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The UK Antimicrobial Resistance Strategy 2013–18: A Qualitative Study of International and Domestic Policy and Action Related to Livestock and the Food Chain

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Antimicrobial resistance (AMR) is an increasingly important challenge within global health, and growing action is being taken by countries across the world. The UK Government established a national AMR Strategy in 2013, encompassing human and animal health. An evaluation of the implementation of the Strategy was commissioned, to feed into a refresh of the Strategy in 2018. This article addresses the implementation of the parts of the Strategy related to food sourced from animals. It is based on 15 semi-structured interviews with policy officials and professionals from UK and international agencies. Four themes comprise the findings from thematic analysis. (1) The UK's advocacy and leadership at the global level to encourage international action, which was praised. However, the UK's actions were limited in permeating complex international food supply chains. (2) Integrating a One Health approach, adopted in the Strategy, which had successfully facilitated bringing together human and animal health sectors, but still lacked input from environmental agencies and integration of the role of environmental factors in understanding and tackling AMR. (3) Changes in antimicrobial use and attempts to reduce AMR brought about by the Strategy, including the disparity in variations of actions and progress between livestock sectors, the pros and cons of antimicrobial usage reduction targets—felt to be best when adapted for each livestock species sector, the preference for voluntary sector-led approaches to reduction in antimicrobial use, and the need for changes in production systems and animal husbandry. (4) The challenges relating to costs, drivers and incentives identified to reduce antimicrobial use, and how research, data and surveillance systems support continued action. In particular, the need for adequate investment and financial incentives to enable changes in production and husbandry to take a more preventative approach, the importance of working with different actors throughout the food chain in each livestock sector, and the need for adequate and consistent surveillance data to measure antimicrobial use and continued research to understand AMR. The findings have implications for how to implement further changes at

both farm and policy level, how to implement harmonized surveillance whilst maintaining sectoral autonomy, the need for a whole food chain approach, and greater integration of research, actions and actors working on environmental factors of AMR.

Keywords: antimicrobial resistance, antibiotic use, policy, livestock, One Health, food systems

INTRODUCTION

Antimicrobial resistance (AMR) is an issue of core concern within global health. Spanning human, animal and environmental health, it is a substantial challenge (Jindal et al., 2015; Aslam et al., 2018). As human health and food production systems have become increasingly reliant on the use of antimicrobials, resistant bacteria have developed and the ability to treat infections and disease is threatened. Though still patchy and not always conclusive, evidence is growing about the increase in resistance and the links between use of antimicrobials in animal and plant health and potential effects in human health (Dutil et al., 2010; Capita and Alonso-Calleja, 2013; Hollis and Ahmed, 2014; Liu et al., 2016; Meis et al., 2016; Yoon et al., 2018). In response, governments and organizations around the world are developing policies to optimize the use of antibiotics, for example, through improving diagnoses, reducing the use of broad-spectrum antimicrobials, and limiting the use of the most important antimicrobials [(Shallcross et al., 2015; Laxminarayan et al., 2016; Mueller and Ostergren, 2016; Podolsky, 2018; Glover et al., 2021; Overton, 2021; see also EMA, 2019) for the European Medicines Agency (EMA) updated categorization of antibiotics].

The UK Government developed an AMR Strategy in 2013: *UK Five Year Antimicrobial Resistance Strategy 2013 to 2018* (Department of Health, 2013), bringing together the Department of Health, Department for Environment, Food and Rural Affairs (Defra) and the UK's public health agencies. The primary objective of the Strategy was to slow the development and spread of AMR. It covered a broad spectrum of health, from human healthcare to veterinary healthcare of companion animals and livestock. The then Policy Innovation Research Unit (PIRU), London School of Hygiene and Tropical Medicine was commissioned to undertake an evaluation of the implementation of the Strategy in partnership with the Royal Veterinary College, in order to contribute to the refresh of the Strategy, planned for 2018 with a view to launching a revised plan the following year.

This article presents findings from interviews with policy officials and professionals involved in implementation of the Strategy in the animal source food chain, undertaken to explore the national and international level responses in a governance context. The findings explore the role of the UK in international AMR policy; the implementation of a One Health approach in the UK as per the Strategy; actions taken so far and underway to reduce the use of antimicrobials and AMR in the UK; and challenges in the UK associated with the costs, drivers and incentives to reduce the use of antimicrobials and AMR, and how research and data support that.

The food chain can be defined as the system of organizations, people, activities and information that encompasses the linkages, governance and values that exist between primary food producers, processors, manufacturers, retailers, consumers and waste managers (adapted from Morgan et al., 2008 and more recent, broader definitions of food systems, e.g., Ingram et al., 2020). In this study, only animal-derived foods were considered because the information available on antimicrobial use and resistance in other foods is currently too limited to be assessed. Whilst fish and seafood, especially farmed fish, also use antimicrobials as part of food production, and are an important consideration for AMR, they are not included in this study. This is because aquaculture is quite a different area of expertise and was beyond the scope of the study. Furthermore, it did not come up in the content of the interview responses and expertise of participants, so there was no data to include on this. Nevertheless, we acknowledge that it should be considered as part of action on AMR. A One Health approach is an aspiration of the Strategy. Similar to several other definitions, the Centers for Disease Control define One Health as "a collaborative, multisectoral, and trans-disciplinary approach — working at the local, regional, national, and global levels — with the goal of achieving optimal health outcomes recognizing the interconnection between people, animals, plants, and their shared environment" (CDCP, 2017). In short, One Health focuses on holistic approaches for the benefit of people, animals and the environment.

The extent to which antimicrobial agents are used in food-producing animals for infection prophylaxis, metaphylaxis and treatment, and their impact on human resistance through the food chain, is increasingly accepted, yet precisely how this comes about remains poorly understood (Bennani et al., 2020). There are concerns that antimicrobial agents used in the food chain are a direct or indirect source of AMR in humans and that excessive use and misuse of antimicrobials could contaminate food for human consumption with resistant bacteria or genes (Capita and Alonso-Calleja, 2013). Furthermore, AMR within the food chain presents a complex challenge because it cuts across animal, human and environmental health, as well as being embedded in international trade, production and consumption. Therefore, it is important to understand the direction of policy and governance of antimicrobial use and AMR within the food chain, to know what characterizes the sector at present, what is already being done and what the challenges are.

A recent literature review by Bennani et al. (2020) highlighted several key factors regarding AMR in the food chain. There are correlations between the use of antimicrobials in animals and the occurrence of AMR in animals, and interventions to reduce use of antimicrobials in animals have been effective in reducing AMR in them. However, the benefits of reduction in antimicrobial use in animals on AMR in humans are difficult to quantify with an association reported mainly for people in

contact with food producing animals (van Alen et al., 2017; EFSA and ECDC, 2019; Bennani et al., 2020). Antimicrobial resistant bacteria can be present in the human food supply chain, which presents a potential exposure route for consumers. Food can be contaminated by AMR pathogens or resistant genes in different ways including contamination of food during agricultural production, presence of resistant genes in bacteria added during food processing, or cross-contamination with resistant bacteria during food processing (EFSA and ECDC, 2019; Bennani et al., 2020). Food processing and preservation techniques can extend the shelf life of food products. The effects of these techniques on bacteria present in food vary but, in general, the number of bacteria is reduced when these techniques are applied. Food processes that reduce the load of, or kill, bacteria decrease the risk of transmission of AMR, possibly to the degree where exposure becomes negligible (Bennani et al., 2020). Microbial genome sequencing has enabled the establishment of some links between the presence of resistant bacteria in humans and animals but, for some antimicrobials, no link has been established (Bennani et al., 2020). The exact fraction of resistant bacteria found in humans originating from animal-derived food is difficult to quantify (Bennani et al., 2020).

The antimicrobial use practices used by livestock production professionals (e.g., farmers, veterinarians, feed providers) are influenced by guidelines, incentives, trends, personal beliefs, attitudes and other drivers [for further insights, see case study reports—*National and Local Implementation of the UK Antimicrobial Resistance (AMR) Strategy, 2013-2018*, Eastmure et al., 2019]. Despite abundant guidelines, regulations and certification schemes in the UK, there is a surprising lack of research on their effectiveness. Many guidelines and requests come from industry (e.g., farm assurance, certification), national governments and international organizations with implementation by a range of bodies and various levels of collaborations. Whereas, the scientific literature and the evaluation of implementation of the Strategy in the pig, poultry, and companion animal sectors provide insights from the perspective of the farmers and veterinarians, this article focuses on the views of governmental and industry bodies with regards the broader picture of antimicrobial use and AMR in relation to the food chain in the UK.

The aim of this study was to investigate antimicrobial use and AMR within animal-derived foods in the food chain, from the perspective of those involved at the national and international policy level in implementing the UK Strategy. The study aimed to address the following research questions, which informed the basis of the interview guide:

1. What is the progress in the implementation of the Strategy domestically and internationally and the current evidence for the effectiveness of the mostly non-regulatory approach policies in the UK?
2. What are the potential gaps in the UK AMR Strategy in terms of addressing actions relevant to AMR and the food chain?

METHODS

Study Design

A qualitative approach using semi-structured interviews was employed. They can be regarded as "expert interviews" because the interviewees have specialist insight and knowledge about the research topic. Interviews, especially with experts, are often used in policy analysis as an effective method to research issues related to policy-making (Bogner et al., 2009). Open-ended questions enable depth and flexibility to explore experiences, sector relationships, recent history and other factors. These help to understand how and why policy is developed and implemented, and reflections as policy changes, that would not otherwise be open to investigation (Murphy and Dingwall, 2016). Fifteen semi-structured interviews were undertaken with policy actors in a range of UK and international agencies to explore their experiences and views of the various initiatives that form the AMR Strategy within the food chain. This article draws principally on findings from those fifteen interviews.

Data Collection

The purposefully selected informants were based in organizations identified as relevant to animal-derived food chains and involved directly or indirectly in livestock production and antimicrobial use policy and regulation. When recruiting informants, the aim was to include representation from different types of organizations and roles within antimicrobial use and AMR reduction in livestock production. Eight of the interviewees were based in UK organizations and seven in European/international organizations, including Government Departments, international bodies and independent sector organizations. As well as the fifteen interviewees specifically selected for their knowledge of policy in the food chain (referenced with codes beginning FC in **Table 1**), there were also some interviews used from other parts of the evaluation which contained data relevant to the current analysis (codes beginning FCX in **Table 1**). Interviewees are detailed in **Table 1**, with interview reference codes used to contextualize quotes in the Findings section. Information in the table has been limited to ensure the anonymity of the participants.

Interviews were conducted in the summer and autumn of 2017, and were face-to-face, by phone or by Skype. The interviews lasted ~1 h. The full interview question guides are available in **Supplementary Data**. The guides include questions on the interviewee's involvement in reduction of AMR, their experiences of implementation of the Strategy including a One Health approach, perceived priorities in the Strategy, use of data to effect change, use of diagnostics in AMR, AMR in the food chain, innovation and biopharma, international cooperation, evolution of implementation of the Strategy, and their opinions about how the future of the Strategy should look.

Whilst this article refers only to food chain statements for animal-derived foods from the 15 interviews, findings were considered and compared in conjunction with findings from another component of the evaluation for context; a case study focusing on poultry and pig farming at a local level

TABLE 1 | Informant descriptions for all people interviewed.

Interviewee reference	Organisation	Role of interviewee	Level
FC1	Veterinary Medicines Directorate (VMD), Defra	Senior Officer	UK
FC2	Department of Environment, Food and Rural Affairs (Defra)	Senior Policy Officer	UK
FC3	Food Standards Agency (FSA)	Senior Policy Official	UK
FC4	European Medicines Agency (EMA)/VMD, Defra	Technical Expert	Europe
FC5	British Veterinary Association (BVA)	Academic, Senior Officer	UK
FC6	Responsible Use of Medicines in Agriculture Alliance (RUMA)	Senior Staff	UK
FC7	World Health Organisation (WHO)	Policy Official	Global
FC8	Food and Agriculture Organisation (FAO) and International Livestock Research Institute (ILRI)	Senior Scientist	Global
FC9	WHO	Senior Officer	Global
FC10	FAO	Technical Expert	Global
FC11	World Organisation for Animal Health (OIE)	Senior Officer	Global
FC12	European Commission (EC)	Senior Staff	Europe
FC13	Department of Agriculture and Rural Development, Northern Ireland Government	Senior Policy Officer and Technical Expert	UK
FC14	Welsh Government	Senior Advisor	UK
FC15	Animal and Plant Health Agency (APHA)	Scientist	UK
FCX1	VMD, Defra	Senior Officer	UK
FCX2	Public Health England (PHE)	Policy Official	UK
FCX3	Department of Health England	Senior Officer	UK
FCX4	Department of Health England	Senior Officer	UK
FCX5	National Health Service (NHS) England	Senior Scientific Officer	UK
FCX6	Department of Health	Policy Official	UK

through interviews with farmers and veterinary practitioners [which comprised part of the final report, *National and Local Implementation of the UK Antimicrobial Resistance (AMR) Strategy, 2013-2018*, Eastmure et al., 2019]. This also somewhat mitigated the lack of grassroots level stakeholder and frontline perspectives (e.g., producers, processors) not captured by interviewing only officials and policy-makers. The inclusion of a representative from RUMA (Responsible Use of Medicines in Agriculture Alliance) aimed to widen voices beyond officials and policy-makers, given it is an organization representing all stages of the food chain including farmers. The context and analysis were informed by publicly available reports and websites, as well as a literature review, since published (Bennani et al., 2020), prepared as part of the evaluation.

Research ethics approval for the study was obtained from the Health Research Authority (IRAS Ref: 220612) and the London School of Hygiene and Tropical Medicine Ethics Committee (Reference: 14396). The project aims were communicated to participants and informed written consent was obtained prior to interviews being conducted and recorded. Interviewees were assured of anonymity.

Data Analysis

All the interviews were digitally recorded and subsequently transcribed *verbatim*. The transcripts were read by members of the research team, who met and discussed early inductive

themes that were identified in the interviews. This early analytical work aided a "constant comparison" approach to qualitative data interpretation (Glaser, 1965) that enables early findings to be discussed amongst the wider research group.

Thematic analysis, consistent with methods outlined by Strauss (1987), was used to explore the key themes shaping approaches to antimicrobial use and AMR reduction, and their relationship to the Strategy. Bearing in mind the key research questions and overall Strategy review, as well as being driven by the questions in the interview guide, a deductive approach was combined with predominantly bottom-up inductive coding, consistent with the Gioia approach (Gioia et al., 2013). Inductive coding means that the codes are derived from the data and there are no set criteria, such as key words or specific questions, driving the analysis and testing the data against a theory. Rather, the transcripts are read and coded openly, reflecting recurrent patterns, to develop concepts and themes in a more exploratory way (Boyatzis, 1998).

Analysis began by reading through all the transcripts to get a sense of the data set, from which preliminary coding categories were developed. This was followed by a more detailed reading of each transcript and an iterative process of adjusting and expanding the codes as necessary to reflect patterns, connections, similarities and differences in the data. The codes were categorized into common, overarching themes. Transcripts were re-read to do a final check for accuracy and consistency

against and across the codes and revise the themes. Four key themes were identified, which are used as headings to organize the findings. Direct quotes from the transcripts are used to illustrate points, along with descriptive summaries of responses.

FINDINGS

The UK Role and Activity in the Global Context of AMR

The importance of AMR as a public health threat in the UK has been increasingly established. Indeed, interviewees commented that the UK had led on raising the profile of AMR not only nationally, but internationally too. It was felt that the Strategy had brought a great deal of pressure for action, which needed to be maintained: *"the first Strategy… the pressure to deliver was very, very high"* (FC6). This was generally seen as positive, in that it helped to mobilize action across many sectors and countries. Furthermore, it provided arguments to support the various changes in practice taking place and needing to take place. One interviewee noted that the Strategy had helped in "*making sure the pressure is felt and maintained*" and that it had "*given space for a transition and that's important, but what needs to be maintained is the pressure for change*" (FC2). Given the UK's prominent international role in many AMR-related initiatives, the interviewees noted the importance of keeping up the pressure, building on work so far, and leading as an example to other nations not only in advocacy but also in actions to reduce antimicrobial use in the UK.

One respondent highlighted the changing role of the UK as agreement and action on AMR has progressed. In the earlier stages when the Strategy was first published, the focus was on achieving "*engagement and awareness at the highest levels*", whereas, "*we're in a somewhat different period now… where highest levels of government have said, 'okay, we acknowledge that there is an important issue… that there has to be an inter-sectoral, multidisciplinary approach', that's why they used One Health repeatedly*", and looking ahead, "*what is critical now is that, at the agency level, at the ministry level, that there is a kind of sustained action to continue addressing AMR*" (FC9). Looking forward, another noted that at the international level, it was the "*coordination support*" that was important, "*not overlapping activities is even more important than, let's say, the funding and such*" (FC12).

Besides the Strategy itself, there were numerous references made to the catalytic impact of the O'Neill Report (O'Neill, 2016), an independent review of AMR from an economic perspective commissioned by the UK Prime Minister and chaired by O'Neill published in summer 2016, which some respondents were more familiar with than the Strategy itself. The sustained impact of this report was acknowledged by several interviewees, including within international organizations: *"the O'Neill Report and the associated material… was very influential in terms of international advocacy and policy pushing"* (FC8), and: *"the UK has been leading in this, so it's not because of the Strategy, but what O'Neill did, and all the big fuss about AMR a few years ago did was to absolutely focus our minds"* (FC6). The O'Neill

Report also shaped some of the ways that action was taken: *"in our Government response to O'Neill, we said the sectors had to come up with things by the end of this year, forget the targets – with a sector plan"* (FC2).

The increase in importance of AMR nationally and internationally, with the UK felt to be taking a leading role, and subsequent pressure for action, was seen to have had a positive overall effect on attitudes within organizations involved in the food chain. One interviewee noted: *"we've seen over time, for example, an obligation on our profession to use antibiotics responsibly as embedded in the code for the profession"* (FC2). The sense of obligation and duty within the food chain had shifted toward a reduction in antimicrobial use. There is more about the role of targets in addressing AMR and the sector-led approach below in the section, Changes in Antimicrobial Use and AMR Action. It was echoed throughout many of the interviews that the importance of antimicrobial use and AMR had been clearly established and that the topic had become prominent on the political agenda nationally and internationally: *"AMR has come up the agenda, the visibility has gone up; we've seen the sectors start to engage to a greater extent"* (FC2). This was attributed in part to the Strategy: *"there's been a step-change during the course of the five-year Strategy actually in the UK"* (FC2), which was seen to have raised the profile of, and political pressure to, address the risk of AMR in the food chain.

The UK was perceived to be a particularly strong leader internationally on the issue of AMR by advocating for its place on the international agenda: *"the UK was taking a lead in trying to keep things going, stir up a bit of activity"* (FC8). The Strategy was seen to have played an important role in this by providing a justification to engage. This is illustrated by the UK leading some of the European and global AMR initiatives: *"the Government had gone to the UN and said, 'we want to lead on this'… we decided as a country we were going to lead on this"* (FC6). However, this comes with responsibility and consequences: *"so the pressure's then on, isn't it? We have to then match that up with action"* (FC6). There were many comments about the need to follow through with action.

In addition, a year after the referendum decision to leave the EU, interviewees acknowledged the unknown possible consequences of Brexit, with the potential for the UK to be a less prominent voice without the clout of the EU, and putting its focus and energy outside the EU: *"there are concerns in relation to Brexit… because the UK will no longer be part of Europe, right now they're more interested in perhaps forging out a stronger role for themselves in international level meetings and activities, because that way, they have visibility outside of Europe"* (FC10). In particular, concerns were voiced about trade priorities: *"inevitably [there] are compromises in trade negotiations, whether combating antimicrobial resistance is an area that the Government would be willing to compromise on would be a political decision"* (FC3). It was stressed that the UK should aim to stay as a global leader in the context of the control of AMR risk in the food chain, and, furthermore, that it should use its high food safety and animal welfare standards as a selling point in trade negotiations: *"What is now yet to be clearly seen, is whether agriculture and health and finance, and so on, at the Ministerial level, is able*

to sustain their commitment… This remains to be seen" (FC9). However, at present, as when the interviews were undertaken, the full orchestration of Brexit and subsequent long-term effects remain unknown: *"What is the actual impact of Brexit is not clear to anybody"* (FC9).

The praise of the UK's leadership beyond activities set out in the Strategy included a demonstrable financial commitment to action through the Fleming Fund (a UK aid programme helping low- and middle-income countries tackle AMR, noted particularly by respondents FC10 and FC11, amongst others). The Strategy was considered to have had a positive impact in raising the importance of AMR internationally, in positioning the UK as one of the world leaders on the issue, and in bringing about action nationally. However, its scope to follow through on action operating at a global scale, across the whole food chain that it is part of, rather than just inside the UK, was questioned. This was seen as problematic in the sense that AMR is an inherently global challenge that stretches beyond national borders; actions limited to UK activities alone will not suffice, where it is integrated into food chains that stretch beyond the UK.

On the Strategy itself, by its nature as a national plan, the scope is limited to the actions of the UK Government, its agencies and industry bodies. Nevertheless, one of the criticisms of the Strategy in relation to the food chain was its almost exclusive focus on the UK, whilst lacking the wider international context of AMR. The latter was described as particularly relevant in the context of food as many food chains are international, as one respondent from an international organization remarked: *"I felt the Strategy was very UK centric, and a problem like AMR… the focus of the Strategy was very, very much towards the UK, and I would certainly like to see it take a much, much, much more international perspective"* (FC8). Another interviewee remarked that the Strategy provided a good understanding of the UK position on the use of antimicrobials, but did not help to understand use in countries that formed part of the international supply chains and the UK activities linked within those.

In relation to this, a respondent acknowledged that the Strategy needed to reach out beyond national food chains and consider international food chains in its actions on AMR: *"we need international partners; this is not something the EU could do on its own, and certainly the UK – this is definitely a global resource challenge"* (FC2). This was, perhaps not surprisingly, particularly prominent amongst interviewees who worked in international organizations: *"it's the global nature of the problem that's not really dealt with adequately by the UK Strategy"* (FC8). Whilst the Strategy is about and for the UK, and the UK has little control beyond domestic issues, some interviewees stressed the importance of including ways to strengthen collaboration with partners integrated in the international food supply chain and governance of antimicrobial use in other countries.

Several respondents commented on the global nature of AMR, and, therefore, the inherent global challenges and need for greater international integration. As one interviewee put it: *"antibiotic resistance… it's a global threat… so the global challenge is a challenge for the UK. If you understand that, then everything we do at UK level is dwarfed by the international challenge"* (FC2). However, the details of what kind of international integration

and with whom were not discussed. Presumably, this would mean more than the UK establishing the Fleming Fund. As one respondent said: *"the idea of [international surveillance] harmonisation is widely bought into, it's in the Global Action Plan, it's in all sorts of things, but I'm not sure that there's a massive amount of progress"* (FC1).

Respondents commented on the root causes of AMR, which went beyond UK borders, and how resistant bacteria cannot be segregated by national borders: *"the problem of AMR in… highly developed countries like the UK is that the improvements there will go on anyway... That's not where the investment is needed, it's dealing with the real root of the problem, which is in these low- and middle-income countries, and if we're ever going to put a serious halt on AMR, then that's where we need to be working… The UK dealing with the problem in the UK is not going to solve the problem at all, because there'll be a constant threat from antimicrobial resistant bugs that are being churned out of other situations, so, they'll be able to contain AMR when it arrives in the UK, but you know, the root cause has to be dealt with if we're to make any progress at all"* (FC8).

Considering that much of the food consumed in the UK is imported (60% of food consumed in the UK in 2017 was imported, Defra, 2017a), there was particular mention of economically developing countries as sources of food: *"the link to the Sustainable Development Goals is quite strong, because when you look globally, the places where the biggest problems lie are the places that have a lot to do in terms of their fundamental capabilities"* (FC2). It was suggested that bodies like the Department for International Development (now the Foreign, Commonwealth and Development Office) needed to have a more prominent role in the Strategy. In addition, it was implied that international development-focused organizations should have greater presence in international AMR collaborations. However, interviewees also noted that successful food chain actions in the UK cannot necessarily be translated successfully elsewhere, and therefore actions needed to be developed according to local contexts: *"the international discussions, we need to be very sensitive to the need to make real progress, and we need to avoid presenting the rest of the world with the UK or the European template that we care to force them into, because it won't work"* (FC2).

Implementation of a One Health Approach in the Strategy

Interviewees working with a One Health perspective highlighted the challenges of integrating a One Health approach in implementation of the Strategy. The "silos" of human health and animal health have reduced in recent years, which has been important in action on AMR. However, as noted in the Introduction, One Health goes beyond the relationship between human and animal health. It takes a holistic, trans-disciplinary and multi-sectoral approach to the interconnected health of people, animals, plants and their shared environments. The term "One Health" was used numerous times during interviews and is stated in the Strategy as a key principle for addressing AMR. Despite this, the term was used in a variety of ways, some of

which departed from the various "official" definitions, or there was a distinct absence of its use in places, which reflected a lack of full understanding and embodiment of a One Health approach. Some interviewees did not mention it at all, whilst others referred to it as an approach which positively shaped the Strategy, although they only spoke about it in the context of human and animal health sectors communicating, neglecting the environmental dimension (which has gradually become more prominent in the understanding of AMR).

The following quote reflects some of the opinions and understandings of the way One Health is employed and hints at an imbalance in the representation and engagement of the different sectors: "*[the Strategy] is also rather public health centric, and I would like to see it take a much stronger One Health approach... it's not that it doesn't pay service to One Health, pay lip service to it... it's mentioned and then it proceeds without it*" (FC8). This interviewee reflected similar sentiments about the implementation. This is illustrative of those interviewees who worked with a One Health perspective, in contrast to those less familiar with the approach. Another interviewee had realized that to be genuinely One Health required "*not human health with some animal health stuff tagged on the end*", and reflecting on some of the earlier work of their organization and collaborators: "*we realised that this was kind of just a human and animal health report, it wasn't really a One Health report*" and that they're now trying to "*include something on the environment*" (FC1). This respondent noted that better coordination between the different parts of the Government Department that this respondent worked for (Defra), which was underway, was crucial to this.

Despite this perceived imbalance, the interviewees agreed that the Strategy had brought together many sectors (both from the food chain and different Government agencies) that had previously not collaborated, which was described as a positive development. What was generally positively discussed was greatly improved communication and collaboration between human and animal health sectors. Some tensions and misunderstandings were still mentioned, but on the whole, these were reported to have diminished, and there were stories of professionals working together across human and animal health, sharing and comparing practices. One interviewee praised a UK cross-sectoral One Health meeting that had taken place in 2017: "*because we had the CVO [Chief Veterinary Officer] and the CMO [Chief Medical Officer] chairing, we managed to get an audience that included people like the Chief Pharmaceutical Officers, and some Senior Medical Microbiology Consultants, and a range of people that were heads of veterinary professions. And it was a very dynamic, interested, courteous professional meeting, and it was exactly what One Health should be*" (FC1).

In the past, it was reported that blame and responsibility had been pushed backwards and forwards between the veterinary and human public health sectors. There remained some residual debate regarding the main responsibility for AMR emergence and spread: "*odd dynamic where you could debate, because of... the lack of the evidence base, the relative importance of AMR in the human field and the animal field, as relates to threats to human health, and that got in the way*", they continue, reflecting on the negative effect of this on collaboration, "*there was... almost one element of denial, with the animal sector feeling that proportionately, [their role in AMR] wasn't sufficiently important to do more than they were already doing, and the human sector feeling that it was important, regardless, and there was not enough being done, and that pressure or tension wasn't really very healthy*" (FC2).

However, in general, the debate on responsibilities in the context of AMR was felt to have been resolved: "*we're working quite closely with human medicine, because how this started was that the human medicine started to blame farmers for the problems... the last thing we need is to start blaming each other, because we're all in this together... now that we've engaged with them, they now understand farming a lot better*" (FC6). This was partly attributed to the need to work together across sectors to address AMR, which was called for in the Strategy. One informant further explained that a lot of the (perceived) mistrust and blaming in the past had been related to a lack of knowledge of what the other sectors were doing, and that sharing and learning from each other had helped to move toward a better mutual understanding. However, in the next stages, it was generally felt that this needed to extend further to engage groups and people who had not so far adopted a One Health approach, such as those still pursuing narrow disciplinary approaches, and those not yet connected to the health communities, e.g., environmental specialists.

While there were positive observations on the progress made in human and animal health sector collaborations, some interviewees argued that there was a distinct lack of discussion regarding the role of environmental and ecological factors within AMR, the Strategy and its implementation: "*thinking about our focus on animal health, well we mustn't forget the environment and the One Health agenda*" (FC2). This was both reflected in the absence in interviews of a mention of environmental factors, or remarks in interviews drawing attention to the lack of knowledge on it: "*the livestock sector and what that means for the environment, and a whole area that needs to be better understood about the environment as an ecosystem... there's a body of work to do*" (FC2). Another remarked: "*the role of the environment... has been identified in our evaluation... it's an important element because we know that the environment is something which is perhaps overlooked in the past*" (FC12). It was felt that even with limited knowledge, aside from increasing research on the topic, more could be done to incorporate environmental factors into the Strategy's implementation.

Many interviewees commented on the complexities of different ways to measure and record antimicrobial use in food chains, and even ways to understand resistance: "*we need to harmonise our gathering and measurement of resistance ... [human and animal health are] not measuring resistance in the same way, so our definition of what antimicrobial resistance means varies, and it will vary between country and it also varies between animal and human health... there's definitely some things to do in that area*" (FC2). Whilst this is at a broader level across human, animal and environmental sectors, it relates to integrated surveillance systems (see the final section within findings on Drivers to reduce AMR and the role of Research and Data), within species sectors. It also highlights again the role One Health

could play, by bringing together surveillance systems across sectors in addressing AMR challenges.

Changes in Antimicrobial Use and AMR Action Brought About by the Strategy

This section outlines some of the main changes in antimicrobial use and AMR management in relation to food chains that interviewees identified to have been facilitated by and associated with the period since the Strategy. These include the variations between different livestock sectors, the role of targets, the sector-led approach (of different animal species sectors) to addressing AMR, oversight of the use of critically important antimicrobials, the role of surveillance, and the challenges of changes needed in production systems and animal husbandry.

It was widely acknowledged that there were considerable differences between the food animal industries in terms of the form and extent of policy implementation. For example, the meat-poultry sector was mentioned to *"have very good data"* (FC6) and to be *"ahead of the game… it's almost now overquoted and the withdrawal of fluoroquinolones for day-old chicks in our meat-poultry sector was a really good example of that"*, but that *"not all sectors are the same"* (FC2). Improving the data available was seen as an important part of antimicrobial use reduction actions, as they can help measure and monitor changes, and were referred to as showing reductions in antimicrobial use over time, noted in particular in the poultry sector. The pig sector was perceived as being similarly progressive: *"pigs are only collecting the data now since AHDB [Agriculture and Horticulture Development Board]… we've set up at AHDB the pig Electronic Medicine Book"* (FC6). In contrast, the dairy, beef and sheep sectors were seen as less advanced in their data: *"Cattle and sheep, there's no data; dairy, there's no data to speak of"* (FC6), although positive progress was noted in these industries: *"We're starting to see…the behavioural change and the willingness to change, not only the use of antibiotics but also the system that surrounds it, so to get that change in the dairy sector you need good hygiene, you need good monitoring, you need to understand your cows at most risk"* (FC2).

The role of targets was mentioned in many of the interviews. Targets refer to the quantity and types of antimicrobials used within the food chain that production should aim for. For example, in 2016, Defra committed to reach the target to multispecies average of 50 mg/kg antibiotic use by 2018 in livestock and fish (BMJ Publishing Group, 2016). The targets discussed were mainly those set out in the O'Neill Report, and they seem to have been generally accepted: *"O'Neill said he'd like to see everyone down to 50 milligrams [50mg/kg of antibiotics used in livestock and fish]… we were given until 2018 to meet these targets… and we accepted that challenge, and we think we'll get there because we're well on the way"* (FC6). The overall target of 50 mg/PCU (population-corrected unit) was agreed in the Defra response to the O'Neill report. Livestock sectors were then charged with agreeing sector-specific targets with the Veterinary Medicines Directorate. This process was supported by the Responsible Use of Medicines in Agriculture Alliance (RUMA) (see RUMA, 2017 report for details).

Respondents described concerns with the perceived simplicity of the targets. An interviewee from RUMA remarked: *"from the agricultural side, I'd like to see us be more sophisticated on targets… we're saying, 'not only do we need you to get to the target, we want to see the critically important ones reduced as well'… We need a more holistic approach to what we're doing. You could just simply have a number, but I think we can do better than that"* (FC6). The challenge of target setting is related to the complexity of antimicrobial use in animal health. The following quote reflects this complexity: *"I don't particularly like these target numbers, because they're too easy, and they're crude… Also, there's a big argument – is it milligrams per kilogram? Is it DCD [defined course dose]? Is it DDD [defined daily dose]? And, most people don't even know what you're talking about, because it's so complicated, and different sectors use different things, and then you've got a WTO [World Trade Organisation] for medicines, EMA [European Medicines Agency] list, all these lists – it's just so confusing"* (FC6). Another interviewee had similar concerns about even broader global targets: *"understanding the animal sector, it's quite clear that global targets could drive not necessarily the right behaviours… [weight-based targets] drive the use of lighter antibiotics, but not where you want… antibiotic used per kilogram production on a PCU [population-corrected unit] basis…"* (FC2).

It was felt that blanket targets not adjusted to each sector were too simplistic, difficult to follow and hard to measure. They missed out nuances such as which type of antimicrobial (e.g., critically important ones or not), how administered and why (e.g., prophylactically or not). Blanket targets could encourage practices that make it easiest to reach the target, rather than improving the overall husbandry practices, animal health, and particular uses of antimicrobials, whereas more specific targets would be more likely to encourage better practices. However, there was general consensus that targets had some role to play, mainly in identifying what to measure and how, and setting benchmarks, even where the context changes and new targets are needed: *"the target's had its function, but the target isn't the end, so I think 'targetry' will remain interesting"* (FC2).

The way in which targets implemented in the UK were felt to be effective were where the sectors were encouraged to respond to them with a great deal of autonomy, whereby they developed particular targets suitable to each sector, and measures to implement them: *"in the meantime, we were then challenged to set targets for each sector in agriculture, which we decided, it would be better if the industry did it for itself, to avoid regulation, and that's what we've been doing for the last year is, we've got a targets taskforce"* (FC6). Upon receiving targets, the livestock sectors in the UK were encouraged to take charge of their own antimicrobial use reduction, monitoring and necessary changes in practices. One interviewee described this process thus: *"a dialogue with our sector... if you don't want a heavy-handed regulation, which we can deploy if really necessary, 'cos this is very politically important, but take control for your sectors on a sector-by-sector basis and deal with those targets, which was a dialogue led by VMD [Veterinary Medicines Directorate], but with a positive role played by RUMA [Responsible Use of Medicines in Agriculture Alliance]"* (FC2).

Changes in livestock production practice and reduction in antimicrobial use required careful coordination, which RUMA had led: "*RUMA stepping into the coordinating position… they've taken on that challenge to assist the sectors with the sectors' willingness, to seek to coordinate that, of course with VMD working very closely, so, this is very partnership working, that then engages the sector leaders, it also engages the veterinary associations that work with those sectors, and they're crucial*" (FC2). Overall, this was felt to have been a successful approach, encouraging the sharing of good practice, healthy competition between farmers and sectors to reduce their antimicrobial use, and a sense of autonomy and agency amongst producers.

Changing practice was not without its challenges, particularly relating to communication. However, from the perspective of interviewees, this seems to have been managed appropriately by each sector: "*I've been amazed how the sector representatives – we had a leading farmer and a vet from each sector, and we made them all meet together in the same room, and then we had observers from the VMD [Veterinary Medicines Directorate], from the FSA [Food Standards Agency] and from Red Tractor, and then we had senior RUMA [Responsible Use of Medicines in Agriculture Alliance] staff there, and they've all helped each other and challenged each other, and it's been really great… Communication is quite difficult, but when you've got a leading farmer and a leading vet who then consults with their group, in species group, of leading people, that's enough, that will do the trick... There is a big change of attitude, they know that things have got to be different*" (FC6).

Considering such positive responses to a generally voluntary approach, one interviewee cautioned against taking a more prescriptive approach in the future development of the Strategy: "*I would hate to see the new Strategy seek to dictate to the sectors and the veterinary profession that relates to them how to do this, because actually the policy that we have pursued is to make them feel responsible and take their own action*" (FC2). Those who commented on the sector-led approach noted that more mandatory regulatory approaches (such as seen in the Netherlands) were also effective, but were not the preferred approach in the UK, where the sector-led style was considered to be a more positive experience for farmers, vets and other actors in the industry, thereby helping to build support for any changes proposed.

Changes in production systems and livestock husbandry were mentioned repeatedly by interviewees. As one explained, "*it's a combination of using less, using it correctly, responsible use, and then only using it when it's necessary, and then preventing, preventing the need to use any at all by having healthy animals, proper facilities, which means investment and all the rest of it*" (FC6).

At the policy level, a focus on general improved animal health was perceived to be a potential "win-win", whereby healthier animals would require less treatment and antimicrobial use, minimizing costs, increasing productivity and therefore profit. However, it was not necessarily that simple, as the costs in making these changes are often great, and most farmers reported already trying to ensure the best animal health within their means [see sections on the poultry and pig sectors in Norfolk and East Anglia in the *National and Local Implementation of the*

UK Antimicrobial Resistance (AMR) Strategy, 2013-2018 report, Eastmure et al., 2019]. Therefore, the changes that should lead to further antimicrobial use reduction are complex and far-reaching: "*not only the use of antibiotics but also the system that surrounds it… There is the whole package of good practice that goes with withdrawing your use of antibiotics*" (FC2).

Factors Identified to Help Further Reduce Antimicrobial Use and Address AMR

This final section examines the challenges identified relating to drivers, incentives and costs of reducing antimicrobial use and AMR, the need for integration of actors throughout the food chain, and how the roles of research, data and surveillance systems facilitate these efforts.

Informants emphasized that reduction of antimicrobial use in animals would require improved animal husbandry and management practices that should help prevent disease, prioritize animal health and thereby reduce the need for antimicrobial use. Some specific ideas for future developments in antimicrobial use and AMR reduction were identified by interviewees; namely, faster and cheaper diagnostics for use in animals (pen-side tests), recognition and rewards for good practice and reduced antimicrobial use, financial support for improved husbandry practices such as those mentioned (especially regarding housing and feeding), and awareness raising among farmers and veterinarians.

However, as one informant noted, "*Change carries a cost*" (FC2). There were some comments and suggestions on the costs, drivers and incentives needed to make the necessary change to reduce antimicrobial use. Adequate facilities were identified as one of the challenges: "*there's a lot of farmers who haven't got good enough facilities, and they're using too much antimicrobials, but sometimes they can't borrow the money… [or]they're too frightened to invest, because if… the market turns, they'll go bust, so, they're sitting there using too much antimicrobials because they haven't got a choice*", to which one proposal was: "*I'm trying to persuade Government, they need some tax breaks – help us help them to get rid of this*" (FC6).

The role of the Government and financial support came up multiple times as a way to encourage and facilitate this change: "*we need to combine financial assistance or tax breaks, or something, in order to improve circumstances where animals are kept, because the more healthy animals we have, the less we're going to use, automatically, and everybody wins*" (FC6). Whilst the hope is that better facilities and overall animal health to reduce antimicrobials will also benefit farmers, respondents emphasized concerns with the availability of the substantial initial investments required to implement improvements.

Apart from government, there are other actors within the system, such as retailers and consumers, civil society groups, and integrators within the profession (integrated production is increasingly common, where production stages are combined into large vertically integrated firms, usually overseen by one common owner who controls the supply chain). Each of these can exercise influence, some with a direct economic impact on producers. One interviewee highlighted: "*There's a whole issue of*

your relationship to retailers and the actions of retailers and we need to avoid actions by anybody, including retailers, that have perverse outcomes or mislead the consumer, so there's a complex issue here around driving forward best practice without creating perverse incentives or the wrong impression" (FC2).

Few informants talked explicitly about the food chain when questioned about *"specific policies on AMR in the food chain"*, but talked about sectoral collaborations in general, and specific actors in the food chain. Many informants talked about (livestock) primary producers in particular, veterinarians and "public health" people. Often, quite vague statements were made in reference to the food chain using phrases such as *"the vets and the rest of the food chain"*. Also, informants pointed at the sectoral allocation of tasks with animal health sectors being responsible for primary production and harvesting and public health agencies being responsible for the retail level and consumers. Some informants commented on the lack of a whole food chain approach and neglect of AMR issues in parts of the food chain other than primary production.

As touched on in previous sections, interviewees noted the limits of current surveillance data within livestock production, and called for the need of adequate data to address AMR. Whilst the Strategy has nudged this forward somewhat—one respondent noted the *"publication of the first combined veterinary sales and AMR surveillance report"* that had not before been published in a *"readily accessible form"* (FC15)—the surveillance was still reported to be inadequate. For example, when discussing use of antimicrobials in the meat-poultry sector, one interviewee explained: *"measuring is really important and our measure is limited, because we only have sales data, we don't have prescription data, and it's very hard to attribute use necessarily to a particular species"* (FC2). For the pig sector, the Agriculture and Horticulture Development Board (AHDB) had made substantial progress with its Electronic Medicines Book, which was mentioned multiple times in relation to its success and usefulness. However, it was still relatively new and similar initiatives, or the same but adapted for other species, had not so far been put in place. One interviewee explained: *"We need a proper national database... And, then we have to make sure it's all integrated... We've got all the data on the farm already, because everybody has to keep it for Red Tractor, farm assurance, but nobody collects it"* (FC6). Thinking about next steps, one respondent highlighted the value of demonstrating impact, which would require an extensive and effective surveillance system, *"to track that reduction in usage and compare it to the incidents of AMR in the target species"* (FC3).

Finally, as well as surveillance data, there was a sustained call for more research funding to allow better understanding of antimicrobial use, AMR and trends over time. As one interviewee put it: *"more than half of the antibiotics consumed globally are in animal production, so proportional to that consumption, there's very, very, very little work going on to understand that, to understand how transmission occurs with the environment, and to understand ways in which that can be dealt with and addressed"* (FC8). For example, setting targets was deemed difficult when, *"we've got very little data"* (FC6). This was also seen as posing a problem in collaborating with environmental organizations and understanding the environmental factors in AMR: *"there's a body of work to do, to strengthen our evidence base as well, our understanding of what is happening in the environment"* (FC2).

Data and research were not only seen as helping to monitor and guide change, but were also seen as contributing to advocacy and maintaining pressure for change: *"We need to continue to have an element that researches and gives a good evidence base, because we need it not only to direct what we do, but also to convince people of the need for change... In relation to animal systems, we need to take delivery of sector-specific plans, consider their strength or otherwise, and keep the momentum"* (FC2).

DISCUSSION

The findings in this article build on a body of literature highlighting the complex challenges of calls for increased action on AMR (see for example Laxminarayan et al., 2013; Littmann et al., 2015; Ferri et al., 2017). According to interviewees, the UK's international leadership, aided not only by the Strategy but also through initiatives such as the O'Neill Report (O'Neill, 2016) and Fleming Fund, has been praised for raising awareness and engagement. Respondents noted a sense of obligation and duty had developed within the livestock food chain sector to reduce antimicrobial use, but that the priority now is to continue with sustained and coordinated action. This has been termed the "implementation gap" by Kirchhelle et al. (2020) when considering AMR as a global issue. Concerns about the UK's influence waning and ability to enact action due to Brexit was raised. This may be with regards to collaboration, funding and international partnership, both with the EU given the legal, economic and political separation, as well as internationally without the clout of being part of the EU. Similar concerns have been discussed by Millstone et al. (2019) on a range of food-related issues. At an international scale, there have also been worries about an increase in AMR and sustained international action and focus on AMR being compromised due to the Covid-19 pandemic (e.g., Rodríguez-Baño et al., 2021). Whilst the Strategy was necessarily UK-focused, this was seen as a challenge when considering the international and border-less nature of AMR and complex global food chains. Furthermore, the challenge for poorer countries in the Global South to manage and mitigate AMR raised the need for things like collaborating with international development-focused organizations. On this issue, Kirchhelle et al. (2020) argue for structural, equitable and tracked hallmarks to support robust international antibiotic policies for maximum benefit at both local and international scales.

To address AMR, one of the calls for increased action has been for livestock production to focus on improving animal health, and for farm veterinary medicine to take a more preventative approach (see for example Littmann et al., 2015; Ruston et al., 2016). Reduction of antimicrobial use in animals will require improved animal husbandry and management practices that should help prevent disease, prioritize animal health and thereby reduce the need for antimicrobials. Some of the practices that have been suggested within livestock sectors to improve animal health overall and prevent infections include optimized

ventilation, lighting and bedding; precision feeding practices including use of probiotics; and high-quality water systems. However, they often require substantial changes in management and husbandry practices as well as investments into building and infrastructure, where the financial risks are often placed on the farmer. Furthermore, farm profits can be irregular and precarious in the UK (see for example Defra, 2017b, especially pig and dairy farms). Consequently, there are concerns, including from the interviewees, that although improving sanitation may lessen the effects that reduced antimicrobial use has on animal productivity, it will likely add costs, which could reduce revenues if improved husbandry is not accompanied by an increase in prices.

While literature on the economic performance related to changes in management practices and resultant reduced antimicrobial use is still sparse, first results in pig sub-sectors in various European countries (not including the UK) show that the implementation of alternative management measures does not affect technical performance, that there is reduced need for antimicrobial use, and that its costs are outweighed by sustained productivity and improved animal health (Levy, 2014; Rojo-Gimeno et al., 2016; Collineau et al., 2017; Postma et al., 2017). A study on pig farmers in the UK evidenced the drivers and behaviors around antimicrobial use, which highlighted their concerns and barriers to change, in particular shouldering the risk of the burden of disease and economic losses from reduced antimicrobial use, on top of the high financial costs in pig production alongside economic uncertainty of the market and pressure from retailers (Coyne et al., 2019). However, further work is needed to explore the impact of reduced antimicrobial use on farm profits in a range of production systems operating under different management structures and further downstream in food chains.

It was striking that most interviewees did not pay much attention to the food chain, instead with their attention mostly on primary production alone. This is problematic when considering the complexity of food chains and the need for whole-chain approaches to address challenges like AMR. For example, regarding incentives, one case highlights well the need to involve all actors involved in the food chain to reduce antimicrobial use, which one interviewee had also referred to. Some supermarkets tried to bring in an "antibiotic-free" meat label, with Karro, one of the leading pork processors in the UK, registering an "antibiotic-free" trademark with the Intellectual Property Office (see IPO, 2016). However, this was met with criticism, especially from animal welfare bodies, who saw it as incentivising farmers to not use antimicrobials therapeutically to treat sick animals when they needed it. It was also seen as promoting a simplistic and confusing label to the public regarding the role of antimicrobials in farming, and whether unlabelled meat meant they were consuming antimicrobials. This is not true, as current regulations and enforcements on antimicrobial use stipulate withdrawal times and food chain inspections to ensure that animal source foods are not contaminated with antimicrobial residues. This stresses the importance of being aware of unintended consequences and the need for integrated work taking a systems approach.

The need for a nuanced approach which takes into consideration the complexities of livestock production in the food chain is evident in the way targets have been managed. There was some debate as to the potential of broad targets for positive impact. However, many European countries have successfully introduced antimicrobial use targets, e.g., Denmark, the Netherlands, Belgium and Germany. For example, the Netherlands brought in mandatory reduction targets, defined as 20% reduction in 2011 and 50% in 2013, extended in 2012 to 70% reduction for total livestock production. Measures included transparency in use, a full ban on new antibacterial drugs in animals, and changes in the animal drug law (Mevius and Heederik, 2014). Within livestock production, there are specific antimicrobial substances used, some of which are also used in human health (Collignon et al., 2016). However, they all differ in terms of what is given, how it is applied, the dosage, the way it is measured, and which substances are considered critically important. Furthermore, many of these attributes differ by animal species, and thus can vary widely across the livestock sectors. This means that having only simple targets does not serve the specific needs of each sector adequately, although they can help to unite and focus all sectors on a single idea.

Many interviewees commented on how the private actors in the agricultural sector in the UK had assumed leadership in the introduction of measures for reducing antimicrobial use and managing AMR, and how this had generally been well-received. This contrasts with other countries such as the Netherlands and France, which have taken a more top-down, regulatory approach to antimicrobial use, as commented by one interviewee. This is not to say whether one approach is better than the other (top-down regulation vs. more voluntary sector-led), only that the UK is taking the latter approach and that it was generally felt that this was positive and effective in the UK context. Indeed, isince the Strategy, each species-sector has been leading its own targets and actions in the UK. Whilst there are positive changes taking place throughout livestock farming in relation to AMR, the difference between different livestock sectors in their degree of action remains inconsistent, with some making great progress and others much less so, as noted by interviewees. Poultry-meat and pig sectors were praised with the most action and progress on data collection and antimicrobial use reduction. However, it is worth nothing that their production systems tend to be some of the largest and most intensive in the UK, with historically high use and reliance on antimicrobials compared to other livestock production, as shown in the Targets Task Force report (RUMA, 2017).

There were calls made by interviewees for better integrated surveillance systems. This was reflected in the review of evidence on AMR in the food chain carried out as part of the wider evaluation of the implementation of the Strategy (Bennani et al., 2020), as well as the research on the views of health care professionals and policy-makers on the use of surveillance data to combat AMR (Al-Haboubi et al., 2020), which concluded that the quality of the current surveillance data in terms of completeness, comparability and attribution of use to livestock species remains limited. The WHO and Centers for Disease Control in the US define surveillance integration as harmonizing

different methods, software, data collection forms, standards and case definitions in order to prevent inconsistent information and maximizing efforts among all disease prevention and control programmes and stakeholders (WHO, 2010). Calls for such integrated surveillance approaches are not new; in 2004 the *Development of a new paradigm for health protection surveillance in the UK* was outlined, calling for the use of integrated surveillance at key points in pathways that can lead to adverse health effects, engagement of relevant agencies from multiple fields and targeting efforts at points in the (food) chain where the biggest impact in terms of risk mitigation could be achieved (Sopwith and Regan, 2004). Despite substantial progress in surveillance harmonization, sectoral differences prevail and further progress in surveillance integration may be hindered by sector-specific metrics and measurements tools and the wide range of (sector-specific) institutions involved in data collection, recording, and reporting (Al-Haboubi et al., 2020). The problem of varying, unharmonized and thus confusing metrics was also mentioned with regard to target-setting and questions came up about the arbitrary nature of targets (Staerk and Knai, 2019; Al-Haboubi et al., 2020). Consequently, there is a tension between a desire for sectoral autonomy and harmonization in surveillance and intervention.

Such cross-sectoral tensions are well-documented in the One Health literature. Integrated approaches to health (such as One Health, Ecohealth, Planetary Health) emphasize the commonalities of human, animal, plant and ecosystem health and call for systems thinking (Lerner and Berg, 2017; Rüegg et al., 2018). In the last two decades, there has been a re-emergence of the recognition that a combined approach to health issues is needed, together with an increasing awareness that environmental health affects the health and livelihood of humans, domestic animals and wildlife, and is an important component for sustainability and resilience of people, animals and ecosystems (Robinson et al., 2016; Destoumieux-Garzón et al., 2018) The knowledge and evidence gap on the environmental side of AMR has been increasingly noted (WHO, 2014; Singer et al., 2016; Thanner et al., 2016; FAO, 2018a,b; Wellcome, 2018). Notably, a considerable proportion of food originates from plants, and antimicrobials are used to treat crop diseases at a substantial scale, but the contribution of this to AMR is thus far poorly understood. Antimicrobial resistance is a common challenge for health, agri-food and environmental sectors (Laxminarayan et al., 2013). A large quantity of antimicrobials used are poorly absorbed in the gut of animals and humans, and excreted in feces and urine. Land application of animal waste as a form of fertilizer is a common practice in many countries and there is increasing concern about the impact of antimicrobial residues in fields, feed and plant food production, recreational environments and waterways (Sarmah et al., 2006; Kümmerer, 2009; Tasho and Cho, 2016). Despite calls for urgent attention to be given to the investigation of the effects of residues in waste and their impact on ecosystems for more than a decade (Sarmah et al., 2006), environmental stakeholders and specialists were described as a neglected part of the One Health Strategy for AMR. Given this awareness among respondents, more vigorous efforts should be made to broaden

participation of environmental actors in AMR action and support integrated research to make sure that AMR is understood and addressed in human and animal populations, the food chain, and in ecosystems.

Importantly, whilst this study has looked at the 2013–2018 Strategy as part of its refresh, the new strategy was published in 2019, *Tackling antimicrobial resistance 2019 to 2024: the UK's 5-year national action plan* (Department of Health Social Care., 2019). As part of the evaluation this study contributed to, and the evolution of the UK 20-year vision for AMR launched in 2020, many of the gaps and criticisms of the 2013–2018 Strategy are being addressed. Ogyu et al. (2020) have developed a quantitative method to analyse and assess national action AMR policies from a One Health approach, including the current UK one. It concluded for all the action plans included in the study, less attention is given to the environment, plant or food sector with policies mainly aimed at human or animal sectors. So far, no analysis exists to directly compare the former Strategy and current National Action Plan. The Department of Health provides a summary of the former Strategy's aims and actions and the new ambitions and actions in the Introduction of the National Action Plan (Department of Health Social Care., 2019).

CONCLUSION

Returning to the research questions, the first asked: what is the progress in the implementation of the Strategy domestically and internationally and the current evidence for the effectiveness of the mostly non-regulatory approach policies in the UK? Overall, the Strategy was felt to have facilitated AMR becoming a priority both nationally and internationally and in mobilizing political pressure for action, and domestic actions taken to reduce antimicrobial use in livestock. The Strategy was credited with contributing to better collaboration and relations between human and animal health sectors, including bringing together government agencies who had not previously worked together. The leadership and engagement among the different livestock sub-sectors were deemed effective in implementing the Strategy's goals and promoting change in the UK. The species-specific targets which each sector had been charged with developing were generally seen as positive. The voluntary, sector-led approach in the UK allowed for substantial autonomy within each livestock production industry, and was praised for being appropriate and effective so far in the UK.

The second research question asked: what are the potential gaps in the UK AMR Strategy in terms of addressing actions relevant to AMR and the food chain? Improving animal health through improved husbandry practices and prevention was highlighted as an important means to reduce antimicrobial use, but these are costly and would require investment, financial incentives and better recognition for farmers who adopt best practice. Whilst engagement has been achieved, the focus should now be on maintaining pressure and following through with promised action, particularly given the UK's potentially reduced prominence following Brexit (unknown at the time of the interviews and details still unknown at the

time of publication). Many of the interviewees felt that there was insufficient consideration in the Strategy, and insufficient action on, the international dynamics of the AMR challenge in complex global food supply chains. Whilst a One Health approach underpinned the Strategy and had helped facilitate better collaboration between human and animal health sectors, there was a lack of the environment components of AMR, including: understanding the role of the environment, the actions underway, and the actors involved in addressing AMR. With regards to the role of research and data, gaps identified were a limited understanding of the links between antimicrobial use in animals and AMR in people (calling for research to understand transmission of resistant bacteria through the food chain to people), and the role of food chain actors other than primary producers in antimicrobial use and AMR. Gaps in surveillance included lack of harmonization between human and animal health, lack of data collection and surveillance systems in some species sectors, and the inconsistency of surveillance systems between different species sectors, with calls for integrated surveillance systems.

DATA AVAILABILITY STATEMENT

The datasets generated and analysed during the study (interview transcripts) are not publicly available due to the non-anonymised nature of the data. However, sections of the datasets can be anonymised and made available from the corresponding author on reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Health Research Authority (IRAS Ref: 220612) and the London School of Hygiene and Tropical Medicine Ethics Committee (Reference: 14396). The project aims were communicated to participants and informed written consent was obtained prior to interviews being conducted and recorded. Interviewees were assured of anonymity. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LB analyzed the data and drafted the article. AM, NM, KS, BH, and EE provided guidance. LB and BH edited the article. HB undertook data collection. HB and BH drafted sections. AM, NM, KS, HB, BH, and EE provided feedback. EE and NM contributed to design. NM secured funding. KS designed the research and undertook data collection. All authors contributed to the design of the study. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.819158/full#supplementary-material

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