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D5.4 First Annual Research Prioritisation Report

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Executive Summary

The issue of antibiotic resistance is unnecessarily exacerbated by excessive and inappropriate use of antibiotics and improper disposal of antibiotic residues. This necessitates antibiotic resistance management strategies to be developed and implemented. In farming, the need for antibiotic treatments can be reduced by using strategies which promote animal health, prevent disease occurrence and spread, and focus on appropriate medical treatments including targeted use of antibiotics only when necessary.

This initial Research Prioritisation Report aims to identify areas to prioritise for future research about antibiotic resistance management in the livestock sector by drawing from the panel discussion from the most recent DISARM public event, the DISARM State of The Art database and results from an online survey based around the key topics selected by the DISARM Community of Practice.

Key areas for attention included; a need for more global cooperation and action regarding antibiotic use in different countries as part of a One Health approach, including improved monitoring systems for antibiotic use; collaboration between all livestock industry actors for a common goal, facilitated by improvements to policy and legislation; and achieving behavioural change at the farm level to reduce antibiotic usage, including development of effective preventive measures, early disease detection methods, rapid on-farm diagnostics and alternative treatments.

The key areas of interest for antibiotic resistance management in livestock farming that were highlighted in this report are:

- Behaviour change to reduce antibiotic usage at the farm level: how to engage with tenacious high-users and facilitate positive attitudes towards improving animal health and reducing antibiotic treatments?
- Early disease detection and rapid on-farm diagnostics including precision livestock technologies: can more/better/affordable options be developed to allow for early intervention in animal health?
- Disease prevention strategies: what are the most effective interventions, and what is the cost-benefit of implementation?
- Health and antibiotic usage monitoring: can different countries establish suitable monitoring systems to allow for benchmarking between individual farms and compare national averages?

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1. Introduction

This report is part of the EU Horizon 2020 DISARM (Disseminating Innovative Solutions for Antibiotic Resistance Management) project. The DISARM Thematic Network links together farmers, veterinarians, advisors, industry members and researchers to share and promote best practice strategies to reduce antibiotic resistance in intensive and grazing livestock systems for cattle, sheep, pigs and poultry. The network will focus on strategies which prevent disease and promote good health in livestock, thereby reducing the need for antibiotic treatments and contributing to an overall reduction in antibiotic resistance.

There is a real benefit in the exchange of innovative approaches; different sectors can learn from the approaches to livestock health adopted by farmers in other sectors or countries. DISARM will be facilitating the exchange of ideas through events and workshops, social media channels, and the project website www.disarmproject.eu which will promote examples of best practice in a number of areas relating to animal health and antibiotic use. The DISARM project also aims to inform future research, funding and policy, in part through annually produced Research Prioritisation Reports.

This initial Research Prioritisation Report aims to identify areas to prioritise for future research about antibiotic resistance management in the livestock sector by drawing from the DISARM State of The Art database and results from an online survey based around the key topics selected by the DISARM Community of Practice. Current knowledge gaps as perceived by relevant stakeholders in the areas of livestock health and antibiotic resistance management will be used to recommend areas for further work in sustainable antibiotic usage.

2. Antibiotic resistance and the role of livestock farming

2.1. Antibiotic resistance and the 'One Health' approach

Since the first antibiotic was discovered by Alexander Fleming in 1928, medical treatments transformed as the number of antibiotics expanded, facilitating advances in medicine and surgery, extending expected lifespans and saving millions of lives. However bacteria are becoming resistant to more and more of the antibiotics we have available, and resistance has been observed against all antibiotics that have been developed[1].

Antibiotic resistance occurs when bacteria adapt to survive in response to antibiotic use. Resistance genes can then spread through populations of bacteria, causing pathogenic bacteria to become 'super bugs' for which our current arsenal of antibiotics are ineffective treatments. Antibiotic resistance is a highly complex problem involving mechanisms which affect both human and animal health, thus requiring action from all sectors[2].

All antibiotic use carries the risk of creating antibiotic resistant bacteria. The issue of antibiotic resistance is unnecessarily exacerbated by excessive and inappropriate use of antibiotics and improper disposal of antibiotic residues. Ultimately, reducing antibiotic usage prevents the selection pressure which causes bacteria to develop antibiotic resistance. These principles apply to both human and animal health and medicine.

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2.2. Reducing antibiotic usage in the livestock sector

In farming, the need for antibiotic treatments can be reduced by using strategies which promote animal health, prevent disease occurrence and spread, and focus on appropriate medical treatments including targeted use of antibiotics only when necessary. It is vital that these general principles can be applied in practical ways on farms whilst maintaining or improving animal welfare and farm economic performance.

2.2.1. Internal and external biosecurity

Biosecurity measures help to prevent the entry and spread of infectious diseases on farms, thereby reducing disease incidence and the need for veterinary antibiotic treatments[3]. External biosecurity aims to prevent the introduction of pathogens onto the farm through, for example, controlling movement of animals and people onto and off farms (including wildlife vectors) and the use of quarantine when buying in stock. Internal biosecurity concerns the transmission of pathogens within the farm boundaries, with stocking density, hygiene and disease transmission mechanisms being important considerations.

2.2.2. Vaccination protocols and breeding for robustness

Vaccines are effective preventative measures for a range of diseases, improving the health, welfare and productivity of cattle, sheep, pigs and poultry. Vaccines mimic infection to allow the animal to launch an immune response and develop immunity without succumbing to the disease. This means animals are more resilient to future infections, showing minor or no symptoms of illness and requiring fewer antibiotic treatments.

Genetics also influence animals' susceptibility to disease and their responses to other physical, environmental and social stressors. Selective breeding for favourable traits can make them more common in future generations. Health-related traits like longevity and growth can act as disease resilience indicators, helping to protect the health status of farmed animals.

2.2.3. Water, feed and gut health

Water quality is very important to ensure good animal health. Contamination of the water source, water pipes, or drinking troughs or nipples put animals at risk of infection and reduce the effectiveness of medicines distributed through the drinking water. Regularly and effectively disinfecting water systems can mitigate these risks. Appropriate feed should be stored such that it is protected from pests and moisture to avoid contamination and spoiling, and provided to animals using clean feeding equipment.

Feed composition is another key element in safeguarding animal health and welfare in livestock production. Diet must be adapted for the age of the animal, as nutritional requirements change as they mature and develop. Animal feeds can be formulated with special ingredients like additives, supplements, and active feed ingredients that can assist in supporting the animals' (gut) health and immune function e.g. prebiotics, enzymes, antimicrobial peptides, chitosan, lysozyme, medium chain fatty acids/triglycerides, or plant extracts/phytogenics.

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2.2.4. Housing and welfare

An environment that meets the needs of animals, limits stress and inhibits infectious disease is another important factor in reducing antibiotic requirements on farms. Housing systems can be optimized to promote animal health and comfort, reduce the occurrence of injuries and disease, and facilitate animal management. Appropriate temperature, ventilation and drainage are key to achieving optimal climate and air quality in a building. It is also important to allow enough space to avoid overstocking and ensure that all animals have adequate access to food and water of good quality, space to move around and rest comfortably with appropriate social contact.

2.2.5. Precision livestock farming

Precision livestock farming is the use of advanced technologies to monitor animal behaviour, characteristics, or other parameters in animals' surroundings in order to determine the health, wellbeing, reproductive, or productive status of animals. Sensor technologies generally measure something about an animal or their environment and feeds this information into a data monitoring system which analyses the data to automatically perform corrective actions or alert the farmer to intervene appropriately. Precision livestock technologies are useful management support tools which provides 24/7 monitoring of the farm and can measure parameters which cannot be detected by even the best farmers' eye. It often provides farms with early-warning systems before any clinical signs of illness appear, allowing for early intervention in health problems to help limit the need for antibiotic treatments.

2.2.6. Neonatal animals

Young animals are particularly susceptible to disease due to their immature immune systems. The health of young animals can be protected by keeping their environment warm, dry, clean, and well ventilated, and feeding them an appropriate diet. Colostrum is very important for acquired immunity in mammals since this first maternal milk feed contains high levels of antibodies as well as growth factors and other elements which set the animal up for life. It is also likely that the early environment, feeding and experiences of young animals have long-term effects on animal health and productivity through epigenetic mechanisms.

2.2.7. Behavioural change

Any antibiotic resistance management strategies require action to be taken by farmers and other industry stakeholders so that solutions can be implemented at the farm and animal level. Motivations and barriers are important considerations in order to enact change. For example, pig farmers in Belgium, France, Germany, Sweden and Switzerland have been found to be more concerned about financial and legal issues related to antimicrobial use than about antimicrobial resistance[4]. Veterinarians are typically responsible for prescribing and overseeing antimicrobial use in animals, but prescribing behavior can be influenced by a range of conflicting interests. For example, the expectation to safeguard public health can be perceived to conflict with the interests of farmers, and veterinarians rely on client satisfaction for repeat business. Furthermore, whilst diagnostic tests can provide valuable insights for prescribing appropriate treatments, they are often considered impractical and are not used due to their cost and the time taken to obtain results, thereby delaying immediate treatment.[5]

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3. Materials and methods

Results for this initial report are based on a short online survey (questions and responses in English language only) which was shared via the DISARM social media channels, newsletter, and the Community of Practice. The next annual reports will utilise more inputs from the Community of Practice and Multi-Actor Farm-Health Teams once these aspects of the project are more fully developed and active.

A survey was designed and made available via a web platform (SurveyMonkey). Data was collected from November 2019 – December 2019. The survey link was promoted through DISARM's newsletter and social media channels and project partners shared the link within their own networks.

The questionnaire included seven questions which aimed to identify research priorities regarding antibiotic stewardship in livestock farming according to relevant professionals.

Questions included were as follows:

1. Which livestock system do you work in predominantly?
2. Which country are you based in predominantly (i.e. country of work)
3. Which of the following research areas do you have expertise in? *
4. Which of the following research areas do you think need more work and development across livestock farming systems? *
5. In your experience, which ONE of the following research areas can make the biggest difference when managing antibiotic resistance in the livestock system you work within? *
6. In your experience, what are the key questions you have with regards to improving animal health?
7. In your experience, what are the key questions you have with regards to slowing the development of antibiotic resistance?

* Categories for these questions were based upon the ten focal discussion topics selected by our Community of Practice (WP2):

   a. External biosecurity (e.g. movement of animals/people, wildlife vectors, quarantine)
   b. Internal biosecurity (e.g. stocking density, disease transmission between animals, hygiene)
   c. Housing for healthy animals
   d. Precision livestock technology for early disease detection
   e. Breeding and genetics for robust resilient animals
   f. Water quality
   g. Youngstock management and rearing (i.e. at first few weeks of life)
   h. Vaccination protocols
   i. Antibiotic management in extensive livestock systems

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j. Feeding and gut health

k. Other (Please specify)

Data were analysed using Microsoft Excel (Microsoft Office 365 Business Version 1911) and open-responses were summarised and grouped according to similar topics to understand trends.

The panel discussion and Q&A session which concluded DISARM's public event in Brussels on 3rd December 2019 was also summarised and used to indicate areas of interest for further research and development. The event was attended 35 external delegates with 62 viewers of the live-streamed online webinar in addition to the DISARM consortium members. The attendees and panels represented a range of industry stakeholders including research institutes, farmer organisations, veterinarians, legislators, consumer organisations and animal feed and pharmaceutical industries.

DISARM's State of the Art database and associated report were also consulted to consider existing research, industry and farm innovations in the area of antibiotic resistance management in livestock farming. The database contains materials which were produced after 2010 in order to obtain the most recent strategies and innovations in the field. Consortium partners provided materials based on their country of work and area of expertise, resulting in 187 entries in the database. These consisted of 76 research papers, 67 farm innovations, and 44 industry innovations.

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4. Results

4.1. Survey responses

The survey generated 46 total responses, with an 85% completion rate. Responses were obtained from 12 countries, with one participant working globally (Table 1). Most respondents worked predominantly with pigs (n=18) and dairy cattle (n=15), no respondents worked predominantly with beef cattle or laying hens (Figure 1).

Table 1 Responses by country of work

Country	Number of Responses
Belgium	13
France	7
Greece	7
Netherlands	4
Spain	3
UK	3
Denmark	2
Romania	2
Cyprus	1
Worldwide	1
Ireland	1
Latvia	1
Austria	1
Total	**46**

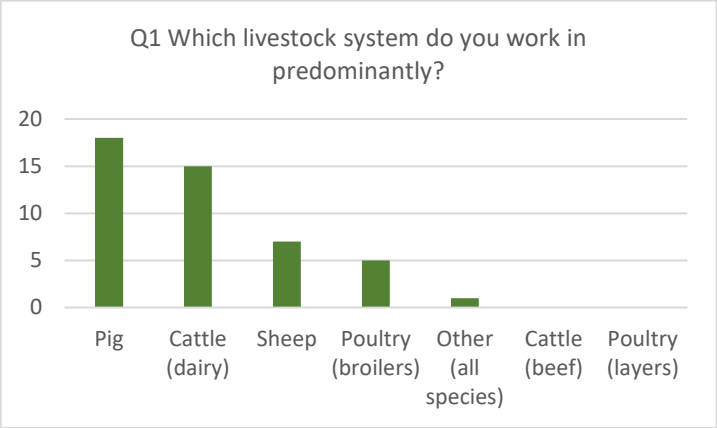

Figure 1 livestock systems respondents predominantly worked within

Respondents had a wide range of expertise. The most common areas of expertise included biosecurity (both internal and external), feeding and gut health, and antibiotic management in extensive livestock systems (Figure 2). Nine respondents detailed other areas including; animal health and welfare, pharmacology, antimicrobial usage and resistance, alternatives for antibiotics, analysis of antibiotics in milk and other matrices, mycoplasma hyopneumoniae in pigs, nutrition, institutional and economic aspects of animal health and production, and decision-making methods.

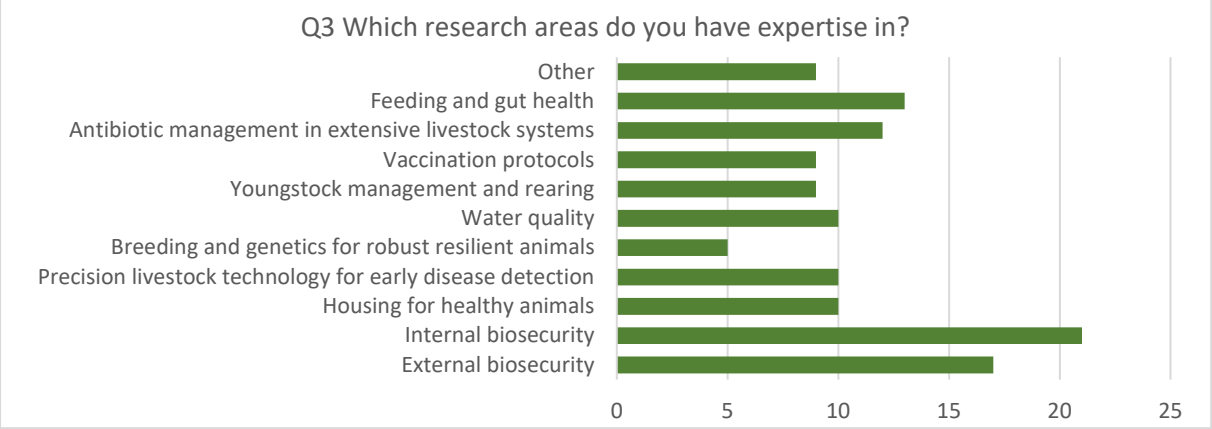

Figure 2 Respondents' areas of expertise

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All provided categories were considered in need of further work (Figure 3). Breeding and genetics for robust, resilient animals was the least frequently selected category (n=8), with two respondents describing other research areas in need of attention: alternatives for antibiotics and institutional aspects and economics. Precision livestock technology for early disease detection (n = 23), antibiotic management in extensive livestock systems (n = 20), and feeding and gut health (n =18) were the most frequently selected areas for more research.

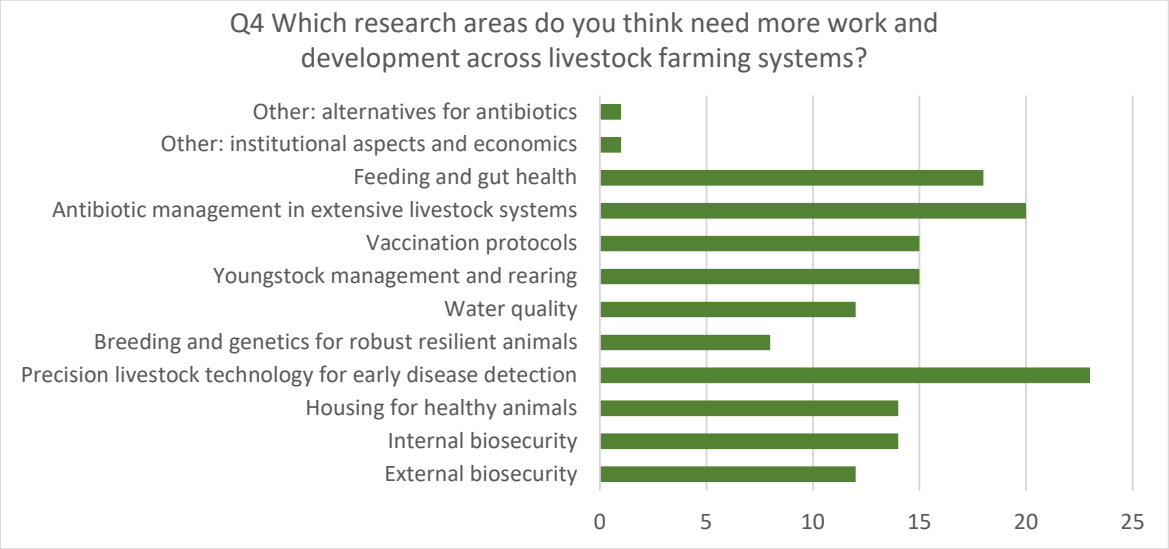

Figure 3 Research areas which respondents believed would benefit from further work.

As shown in Figure 4, precision livestock technology was also considered to have greatest impact on antibiotic resistance management in livestock systems (n = 9), closely followed by internal biosecurity (n = 8), and feeding and gut health (n = 7). Other categories provided by participants include fast on-farm diagnostics and institutional aspects e.g. soft (unwritten rules, networks, habits) and hard (standards, regulations) institutions to motivate behavioural change.

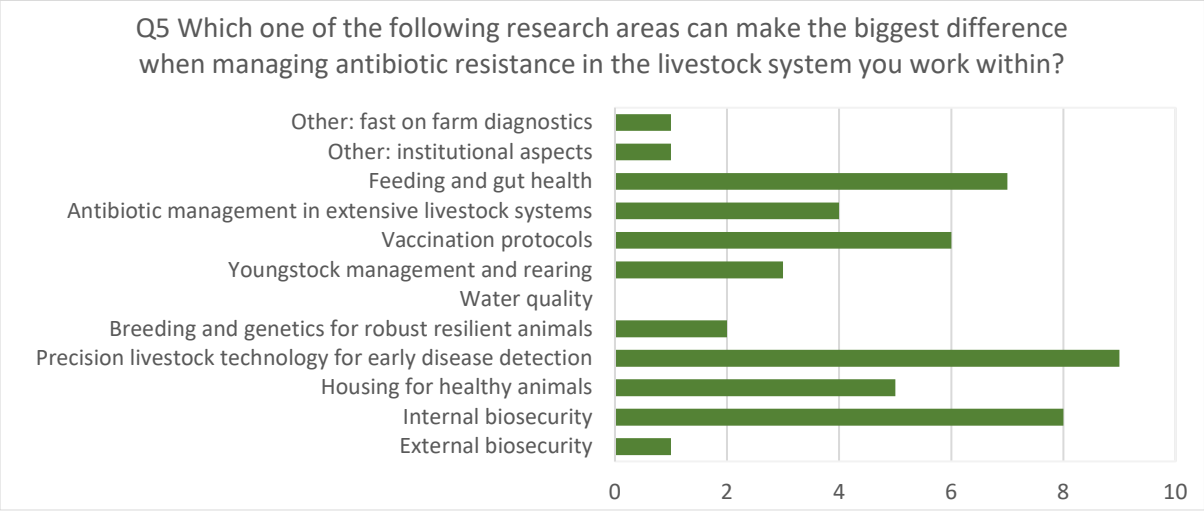

Figure 4 Areas which respondents perceived to have the biggest impact on antibiotic resistance management on farms.

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Queries regarding the improvements of farmed animal health were grouped into seven categories (Table 2). Key concerns included how to motivate behaviour change in all industry actors to practice disease prevention strategies, the need for measurable impacts from implementing disease prevention strategies, demand for improved on-farm diagnostics for early disease detection and identification of antibiotic resistant bacteria, facilitation for precision treatments of antibiotics and demand for the development of alternative treatment options to use alongside or as a replacement for antibiotics.

Table 2 Responses to Q6, key questions regarding improving animal health, grouped and summarised.

Topic Area	Specific Queries
Behaviour change	How to involve farmers and veterinarians who choose to use more antibiotics than needed (i.e. personal preference rather than old housing/other systemic disease causes)?
	How to change practices and organisation to improve disease prevention? How to convince farmers and the whole chain of production to move and improve? How to motivate industry members to adopt biosecurity measures?
	Are suggested improvements feasible for the farmer and practical at the farm/animal level? Do alterations require qualified staff/training?
Health and AB monitoring	What animal health and performance data is monitored in all different countries and what is done with it?
	At which point in animal husbandry do antibiotics get used as a precaution? Can we eliminate preventive use of antimicrobials in all countries?
Preventive health management	How can the resilience of animals be improved?
	What is the impact of water quality and nutrition, and stocking rate and ventilation, on animal health and antibiotic requirements?
	How to prevent livestock experiencing excessive stress? Could stress indicators such as acute phase proteins be used to improve the health status of the herd and reduce antibiotic usage?
	What kind of management, housing and production systems best ensure good animal health and prevent disease? How to optimise internal biosecurity?
	How to define animal health?
	What can we do to eliminate young livestock sensitivity in the first week of life?
	Longer sucking period (pigs): mother's milk contains IgA that are fundamental for building mucosal immunity in the gut, 28 days could be too short.
Early disease detection	How to detect mild symptoms or early onset of problems?
	How to best use rumination data as an early health alert for specific (metabolic) disease.
	Can more/better diagnostics for be developed, preferably for use on-farm?
Cost-benefit analysis	How can we improve animal health without decreasing the financial status of the farmer? Is it possible to do a cost-benefit e.g. of biosecurity measures?
	What is the balance between productivity and resistance?
	What are the measurable impacts of different health improvement strategies? Particularly across the main areas: biosecurity, genetics, and precision livestock technologies.
	How far can you go in giving animals a natural environment whilst keeping antibiotic usage low?
Reducing antibiotic resistance	How to facilitate precision treatments for individual animals?
	Do antibiotics used on farms contribute to antibiotic resistance in humans?
	How can a farmer confirm that they have resistant bacteria in order to then try to reduce the antibiotic resistance?
	What is the amount of medication in feed and water ingested by individual animals?
	How to reduce antibiotic usage in resistance animals?
Alternative treatments	Are bacteriophages a valuable alternative treatment?
	What type of rigid legislation is needed for use of alternative products to antibiotics?
	What alternative treatment methods are available?
	How can we deal with multi-factor diseases e.g. pulpy kidney which is a multifactor disease?

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With regards to slowing the development of antibiotic resistance, respondents' queries were based around antibiotic resistance management, behaviour change, and antibiotic treatments (Table 3). Responses about the antibiotic resistance management concerned the scope of strategies beyond just lowering antibiotic usage, the need for animal-tailored diagnostics and an improved understanding of how agriculture contributes within a One Health context and the need for improved antibiotic use and resistant monitoring and a global approach. It was stressed that antibiotic treatments should be used appropriately, but the systems in place may not guarantee this at the farm level, requiring behavioural change. As new alternative treatments are developed, behaviour change will again be an important consideration when convincing farmers and veterinarians to use the new treatments alongside, or instead of, antibiotics.

Table 3 Responses to Q7, key questions regarding slowing the development of antibiotic resistance, grouped and summarised.

Topic Area	Specific Queries
Antibiotic resistance management	What are other possibilities besides only lowering antibiotic usage? E.g. health plans, biosecurity management, prophylaxis and prevention?
	Better and more efficient diagnostics: we need to establish clinical breakpoints for livestock to allow more animal-tailored diagnostics (agar diffusion test is now based on clinical breakpoints from humans)
	Which key players/factors are the most important in a One Health context? What is the role of the agricultural environment in spreading antimicrobial resistance? We need more insights into the spread of antibiotic resistance.
	Can we improve the system for measurement of farm-level usage of antibiotics? Can we maintain accurate records on levels of resistance?
	How can enhancing infection control actions prevent spread of infections? Would it help to slaughter animals with low immunity?
	What influence do bacteria in the environment have? What is the impact of manure from animals treated with antibiotics spread onto fields and can we minimise transfer from manure?
	When and how will developing/LMI countries catch up with EU standards regarding antimicrobial usage without jeopardising animal health?
Behaviour change	How do we implement strategies for reducing antibiotics? How can we work with tenacious high users of antibiotics resistant to stimuli encouraging lower use of antibiotics?
	Is retail allowing farmers to let animals grow slowly and in more extensive systems to reduce antibiotic use?
	How to change behaviour/beliefs on what is best practice when deciding to administer drugs to animals?
	Can we overcome the lack of adapted products and lack of staff to care for animals?
	Are animal producers ready to embrace new biotechnological methodologies instead of antibiotics?
Antibiotic treatments	Are there alternative treatments available e.g. for severe mastitis?
	Can we use antibiotics for more targeted reasons, and develop new types of antibiotics for these purposes?
	Is there scope to combine antibiotic and bacteriophages for more effective treatments (application of antibiograms and new strategies against bacteria)?
	It is important to use appropriate and effective antibiotics at the right dose and for the correct duration – who advises and control the farmers' administration actions? What are the best admission methods, protocols for treatment? Can we eliminate group treatments completely?

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4.2. Insights from the public event

Areas of discussion covered during the public event included: links to human health; roles of veterinarians, legislation, retail and society; and antibiotic requirements. These areas are summarised below.

4.2.1. Links to Human Health

Reducing antibiotic use in farm animals is important for farmers' own health. Less resistance in bacteria from animals leads to less risk of transfer of resistance to farmers themselves and further spread to other humans (e.g. when visiting a hospital). However, it can be challenging to convince farmers that antibiotic treatments in their livestock and the (likely) resulting resistance can be a risk to themselves and other persons, particularly since farmers often are not aware of their usage of antibiotics.

4.2.2. Role of veterinarians

The role of veterinarians should not be underestimated. Veterinarians are important advisors for farmers who have an important role in stimulating the reduction of antibiotic usage whilst prescribing the correct dosages of appropriate antibiotics. A shift in the mindsets of veterinarians and farmers to focus on disease prevention business models rather than treatment-focused transactions. However, it must be stressed that doctors also have a role to play in encouraging appropriate use of antibiotics in human medicine. Veterinarians and doctors should encourage and support each other as part of a One Health approach.

4.2.3. Role of legislation

The feed industry suggest that nutrition can play a role in the reduction of antibiotic requirements, but some potential solutions are blocked by current legislation. Governments should improve regulations to enforce responsible use of antibiotics, and there is a need for a transparent system (comparable across countries) for benchmarking farms based on antibiotic use and animal health data.

4.2.4. Role of retail and society

Farmers should be incentivised to achieve good animal health and low antibiotic requirements. Improved marketing and premium pricing for such products could make antibiotic reduction strategies more appealing and advantageous to farmers. The issue of antibiotic use in livestock farming requires society discussion about how we want to keep animals? Do consumers want to pay the lowest price possible for meat and animal products, or pay more which allows for better animal health and welfare?

4.2.5. Antibiotic usage

A balance must be found between reducing antibiotic usage and maintaining animal welfare. Appropriate doses and duration of treatments should be used as underdosing has a negative effect on antimicrobial resistance. If treating with antibiotics, treat well. It is not possible to achieve zero antibiotic use (with the current lack of available alternative treatments) in the livestock sector, as some animals will get ill and require treatment.

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4.3. Entries in the DISARM State of the Art Database

Most entries in the database involved pigs or multiple species, whereas sheep and beef cattle were the subject of the fewest number of materials. The most frequently covered topics included; antimicrobial usage reduction strategies, biosecurity, feed and gut health, pathogen management, and housing and welfare. This may have reflected the expertise of the consortium members who provided materials for the database rather than biases in the wider research and knowledge base.

4.3.1. Reducing antibiotic use

Most research papers concerned monitoring and surveillance of antibiotic use or animal health/disease status. Many concerned prudent use or behavior, including attitudes of veterinarians and farmers and cost-benefit assessments of antimicrobial reduction. Many initiatives were described where a motivated group of farmers have a collective goal to use antibiotics more prudently and usage statistics were used for benchmarking purposes. Some rapid on-farm diagnostic tools were also presented, e.g. a stethoscope that automatically interprets lung sounds to diagnose respiratory disease in calves, mathematical epidemiologic models to predict disease, coaching models and e-learning tools.

4.3.2. Biosecurity

Biocheck.UGent, a scoring system developed by the University of Gent to measure and quantify the level of biosecurity on farms to provide a risk-based weighted score, was commonly used by database entries. Another poultry-specific tool, PULSE, developed by AIRVOL and ITAVI also give farmers insight into aspects of their farm that are well taken care of regarding biosecurity and aspects that require attention to prevent diseases entering or spreading through the farm. Other industry innovations included RFID track boots which can help to create awareness about internal biosecurity, i.e. changing boots and clothing between age categories in a farm, and HyCare® system which is focused on the hygiene of housing by coating walls and floors for easy cleaning, disinfection and vermin control.

4.3.3. Feed and gut health

Colostrum management, including nutrition of the mother during pregnancy and the provision of good quality, uncontaminated colostrum to newborn mammalian animals was stressed. Various entries addressed feed composition and potential dietary feed additives which might reduce the use of antimicrobials without significant negative effects on performance indicators.

4.3.4. Pathogen management

Entries included recommendations for vaccination to protect animals against diseases and managing sick animals. Alternatives to antibiotic treatments were described e.g. administration of cola or good bacteria for tackling enteric disease. Selective dry cow management and guidelines for separating sick animals from healthy ones also featured. An infrared thermography app to detect sick animals was included as a diagnostic tool and a nitrogen foam for culling diseased poultry and pigs could be used for on-farm euthanasia.

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4.3.5. Housing and welfare

Entries included in the database showed that providing environmental and social enrichment in animal housing can reduce susceptibility to infection, positively influencing behavioural state, immunological response and clinical outcomes. A climate monitoring system and manure removal method were also presented as innovations to create a healthy environment. The use of clay as a litter conditioner for reduced humidity and improved hygiene and a dairy flooring concept for drier conditions and improved foot health were also included.

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5. Discussion

According to the survey, precision livestock technology and feeding and gut health were areas which were both considered in need of further work and to have the greatest impact on antibiotic resistance management in livestock systems. Precision livestock technology received little attention during the public event and was the subject of few entries in the State of the Art database, although some examples of technology to detect illness or facilitate internal biosecurity were included. Feeding and gut health was discussed during the public event, suggesting that legislation was impeding some advances in nutrition which could help reduce antibiotic requirements in livestock farming. Feed and gut health was also included in the State of the Art database, focusing on colostrum management for newborn animals and potential dietary feed additives.

Attitude and behaviour of farmers, veterinarians, industry stakeholders and consumers were issues raised from the survey, public event and State of the Art database. Farmers and veterinarians must be convinced of the need to reduce antibiotic use for farm animals before taking action. Behavioural change strategies, cost-benefit analyses, antibiotic use and animal health surveillance/monitoring and policy may all play a role. Collaboration between government, veterinary organisations and other important stakeholders within the livestock sector resulted in significant reduction in antimicrobial usage of farms in the Netherlands through a combination of compulsory and voluntary actions with clear reduction goals[6]. In some cases, preventing disease (thereby reducing antibiotic requirements) might require changes to infrastructure e.g. newer buildings with easily disinfected materials to house animals, or other long-term investments to protect against the need for short-term antibiotic solutions to animal health problems. Such changes could potentially be facilitated by providing funding or incentives.

Early disease detection, preventive health management and other methods for reducing antibiotic resistance and alternative treatments were also indicated as areas of interest from the survey and State of the Art database. Any solutions must be feasible, affordable and practical at the farm level, so tools like Biocheck.UGent can provide useful assessment of where investments should be made to improve farm biosecurity. Vaccination protocols are an important aspect of preventive health management, but to maintain the quality and efficacy of vaccines, they must be transported and stored appropriately which may not always be achieved on farms[7]. There was particular demand for the development of effective, rapid on-farm diagnostics to facilitate appropriate treatment of disease.

The data presented here are not fully representative of all livestock sectors and countries. The protocols for adding to the State of the Art Database are due to be reviewed and it will be discussed how to best reflect existing research, farm and industry innovations from a range of countries, whilst minimising the bias introduced by consortium members' nationality and area of expertise. Ahead of the next research prioritisation report due in December 2020, survey design and collection protocols will be established earlier, so that translations can be included and survey responses can be requested at DISARM events and activities. The next version of the survey will request data on respondents' occupation so that the concerns of farmers, researchers/academics, farm advisor, industry company representatives, or veterinarians can be assessed to provide greater insight.

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6. Conclusions

The data presented in this report are indicative of some key areas for attention. Firstly, there is a demand for more global cooperation and action regarding antibiotic use in different countries as part of a One Health approach, including improved monitoring systems for antibiotic use. All livestock industry actors should work together towards a common goal which might be facilitated by improvements to policy and legislation. A key area of interest was in achieving behavioural change at the farm level to reduce antibiotic usage, by showing farmers the cost-benefit of suggested solutions, the most effective interventions for their farm, and development of effective preventive measures, early disease detection methods, rapid on-farm diagnostics and alternative treatments.

7. Recommendations

The key areas of interest for antibiotic resistance management in livestock farming that were highlighted in this report are:

- Behaviour change to reduce antibiotic usage at the farm level: how to engage with tenacious high-users and facilitate positive attitudes towards improving animal health and reducing antibiotic treatments?
- Early disease detection and rapid on-farm diagnostics including precision livestock technologies: can more/better/affordable options be developed to allow for early intervention in animal health?
- Disease prevention strategies: what are the most effective interventions, and what is the cost-benefit of implementation?
- Health and antibiotic usage monitoring: can different countries establish suitable monitoring systems to allow for benchmarking between individual farms and compare national averages?

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