

# FACTORS INFLUENCING ANTIMICROBIAL RESISTANCE IN FOOD SYSTEMS

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# RECOMMENDATIONS FOR LONG-TERM GOVERNANCE UNDER A CHANGING CLIMATE

## Research Brief

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For a copy of this research brief and for more information about the study, please visit:

<https://uwaterloo.ca/foodborne-disease-epidemiology-group/research/amresilience>

## INTRODUCTION

**Antimicrobial resistance (AMR)** claimed an estimated 1.27 million lives in 2019 making it a leading cause of death worldwide.<sup>1</sup> **Antimicrobial use (AMU)** in human and veterinary medicine and in food production is a major cause of AMR.<sup>2</sup> Poverty, poor sanitation, increased connectivity including international trade and many other factors also drive AMR development and its spread through the food system, into the environment and across geographic borders contributing to resistant infections in humans.<sup>3-8</sup>

**Climate change** is one factor among others (e.g., population and economic growth) that will likely increase the emergence and spread of AMR. Increasing temperatures will create physiological stress in animals and humans and increase risks of infectious diseases.<sup>9-11</sup> Risks of flooding in some areas may drive migration and cause overcrowding that bring humans and animals closer together, increasing the incidence of infectious diseases and amplifying AMR transmission particularly in areas with poor sanitation.<sup>10-12</sup> These infections, and others, will require antimicrobials for treatment if health is to be maintained.

Without effective intervention, AMR is projected to claim millions more lives, burden health systems and cost trillions of dollars in global economic losses by 2050.<sup>13,14</sup> Many approaches have been taken to address AMR with variable impacts. Because AMR implicates human, animal and environment sectors, there is a need to work across these sectors in an integrated manner to better understand how to effectively manage AMR and AMR impacts long-term under changing climatic conditions.

This research brief addresses key knowledge gaps in our understanding of AMR by examining the Swedish/European food system.<sup>15</sup> The Swedish/European food system provides a relevant setting to understand how nations can reduce AMR while contending with imported foods produced with varying AMU practices and varying national, regional and international forces. **To this end, our brief lists the recommendations identified by participants to inform responses by decision-makers in different sectors to address AMR under a changing climate and ensure a future with effective antimicrobials for improving health.**

### KEY MESSAGES:

- AMR development, spread and impact are driven by a complex web of factors that span, human, animal, agriculture, and environment sectors.
- Reducing AMR and AMR impacts requires multi-pronged interventions that target human, animal, agriculture, and environment sectors and planning for unintended health, social or economic consequences.
- Interventions that address AMR and climate change together, achieve the Sustainable Development Goals and are underpinned by multistakeholder participation and global collaboration are essential to mitigating AMR.
- An urgent need to act NOW or the fight against AMR will be lost.

## METHODS

Using the Swedish/European food system as a case study, we conducted a series of workshops involving European participants with expertise from sectors that may directly or indirectly influence AMR emergence and spread. Through our in-depth qualitative explorations, participants with expertise in epidemiology, food safety and microbiology, veterinary sciences, aquatic sciences and aquatic foods, agricultural crops and policy, farm animal welfare, human medicine, nursing, public health, public health advocacy, consumer advocacy, pharmaceutical marketing, pharmaceutical law, trade and economics, urban agricultural innovation, sustainable foods and innovation, dietetics, peace and conflict resolution, and leadership co-produced:

- a visual model that captures the wide range of factors that drive AMR and that AMR impacts related to the food system, including where we might intervene to mitigate AMR; and
- rich descriptions of the sustainability of selected interventions under a future changing climate.

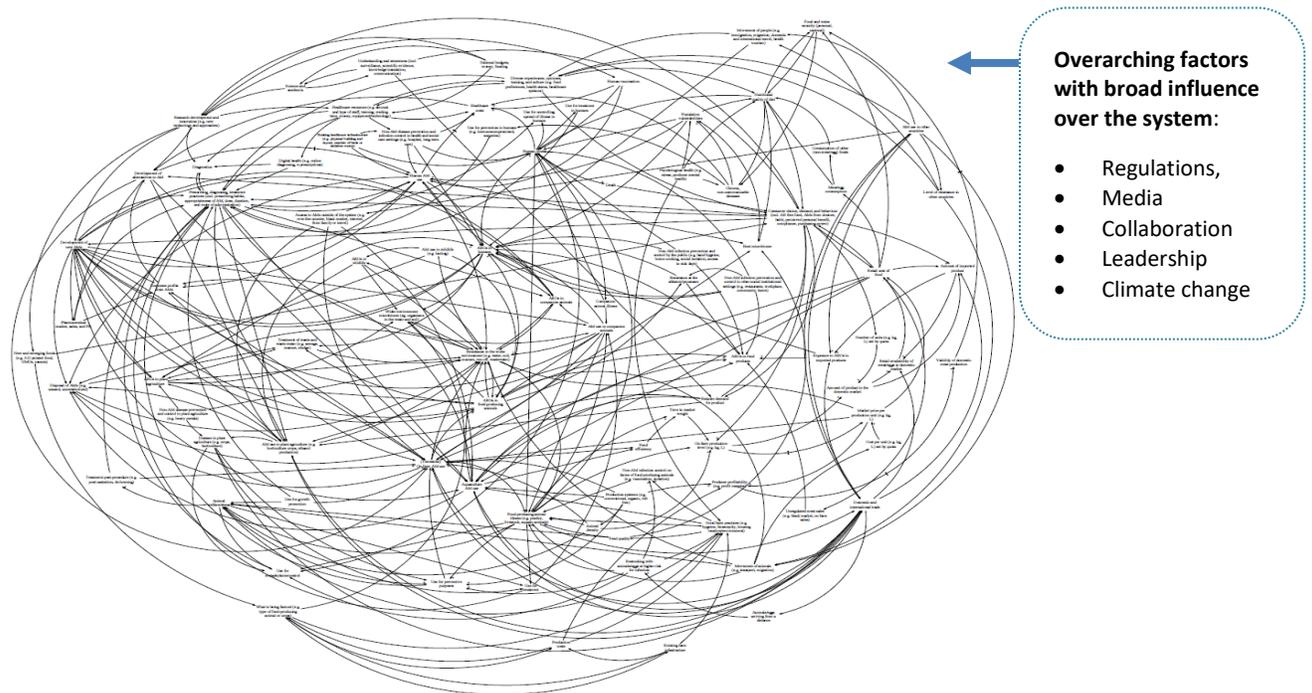
**Building the model of AMR in the food system:** In 2019, we conducted two workshops with 17 participants in Stockholm, Sweden. Participants created a visual model depicting the factors influencing AMR relevant to the Swedish/European food system by translating an initial model of AMR in the Canadian AMR system<sup>16</sup> to their context, and identified potentially promising places in this model for intervention to address AMR. The initial CLD and our approach was based on a Public Health Agency of Canada study that explored the factors influencing AMR in the Canadian food system with funding from the Canadian Safety and Security Program with Defence Research and Development Canada.<sup>17</sup> Participants' input was captured via verbatim transcripts, draft visual models, and field notes, that were then coded to identify factors and their inter-connections and determine feedback loops. We also used thematic analysis to describe the AMR dynamics illustrated in the visual model, and places for intervention. The visual model and themes were confirmed via participant feedback.<sup>15</sup>

**Modelling the impacts of interventions under climate change:** In 2020, we conducted two workshops and two 90-minute interviews (online due to COVID-19) with eight participants who had participated in the 2019 workshops. Here, participants explored how two interventions, ***taxation of antimicrobials at point of sale*** and ***infection prevention measures***, could each successfully address AMR in Sweden in the year 2050 under a changing climate. These interventions were selected because they are operationalized in varied ways in different countries<sup>18,19</sup> and can apply to different sectors. Participants also identified actions to take starting in the year 2030 to ensure success in 2050. Verbatim transcripts and field notes were thematically analyzed to produce a narrative describing what the year 2050 would need to look like for each intervention to succeed in addressing AMR, and what we need to do in the year 2030 to achieve success in 2050. Narratives were confirmed via participant feedback.

## RESULTS

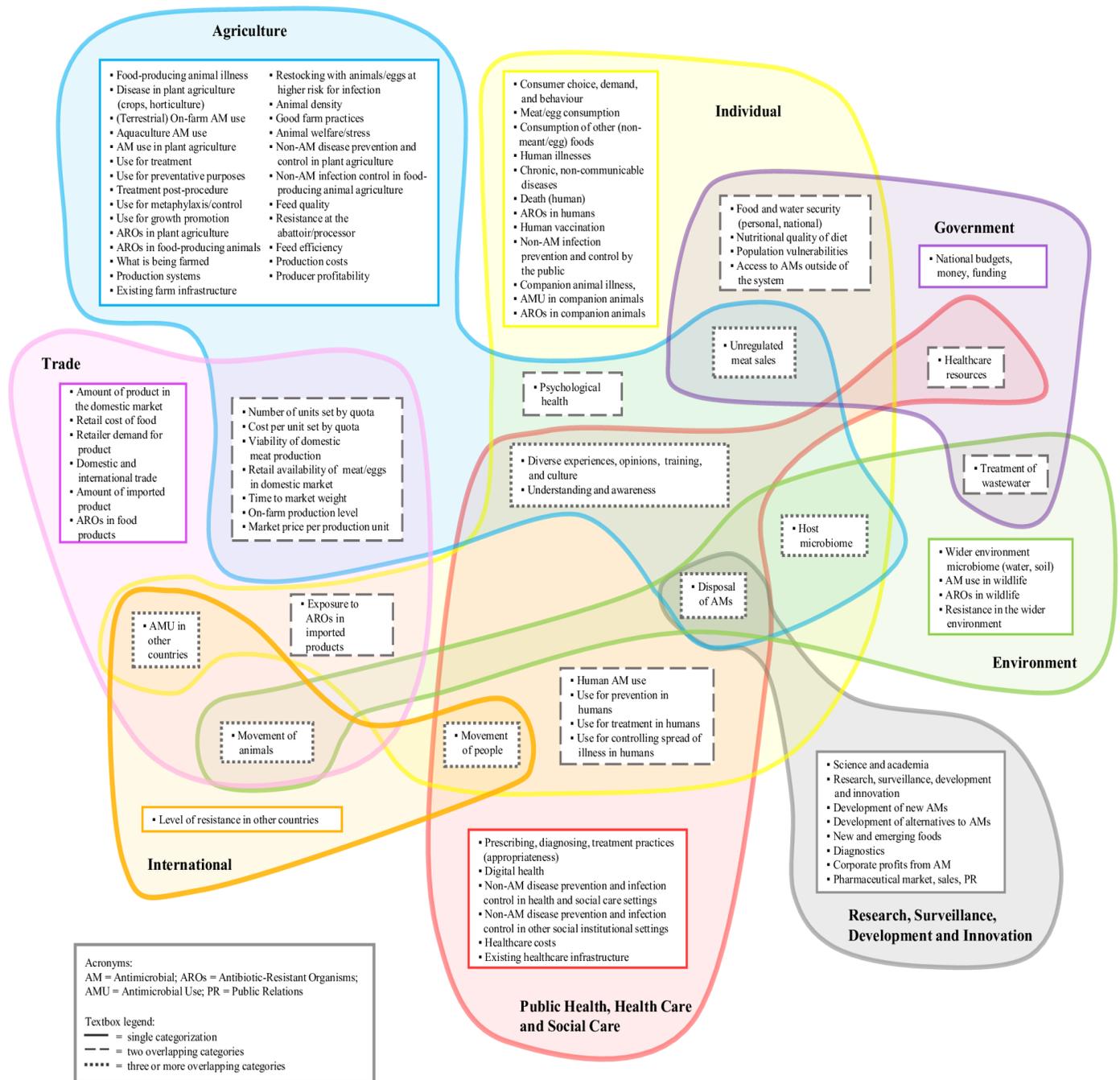
### AMR in the Swedish/European Food System is driven by a complex web of interactions

The visual model of factors influencing AMR in the Swedish/European food system contained 91 factors connected by 331 relationships (Figure 1). These 91 factors were specific to individual, government; agriculture (food production); environment; trade; research, surveillance, development and innovation; public health, health care and social care; and international (e.g., movement of people via travel) influences (Figure 2). There were also five ‘overarching factors’ that impact the whole AMR model: regulations, media, cross-sector and international collaboration, leadership, and climate change.<sup>15</sup>



**Figure 1** Visual model of 91 factors influencing AMR in the Swedish/European food system plus 5 factors with broad influence over the system.<sup>15,a</sup>

<sup>a</sup> For a zoomable version of the CLD, visit: <https://doi.org/10.1371/journal.pone.0263914.s008> from Lambraki IA, Cousins M, Graells T, Léger A, Henriksson P, Harbarth S, Troell M, Wernli D, Sogaard Jørgensen P, Desbois AP, Carson CA, Parmely JP, Majowicz SM. Factors influencing antimicrobial resistance in the European food system and potential leverage points for intervention: A participatory, One Health study. PLOS ONE 2022; 17(2): e0263914.



**Figure 2** 91 factors influencing AMR in the Swedish/European food system by 8 categories<sup>15,b</sup>

<sup>b</sup> For a zoomable version, visit:

<https://journals.plos.org/plosone/article/figure?id=10.1371/journal.pone.0263914.g001> from Lambraki IA, Cousins M, Graells T, Léger A, Henriksson P, Harbarth S, Troell M, Wernli D, Sogaard Jørgensen P, Desbois AP, Carson CA, Parmely JP, Majowicz SM. Factors influencing antimicrobial resistance in the European food system and potential leverage points for intervention: A participatory, One Health study. PLOS ONE 2022; 17(2): e0263914.

## **Addressing AMR requires a multi-pronged approach and plans to address unexpected consequences**

Participants identified places for intervention that have potential to shift the system to effectively address AMR, including:

- improving non-antimicrobial infection prevention and control measures in five different places: on-farm, at home, workplaces, health and social care facilities, and the community;
- increasing investments in a range of issues such as providing universal health care for all; promoting healthy lifestyles, providing insurance to farmers;
- reducing humans' and animals' stress levels and promoting peoples' mental health;
- changing consumer demand (e.g., for antimicrobials, food products, services);
- changing retailer and public procurement standards to push suppliers to provide commodities that align with antimicrobial stewardship, animal welfare friendly and sustainable food production practices;
- improving awareness and education efforts of the public and different sectors about AMR, healthy living and sustainability, such as farm workers, health care staff and students in schools;
- conducting research on a range of issues (e.g., researching the microbiome and gut microflora);
- developing accurate measures of AMU and antimicrobial disposal and supporting surveillance of AMR in the environment;
- targeting regulations, standards and agreements (e.g., setting AMU limits in medicated feed, and AMR limits on imported foods), and regulating infection prevention and control measures in different settings;
- fostering collaboration between sectors (e.g., industry, government) within and across countries to facilitate information sharing and enable adaptation of actions based on lessons learned; and
- encouraging leadership to redefine the values and goals that drive how society and businesses operate (i.e., value health and well-being over profits).

However, many of these places for intervention were part of highly networked feedback mechanisms, making change difficult and indicating that intervening at these places could create changes in many other connected parts of the system in unpredictable and potentially negative ways. This demonstrated how complex it is to find actions to mitigate AMR and the need for planning to minimize unexpected health, social or economic consequences.<sup>15</sup>

## Addressing AMR under a changing climate requires achieving the Sustainable Development Goals

Participants described three future scenarios that explained how *taxation of antimicrobials at point of sale* and *infection prevention measures* were each successful in addressing AMR in Sweden under a changing climate in the year 2050. Because participants recognized AMR as a global problem that requires global solutions, each future scenario looked beyond Sweden's borders:

### TAX BURN OUT

In this future scenario, participants described *taxation of antimicrobials at point of sale* as a low-impact intervention that creates inequities and thus fails to address AMR on its own. Participants stressed that if taxation of antimicrobials were to be part of any AMR mitigation success story, the intervention would need to be implemented in present time and tax dollars should be directed into multi-pronged actions that are implemented in a future world that resembles the "Addressing the Basics" scenario.

### ADDRESSING THE BASICS

In this future scenario, participants identified *infection prevention measures* as highly impactful at containing AMR in 2050 because they would reduce the need for antimicrobials, and contribute to achieving the Sustainable Development Goals (SDGs), which are essential to addressing inequities underpinning AMR and climate change, and to stabilize climate-induced mass migration and conflicts.

Key elements for 2050 success:

- Society economically values health which drives policies.
- Countries collaborate and share resources, building each others' capacity to address AMR and climate change.
- The public lives healthier lifestyles and demands foods produced sustainably, with high animal welfare standards, and in alignment with AMR mitigation efforts.
- Food production and environmental innovations and technologies are adopted, reducing AMU, AMR and climate change impacts.

### SILOED NATIONS

In this future scenario, participants described a movement towards nationalism and protectionism that would lead some governments to move strategic industries (e.g., pharmaceuticals, food and energy) home to ensure security of domestic supply. This movement from global to local value chains builds walls that compromise international trade, cooperation and sharing of resources with countries that need help to achieve the SDGs and address AMR under a changing climate, thus derailing the future described in "Addressing the Basics" and threatening health and well-being of all.

## RECOMMENDATIONS TO ADDRESS AMR UNDER A CHANGING CLIMATE

These recommendations were those identified by participants during the above research, and are relevant for decision makers in government or in human, animal, environment sectors at subnational, national and international levels. Recommendations focus on how to improve governance of AMR across human, agriculture (food production) and environment sectors to prevent and control its development and spread long-term, under evolving climate change conditions. Participants stressed the urgent need to act **NOW** otherwise the fight against AMR will be lost.

### 1. Target AMR directly

#### 1.1 *Expand the focus beyond antibiotics to all agents that contribute to resistance*

- a. Invest in research to better understand the independent and interacting impacts of all agents, such as antifungals, pesticides and chemicals like detergents, and create appropriate standards to better manage their use.

#### 1.2 *Invest in the implementation of AMR National Action Plans*

- a. Provide the resources and capacity necessary to develop and implement AMR National Action Plans. Provide support to countries that need help with their AMR National Action Plan roll out.
- b. Develop mass reach campaigns to garner public awareness and support National Action Plans. Consider marketing AMR as a One Health or One Welfare problem.

#### 1.3 *Invest in research and surveillance of AMU and AMR*

- a. Invest in research and surveillance to identify precise measures of AMU and antimicrobial disposal in human, animals and the environment, and AMR transmission in the environment.
- b. Set up surveillance on imported foods to be able to enforce AMR limits with consideration of how to minimize potentially undesirable impacts on exports from third world countries.

## **1.4 *Invest in continued research and innovation to improve diagnosis and treatment, develop new antibiotics and alternatives to antimicrobials***

- a. Develop rapid diagnostics that distinguish between microorganisms, and better understanding of antimicrobials appropriate for the infection, species type (e.g., livestock), and stage of life (e.g., adult) to best inform treatment recommendations.
- b. Invest in developing alternatives to antimicrobials (e.g., probiotics) and better understanding of the microbiome and gut microflora of humans and animals.
- c. Incentivize the innovation system to develop new antibiotics through public-private partnerships and developing sustainable business models that delink volume of sales from manufacturer reimbursement.

## **2. Target AMR indirectly**

### **2.1 *Address AMR and climate change as interlinked issues***

- a. Invest in research to examine the interconnections between AMR and climate change.
- b. Release funds from relevant portfolios, such as health and environment, to advance AMR and environment issues where there is co-benefit.
- c. Assess the impact of production processes that contribute to AMR (e.g., food production) and their environmental costs to determine policy options that reduce risk.
- d. Institute public procurement agreements that put pressure on suppliers to change production practices and systems to support antimicrobial stewardship and good farm practices.
- e. Engage in transparent discussions about the pros, cons, and ethical implications of using promising technologies (e.g., genetically-modified foods, CRISPR) to produce food products that can: prevent infections in food animals and plants; grow in conditions of drought; or require reduced or no antimicrobial use.
- f. Incentivize companies to develop environmental technologies to ensure access to adequate and clean water for all, including in water scarce conditions.
- g. Provide proper sanitation and infrastructure to ensure access to adequate and clean water.

## **2.2 *Achieve the SDGs as a key leverage point to address problems that underlie AMR and climate change***

- a. Prioritize and continue to measure progress towards the achievement of the SDGs as these actions will help to address AMR under a changing climate. Achieving the SDGs has been identified as a major priority and leverage point for intervention for addressing both AMR and climate change<sup>20-22</sup>
- b. Invest national budgets into the provision of universal health care that support health equity while helping to promote antimicrobial stewardship.
- c. Provide an adequate level of social welfare for all to support health equity and help people to rise out of poverty and associated conditions that contribute to AMR (e.g., poor nutritional intake and living conditions).
- d. Develop policies and invest in improving the conditions under which people live - access to clean water, affordable and nutritious food and animal feed, proper housing, toilets and sanitation (e.g., water treatment facilities), and education – key problems that underlie many public health problems, including AMR.

## **2.3 *Invest in health promotion and disease prevention to contribute to SDGs achievement***

- a. Invest national budgets into health promotion, mental health, and chronic and infectious disease prevention in humans and animals to help reduce the need for antimicrobials.
- b. Invest in ensuring health and social care services have adequate numbers of trained infection prevention and control staff that support antimicrobial stewardship.
- c. Provide paid sick days to all, including transient and seasonal workers, to enable people the ability to afford time off to prevent the spread of infectious illnesses that may necessitate antibiotic treatment.
- d. Provide financial support (e.g., insurance) to farmers to compensate for losses due to infectious disease outbreaks.
- e. Provide farmers with economic incentives (e.g., rebates) to implement good farm practices, animal welfare standards and promote appropriate AMU.
- f. Develop blockchain technology in the food supply chain to detect infectious outbreaks at their source and improve food safety.
- g. Institute codes of practice for international travel to reduce the spread of infectious illnesses, including spread of highly resistant infections.

## **2.4 *Change norms that influence AMR under a changing climate***

- a. Invest in education and training among prescribers, dispensers and users of antimicrobials about which antimicrobials to use and when, risks of antibiotic use at individual versus population levels, AMR spread, and the health and economic value of implementing non-antimicrobial infection prevention and control measures and farm animal welfare practices to reduce AMR development and spread under a changing climate.
- b. Tailor education and training materials to audiences in specific workplaces or settings (e.g., abattoirs, health and social care facilities, restaurants, and communities). Focus on people at front-line (e.g., farmers, farm employees including seasonal workers, staff providing health or social care in the community).
- c. Invest in student education on AMR, climate change, how to grow food using sustainable methods, health promotion and chronic disease prevention, and infection prevention and control, from early school and onwards throughout their educational trajectory to make them aware of the value of antimicrobials and climate change mitigation for humanity.
- d. Examine pros and cons of instituting labelling of antimicrobial and carbon footprint and animal welfare standards on products and services (e.g., foods, hospital facilities) to inform consumer choices.
- e. Develop social marketing campaigns with hard hitting messages about living with the negative impacts of AMR and how to use antimicrobials appropriately to motivate behaviour change.

## **3. Develop coordinated multi-pronged actions using a whole-of-government and all-of-society approach and engage in adaptive learning**

### **3.1 *Develop policies that interlink AMR and climate change***

- a. Because AMR is a major health threat and develops and spreads from the actions of different sectors, government departments (health, agriculture, environment, transportation, finance and more) must work together to develop coordinated policies and actions that address the shared goal of mitigating AMR under a changing climate within and across countries, globally.
- b. Engage stakeholders from human, animal, agriculture, aquaculture, and environment sectors in policy development and implementation to ensure proposed actions fit real-

- world realities, address potential unintended consequences, and improve policy adoption and impact.
- c. Develop policies that assess health equity impacts to ensure they address and do not exacerbate disproportionate burdens on vulnerable or priority populations.

### **3.2 *Strengthen relationships***

- a. Develop and strengthen collaboration and cooperation between countries, within and between governments and other sectors to find solutions to the global AMR problem.
- b. Assess how actions to address AMR under a changing climate may inadvertently shift the burden to other countries. For instance, setting AMR targets on imported foods may be costly for other countries to comply. Work with countries that need help to build capacity to achieve the SDGs and address AMR under a changing climate by sharing knowledge, human capital, and resources.
- c. Institute mechanisms for governments and private and public organizations from high income and low and middle income countries to learn from one another by sharing evidence from research and practice about initiatives that directly and indirectly address AMR and AMR impacts, climate change, SDGs and disease prevention, including success stories and lessons to facilitate learning and the potential for other jurisdictions to adopt similar approaches.

### **3.3 *Plan with futures in mind***

- a. Engage stakeholders from different government departments and other sectors in ongoing long-term planning exercises to envision potential futures, the values and goals that underpin them and their benefits and consequences to better plan strategies that strive towards a future that addresses AMR effectively, sustainably, and ethically.

### **3.4 *Monitor and evaluate actions and engage in adaptive learning***

- a. Conduct and draw on research, surveillance, monitoring and evaluations to determine the effectiveness of actions that directly and indirectly influence AMR, such as the implementation and outcomes of AMR National Action Plans and actions that address climate change, the SDGs and health promotion and disease prevention, to identify what interventions work best (independently or in combination) and adapt actions in response to changing circumstances and lessons learned.

- b. Draw on lessons learned from the COVID-19 pandemic such as the importance of infection prevention measures, how to avoid poor international collaboration and its negative consequences, and how to communicate consistent evidence-based public health messaging.
- c. Advocate to get and keep AMR high on government policy agendas regardless of new crises. Using success stories and lessons learned to highlight to decision-makers how AMR under a changing climate could be the next and even bigger pandemic.

## WHAT IS NEW IN THIS RESEARCH

Recognizing AMR as an all-of-society issue,<sup>23</sup> our study broadened current scientific understanding of factors that contribute to AMR, by bringing together people with expertise in AMR and expertise in other content areas that may not usually be engaged in discussions about AMR but may influence or be impacted by the AMR problem across human, animal and agriculture sectors. By doing so, we were able to illustrate how numerous factors interact, and how some factors, that can impact the entire system (e.g., regulations, the impact of the media on spreading accurate and misinformation, evolving climatic changes, the importance of international collaboration) are important to effectively mitigate AMR.

To our knowledge, this is also the first study to explicitly explore how to successfully address AMR under a changing climate over the next 30 years with findings stressing the need for immediate action to address AMR and climate change as interlinked issues and achieve the SDGs. This finding reinforces recommendations for different government departments and sectors to work together and develop policies and actions that address the shared goal of tackling AMR and climate change. Our study offers a model of AMR and scenarios of plausible futures, as tools to help governments, industries, the health sector, advocates and the public visualize the complexity of AMR, their roles, and to explore how interventions might impact AMR and other aspects of our lives, under a changing climate.

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