011 (104). Despite these numerous initiatives, the harmonization process is said to be slow due to problems including weak national regulatory systems, financial problems, lack of institutional capacity, and challenges related to human resources (96).

Donations and Vaccine Banks

Donations and vaccine banks also contribute directly to the availability of veterinary drugs in SSA. In the human health area, Various authors (105–109) described the three main situations in which governments, companies, and NGOs donate drugs: emergency aid, development programs, de-stocking of unsold and almost expired drugs. Donations can also contribute to the improvement of drug access through a transfer of technology. For example, from 2018 to early 2021, the FAO and the EU donated equipment needed for the production of thermo-tolerant vaccines against PPR in Ethiopia. This donation has boosted the national production capacity and supported the National PPR Eradication Campaign (110, 111).

Donations can also be used to protect the commercial interests of the country making the donation. A donation of foot-and-mouth disease (FMD) vaccines made by the government of Botswana to Zimbabwe in 2017 is a case in point. The country donated over 473,200 doses of vaccines manufactured by the Botswana Vaccine Institute (BVI) in order to help Zimbabwe control outbreaks of FMD at their shared border (112).

The OIE (113) defines vaccine banks in its Manual of Diagnostic Tests and Vaccines for Terrestrial Animals (chapter 1.1.10) as "antigen or vaccine reserves, which can be of different types". These banks enable the rapid supply of emergency stocks of vaccines in case of outbreaks, and lower delivery costs for systematic mass vaccination campaigns (114). According to

Lombard and Füssel (115) and the OIE (116), banks are supplied by vaccine producers selected through international tenders. The cost of vaccines and their transportation to the recipient countries are generally borne by donors. To date, the OIE has set up two vaccine banks: one for avian influenza, and one for the PPR.

The avian influenza bank created in 2006, and now closed, received financial support from the EU through the PACE program and delivered 62,017 million doses of vaccines to six countries in SSA: Mauritania, Senegal, Egypt, Mauritius, Ghana, and Togo (117). In 2013, the OIE created the PPR vaccine bank under the Vaccine Standards and Pilot Approach to PPR Control in Africa Project (VSPA) with funding from the Gates Foundation and the World Bank through the Regional Sahel Pastoralism Support Project (PRAPS) (118). The Botswana Vaccine Institute (BVI) was chosen, after an international call for tender, to supply the PPR vaccines and the corresponding quantities of vaccine diluent (118). Different access modalities were deployed: direct purchase by a country (Togo), purchased through donors, or as part of regional programs (Burkina Faso, Ghana and Mali, Chad, Mauritania, Niger, and Burundi), or within the context of an emergency (Burundi in 2018). This vaccine bank has not only ensured the timely supply of high-quality vaccines complying with international standards, but it also facilitates the harmonization of PPR control methods in SSA. Regional organizations play a part as well. The Continental Veterinary Vaccine Bank was created in 2018 by the African Union and its Pan-African Veterinary Vaccine Center (PANVAC) with the support of the FAO, the OIE, the EU, the Gates Foundation, USAid, GALVmed, and certain countries (119). It mainly focuses on the prevention of a resurgence of Rinderpest.

Public-Private Partnerships

Over the last decade, public-private partnerships (PPPs) have become an increasingly common method of improving access to veterinary drugs. PPPs are defined as "a collaborative approach in which the public and private sector share resources, responsibilities and risks to achieve common objectives and mutual benefits in a sustainable manner" (120, 121). Recently, the OIE (121) published guidelines for PPPs in the veterinary domain. According to these guidelines, PPPs enable the development of animal health services, policies, and trade to a scale, quality, or degree of geographic coverage that would be unattainable for the public sector alone. PPPs can contribute to the improvement of access to drugs, reinforcement of veterinary services, encouragement of technology transfer agreements, and an increase in R&D into new drugs (121–123).

Over the last few years, different actors (governments, international organizations, NGOs, private companies, philanthropic foundations) have increasingly promoted the value of PPPs. At an international level, many authors in the humane health sector have documented the importance of PPPs and note their implementation as evidence of the increasingly proactive role played by the private sector in global decision-making processes, including in UN activities (108, 124–127). In the veterinary domain, their importance was further emphasized in the OIE Performance of Veterinary Services (PVS) pathway diagram (122), but a limited number of examples of PPPs are available.

The PPP initiated by the Gates Foundation and Zoetis in 2017 within the framework of the African Livestock Productivity and Health Advancement (ALPHA) initiative is one such example. The Gates Foundation pledged an investment of $14.4 million over 3 years (later extended to 5 years until 2022) to bolster the sustainable growth and development of the livestock sector in SSA (primarily in Nigeria, Ethiopia, Uganda, and, more recently, also Tanzania) (128). The partnership aims to improve access to veterinary drugs and services, provide training and education, and implement diagnostic infrastructure (128). Zoetis' role was to: establish basic infrastructure; increase the reliable supply of quality veterinary drugs, diagnostics, and services; develop veterinary laboratory networks and dialogue with government stakeholders to understand local requirements and needs, including regulatory issues (128). The governments of these countries were not directly involved in the partnership, but this example shows how the PPPs can be complementary to public action, which could provide some of the efficiency, management capacities, and culture of evaluation more commonly associated with the private sector.

PPPs can strengthen veterinary services in SSA. The PPP signed in 2011 between the Gates Foundation and Sidai Africa (a private company supplying livestock and crop inputs, and training to farmers and pastoralists across Kenya) pledged to build around 150 branded franchise outlets to facilitate the supply of good quality and affordable veterinary products to 300,000 livestock-keeping households in rural Kenya over a 4-year period (129). While this is not a direct partnership with a government, this PPP demonstrates how the Kenyan government has enabled the private sector to complement its provision of veterinary services and provide veterinary products to rural areas (120).

CONCLUSION

The different sources mobilized in our paper show that despite differences between and within countries, the Sub-Saharan African drugs market as a whole holds little appeal for international pharmaceutical companies compared to other geographical areas such as emerging Asian countries. It remains peripheral in the global market for modern veterinary drugs, with the exception of South Africa where most of the market is concentrated. The market supply chains are largely unregulated and highly fragmented in terms of registration procedures and market authorization. The distribution chains are weak economically and lack professionals as a consequence of the wave of privatization of veterinary services seen in the 1980s. Therefore, in various countries, we see a dual system for veterinary medicines. On the one hand, the public sector, supported by development organizations, supplies small-scale farmers, mainly in rural areas, but with limited and irregular resources. It focuses on the distribution of vaccines and parasiticides through large-scale campaigns. On the other hand, the largely unregulated private sector supplies the growing market of commercial and industrial livestock farming It relies on private veterinarians, a variety of wholesalers, and retailers (pharmacies, agricultural stores, etc.) including unqualified ones, all tending to cluster in urban and peri-urban areas.

Arrangements have been implemented at the international level to improve drug access in SSA and the efficiency of drug supply chains. They provide "traditional" supports to the different functions of the national veterinary services. Significant efforts have also been made to support national legislation on veterinary drugs (in particular to include the issue of AMR), harmonization of the registration procedures of drugs in SSA, and different arrangements to improve availability (donation, vaccine banks) relying increasingly on PPPs and the involvement of pharmaceutical companies in the drafting and implementation of public policies.

Several conclusions can be drawn for AMR policies and on policies that intend to turn animal health services into a global public good. These policies need to be informed by a better understanding of the drivers behind and the components of access to veterinary drugs in different regional and national contexts. Analysis of what stimulates the use of veterinary drugs in animal farming should not rely too heavily on farmer-veterinarian interactions or on cognitive and psychological factors that shape individual behaviors. These factors are over-emphasized by the studies based on the KAP—Knowledge Attitude and Practices—methodology because the use of drugs by farmers depends greatly on their accessibility. First, there is a need to identify the reasons for low accessibility, which we can divide into low availability (geographic accessibility, potential drug deserts), quality (of drugs, advice, and medical equipment), and economic affordability. In particular, economic studies on affordability are essential if we are to understand the price formation process and how relative prices of drugs influence the decisions of stakeholders. Assessment of drug access should also include the capacity of the whole supply chain to face epidemics and emergencies. Secondly, evolutions in international policy arrangements for veterinary supply chains show the increasing role played by commercial actors in selecting which drugs are made available and under what conditions. This has been made possible by the weak regulation of supply chains and public veterinary services. Policies should balance the interests of the various stakeholders, being careful not to reinforce bias toward certain diseases deemed "interesting" while others, which may still be important for veterinary public health, are neglected.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

GJ, AH, and MF: conception and design of the work, data collection, data analysis and interpretation, and drafting the manuscript. All authors contributed to the article and approved the submitted version.

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