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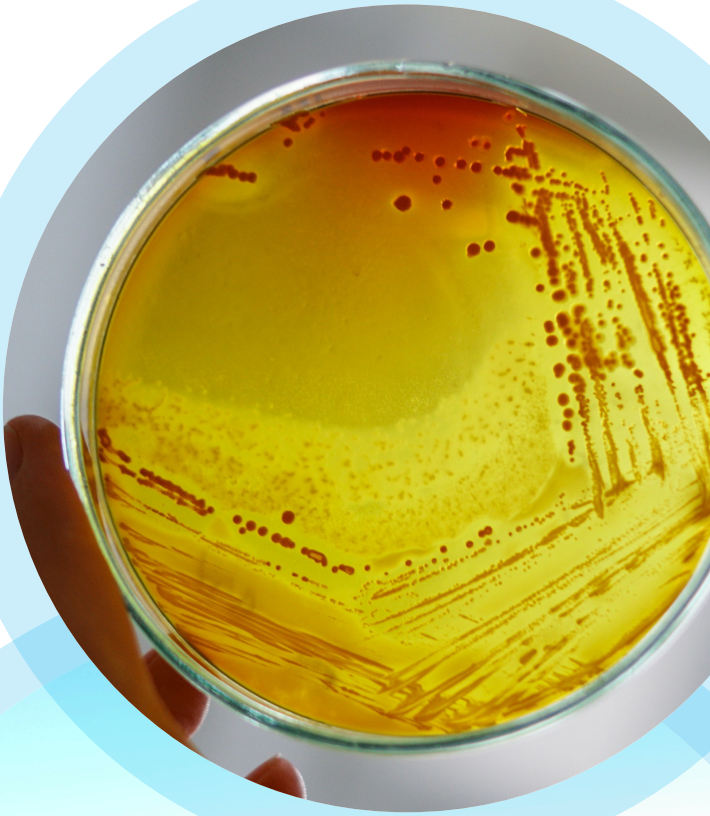

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One Health Research into Antimicrobial Resistance (AMR): A Register of the Research Literature, Projects and Collaborations in Scotland.

N. Holden, L. Avery, T. Schneiders, K. Scott, S. Tongue, E. Watson

Hydro Nation International Centre

The James Hutton Institute

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Contents

Executive Summary

Introduction

Antimicrobial resistance (AMR) is a global priority health issue and one of the biggest challenges of our time. Coordinated international efforts have resulted in the formation of governmental National Action Plans (NAP), with specific commitments to address different aspects of AMR and antimicrobial use. The UK NAP (2019-2024) takes a One Health perspective to AMR that considers human and animal health, agriculture, environment, food and waste aspects together, as well as the connections between them. Of the 25 research commitments in the UK NAP implementation plan, six are of specific interest for related research activities within Scotland (Table 1). All references to, and quotes from, NAP commitments relate to the NAP published in January 2019 [1]. Although there is a range of ongoing AMR activities in Scotland, from fundamental bioscience, epidemiology and drug developments, through to behavioural science and stewardship, there are few mechanisms that provide an overview of activities at a national level. Furthermore, activities are carried out by multiple types of organisations with complementary vested stakeholders, including higher education and research facilities, clinical health, veterinary and environmental organisations, and commercial businesses. Together, this generates a multi-dimensional mosaic of AMR-related activities. Therefore, to gain oversight and provide strategic direction for policy makers, it is helpful to generate an overview of the activities.

Objectives of the work

The overall aim of the work was to provide an overview of the Scottish research landscape of AMR research from a One Health perspective and demonstrate the Scottish research landscape links to NAP commitments. The objectives of this project were:

i. Bring together an advisory group of sectoral leads from across the One Health agenda, encompassing human health; animal health; environment; waste in water; and food.

ii. Identify key research institutions and individuals working in the field.

iii. Produce a register of key Scottish AMR research projects and collaborations across the One Health sectors from the last five years, with key publications, locations, and funding sources (where available), and map these to related NAP research commitments.

Research questions

The project addressed two questions:

1. What published research projects and collaborations have been undertaken in Scotland in the last five years, completed or ongoing, that contribute to research commitments under the UK Government National Action Plan on AMR (NAP) 2019-24 (including multi-sectoral data and evidence gathered from human and animal health, agriculture, environment, food and waste)?
2. What projects, and which researchers and collaborations can be mapped onto the NAP research priorities?

Key findings and policy implications

Overall, a broad range of AMR activities from multiple institutions across Scotland were identified. Multiple activities related to key areas of interest (Table 1) in leadership and capacity for fundamental research (NAP Commitment 'Sustainable investment in basic research'), and in AMR related to transmission in the food chain (NAP Commitment 'Better Food Safety'). Particularly strong areas relate to AMR in animals in terms of laboratory capacity and surveillance of AMR in animals as well as understanding how AMR spreads between humans, animals and the environment. Another very strong area is in lowering the burden of human infection, by turning research into practice for effective infection prevention and control (IPC). This is reflected in strategic actions that pull together specific activities and actors for added value, and link to partners elsewhere.

Areas with limited representation were at the end of the translational pipeline for end-user application, e.g., in wider access to therapeutics (NAP commitment code 4.3.1, Excel Table 1; SOHAR register here), development of vaccines or alternative treatments (code 4.5.2), and associated areas such as quality assurance of AMR health products (code 4.6). This extended to international reach in development of new treatments (code 1.1.1). It may reflect the barriers in transforming the fundamental discovery phase of the science into practical solutions and may also relate to the data not in the public domain that is commercially sensitive.

Recommendations

There are two main considerations for future work in AMR: to maintain and reinforce the strengths, and to

address less well-represented areas related to food, environment and translational applications of product development. These are laid out as four individual areas related to policy (i-iv) and two for research (v-vi):

i. Scotland needs to play to its strengths and continue to invest in international quality science, in infection prevention and control for livestock (code 2.3.1/4) and humans (code 2.1.4), and related laboratory capacity for AMR surveillance (code 3.4), as well as in environmental contamination (code 2.4.1) (Fig. 2). This will reinforce the reputation for Scotland as a world-leader and continue to foster national and international networks.

ii. There is a gap in provision for activities in relation to transmission of AMR via the food-chain. The representation is relatively small compared to other areas and from a limited set of researchers. In parallel, the potential for flow of AMR through the whole food supply chain needs to be considered to understand the contribution of food in the development of clinically relevant resistance. Scotland is well-placed to build on this body of work to help provide more definitive answers for these aspects of AMR and pharmaceutical transmission.

iii. The One Health aspects of AMR cover the wider environment, both for transmission and for the factors that drive resistance. Although Scotland has a reasonable representation from the environmental sciences, in particular for water, the work is limited to a small set of researchers. There are knowledge gaps for the role of agricultural soils and the link to agronomic practices. This is particularly relevant in the context of sustainable, circular agricultural practices that re-introduce waste into productive land. Scotland has an excellent platform from where to build capacity and evidence in these areas.

iv. The largest gap in activities related to translation of the fundamental science to end-user applications, either for alternatives to antimicrobials for treatments or diagnostic tools. Translation of discovery science necessitates direct industry involvement, together with stakeholder engagement. Therefore, more involvement with commercial partners is required, bringing in support from relevant funding agencies. There is also potential to build stronger partnerships with the NHS in this aspect. This point also raises the issue of commercial activities that may be outwith the public domain.

v. The SOHAR register is a testament to the broad scope of activities related to AMR. It presents an excellent opportunity to generate an 'AMR One Health' forum. This would focus the research community for dialogue, knowledge exchange and collaborations that aid in addressing policy needs and push boundaries of frontier science. It also serves as a route for keeping the register of activities up-to-date.

vi. Since the SOHAR register is a snapshot of activities, there is a need to maintain and update the register, and to convert it into an online, open access user tool. It will have wide appeal and broad impact for a range of uses. The research community is well placed to oversee conversion of the register into an interactive dashboard supported by explanatory text for the common themes and topics.

1. Introduction

The World Health Organization has identified AMR as a global health security threat, estimating that it may cause as many as 10 million deaths per year by 2050 [2]. There are also financial implications, with antibiotic resistance estimated to add over £1 billion per year to hospital treatment and societal costs across the EU [3].

The Scottish Government supports the UK Government's five-year National Action Plan (NAP) "Tackling antimicrobial resistance 2019 to 2024" and the accompanying UK twenty-year Vision for Antimicrobial Resistance that by 2040 antimicrobial resistance is effectively contained, controlled and mitigated, which were published in January 2019 [4, 5]. The NAP contains commitments to lower the burden of human and animal infections, minimise environmental contamination, maximise food safety, optimise the use of antimicrobials in humans and animals and improve surveillance of AMR in humans and animals. All references to, and quotes from, NAP commitments relate to the NAP published in January 2019 [1].

1.1 Background

In 2015, Member States of the World Health Organization (WHO), Food and Agriculture Organization (FAO) and World Organisation for Animal Health (OIE) endorsed a Global Action Plan on Antimicrobial Resistance (GAP) [6]. Its five strategic objectives provide a framework for national action plans (NAPs) to combat AMR, over the following decade (i.e., to 2025) viz.:

- improve awareness and understanding of antimicrobial resistance;
- strengthen knowledge through surveillance and research;
- reduce the incidence of infection;
- optimize the use of antimicrobial agents;
- ensure sustainable investment in countering antimicrobial resistance.

The GAP was reaffirmed in 2016 as a global blueprint for tackling AMR, with 193 Heads of State adopting resolution A/RES/71/3 during the sitting of the 71st session of the UN General Assembly. A 'Framework for Action' puts AMR in the wider context of the UN Sustainable Development Goals (SDGs), with particular relevance to Goal 3 to 'ensure healthy lives and promote well-being for all at all ages', which aims to reduce communicable diseases and reduce death and illness from air, water and soil contaminants; Goal 6 to 'ensure availability and sustainable management of water and sanitation for all', which aims to reduce pollutants in water; and Goal 12 to 'ensure sustainable consumption and production patterns', which aims to reduce food waste and promote sustainable production. The UK established a NAP for AMR prior to the GAP agreement, in 2000. This was consolidated in 2013 with a five-year action plan that took a One-Health perspective, which took human and animal health, agriculture, environment, food and waste aspects together, as well as the connections between them. The current five-year plan, 2019-2024, uses the UN Interagency Coordination Group on Antimicrobial Resistance (IAGC) framework to set out the commitments across humans, animals, food and the environment [1]. Its aim is to realise longer-term ambitions and goals, as detailed in the twenty-year UK vision. The framework identifies three main ways of tackling AMR and 15 different 'content areas'. The IACG framework describes the main content areas, five 'levers', showing how they can be addressed, and three 'enablers' with the preconditions necessary to apply the levers successfully.

The content areas to tackle AMR are:

1. Reduce need and unintentional exposure.
2. Optimise use of antimicrobials.
3. Invest in innovation, supply and access.

The five levers to address content areas are:

1. Awareness and capacity building.
2. Measurement and surveillance.
3. Funding and financial incentives.
4. Policy and regulation.
5. Championing and piloting.

The three enablers to apply the levers are:

1. NAPs, systems strengthening and SDG alignment.
2. Global governance and coordination.
3. Coalition building and political commitment.

There are 25 commitments in the NAP relating to research, of which six are of particular interest to Scotland (Table 1). These fall into the content areas of 'basic research' and sustainable investment; 'development of and access to diagnostics'; and 'food safety'. To understand the landscape of AMR activities in Scotland it is helpful to determine the spread of effort.

1.2 Research to date

Work on AMR in Scotland is carried out by a range of institutions, from research institutes, universities and

Table 1. Key commitments of interest for Scottish Government and Food Standards Scotland. The main content areas, commitment headers and NAP commitment codes are provided.	
NAP Code	**Commitment**
Sustainable investment in basic research: Provide strategic leadership in AMR research	
4.1.1a	Support coordinated AMR related research on priority areas (including tuberculosis (TB)).
4.1.2a	Develop multidisciplinary networks to enhance our ability to undertake predictive analysis and inform interventions across all sectors.
4.1.1b	Continue to develop the scientific capacity needed to support and deliver ongoing high-quality research in infectious disease, prevention and microbiology related disciplines.
4.1.2b	Continue to influence global research strategies on AMR-related topics through JPIAMR and the Global AMR R&D Hub, ensuring the alignment of UK funded research and emphasising the need for research to be useful for front line teams.
Development of, and access to, diagnostics: Incentivise R&D for new diagnostics	
4.4.1a	Address R&D gaps, including the identification of biomarkers.
Better Food Safety: Strengthen the evidence base for AMR and food safety	
2.5.1b	Explore research collaborations and partnership working to improve the scientific evidence base, including contributing to the Codex AMR taskforce.
2.5.1c	Do a third infectious intestinal disease (IID) study to gather population-based data on the gut resistome (under way).

higher education institutions and other at-arms-length organisations, including the bodies of specific expertise and public health authorities. Investments in AMR research activities have come from Scottish Government (SG) through various routes, including Scottish Healthcare Associated Infection Prevention Institute (SHAIPI), the Rural and Environmental Science and Analytical Services (RESAS) Strategic Research Programme, Epidemiology, Population health and Infectious disease Control (EPIC) and the Centres of Expertise on Water (CREW). Food Standards Scotland (FSS) and the Scottish Environment Protection Agency (SEPA) have also commissioned and supported work on AMR. Since 2014, Health Protection Scotland (HPS) and partners, (the Scottish Antimicrobial Prescribing Group (SAPG), and NHS Education Scotland (NES)), delivered a Scottish AMR strategy, 'Controlling Antimicrobial Resistance in Scotland' (CARS) and a refreshed Scottish Management of Antimicrobial Resistance Action Plan (SCOTMARAP) (2014–2018) [7]. AMR and antimicrobial usage (AMU) in Scotland are reported annually by National ARHAI (Antimicrobial Resistance and Healthcare Associated Infection) Scotland in the SONAAR report on Scottish One Health antimicrobial use and antimicrobial resistance. The CARS group commissioned work in 2016 to review research literature on AMR and to identify and recommend research opportunities [8-10].

1.3 Aim and purpose

The aim of the SOHAR project is to produce a One Health AMR activity directory that lists Scottish AMR-related research projects and collaborations across One Health sectors from the last five years, detailing key publications, locations, and funding sources (where available), and mapping where these relate to NAP research commitments. This report describes the register and alignment with the NAP commitments.

2. Methods

A research group was identified to cover the different topic areas relevant to One Health (Appendix 1: Individuals and affiliations). Researchers with expertise in each area were contracted to search for Scottish-related research activities including projects or outputs. The work was guided by a steering group comprising representatives from Scottish Government, SEPA, FSS and EPIC (Appendix 1: Individuals and affiliations). The list of NAP commitments was separated into 'Research' and 'Other' and labelled for identification (Table 2: NAP commitments, SOHAR register here).

Agreed criteria for data collection:

- Activities were categorised into six broad disciplines (Environment and Transmission; Transmission from Wildlife; Transmission from Food; Animal Epidemiology and AMR Usage; Clinical AMR; Detection and Surveillance; Other).
- Research activities (projects and/or outputs) were collected from 2015 to current time (July 2021).
- Active Scottish participation: researcher/affiliation based in Scotland, activity carried out in Scotland and/or data collected in Scotland (could be used in wider national/international studies).

- Funding source (if known), and where the information was readily available, amount of funding.
- Relevant links to activity, e.g., peer-reviewed publications; project websites.
- Association with relevant NAP commitment(s). Data that didn't fit the NAP commitments is indicated in the SOHAR register as 'unmapped' (Excel Table 1 and 2: SOHAR register here).
- Scope of the activity based on its breadth, and significance of the activity in relation to the NAP commitments, scored using a semi-quantitative matrix (Appendix 4: Supplementary figure). A score of 0 (low) to 9 (high) was allocated based on expert opinion for a scale of the activity (broad; moderate; narrow in focus) and its significance (high; moderate; low in relevance).

Data were collected from a variety of sources, including published literature, funding portals, conference websites, grey literature by the project team. All information was collated from widely accessible sources in the public domain. The data entries were added to the data entry form with the following headers, and provided a unique ID:

- Topics
- Main individuals/affiliations
- Short description
- Associated publications (inc. DOI)
- Funder
- Status
- Network
- Relevance to SOHAR
- Relevant NAP commitment(s)

Data entries were extracted from the collated forms in a table format for cleaning, filtering, and analysis (in MS Excel format). Data were cleaned for: (i) standardisation in formatting and text presentation; and (ii) the main individuals (and affiliations) associated with each piece of work were (in most cases) reduced to include only the main authors, e.g., corresponding author for published works, or main supervisors for ongoing projects. The first four NAP commitments were also extracted into individual columns to assist with analysis. A quantitative summary for the major categories and NAP commitments was generated to show where the major effort lay, using MS Excel in-built tools for grouping and totalling.

Associated definitions and acronyms are explained in the Appendix 5: Glossary, definitions, and abbreviations.

3. Findings

The SOHAR register

The register was generated according to criteria agreed by research and steering groups (see Methods). The data were grouped by these criteria into general categories and mapped to the NAP commitments (Table 2: NAP commitments and resulting SOHAR register here). The entries provide the main individuals and their affiliations associated with the activity, as well as a short description, and where possible, a unique identifier/weblink to any outputs. Since the agreed criterion directly related to Scotland, i.e., the work was carried out in Scotland and/or used Scottish datasets, some entries are represented by non-Scottish affiliations. Where the information was available, any networks and associated funders were assigned, and in a few cases, it was possible to assign a budgetary value to projects. Finally, perceived relevance to Scottish One Health AMR work was assigned based on a semi-quantitative matrix for 'significance' and 'scale of the project', on a subjective basis (in Methods and Appendix 4: Supplementary figure).

A total of 287 entries were collected. Some entries aligned to multiple categories, generating a total of 402 representations (Fig. 1). The main effort was relatively evenly distributed between the main topics of Animal Health, including Epidemiology and AMR usage; Clinical AMR; and Detection and Surveillance, whilst Transmission from Food or from Wildlife were least represented. The coverage was reflective of where we understand the wider knowledge base for AMR in One Health to be. A relatively large proportion did not fall easily into the originally agreed disciplines and were categorised as 'Other', with detail on the topic area in the Short Description' provided in the main table (Table 2: SOHAR register here). These were generally thought to be in emerging areas, e.g., in social science aspects.

The register comprises a range of entries covering research outputs, e.g., peer-reviewed publications, policy-relevant notes, conference proceedings and registered projects. Therefore, it is necessary to bear in mind that there could be some overlap between projects and their outputs. This also means that the weighting is not even between entries, hence the attempt to assign a score based on the scale of the activity, for example a single entry may be for a large-scale project of broad scope and high significance, or it could be for a single knowledge exchange activity like a contribution to conference proceedings, hence of much narrower scope.

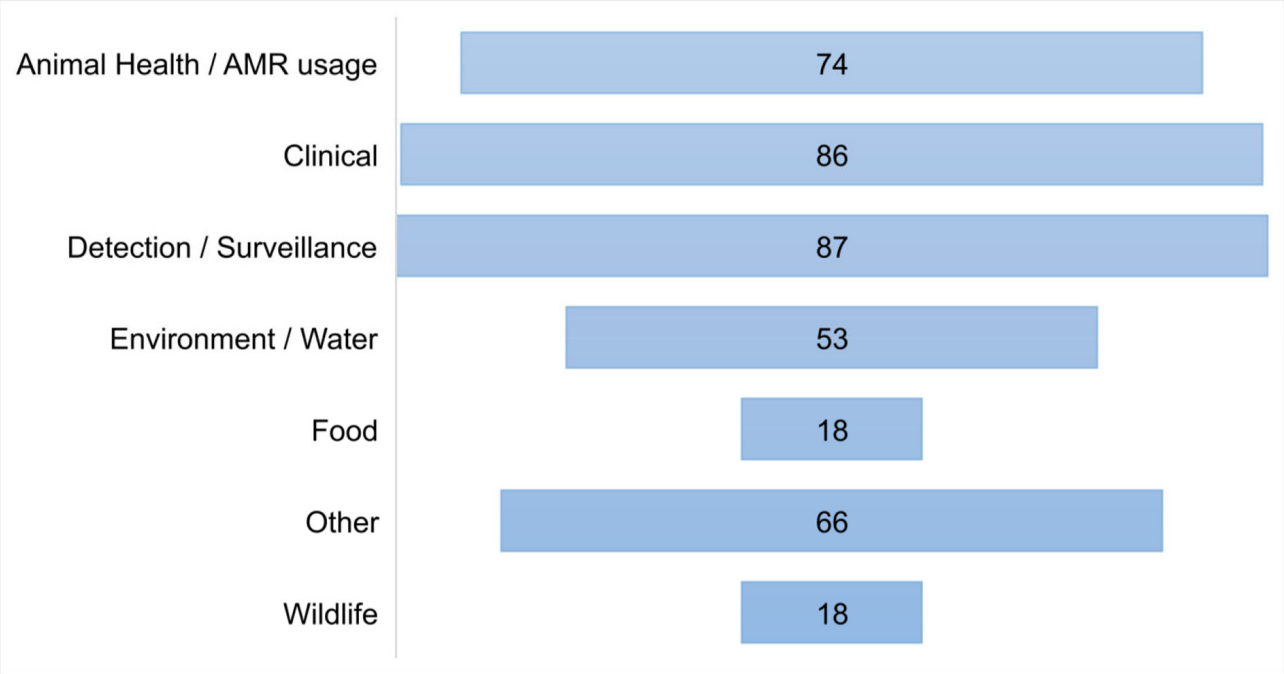

Figure 1. The main categories assigned, for which some entries were allocated to multiple categories.

3.1 Mapping to NAP commitments

Data entries were often mapped to multiple NAP commitments, so that in total 522 matches were made, of which 514 fell into the category of 'Research' commitments, and 14 mapped to 'Additional' non-research commitments (Table 2: NAP commitments for a description of the commitments and codes; Table 2: SOHAR register here for the entries). The most highly represented areas were for the Research-based commitments in (Fig. 2A):

- 'Stronger laboratory capacity and surveillance of AMR in animals' (code 3.4).
- 'Lower burden of animal infection: Better understand how AMR spreads between and among humans, animals and the environment' (code 2.3.4).

The best represented areas in the non-research 'Additional' commitments (Fig. 2B) are in:

- 'Optimal use of antimicrobials in animals and agriculture: Strengthen stewardship for responsible use' (code 3.2.1).

The Research commitments that were not covered or had low representation were included in (Fig. 2). As the register represents entries that are in the public domain, it is recognised that some information relevant to less well represented areas has restricted access, such as commercial research, and is not included here.

- 'Better quality assurance of AMR health products' (code 4.6).
- 'Wider access to therapeutics for those who need them: Support global initiatives to increase access' (code 4.3.1).
- 'Development of and access to diagnostics: Stimulate more R&D into vaccines and alternatives' (code 4.5.2).
- 'At a Global Level: Developing new treatments' (code 1.1.1).

For the areas of key interest to activities in Scotland (Fig. 2C), data entries related to 'Sustainable investment in basic research' for 'Provide strategic leadership in AMR research' (code 4.1.1) were represented in 16 entries, while 'Strengthen insight and capacity for doing high-quality research' (code 4.1.2) were represented in nine entries, some of which overlapped (Table 3A, B). The other area of SG key interest is in 'Development of, and access to, diagnostics: Incentivise R&D for new diagnostics' (code 4.4.1), which was represented with 17 entries (Table 3C). FSS contributes to research NAP commitment 'Better Food Safety' for 'Strengthen the evidence base for AMR and food safety' (code 2.5.1), for which there were 18 entries (Table 3D). The related commitment not under the 'Research' heading is 'Promote good practice across the food chain' (code 2.5.2), for which there was a single entry.

It was clear that in addition to mapping research activities to NAP commitments, there were a good number of consolidated activities that were far broader in scope than any one individual or even group of commitments. Examples of these are listed under the Appendix 2: Wider activities (not an exhaustive list). They demonstrate excellent coordination between different groups to address strategic requirements. For example, generation of the Scottish One Health Antimicrobial Use and Antimicrobial Resistance (SONAAR) report, is a collaboration between public health organisations to provide evidence to inform

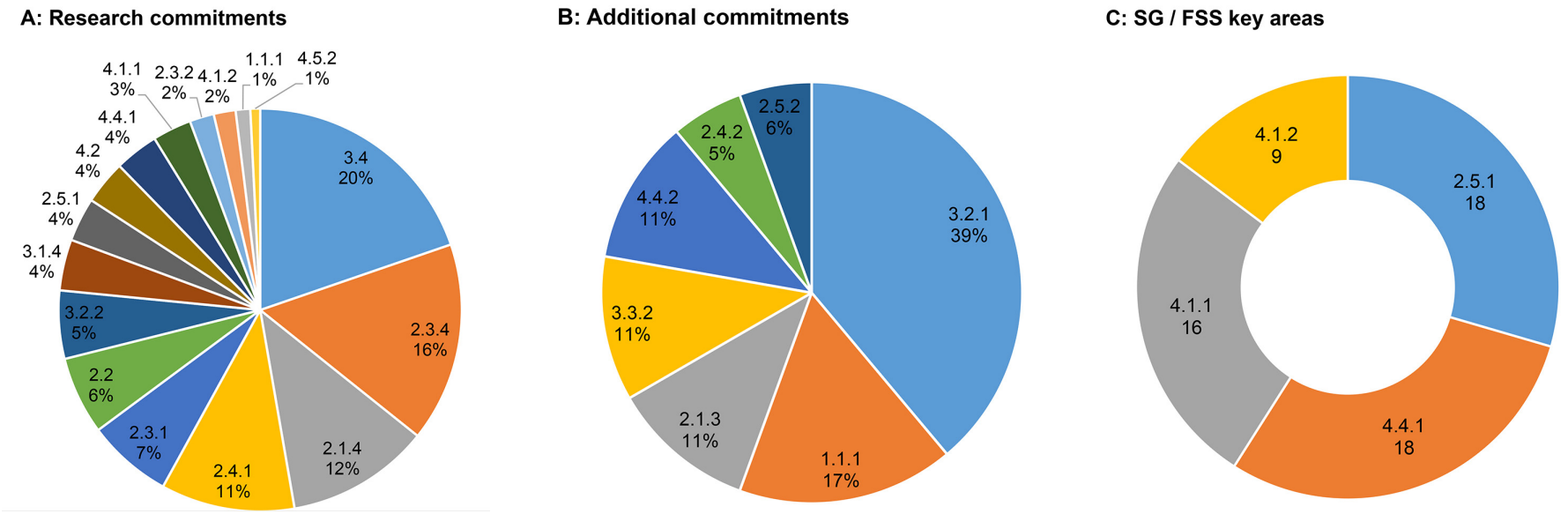

Figure 2A-C. Distribution of NAP associations (A: Research commitments, B Additional commitments, SG/FSS key areas).

Data entries were mapped to NAP commitments (with many entries mapped to multiple commitments), divided in the classes assigned as 'Research' (A), or 'Additional' (B), according to the UK plan. Selected activities mapped to specific NAP commitments (C). The code refers to each NAP commitment (Table 2 : NAP commitments; SOHAR register here) and the number of relevant entries is expressed as a percentage of the total for A (n = 514) and B (n = 14), or the numerical value for C. Commitments with no representation are 4.6 (A), and 2.1.1, 2.1.2, 3.1.2, 3.1.3, 3.3.1, 4.3.2, and 4.5.1 (B).

Tables 3A-D. Activities that map to SG contribution to NAP commitments classed as 'Research' in the UK NAP: in Sustainable investment in basic research (codes 4.1.1, 4.1.2), Development of, and access to, diagnostics (code 4.4.1) and FSS interest for NAPs in Better food safety (code 2.5.1).

Table 3A. Commitment code 4.1.1 activities on 'Sustainable investment in basic research: Provide strategic leadership in AMR research'.

Activity ID	Main individual associated	Type of activity
12	Mark Woolhouse (University of Edinburgh)	Publication: Opinion paper on AMR and transmission for farm animals and wider environment. Suggestion that 'an intergovernmental panel, akin to the Intergovernmental Panel on Climate Change, could be an appropriate vehicle to actively address the problem.'
18	SULSA (Scottish Universities Life Science Alliance)	Conference: Delegates shared their expertise and explored how Scotland can work together to address antimicrobial resistance (AMR). Technology and Innovation Centre at the University of Strathclyde, Glasgow.
24	Cheryl Ashworth (Roslin Institute and R(D)SVS, University of Edinburgh)	Paper: The role of dietary fibre in pig production, with a particular emphasis on reproduction. Jarrett, Selene; Ashworth, Cheryl J. Review article.
29	Matthew Holden (University of St Andrews)	Publication: Holistic approach towards unravelling antibiotic resistance in East Africa.
95	Brian Godman (Strathclyde Institute of Pharmacy and Biomedical Sciences); Andrew Sexton (University of Glasgow)	Publication: A survey of resistance rates and antibiotic use in hospitals in Kurdistan and Iraq.
115	A. Smith, D. Lindsay (contributors, University of Glasgow, Scottish Reference Laboratory)	Publication: This study describes the molecular epidemiological surveillance of emerging antibiotic resistant strains of *Streptococcus pyogenes*.
134	J. Sneddon (Scottish Antimicrobial Prescribing Group)	Publication: This study describes the development and implementation of a sustainable model in antimicrobial stewardship.
141	J. Sneddon, R.A. Seaton (Scottish Antimicrobial Prescribing Group, University of Glasgow)	Publication: This study describes the implementation and support of antimicrobial stewardship policies and programs in Ghana by SAPG.
142	J. Reilly (Glasgow Caledonian University)	Publication: This study reports on a point prevalence study across 31 countries in the EU/EEA and highlights key areas for national and European action.
186	Katherine Keenan (University of St Andrews);	Project: Holistic approach to unravel antibacterial resistance in East Africa (HATUA).
206	Alison MacFadyen, Katarina Oravcová (University of Glasgow)	Conference proceedings: Genomic and phenotypic characterisation of multi-drug resistant *Escherichia coli* carried by meat handlers and slaughterhouse meat from North-Western Tanzania.
208	Stefan Rooke (University of Edinburgh)	Conference proceedings: Resolving complex mobile genetic elements with nanopore sequencing MinION sequencing of Kenyan *E. coli* isolates to identify cocarriage of multiple AMR genes on linked transposable elements.
224	Andrew Desbois (University of Stirling)	Publication: 'Identifying hotspots for antibiotic resistance emergence and selection, and elucidating pathways to human exposure: Application of a systems-thinking approach to aquaculture systems'.
225	Mark Woolhouse, Melissa Ward (contributors, University of Edinburgh)	Publication: 'Clinically relevant antimicrobial resistance at the wildlife–livestock–human interface in Nairobi: an epidemiological study'.
226	Colette Mair, Louise Matthews (contributors, University of Glasgow)	Publication: 'Antimicrobial resistant enteric bacteria are widely distributed amongst people, animals and the environment in Tanzania'.
227	Colette Mair, Louise Matthews, Ruth Zadoks (contributors, University of Glasgow)	Publication: 'Identification of risk factors associated with carriage of resistant *Escherichia coli* in three culturally diverse ethnic groups in Tanzania: a biological and socioeconomic analysis'.

Table 3B. Commitment code 4.1.2 activities on 'Sustainable investment in basic research: Strengthen insight and capacity for doing high-quality research'.		
Activity ID	**Main individual associated**	**Type of activity**
12	Mark Woolhouse (University of Edinburgh)	Publication: Opinion paper on AMR … *duplicated in 4.1.1*
18	SULSA (Scottish Universities Life Science Alliance)	Conference: Over two days… *duplicated in 4.1.1*
43	Sue Tongue, Costa, Shrestha, Stephen West (SRUC); Mandy Nevel (AHDB); McGowan (Scottish Pig Producers)	Project: AMU/AMR in pigs - Data collation and analysis of antibiotic usage, health and production data in Scotland, qualitative social science - usage, interventions, attitudes; economic assessment of optimising antibiotic use on farms and using alternatives to antibiotics.
45	SAVSNET	Project: Electronic Health Record data supplied by over 500 veterinary sites in the UK have joined up to SAVSNET.
175	V.K. Thakur (SRUC)	Publication: Insights into the synthesis and mechanism of green synthesized antimicrobial nanoparticles, answer to the multidrug resistance.
176	J. Thompson (SRUC Veterinary Services)	Project: Publications: Patterns of antimicrobial resistance in *Streptococcus suis* isolates from pigs with or without streptococcal disease in England between 2009 and 2014.
188	N. Holden (SRUC) and other Scottish MRPs	Webpage: Summarising what is being done across the SRPs - Antimicrobial resistance: bringing Scottish expertise together to find the solutions.
193	G. Foster (SRUC Veterinary Services) and others	Publications: Use of diagnostic data from voluntary submissions; livestock, companion animals, aquatic, avian and other species.
199	K. Reyher (University of Bristol); SRUC Veterinary Services	One Health AMR Research Data Platform: An initiative to assess the benefits of linking major sources of AMU and AMR data currently collected by the UK livestock industry.

Table 3C. Commitment code 4.4.1 activities on 'Development of, and access to, diagnostics: Incentivise R&D for new diagnostics'.		
Activity ID	**Main individual associated**	**Type of activity**
16	Till Bachmann (University of Edinburgh)	Publication: Schulze H, Wilson H, Cara I, Carter S, Dyson EN et al. 'Label-free electrochemical sensor for rapid bacterial pathogen detection using vancomycin-modified highly branched polymers'. Sensors 2021;21(5).
30	University of Strathclyde (Civil and Environmental Engineering)	Project: Real time detection and management antibiotic residues in milk. Development of low cost printed sensors, combined with electrochemical techniques to create a fully integrated sensor and instrument, capable of identifying the presence of antimicrobial residues within milk.
98	Stefan Rooke, Mark Woolhouse, Till Bachmann and Ross Fitzgerald, (University of Edinburgh)	Publication: 'Using genome sequence data to combat antimicrobial resistance. Evaluates nanopore sequencing as a surveillance tool in rural Western Kenya, enabling a more decentralised means of genome-level surveillance'.
103	Melanie Jimenez (University of Glasgow)	Publication: New microsystems for antimicrobial resistance. Project aimed to develop microsystems to quickly and automatically concentrate microbes and improve detection procedures, raise awareness by promoting new diagnostic approaches by engaging with health professionals and patients.
161	Damion Corrigan, Alexander Macdonald (University of Strathclyde)	Publication: 'Recent advances in biomedical, biosensor and clinical measurement devices for use in humans and the potential application of these technologies for the study of physiology and disease in wild animals'.
162	Till Bachmann (University of Edinburgh)	Project: AMR Dx Global. International network individuals and organisations focussed on training and capacity building in the field of rapid diagnostics to tackle the global threat of antimicrobial resistance.
163	Till Bachmann (University of Edinburgh)	Publication: 'AMR Rapid Diagnostic Tests - AMR-RDT'. Multi-sectoral, multi-stakeholder and interdisciplinary working group with global reach.
170	M Hutchings, Hall (SRUC)	Project: Development of qPCRs to quantify AMR gene copy number in livestock, for five AMR genes.
177	Ann Bruce, Joyce Tait, Geoffrey Banda, Katie Adam, Vera Mugittu (University of Edinburgh)	Diagnostic innovation and livestock (DIAL): Towards more effective and sustainable applications of antibiotics in livestock farming.
204	Derek Brown (Scottish Microbiology Reference Laboratory (SMiRL), Glasgow)	Conference proceedings: Compared data from analysis of a large European multi-country *Salmonella* Enteritidis outbreak associated with Polish eggs was characterized by WGS-based analysis with various European institutes using different workflows to identify epidemiologically linked isolates.
208	Stefan Rooke (University of Edinburgh)	Conference proceedings: *duplicated in 4.1.1*

Activity ID	Main individual associated	Type of activity
213	Till Bachmann (University of Edinburgh)	Publication: 'Improving performance of a rapid electrochemical MRSA assay: Optimisation of assay conditions to achieve enhanced discrimination of clinically important DNA sequences under ambient conditions'.
217	Till Bachmann (University of Edinburgh)	Publication: 'Temperature-enhanced mcr-1 colistin resistance gene detection with electrochemical impedance spectroscopy biosensors'.
219	Karen Faulds (University of Strathclyde)	Publication: 'SERS detection of multiple antimicrobial-resistant pathogens using nanosensors'.
220	Stuart, Hannah (University of Strathclyde)	Publication: 'Development of a rapid, antimicrobial susceptibility test for *E. coli* based on low-cost, screen-printed electrodes'.
221	Damion K. Corrigan (University of Strathclyde)	Publication: 'Rapid antibiotic susceptibility testing using low-cost, commercially available screen-printed electrodes'.
290	Tim Ryan (Epigem Ltd; University of Glasgow)	Project: Develop a diagnostic tool by integration of advances in single-cell Raman spectroscopy, microfluidics and lab-on-a-chip and world-leading clinical expertise.

Table 3D. Commitment code 2.5.1 activities on 'Better Food Safety: Strengthen the evidence base for AMR and food safety'.

Activity ID	Main individual associated	Type of activity
10	Food Standards Scotland, Geoff Foster (SRUC)	Reports: *E. coli* collected from enteric samples of healthy animals tested as a measure of the background resistance in livestock entering the food chain.
12	Mark Woolhouse (University of Edinburgh)	Publication: Opinion paper… *duplicated in 4.1.1*
20	Charles W. Knapp (University of Strathclyde, Glasgow)	Publications: Investigating carriage of AMR in lactic acid bacteria (including a probiotic *Lactobacillus* species) isolated from fermented olives.
21	Charles W. Knapp (University of Strathclyde, Glasgow)	Publication: Presence of AMR genes in bacteria present in traditional fermented foods.
25	Emmanuel Okpo (Public Health Directorate, NHS Grampian, Aberdeen)	Publication: An outbreak of an unusual strain of *Listeria monocytogenes* infection in North-East Scotland.
30	University of Strathclyde (Civil and Environmental Engineering)	Project: Real time detection and management antibiotic residues in milk
33	University of Edinburgh (School of Biomedical Sciences)	Project: Establishing drivers for the generation and transmission of antimicrobial resistance in the food chain.
34	Peter Kaiser, Mark Stephens, Paul Hocking (University of Edinburgh, Roslin Institute)	Project: Chicken and *Campylobacter* carriage: mapping resistance to *Campylobacter* in chicken.
35	Ruth Zadoks (University of Glasgow)	Project: Antimicrobial resistance in foodborne enteric pathogens and commensals.
164	Food Standards Scotland; SRUC Veterinary Services	Report: Annual slaughter-house based survey.
166	Randall, Smith, Tongue, Evans (APHA, SRUC)	Project; Publication Survey for and characterisation of antibiotic resistance in *Enterobacteriaceae* from beef cattle in England, Wales and Scotland.
167	Randall (APHA), others	Project: EU surveillance - 2017 - Surveillance study of antimicrobial resistance in bacteria isolated from chicken and pork sampled on retail sale in the United Kingdom.
197	Tongue, Webster (SRUC); SERL, SSCdRL, Scientific Services	Publication: Microbiological survey of retail fresh beef mince in Scotland 2019.
204	Derek Brown (Scottish Microbiology Reference Laboratory (SMiRL), Glasgow)	Conference proceedings: *duplicated in 4.4.1*
206	Alison MacFadyen, Katarina Oravcová (University of Glasgow)	Conference proceedings: *duplicated in 4.1.1*
207	Ghaith Fallata (University of Glasgow)	Conference proceedings: Investigation of the impact of food preservatives on avian pathogenic *Escherichia coli* (APEC) and their role in driving zoonotic disease.
215	Gavin Paterson (RDVS), (University of Edinburgh, Roslin Institute)	Publication: 'Prevalence and characterisation of methicillin-resistant staphylococci from bovine bulk tank milk in England and Wales'.
239	Ken Forbes, Bruno Lopes (University of Aberdeen)	Publication: Component of project 'Characterisation of AMR genes in relation to *C. jejuni* transmission through the food chain'. Poster presentation at Campylobacter, Helicobacter and Related Organisms 2019 conference, Belfast.

the development of local and national interventions and initiatives to tackle AMR. A second example is 'Scotland's Healthy Animals', a multi-organisation One Health initiative combining human health, farm and companion animals, wildlife, the environment, food and water with the aim of providing guidance to all animal owners, animal health professionals and the public on keeping animals healthy. Since animal health is inherently linked to microbial diseases, there is a strong component related to AMR. Scotland also has representation in multiple international initiatives, including in Ireland (e.g., AMR in waters via the Shared Agencies Regulatory Evidence Programme network) and JPIAMR (e.g., for *Klebsiella* in the environment).

3.2 Limitations of the work

The data comprising the register were collected by a set of individuals with expertise aligned to each of the main topic areas, and the criteria for data collected were agreed by the steering group (see Methods), based on our understanding of the scope of the NAP commitment topic areas. However, following data collation, it became clear that there were additional research activities in other areas, less well represented in the NAP commitments, for example in Social Sciences. Nonetheless, Scotland has active research in this area, therefore this and other aspects of broader scope were included in the register and categorised as 'Other'.

Data collection was done on a qualitative basis, meaning that there were subjective differences in scoring the 'relevance to One Health AMR work' for each activity. Therefore, this aspect serves as a guide for the overall relevance and scope of each activity but was not used in the final data analysis.

The NAP commitments are written as defined statements, with specific remit. This meant that some activities that were not wholly covered by the remits either could not be mapped directly and were assigned as 'Unmapped' (n=18, e.g., Activity numbers 81, 83, 90, 202), or had only limited relevance, with the relevant codes on the register marked in brackets (n=16, e.g., Activity numbers 24, 45, 188, 203). Many of the activities focussed on obtaining fundamental research and knowledge gathering, so although they may have had some relevance to specific commitments, they do not span the full remit of the commitment in terms of delivery, or in realising the impact of the research. As such, mapping activities to the commitments does not necessarily imply complete or direct relevance, so the outcome of the investigation needs to be interpreted with some caution and attention to the detail of the activity itself. Finally, it was recognised that mapping was a subjective task, and so does not provide a definitive categorisation of the activities, especially where the direct relevance was less clear.

4. Conclusions and recommendations

4.1 Strengths and weaknesses in Scottish AMR research

Overall, a broad range of AMR activities from multiple institutions right across Scotland were identified. Activities related to key areas of interest in leadership and capacity for fundamental research (termed 'Sustainable investment in basic research', Table 3A, 3B) and for AMR related to transmission in the food chain (termed 'Better Food Safety', Table 3D). Particularly strong areas relate to AMR in animals, in terms of laboratory capacity and surveillance of AMR in animals as well as understanding how AMR spreads between humans, animals and the environment. Another particularly strong area is in lowering the burden of human infection, by turning research into practice for effective infection prevention and control (IPC). This is reflected in some strategic actions that pull together specific activities and actors for added value, and link to partners elsewhere (Appendix 2: Wider Activities). The broad scope of Scottish activities on AMR was reflected in some of the challenges in making direct associations or maps (Fig. 1).

Areas with limited representation were at the end of the translational pipeline for end-user application, e.g., in wider access to therapeutics (code 4.3.1), development of vaccines or alternative treatments (codes 4.5.2), and associated areas such as quality assurance of AMR health products (code 4.6). This extended to international reach in development of new treatments (code 1.1.1). It may reflect the barriers in transforming the fundamental discovery phase of the science into practical solutions or alternative treatments, diagnostics and vaccines related to resistance, which have been documented for commercialisation. For example, in April 2021 just 10 products are being marketed for priority pathogens: one for tuberculosis and none for the Clostridioides (https://dashboard.globalamrhub.org/reports/pipelines/pipelines). It may also relate to the data used to populate the register, which was publicly available and by definition does not include any commercially sensitive developments.

4.2 Impacts of the register

The SOHAR register has the potential to deliver multiple impacts for multiple audiences. It allows stakeholders and organisations with any vested interest in AMR to identify the strengths as well as gaps that need to be addressed in more detail. Specific policy-relevant areas may relate to antimicrobial usage (clinical or veterinary); the impact of changing agricultural policies and practices or waste management strategies; or food policies and

changes in food systems. Stakeholders like the FSS have a business objective to explore opportunities and further requirements for AMR surveillance in the food chain, for which the register identifies evidence gaps and shows where support for further research in relation to the food chain can be provided. More generally, Scottish Government policy teams plan to use the research register as a valuable resource to inform discussions across the One Health sectors and assist in the development of evidence-based policy. The register provides an oversight of the types and distribution of research efforts, allowing a degree of quality assurance assessment in terms of the activity type, scope and its method of delivery. It gives oversight for technical diagnostics and surveillance supporting innovation and commercialisation activities. Thus, it provides a rich data source that will be of utility to a wide audience, from scientific to policy and industry.

The Scottish Environment Protection Agency (SEPA) has a primary (statutory) purpose to protect and improve the environment (environmental success) in ways that, as far as possible, create health and wellbeing benefits (social success) and sustainable economic growth (economic success). SEPA has a wide range of regulatory powers and seeks to use them effectively and efficiently to deliver this purpose and help Scotland become a more sustainable, prosperous, and equitable nation (see One Planet Prosperity). SEPA recognises the complexity and interconnections between many of the global environmental challenges of our time (such as biodiversity loss, climate change, microplastics, and antimicrobial resistance) and the need to work with and through a multitude of stakeholders, businesses and communities in helping Scotland respond to these challenges. It recognises the importance of robust evidence to influence, inform, and drive forward environmental policy, regulation, and practice and deliver multiple benefits through interventions. Sector Plans and Sustainable Growth Agreements form an integral part of SEPA's approach to delivering its regulatory strategy One Planet Prosperity. SEPA has started to identify and consider the evidence requirements to address AMR and associated hazardous substances through its sector plans. The SOHAR register will help SEPA understand more about the research on AMR that has been conducted in Scotland over the last five years, identifying strengths and weakness and possible areas and partners for future collaboration in contributing to Scotland's delivery of work for the NAP and other associated drivers.

4.3 Policy recommendations

There are two main considerations for future work in AMR: to maintain and reinforce the strengths, and to address less well-represented areas related to food, environment and translational applications of product development. This is laid out as four policy-relevant areas (i-iv) and two research areas (v-vi):

i. Scotland should play to its strengths and continue to invest in international quality science, as demonstrated in infection prevention and control for livestock (code 2.3.1/4) and humans (code 2.1.4), and related laboratory capacity for AMR surveillance (code 3.4), as well as in environmental contamination (code 2.4.1) (Fig. 2). This will reinforce the Scottish reputation as a world-leader providing underpinning research. There is also good evidence of strong national and international networks, emphasising the collaborative nature of such activities (Table 2: SOHAR register here and Appendix 2: Wider Activities).

ii. A potential link between livestock (and crop) production and the human clinical outcome of AMR is via food. Although there is some representation related to transmission via the food-chain, it is relatively low and limited to a small set of researchers, reflecting it as an emerging area in AMR. In addition to more capacity building, the nature of the work needs further consideration: to understand the contribution of food in the development of clinically relevant resistance, the potential flow of AMR through the whole food supply chain needs to be considered, beyond just surveillance of food products. Thus, Scotland can build on this body of work to help provide more definitive answers.

iii. The One Health aspects of AMR cover the wider environment, for selection, dissemination and transmission and for the factors that drive resistance. Within the register, there is reasonable representation from the environmental science disciplines, in particular for water. This is positive since water as a transmission pathway is often overlooked in the One Health context relative to livestock or animal-associated transmission. However, the activities are limited to a small set of researchers. Furthermore, there are knowledge gaps for the role of agricultural soils and the link to agronomic practices in potential transmission of resistant microbes and associated pharmaceuticals and other environmental pollutants. This is particularly relevant in the context of sustainable, circular agricultural practices that re-introduce waste into productive land. Scotland is particularly well-placed and has strong international reputation in these areas and should therefore take advantage by investing more effort in environmental transmission pathways.

iv. The largest gap related to translation of the fundamental science to end-user applications, either for alternatives to antimicrobials for treatments or diagnostic tools. Although 'Detection and Surveillance' was selected as one of the main topic areas, translation of fundamental or discovery science necessitates direct industry involvement, together with stakeholder engagement in clinical/veterinary health, or environmental protection/and

crop production. There is currently a wealth of evidence to show the strong relationships between Scottish researchers and key stakeholders [11], together with some excellent examples of industry-led projects, e.g., within the Global AMR Innovation Fund (GAMRIF) portfolio. Therefore, it should be a straightforward task to encourage more involvement with commercial partners within and beyond Scotland. Funding agencies can play a key role here (e.g., Innovate-UK), and Scottish Enterprise as key partners, as they have a good history of mapping research effort to industry needs. A related point is the potential for stronger partnerships with the NHS, who have existing infrastructure and can benefit from academic expertise through partnering.

4.4 Research recommendations

v. The SOHAR register is a testament to the broad range of activities related to AMR in Scotland. By identifying leading actors in AMR, it presents an ideal opportunity to generate an 'AMR One Health' forum to provide a research community focus and encourage dialogue on developments in field of AMR, facilitating organisation of knowledge exchange events. The forum would promote collaborations to help address policy needs and push the boundaries of frontier science. Finally, it would also serve as a route for keeping the register of activities up-to-date.

vi. The SOHAR register is, by default, a snapshot of research activities. Therefore, there is a good case for the research community to maintain and update the register, at least annually, and to convert it into an online, open access user tool. It will have wide appeal and broad impact for a range of uses. It can be presented as an interactive dashboard to query different aspects of the work, but according to user requirements, supported by explanatory text for common themes and topics. The steps required to convert the register into a user-friendly and maintained resource are discussed in Appendix 3: Continuance.

5. References

1. HM Government. 2019. Tackling antimicrobial resistance 2019–2024. https://www.gov.uk/government/publications/uk-5-year-action-plan-for-antimicrobial-resistance-2019-to-2024.
2. O'Neill J. 2016. Review on Antimicrobial Resistance. https://amr-review.org/home.html [accessed October 2021].
3. European Commission. 2017. EU Action on Antimicrobial Resistance https://ec.europa.eu/health/antimicrobial-resistance/eu-action-on-antimicrobial-resistance_en [accessed October 2021].
4. Anderson M, Schulze K, Cassini A, Plachouras D, Mossialos E. 2019. A governance framework for development and assessment of national action plans on antimicrobial resistance. *The Lancet Infectious Diseases,* 19(11):e371-e384.
5. HM Government. 2021. Antimicrobial resistance (AMR) https://www.gov.uk/government/collections/antimicrobial-resistance-amr-information-and-resources [accessed October 2021].
6. World Health Organization. 2015. Global action plan on antimicrobial resistance. Geneva, Switzerland 2015.
7. Scottish Government. 2014. Scottish Management of Antimicrobial Resistance Action Plan 2014-18 (ScotMARAP2). Edinburgh, UK.
8. Reilly J, Mullings A. 2017. The national agenda for Healthcare Associated Infection, Antimicrobial Resistance and Infection Prevention and Control in Scotland: Structures, current priorities and programmes. *Journal of Infection Prevention,* 18(4):210-212.
9. Stanton IC, Bethel A, Leonard AFC, Gaze WH, Garside R. 2020. What is the research evidence for antibiotic resistance exposure and transmission to humans from the environment? A systematic map protocol. *Environmental Evidence,* 9(1):12.
10. Smith M, King C, Davis M, Dickson A, Park J et al. 2018. Pet owner and vet interactions: exploring the drivers of AMR. *Antimicrobial Resistance & Infection Control,* 7(1):46.
11. SEFARI Gateway. 2020. Antimicrobial resistance: bringing Scottish expertise together to find the solutions. https://sefari.scot/research/antimicrobial-resistance-bringing-scottish-expertise-together-to-find-the-solutions [accessed October 2021].
12. Haddaway NR, Macura B, Whaley P, Pullin AS. 2018. ROSES RepOrting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Environmental Evidence,* 7(1):7.
13. Haddaway NR, Feierman A, Grainger MJ, Gray CT, Tanriver-Ayder E et al. 2019. EviAtlas: a tool for visualising evidence synthesis databases. *Environmental Evidence,* 8(1):22.
14. Rubio DM, Schoenbaum EE, Lee LS, Schteingart DE, Marantz PR et al. 2010. Defining translational research: implications for training. *Academic Medicine,* 85(3):470-475.

Appendices

Appendix 1: Individual and affiliations

Table A1: Research group members

Expert	Institution	Topic area
Lisa Avery	James Hutton Institute	Environment and water transmission
Karen Scott	Rowett Institute	Transmission from food
Thamarai Schneiders	University of Edinburgh	Clinical AMR
Sue Tongue	SRUC	Animal epidemiology and AMR usage
Eleanor Watson	Moredun Research Institute	Detection and surveillance; transmission from wildlife

Steering group members

Expert	Institution	Topic area
Kate Anderson	Scottish Government	Human health
Elizabeth Burgess	Scottish Government	Human health
Vivienne MacKinnon	Scottish Government	Animal health
Nia Ball	Scottish Government	Animal health
David Lister	Scottish Government	Environment
Barry Greig	Scottish Government	Waste in water
Emma Agnew	Food Standards Scotland	Food safety
John Redshaw	SEPA	Environment, water
Dominic Mellor	EPIC	Animal health
Sharon Pfleger	NHS Highland	Clinical

Appendix 2: Wider activities

In addition to the activities that match the criteria for inclusion in the SOHAR register, there is a large body of work that has relevance to AMR One Health activities in Scotland. Some of these are included in the following table. National and global initiatives are included since they have direct involvement with Scottish data or individuals but are not possible to capture as a single 'activity' on the SOHAR register, e.g., SONAAR or WHO reports. Several EU reports and resources have direct relevance or use of data. Activities in neighbouring countries includes direct Scottish involvement, e.g., with the Irish EPA via the ShARE network, as steering board members, or providing input for policy documentation. Since AMR defines a wider term than just antibiotic resistance (i.e., only related to bacteria), some of the entries also relate to other drugs that can generate resistance, e.g., pharmaceuticals, and to resistance in fungi.

Table A2: Research relevant to AMR One Health activities in Scotland

SONAAR, VAARS and RUMA Reports

Surveillance data produced related to clinical and veterinary AMR and use in Scotland and the wider UK (accessed October 2021).

https://www.hps.scot.nhs.uk/web-resources-container/scottish-one-health-antimicrobial-use-and-antimicrobial-resistance-in-2019/

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/950126/UK-VARSS_2019_Report__2020-TPaccessible.pdf

https://www.ruma.org.uk/

Scotland's Healthy Animals

A website that provides guidance to all animal owners, animal health professionals and members of the public on keeping animals healthy: includes substantial content on AMR and AMU (accessed October 2021).

https://www.scotlandshealthyanimals.scot/

Review of airborne antimicrobial resistance

Published by the Environment Agency, 18/02/2020 (accessed October 2021).

Review of airborne antimicrobial resistance - GOV.UK (www.gov.uk)

Framework for environmental AMR in England

Environment Agency, 30/10/2020 (accessed October 2021).

Framework for understanding environmental antimicrobial resistance in England - GOV.UK (www.gov.uk)

One Health AMR coalition (England-Wales)

The universities of Bath, Bristol, Cardiff and Exeter and Rothamsted Research Institute formally launched their new 'One Health' antimicrobial resistance research consortium, the GW4 Alliance (Director: Dr Joanna Jenkinson). The aim is to become the UK's leading interdisciplinary 'One Health' AMR research consortium, recognised worldwide (accessed October 2021).

Research news - Exeter in GW4's world-leading One Health approach to tackling antimicrobial resistance pandemic - University of Exeter

GW4 Antimicrobial Resistance Alliance (gw4amr.com)

One Health Breakthrough Partnership (OHBP)

Some members of the SOHAR project steering group are also actively involved in the One Health cross-sector partnership addressing issues in Scotland (OHBP), including the presence of pharmaceuticals in the environment: https://spice-spotlight.scot/2020/06/02/pharmaceuticals-in-the-environment-introduction-and-cross-sector-partnership-addressing-the-issue-in-scotland/ .

New reports:

https://www.bbc.co.uk/news/uk-scotland-highlands-islands-51007527

and https://www.gov.scot/policies/water/hydro-nation/

(accessed October 2021).

Environmental AMR: Policy and regulation

References related to environmental AMR in policy and regulation (accessed October 2021):

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5088501/

https://www.gov.uk/government/publications/framework-for-understanding-environmental-antimicrobial-resistance-in-england.

Projects supported through UK government DHSC

All projects currently funded by the Global AMR Innovation Fund (GAMRIF) (accessed October 2021).

Projects supported by DHSC through the Global AMR Innovation Fund (publishing.service.gov.uk)

Irish EPA funded AREST and PIER AMR Projects

Scotland is involved in these projects via the ShARE network, with representation from SEPA as steering group members (accessed October 2021).

ShARE link via SEPA: https://www.sepa.org.uk/about-us/how-we-work/our-research/five-agencies-share-programme/

https://www.nuigalway.ie/medicine-nursing-and-health-sciences/medicine/disciplines/bacteriology/research/arest/

https://www.youtube.com/watch?v=ZiH2hgriiOY

https://www.nuigalway.ie/medicine-nursing-and-health-sciences/medicine/disciplines/bacteriology/research/pier/

http://erc.epa.ie/smartsimple/displayProject.php?projectCode=2018-HW-LS-2

Science Foundation Ireland Project

SMARTIE: Spatiotemporal Modelling of Antimicrobial Resistance in the Irish subsurface Environment (accessed October 2021).

Research Projects | Spatiotemporal Modelling of Antibiotic Resistance in the Subsurface Environment (SMARTIE) | UCC ERI

Groundwater resources as a global reservoir for antimicrobial-resistant bacteria - ScienceDirect

Ireland's National Action Plan for AMR 2017-2020 and 2021-2025

Ireland's National Action Plan for Antimicrobial Resistance 2017-2020 (iNAP): https://www.gov.ie/en/publication/babe6-irelands-national-action-plan-for-antimicrobial-resistance-2017-2020-inap/#

An updated NAP (iNAP2) was announced in Aug 2021: https://www.gov.ie/en/publication/d72f1-joint-action-on-antimicrobial-resistance/

An Irish Times article on behavioural science approach from Teagasc: 'Vets will receive extensive training in motivational interviewing while a cohort of farm advisers will receive training in behaviour change techniques such as action planning, goal setting, cognitive restructuring, and framing. These vets and farm advisers will then implement their training over two years with specially selected dairy and pig farms.': Teagasc project aims to reduce antibiotic use in agriculture (irishtimes.com), (accessed October 2021).

JPIAMR network

The Joint Programming Initiative on Antimicrobial Resistance (JPIAMR), is a global collaborative organisation and platform, engaging 28 nations and with support from the European Commission to curb antimicrobial resistance (AMR) with a One Health approach: JPIAMR – Joint Programming Initiative on Antimicrobial Resistance

Project dashboard: Mitt nya ark (vr.se)

JPIAMR-VRI Digital Platform

The JPIAMR-VRI (Virtual Research Institute) Digital Platform is a free access point for the entire AMR community to facilitate knowledge exchange and data sharing of antimicrobial resistance research data across the globe.

https://www.jpiamr.eu/activities/jpiamr-vri/jpiamr-vri-digital-platform/

(accessed July 2021)

WHO surveillance report 2021

Record response to WHO's call for antimicrobial resistance surveillance reports in 2020 (reported as per 9th June)

GLASS overview: Surveillance, Prevention and Control of Antimicrobial Resistance (AMR) (who.int)

(accessed October 2021).

Food and Agriculture Organization of the United Nations (FAO): Antimicrobial resistance

The FAO plays a key role in supporting governments, producers, traders and other stakeholders to move towards the responsible use of antimicrobials in agriculture.

Its 39th Conference (in June, 2015) adopted Resolution 4/2015 on AMR which recognized that it poses an increasingly serious threat to public health and sustainable food production, and that an effective response should involve all sectors of government and society: http://www.fao.org/antimicrobial-resistance/en/.

In 2021, the FAO will revise the Codex 'Code of Practice to Minimize and Contain Foodborne AMR': http://www.fao.org/fao-who-codexalimentarius/news-and-events/news-details/en/c/1393151/

(accessed October 2021).

The One Health European Joint Programme (OHEJP)

In line with the "Prevent-Detect-Respond" concept, the main focus of the new OHEJP is to reinforce collaboration between institutes by enhancing transdisciplinary cooperation and integration of activities by means of dedicated Joint Research Projects, Joint Integrative Project and through education and training in the fieldsof Foodborne Zoonoses (FBZ), Antimicrobial Resistance (AMR) and Emerging Threats (ET).

About - One Health EJP

(accessed October 2021).

Third joint inter-agency report on integrated analysis of antimicrobial agent consumption and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals in the EU/EEA section

'Antimicrobial consumption and resistance in bacteria from humans and animals'

This report provides an integrated analysis of possible relationships between AMC in humans and food-producing animals and the occurrence of AMR in bacteria from humans and food-producing animals.

This report was produced as a collaboration between the European Centre for Disease Prevention and Control (ECDC), the European Food Safety Authority (EFSA) and the European Medicines Agency (EMA). It is the third joint inter-agency report on integrated analysis of antimicrobial agent consumption and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals (JIACRA), prepared by the three agencies at the request of the European Commission (EC) (accessed October 2021).

ECDC/EFSA/EMA third joint report on the integrated analysis of the consumption of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from humans and food-producing animals (JIACRA II) (europa.eu)

Appendix 3: Continuance

To maintain its utility, there is a need to both maintain and update the database, as well as to make it available to vested individuals/groups. This is beyond the scope of the current project and forms a logical step 2 to the work.

Our recommendation is that the follow-up piece of work employs this approach for visualisation and dissemination of the data on an open access webpage, as an interactive dashboard. The register can be made accessible online, with signposting from the webpages of interested parties. The source data (i.e., Table 2: SOHAR register here) should be accessible as supplementary information on the website, at a minimum. Conversion will involve expertise for data handling, database management and webpage design to establish the website and scientific expertise

to update the register on an annual basis. The whole project can be overseen as part of an existing umbrella group, or as a deliverable of the SG RESAS Strategic Research Programme, or Underpinning Capacity, to allow continued updates and maintenance. A route to step 2 for dissemination, sharing, maintaining and updating the register could be:

1. Transfer the register to a tool that allow queries to be made and generates interactive, downloadable tables and figures as a data dashboard.
2. Identify a web-based portal that can host the database and outputs, e.g. CREW, SEFARI Gateway or a Scottish Government run site. Then launch and maintain webpage for SOHAR register.
3. Initiate regular updates (e.g., annual) by scientific expertise team to include additional research activities for that year. Potentially, researchers listed in the SOHAR register could provide their own updates (notwithstanding any security requirements).

A relevant piece of work by the University of Exeter [9] generated a protocol to map data on current evidence relevant to AMR in the environment and the effect on human health, as well identifying research strengths and weaknesses. The aims are to produce two evidence maps: (i) on the research evidence on AMR exposure and transmission to humans from the environment; from measurable health outcomes or estimated exposure of risk in humans from direct contact/consumption of environmentally sourced AMR bacteria; and (ii) the research evidence on the prevalence of resistant bacteria in the environment in the UK. The review and mapping exercise follows the ROSES (RepOrting standards for Systematic Evidence Syntheses) principle [12], and the findings will be made available in a downloadable table and the maps presented using an open access and open source tool, EviAtlas [13]. A larger and more comprehensive dashboard has been generated for a global overview of AMR work into drug development, the Global AMR R&D Hub. It is presented as a dynamic dashboard to query projects and funding by geographical area, sector or funder (https://dashboard.globalamrhub.org/). This type of tool requires ongoing investment for its maintenance. Therefore, there are multiple considerations for how best to convert the register into a user tool.

Appendix 4: Supplementary figure

		Significance		
		High	Moderate	Low
Scale of the activity	Broad	9	6	3
	Moderate	6	4	2
	Low	3	2	1

Figure S1. Semi-quantitative matrix used to assess Scope and Significance of research activities, with respect to the NAP commitments. Researchers allocated a score based on their expert opinion for a scale of the activity (broad; moderate; narrow in focus) and its significance (high; moderate; low in relevance). The output is provided in Table 2 (SOHAR register here) for the entries.

Appendix 5: Glossary, definitions and abbreviations/acronyms

Antimicrobials: a range of natural and synthetic compounds (including antibiotics, antivirals, antifungals and antiparasitics) which are used to prevent and treat infections in humans, animals and plants. The antimicrobials target microbes (e.g., bacteria, fungi, and parasites) to reduce their viability, and can be derived from a wide range of sources, including peptides from eukaryotic hosts (e.g., defensins), chemicals (e.g., heavy metals), or synthetic compounds (e.g., medicines, some fungicides).

Antimicrobial resistance (AMR): the ability/evolution of microbes to resist the action of antimicrobial compounds. The microbes no longer respond to antimicrobial treatment, medicines become ineffective, this can result in infections that persist and can spread. AMR is a natural biological phenomenon, but it is affected by factors such as the overuse of medicines (animals and humans) or poor infection control. In particular, antibiotic resistance has become an increasing global concern.

Antibiotics: a range of natural and synthetic compounds generated by a wide range of microbes, both bacteria and fungi, which specifically target bacteria to reduce their viability. They act in a variety of ways including: disrupting microbe cell walls, preventing fundamental cellular processes like protein translation, or interfering with DNA function. Intentional use of antibiotics occurs in veterinary, clinical and in some countries, arable settings.

Their occurrence in natural settings (e.g., in the wider environment, and within the host microbial community), is part of normal microbial ecology functions.

Antibiotic resistance: the ability of bacteria to resist the action of clinical and veterinary antibiotics. Resistance occurs via a range of mechanisms including efflux (pumping) the drugs outside the cell, degradation, or inactivation of the antibiotic within the cell.

Antimicrobial usage (AMU): the intentional application of AMR compounds. Antimicrobials need to be used appropriately and with due consideration of the unintended consequences, such as the risk of increasing AMR. This is known as the concept of 'antimicrobial stewardship' to govern appropriate use and consideration of unintended consequences AMU.

Antimicrobial genetic determinants: intrinsic resistance elements in microbes encoded in the genome, such as genes that encode functional proteins, which may target antimicrobials directly or function as efflux pumps. Some elements may be regulatory untranslated regions that influence expression of resistance genes.

Basic, applied and translational research: 'Basic' research generates fundamental knowledge and understanding e.g., from laboratory studies. It is a means of answering practical problems, though may not provide a complete specific answer. 'Applied' research aims to provide the complete answers. 'Translational' research transforms scientific discoveries into applications or practical solutions (adapted from definition in [14]).

Acronyms	Name
AMR	Antimicrobial Resistance
AMU	Antimicrobial Usage
ARHAI	Antimicrobial Resistance and Healthcare Associated Infection
CARS	Controlling Antimicrobial Resistance in Scotland
CREW	Centre of Expertise for Waters
EPIC	(Epidemiology, Population health and Infectious disease Control) Centre of Expertise on Animal Disease Outbreaks
FAO	Food and Agriculture Organization
FSS	Food Standards Scotland
GAP	Global Action Plan on Antimicrobial Resistance
HPS	Health Protection Scotland
IPC	Infection Prevention and Control
JHI	James Hutton Institute
NAP	National Action Plan
NES	NHS Education Scotland
OIE	World Organisation for Animal Health
RESAS	Rural and Environmental Science and Analytical Services
SAPG	Scottish Antimicrobial Prescribing Group
SCOTMARAP	Scottish Management of Antimicrobial Resistance Action Plan
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
SHAIPI	Scottish Healthcare Associated Infection Prevention Institute
SOHAR	Scottish One Health AMR Register
SONAAR	Scottish One Health Antimicrobial use and Antimicrobial Resistance
SRUC	Scotland's Rural College
WHO	World Health Organization

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