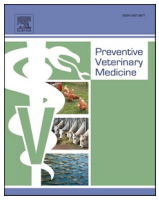
Preventive Veterinary Medicine 220 (2023) 106025

Contents lists available at ScienceDirect

Preventive Veterinary Medicine

journal homepage: www.elsevier.com/locate/prevetmed



# Interventions to change antimicrobial use in livestock: A scoping review and an impact pathway analysis of what works, how, for whom and why

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ARTICLE INFO

*Keywords:*
Antibiotic use
Antibiotic resistance
Animal health
Behavioral change
Transition pathway
Impact assessment

ABSTRACT

Antimicrobial resistance (AMR) is a public health threat responsible for 700,000 deaths per year worldwide. Antimicrobial use (AMU) in livestock contributes to AMR in animal and public health. Therefore, it is essential to implement effective interventions towards better AMU in livestock. However, there is a lack of evidence to inform decision-makers of what works, how, for whom and why and how effective interventions can be adapted to different contexts. We conducted a scoping review and an impact pathway analysis to systematically map the research done in this area and to inform evidence-based and context-appropriate policies. We followed the PRISMA-ScR requirements and searched Web of Science, PubMed and Scopus databases to identify studies in English or French languages, in open access and published between 2000 and 2022. We selected thirty references addressing twenty-eight different interventions that were successful in changing AMU in livestock. We used an impact pathway logic model as an analytic framework to guide the technical aspects of the scoping review process and to identify the complex relationships between outputs, outcomes, impacts and contextual factors. A majority of interventions managed to improve AMU by changing herd and health management practices ($n_i$=18). We identified intermediate outcomes including change in the veterinarian-farmer relationship ($n_i$=7), in knowledge and perception ($n_i$=6), and in motivation and confidence ($n_i$=1). Twenty-two studies recorded positive impacts on animal health and welfare ($n_i$=11), technical performances ($n_i$=9), economic performances ($n_i$=4) and AMR reduction ($n_i$=4). Interventions implemented different strategies including herd and health management support ($n_i$=20), norms and standards ($n_i$=11), informational and educational measures ($n_i$=10), economic support ($n_i$=5). Studies were mainly in European countries and in pig and large ruminants farming. Most interventions targeted farmers or veterinarians but we identified other major and influential actors including authority and governmental organizations, academics and research, organization of producers or veterinarians, herd advisors and technicians, laboratories, and public opinion. Key success factors were knowledge and perception ($n_i$=14), social factors ($n_i$=13), intervention characteristics ($n_i$=11), trajectory and ecosystem of change ($n_i$=11), economic factors ($n_i$=9), herd and health status ($n_i$=8), data access and monitoring ($n_i$=4). This review describes a paucity of impact assessment of interventions towards better AMU in livestock. There is no one-size-fits-all transition pathway but we inform decision-makers about the most successful interventions that work, how, for whom and why. The impact pathway analysis provided a holistic view of the successful change processes and the complex relationships between outputs, outcomes, impacts and contexts.

## 1. Introduction

Antimicrobial resistance (AMR) is a major global threat causing disastrous long-term impacts on public health, economy and global development. AMR is responsible for at least 700,000 deaths per year worldwide and this number could rise to 10 million by 2050 (O'Neill, 2016). Even if the quantification of the burden of AMR in public health attributable to antimicrobial use (AMU) in livestock remains challenging, there is growing scientific evidence of this causal relationship and the human population's exposure to antimicrobial-resistant pathogens via the food chain or the environment (Hoelzer et al., 2017; Landers et al., 2012; Silbergeld et al., 2008). It has been estimated that the global

*Abbreviations:* AM, antimicrobial; AMR, antimicrobial resistance; AMU, antimicrobial use; ToC, theory of change.

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https://doi.org/10.1016/j.prevetmed.2023.106025
Received 1 November 2022; Received in revised form 25 July 2023; Accepted 11 September 2023
Available online 21 September 2023

consumption of antimicrobials (AMs) in food animal production will rise by 67% between 2010 and 2030; due to the growing number of animals raised for food production and a shift towards intensive farming systems to meet the increasing demand (Boeckel et al., 2015).

Considering the potential risk for food animal production to contribute to AMR in animal and public health, it is essential to provide evidence and understanding to inform decision-makers about the mechanisms underlying interventions' effectiveness and how they can be adapted and transferred to another context. Indeed, public health and agricultural interventions are complex and context-dependent (Joly et al., 2016; Minary et al., 2018). Therefore, there is a need for a systemic and holistic approach to identifying the transferable intervention's elements which participate in its effects, including potential adverse impacts on farm economics or animal health, and the contextual elements which influence results and must be taken into account when transferring the intervention (Aarestrup, 2015; Lewin et al., 2017; Minary et al., 2018).

The theory of change (ToC) is a theory-based approach broadly used in public health literature to assess interventions. ToC allows for the capture of intervention complexity by describing how an intervention generates long-term impacts in a specific context through a logical sequence of intermediate outcomes (Blundo Canto et al., 2020; Breuer et al., 2016). An impact pathway is a logic model of a ToC that represents the causal relationships between resources mobilized by the intervention (inputs), the intervention's products (outputs), the changes in practices, behavior and interactions of the actors associated with the use, adaptation or transformation of these outputs (outcomes) and the impacts to which these outcomes contribute in the long term. Logic models are valuable in the conceptualization and development of systematic reviews of interventions. As an analytic framework, logic models ease the translation of evidence into policy (Anderson et al., 2011; Springer-Heinze et al., 2003).

Previous systematic reviews have found evidence to support a range of effective interventions to change AMU in animal health. For example, one explored the associations between different interventions that restrict AMU in animal productions and their impacts on AMR (Tang et al., 2019). Another one provided intervention narratives and summarized the significant facilitators and barriers to farmers' and veterinarians' antimicrobial stewardship (Gozdzielewska et al., 2020). Some reviews and studies used the theory of planned behavior approach and focused on psychological and behavioral factors that influence AMU practices (Chambers et al., 2020; McKernan et al., 2021; Speksnijder and Wagenaar, 2018). However, the complexity of interventions and their underlying ToC remain difficult to holistically unravel.

To our knowledge, there are few impact assessments of the interventions that succeed in changing AMU practices in livestock and it is unclear what kind of information is available in the literature about what works, how, for whom and why. For these reasons, a scoping review and an impact pathway analysis were conducted to systematically map the research done in this area, as well as to identify any existing gaps in knowledge. We aimed to inform evidence-based and context-appropriate policies.

## 2. Methods

We conducted a scoping review to provide an overview of the emerging evidence base on the interventions that managed to change AMU in livestock. The review was carried out according to PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping review) requirements (Tricco et al., 2018). The methodology followed the steps described by Arksey et O'Malley: 1) identifying the research question; 2) identifying relevant studies; 3) selecting eligible studies; 4) charting the data; 5) collating, summarizing, and reporting the results (Arksey and O'Malley, 2005; Levac et al., 2010).

### 2.1. Identification of the research question

The purpose of our scoping review is to investigate the existing successful interventions in livestock that aimed at changing AMU to understand what works, how, for whom, and why. We considered a successful intervention as an intervention that managed to change practices towards a reduced or prudent AMU. We used the PICo (Population/Problem, Interest, Context) framework to define the qualitative research question and the related search terms to include in the search strategy (Lockwood et al., 2015; Munn et al., 2018). The problem of interest is AMU to treat bacterial infections and contributing to antibiotic resistance. The interest relates to any intervention aiming to change AMU. We defined intervention as a set of activities intended to influence AMU; for example, stewardship programs, national strategic plans, education or communication strategies, legislation, etc. The context of intervention is the livestock setting including pig, poultry, and large and small ruminants farming. To identify all relevant studies, we formulated a broad research question: "What are the interventions that aim to change AMU in livestock?" and we used the Medical Subject Headings (MeSH) thesaurus[1] and different online dictionaries (Reverso medical dictionary[2], Termscience dictionary[3]) to select search terms. Table 1 shows the search terms related to each PICo component.

### 2.2. Identification of relevant studies

We searched Web of Science, PubMed and Scopus databases estimating they cover the entire literature on the AMU issue. We limited the search to all types of studies in English and French languages, in open access and published between January 1st, 2000 and July 26th, 2022. Most studies were published post-2000, so we anticipated the effect of the time limitation to be minimal. Within the same PICo component, the search terms were linked by the Boolean connector "OR" and the three resulting search strings were linked by the Boolean connector "AND". The final search strategy for Scopus can be found in the Supplementary material (S1 List). Additional studies identified through an exploratory literature review on the same topic were included in the selection process[4].

**Table 1**
Definition of PICo components and related search terms included in the search strategy.

| PICo components | Definition | Search terms |
|---|---|---|
| Problem | Antimicrobial use | antibiotic use, antimicrobial use, antibiotic usage, antimicrobial usage |
| Interest | Any intervention that aims to change antimicrobial use | intervention, program, project, planning, plan, initiative, action, strategy, policy, guideline, regulation, legislation, control, monitoring, stewardship |
| Context | Livestock | veterinary, veterinarian, farm, farming, farmer, livestock, husbandry, breeding, herd, animal, cattle, cow, calves, veal, beef, dairy, sheep, goat, poultry, chicken, broiler, hen, duck, pig, swine, pork, hog, sow, piglet |

[1] https://www.nlm.nih.gov/mesh/meshhome.html
[2] https://dictionary.reverso.net/medical-french-english/index.html
[3] http://www.termsciences.fr/
[4] https://www.roadmap-h2020.eu/uploads/1/2/6/1/126119012/roadmap_d6.1_-_literature_review_of_impact_assessment_applied_to_changes_amu_initiatives_revised_04.05.2021.pdf

### 2.3. Study selection

The studies were selected through two screening phases: 1) a first screening applied to the titles and abstracts; 2) a second screening applied to the full texts. Nine exclusion criteria were used to select references at each phase (EC 1 to EC 9 in Table 2). An additional exclusion criterion (EC 10 in Table 2) related to the lack of rigor or relevance according to the objective of the review was applied during the second screening phase. The aim was to determine whether the study provided relevant evidence and whether the conclusions drawn by the researchers made a sufficiently credible contribution to the understanding of interventions' ToC. Exclusion criteria were tested on forty references and validated by all authors. The study selection process was performed on the free, open-source reference management Zotero software and a Microsoft Excel database. A flow chart diagram of this selection process was designed based on the PRISMA approach.

### 2.4. Data charting process

Data extraction of the eligible references was performed by one author on the Nvivo qualitative data analysis software. Variables were previously validated by all authors. Each reference was identified as a case study and categorized according to a file classification including data on reference characteristics (e.g., author name, year of publication, title, scientific journal, type of reference, electronic database, language, type of study, sub-type of study, type of analysis, study period), and a case classification including data on intervention characteristics (e.g., name of the intervention, year of implementation, country, world region, type of production system, animal species, type of governance approach, specificity of the intervention). To answer our research questions (What works? How? For whom? And why?) and to understand the underpinning ToC of successful interventions in livestock, we performed a thematic content analysis of the references to identify codes and sub-codes (Vaismoradi et al., 2013). We used an impact pathway logic model as an analytical framework to deductively started with a set of predetermined codes (strategies and outputs, outcomes, impacts, actors involved in interventions or influencing their success, levers and key success factors, barriers and failure factors, monitoring of change and indicators) (Anderson et al., 2011) (Table 3). Then we inductively identified sub-codes throughout the qualitative analysis process. The detailed list of variables and related definitions and assumptions are presented in the Supplementary material (S2 List).

### 2.5. Synthesis of results

We present the range of evidence based on an impact pathway analytical framework that aims to describe the cascade of causes and effects leading from an intervention to its desired impacts (Anderson et al., 2011; Temple et al., 2016). First, we provide the list of references and the number of interventions ($n_i$) for each variable used to answer our research questions and we describe what works, how, for whom and why through an analytical summary of the extracted qualitative data. For robustness of evidence, we only included outcomes and impacts monitored by indicators or controlled. Then, we quantified and presented the relationships between outputs, outcomes, and impacts in the form of a generic impact pathway that provides a graphical representation of the interventions' ToC.

**Table 2**
Exclusion criteria used during screening phases to select eligible studies. AMU, antimicrobial use; AMR, antimicrobial resistance; ToC, theory of change.

| Exclusion criteria (EC) | |
|---|---|
| EC 1 | Studies not dealing with intervention aiming to change AMU practices |
| EC 2 | Studies not providing information on the intervention context or on the generated AMU outcomes |
| EC 3 | Studies dealing with the causal relationship between AMU and AMR |
| EC 4 | Studies dealing with transmission of AMR |
| EC 5 | Studies dealing with other antimicrobials than antibiotics such as antivirals, antifungals and antiparasitics |
| EC 6 | Studies testing different alternative treatments or antibiotic administration in laboratory and evaluating and comparing clinical outcomes |
| EC 7 | Studies dealing only with human health |
| EC 8 | Studies not dealing with pig or poultry or ruminant farming (for example, studies dealing only with aquaculture were excluded) |
| EC 9 | Studies only dealing with factors influencing AMU but not dealing with intervention |
| EC 10 | Studies not sufficiently rigorous and relevant to understand the underpinning ToC of the intervention and to answer to our research questions (what works, how for whom and why?) |

**Table 3**
List of research questions and their associated variables that provide pieces of evidence used for the data charting process.

| Research questions | Variables |
|---|---|
| What works? | Outcomes |
| | Impacts |
| How? | Strategies and outputs |
| | Type of governance approach |
| | Specificity of the intervention |
| For whom? | Actors |
| | Country |
| | World region |
| | Type of production system |
| | Animal species |
| Why? | Levers/key success factors |
| | Barriers/failure factors |

## 3. Results

### 3.1. Selection of sources of evidence

After duplicates were removed and additional references included, a total of 1786 references were identified from searches of electronic databases. Based on titles and abstracts, 1472 were excluded, with 314 full-text references to be retrieved and assessed for eligibility. Of these, 284 were excluded for the exclusion criteria. The study selection process is presented in the Supplementary material (S3 Table). The remaining 30 references were considered eligible for this review (Fig. 1).

### 3.2. Characteristics of sources of evidence

Most of the included references (n=24) were published after 2015. Twenty-seven of them are research articles, two are congress communications and one is a book. Seventeen references are classified as interventional studies and thirteen references are classified as observational studies (Ranganathan and Aggarwal, 2018; Thiese, 2014). All the file classification is presented in the Supplementary material (S4 Table). Two references written by Morgans et al. (2018, 2021) deal with the same farmer action groups intervention and Jensen et al. (2014) and Lopes Antunes and Jensen (2020) studied the same Yellow Card intervention. Therefore, twenty-eight interventions were studied in the thirty selected references and included in analysis. All the case classification is presented in the Supplementary material (S5 Table).

### 3.3. Synthesis of results

#### 3.3.1. What works?

All the interventions were successful in reaching an overall AMU reduction ($n_i$=28). Nineteen interventions recorded other positive outcomes resulting from the appropriation of their outputs by actors: changes in herd and health management practices ($n_i$=18), in the veterinarian-farmer relationship ($n_i$=7), in knowledge and perception regarding AMU, AMR, herd and health management ($n_i$=6) or in motivation and confidence to change ($n_i$=1). Nineteen interventions recorded positive impacts on animal health and welfare ($n_i$=11), technical

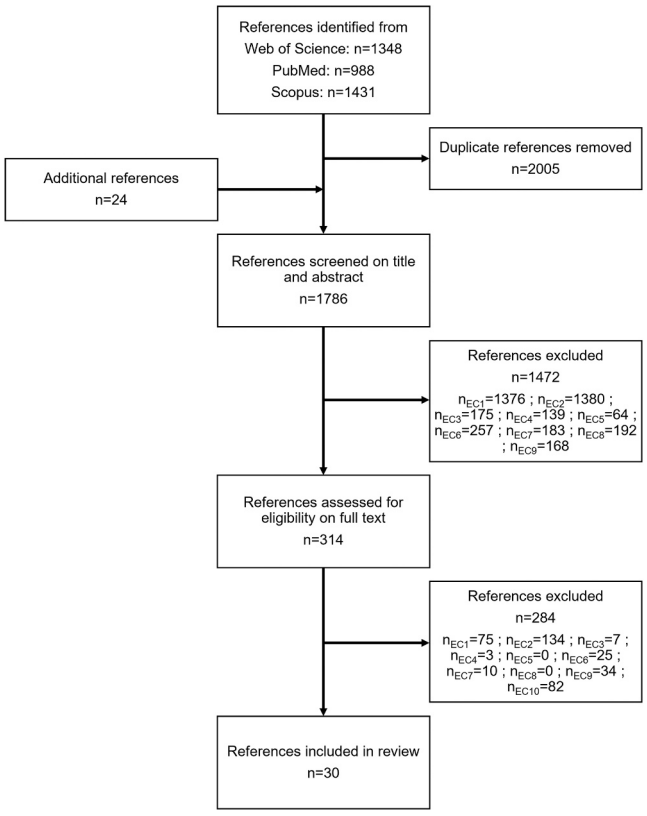


**Fig. 1.** PRISMA flow chart diagram of the study selection process for inclusion in the scoping review. EC, exclusion criterion; n, number of references.

performances ($n_i$=9), economic performances ($n_i$=4) or AMR reduction ($n_i$=4). Some of these interventions were partially successful and simultaneously recorded null (or not significant) ($n_i$=12) or negative ($n_i$=8) outcomes and null (or not significant) ($n_i$=17) or negative ($n_i$=7) impacts (Fig. 2). Null ($n_i$=9) or negative ($n_i$=8) AMU outcomes are temporary in response to an event such as the presence of a disease (Bernaerdt et al., 2022; Gerber et al., 2021; Jensen et al., 2014), or relate to only one category of animals at risk (Bernaerdt et al., 2022; Echtermann et al., 2020), or relate to some categories of AMs to replace the use of critically important AMs (Hubbuch et al., 2021). Null ($n_i$=3) or negative ($n_i$=1) outcomes regarding herd and health management are the non-use of outputs such as tests and treatment protocols (Bourely et al., 2018; Raymond et al., 2006). Null ($n_i$=14) or negative ($n_i$=5) impacts on animal health and welfare, null ($n_i$=7) or negative ($n_i$=2) impacts on technical performance, and null ($n_i$=2) or negative ($n_i$=1) economic impacts are also temporary or concern only one part of the population targeted by the intervention (actors or animals) or one part of all the measured indicators to assess one variable. The level of success of interventions in achieving desirable changes is influenced by different factors described in section 3.3.4. The different indicators and data collected to assess these outcomes and impacts are reported in the Supplementary material (S6 Table).

### 3.3.2. How?

Most of the selected interventions implemented herd-specific strategies ($n_i$=17) and adopted a bottom-up governance approach ($n_i$=18) promoting local initiatives and actors' self-determination through capacity and skills building (S5 Table in Supplementary material). Strategies were classified into four categories: herd and health management support ($n_i$=20), norms and standards ($n_i$=11), knowledge ($n_i$=10) and economic support ($n_i$=5). The strategies that aimed to improve herd and health management through biosecurity and preventive measures are the most commonly implemented and include different outputs such as herd and health protocols ($n_i$=15), farm visits with other farmers or veterinarians, or technical advisors or researchers ($n_i$=12) (Ivemeyer et al., 2012), farmer groups ($n_i$=3), coaching and guidance by veterinarians, technical advisors or researchers ($n_i$=7), diagnosis tools and analyzes ($n_i$=4). Most of the interventions that aimed to implement norms and standards strategies produced mandatory measures ($n_i$=10) through legislation on AMs prescription ($n_i$=7), compulsory guidelines ($n_i$=2) (Ungemach et al., 2006; Wierup et al., 2021), AMU thresholds ($n_i$=3), AMU monitoring and benchmarking ($n_i$=4), control and sanctions ($n_i$=4), mandatory herd and health plan ($n_i$=3), mandatory one-to-one veterinarian and farmer relationship ($n_i$=2), compulsory training ($n_i$=1). Not mandatory measures ($n_i$=4) include guidelines ($n_i$=3), and professional consensus on AMU rules ($n_i$=1). The strategies that aimed to improve knowledge are based on educational ($n_i$=9) or informational ($n_i$=5) outputs. Educational outputs include training courses ($n_i$=7) or group works ($n_i$=3). Informational outputs include publications and press releases ($n_i$=1), guidelines and manuals ($n_i$=3), lectures and meetings ($n_i$=1), group works and experience sharing ($n_i$=1), communication tools ($n_i$=11). Only five interventions implemented economic strategies based on free testing tools ($n_i$=3), financial incentives ($n_i$=3), or economic cost compensation ($n_i$=1) (Fig. 3). Half of the studies included interventions that implemented several types of strategies. We noticed that the same output could be useful to implement different strategies; such as guidelines to improve knowledge or to stimulate the change of norms and standards. The different strategies and outputs implemented are reported for each reference in Supplementary material (S6 Table).

### 3.3.3. For whom?

Most of the studies included interventions implemented in Europe ($n_i$=25): Belgium ($n_i$=6), Switzerland ($n_i$=5), France ($n_i$=5), Netherlands ($n_i$=5), Denmark ($n_i$=4), Germany ($n_i$=4), Sweden ($n_i$=4),

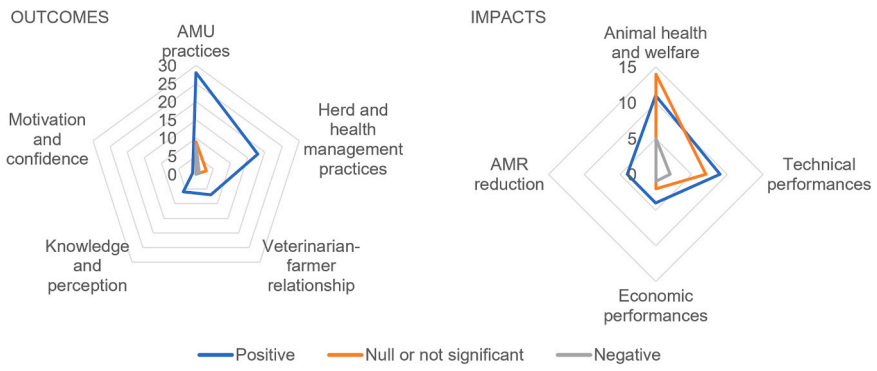


**Fig. 2.** The number of interventions generating positive, null or not significant, negative outcomes and impacts per category. AMU, antimicrobial use; AMR, antimicrobial resistance.

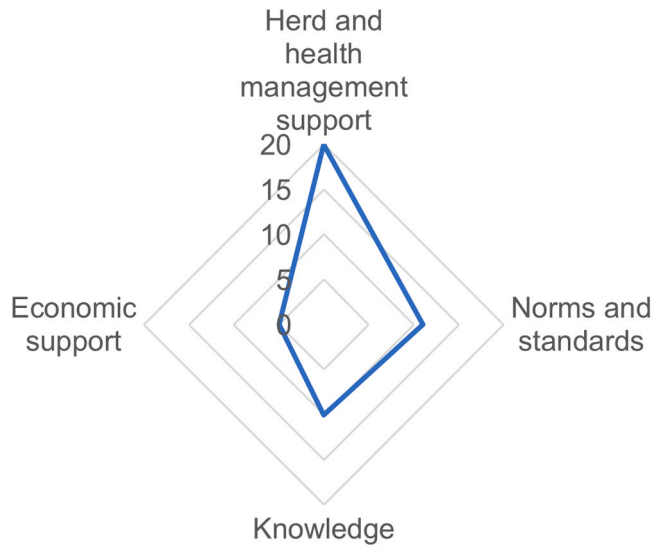


**Fig. 3.** The number of interventions per category of implemented strategies.

United Kingdom ($n_i$=2), Norway ($n_i$=2), Finland ($n_i$=1), Austria ($n_i$=1). Five studies included interventions implemented in several European countries. Two interventions were implemented in the United States and one in Vietnam. The included studies dealt with interventions implemented on dairy cattle ($n_i$=11), calves ($n_i$=2), pig ($n_i$=9) and broiler poultry ($n_i$=3) sectors or with interventions that were not specific to a sector ($n_i$=3). Data on production system settings were not available for most of the studies. More information is presented in the Supplementary material (S5 Table).

A wide variety of actors were involved in the identified interventions. Farmers ($n_i$=26) and veterinarians ($n_i$=27) were the main actors targeted by the interventions to change their practices. They were therefore major actors in the intervention and particularly involved through bottom-up and herd-specific approaches in the design of herd protocols. They were influential because success depends on their appropriation of outputs and their compliance with strategies. They were also the main actors impacted by strategies. Veterinarians were involved in generating outputs (herd protocols, technical advice) (Collineau et al., 2017b; Raasch et al., 2020; Rojo-Gimeno et al., 2016), monitoring and collecting data, recruiting farmers and sometimes facilitating (Morgans et al., 2021). They could also influence farmers through their practices (Abdelfattah et al., 2021; Bourely et al., 2018; Roskam et al., 2019). Herd advisors and technicians ($n_i$=8) were also targeted by intervention or were initiators in collaboration with other actors (Lam et al., 2017). They could also generate outputs (technical advice) (Poizat et al., 2018; Postma et al., 2017; Rajala-Schultz et al., 2021) and influence the success of the intervention through their practices or indirectly by advising farmers (Bourely et al., 2018; Lam et al., 2017).

Governmental authorities and organizations ($n_i$=12) and academics ($n_i$=17) were major actors and particularly in the initiation of interventions. Governmental authorities and organizations ensured the ethical nature of the interventions (Becker et al., 2020), provided inputs in terms of funding and also generated outputs that enabled the implementation of legislative strategies (guidelines, law, AMU threshold, etc.). In interventional studies, researchers recruited participants (i.e., the actors targeted by the intervention), ensured the ethical nature of the intervention (Caekebeke et al., 2021; Morgans et al., 2021), collected and analyzed the data necessary for the intervention or for its evaluation, generated outputs requiring scientific knowledge (health protocols, guidelines) and sometimes ensured facilitation when the intervention required the setting up of meetings between actors (Bennedsgaard et al., 2010; Morgans et al., 2018, 2021). A university animal hospital participated in an intervention as an actor that could change its prescription practices (Hubbuch et al., 2021).

Organizations of producers (including the different actors in production, processing and marketing) ($n_i$=15) and organizations of veterinarians ($n_i$=9) were major actors and supported the research in the recruitment of participants in intervention studies. They could also initiate and fund interventions in collaboration with governmental authorities or academics. They collected useful data on livestock, veterinary infrastructure and practices and generated useful outputs for the implementation of strategies (diagnosis, courses, technical advice, guidelines). They could also be involved in facilitation (Morgans et al., 2021).

Laboratories (led by veterinarians or cooperatives or independent) ($n_i$=4) had a major role in collecting the data needed for the intervention and could influence its success through their ability to support veterinarians in changing their practices (Bourely et al., 2018; Rajala-Schultz et al., 2021; Verliat et al., 2021; Wierup et al., 2021). Public opinion ($n_i$=4), including consumers and media, could influence interventions by exerting social pressure on major actors. The media could also play a major role by producing outputs (press releases) necessary for the intervention. Several studies reported the involvement of other actors ($n_i$=4) such as external facilitators (Morgans et al., 2018, 2021; Poizat et al., 2018; Speksnijder et al., 2017) and IT technicians (Poizat et al., 2018). One study also mentioned the role of pharmacists who were AM prescribers and targeted by the intervention (Rajala-Schultz et al., 2021). The number of interventions per category of actors playing a role in success of intervention is presented in Fig. 4 and the list of associated references is reported in Supplementary material (S6 Table).

### 3.3.4. Why?

Several contextual factors could act as barriers or levers for change in the compliance of actors with the intervention. Some studies ($n_i$=25) assessed or discussed the plausible key factors of success or failure of the interventions. Social factors such as actors' involvement, influence and interactions were key to success ($n_i$=13). In particular, trustful veterinarian-farmer relationships allowed adapted and necessary guidance of the farmers along the intervention process. On the contrary, some veterinarians remained unconvinced of the intervention use, negatively influenced farmers' change of practices or did not provide the needed advisory service. Trust and solidarity among farmers were also key success factors of peer-learning and confidence in AMU change. Peer pressure and the possibility to compare farm results encouraged farmers to improve practices by generating pride in being an example for others (Echtermann et al., 2020; Lam et al., 2017; Morgans et al., 2018, 2021). There was also peer pressure among veterinarians who copied colleagues' good or bad AMU practices, making the change difficult for the new generation of professionals who were more aware of the AMR issue (Bourely et al., 2018). Collaboration between different actors

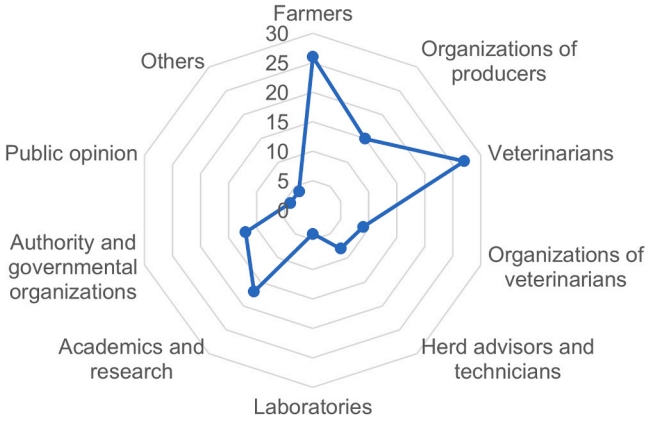


**Fig. 4.** The number of interventions per category of actors.

contributed to improved practices. On the contrary, the lack of veterinarian-laboratory interactions (Bourely et al., 2018) and the influence of drugstores that deliver AMs without prescription and advice negatively impacted the success of interventions (Phu et al., 2021). General opinion on the AMR issue and intensive livestock, increased by media, pressured AM users and governments to implement measures (Lam et al., 2017; Speksnijder et al., 2015; Wierup et al., 2021).

Another key factor was knowledge and awareness on AMU and AMR among AM users and consumers ($n_i$=14). Providing information and education increased concern for human and animal health and therefore the willingness to change practices. Knowledge of good herd and health management practices was also a lever of change (Jensen et al., 2014). On the contrary, a knowledge gap and the perception that change could negatively impact technical performance were barriers (Morgans et al., 2021; Postma et al., 2017). Advice of veterinarian and impact assessment research based on monitoring of data could allow to remove these barriers. Indeed, an efficient data collection system, including adapted indicators on AMU, AMR and herd and health parameters, and data access were identified as key factors to provide knowledge, and recommendations and build evidence-based interventions ($n_i$=4). Transparency of data encouraged actors to change through social pressure.

Herd and health management practices such as a low animal density, prevention measures at the farm level and long-term control and eradication of disease measures at the national level (Raasch et al., 2020; Wierup et al., 2021) could decrease infectious pressure and, therefore, the need for AMU ($n_i$=8). On the contrary, inadequate farm infrastructures, lack of trained staff, lack of written protocols, high animal density, disease prevalence, AMU habits such as metaphylactic treatment and self-medication (Bourely et al., 2018; Jensen et al., 2014; Raymond et al., 2006) negatively influenced the success of interventions. Herds with a higher AMU before intervention achieved a larger reduction than herds where AMU was already very low and where there was not much room for further reduction.

There were also economic factors related to direct (antibiograms, vaccination, etc.) and indirect (increased disease prevalence, etc.) cost of herd and health management strategies that hindered farmers' AMU change. The fact that veterinarians have an economic conflict of interest by being prescribers and deliverers of AMs and the cost of their advice could be a barrier (Raymond et al., 2006; Speksnijder et al., 2015). On the contrary, economic factors were levers in some interventions: niche market opportunity, positive economic impacts of change, sufficient financial resources and incentives to implement measures, low cost of measures, fear of financial sanctions ($n_i$=9).

Interventions occurred in a more global spatial and temporal environment of changes and initiatives towards better AMU or herd and health management practices that could positively ($n_i$=11) or negatively ($n_i$=1) influence their success. For example, international and national legislations, particular events and general opinion allowed actors to anticipate or continuously adapt their practices. On the contrary, the lack of harmonization in regulations between countries influenced negatively by leading to distorted competition (Bourely et al., 2018).

Finally, the way interventions were implemented could positively ($n_i$=11) or negatively ($n_i$=5) influence their success. Voluntarily and participatory approaches increased compliance by involving motivated actors. Facilitation was a key success factor (Morgans et al., 2018; Speksnijder et al., 2017) but the lack of time and the reluctance of recruiters of participants impacted participatory interventions. In some interventions, a persuasive approach was more sustainable than a restrictive approach (Phu et al., 2021) whereas, in others, restrictions and mandatory AMU targets were necessary (Speksnijder et al., 2015). Herd-specific interventions that provided clear information on strategies, guidance, follow-up and feedback increased actors' compliance and ownership. Feasibility of the intervention was important by implementing limited objectives and ensuring continuity of actions. On the contrary, a non-voluntary participation (Poizat et al., 2018), high number of strategies (Gerber et al., 2021; Speksnijder et al., 2017), short implementation time and constraints related to meetings (Morgans et al., 2018; Poizat et al., 2018) and use of tools were failure factors. The number of interventions per category of key success factors and failure factors is presented in Fig. 5 and the list of the associated references is reported in Supplementary material (S6 Table).

### 3.3.5. *Impact pathways of successful interventions*

The successful interventions did not follow a single but various and complex pathways to achieve changes in AMU practices. Several strategies targeted intermediate outcomes and different outputs could be produced to contribute to the same outcome. Fig. 6 is a logic model that represents these different impact pathways and the strength of evidence supporting them.

Most of the successful interventions implemented herd and health management support strategies ($n_i$=20) (see section 3.3.2). We assumed that all of these interventions indirectly fostered change in AMU practices by veterinarians or farmers through concurrent change in herd and health management practices that reduce the risk of potential negative impacts. Besides some of these interventions measured positive impacts on animal health and welfare ($n_i$=8), technical performances ($n_i$=9), economic performances ($n_i$=3) and AMR reduction ($n_i$=2). Some of these herd and health management strategies contributed to generating interrelated intermediate changes in knowledge and perception ($n_i$=2) (Bennedsgaard et al., 2010; Morgans et al., 2018, 2021) and motivation and confidence ($n_i$=1) (Morgans et al., 2018, 2021) through peer learning in farmer groups. These intermediate outcomes could directly encourage farmers to change their herd and health management and AMU practices. Herd and health management strategies could generate a change in the veterinarian-farmer relationship ($n_i$=2) directly through the implemented collaboration process (Speksnijder et al., 2017) or through the motivation to change (Morgans et al., 2018). This relationship contributed to changes in herd and health management and AMU practices.

One way to directly contribute to changes in AMU practices was by implementing norms and standards ($n_i$=11) through mandatory ($n_i$=10) and/or not mandatory ($n_i$=4) measures. Mandatory measures also contributed to a change in the veterinarian-farmer relationship ($n_i$=4) through regulation on AMU (Abdelfattah et al., 2021; Bourely et al., 2018) or through a mandatory one-to-one veterinarian and farmer relationship (Lam et al., 2017; Speksnijder et al., 2015). This relationship may have contributed to better herd and health management and AMU practices. These norms and standards interventions generated positive impacts on animal health and welfare ($n_i$=3), economics ($n_i$=1) and AMR reduction ($n_i$=4).

Another way to contribute to a change in AMU practices was by implementing strategies that aimed to change knowledge or perception

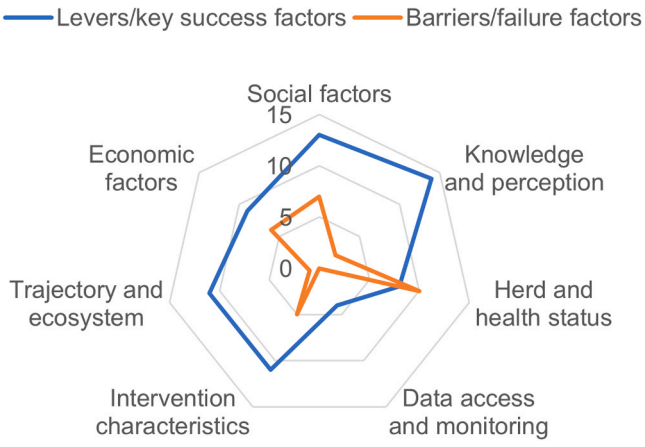


**Fig. 5.** The number of interventions reporting hypothetical or assessed levers/key success factors and barriers/failure factors per category.

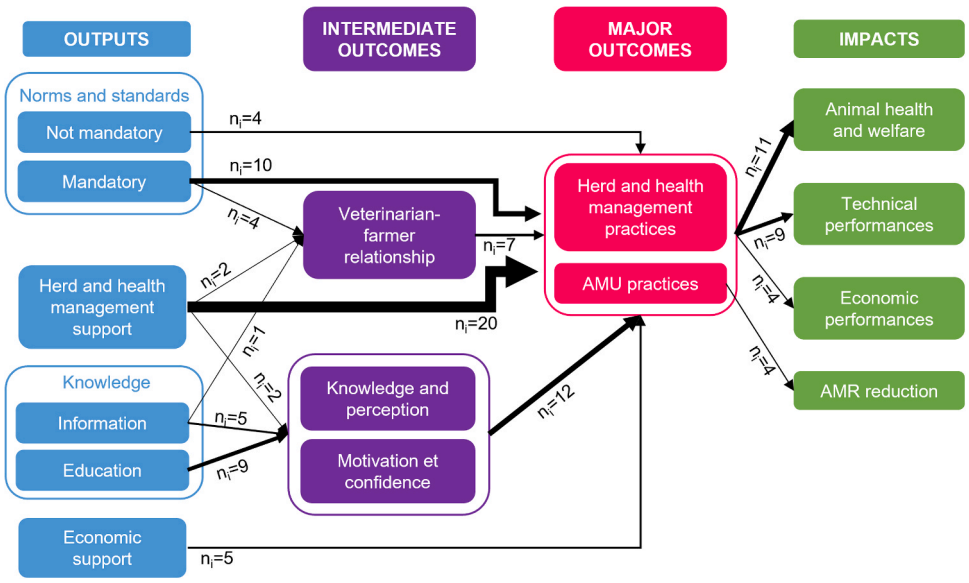


**Fig. 6.** Summary of plausible impact pathways of successful interventions in achieving AMU changes in livestock. AMU, antimicrobial use; AMR, antimicrobial resistance; $n_i$, number of intervention supporting this plausible causal relationship.

on the AMR and AMU issue ($n_i$=10) through educational outputs ($n_i$=9) or informational outputs ($n_i$=5). We assumed that all of them indirectly contributed to a change in herd and health management and AMU practices through an intermediate change in knowledge and perception. One also contributed to changing the veterinarian-farmer relationship through a manual designed to encourage producers to work with their veterinarian (Raymond et al., 2006). These interventions generated positive impacts on animal health and welfare ($n_i$=4), technical performances ($n_i$=3) (Roskam et al., 2019; Turner et al., 2018), economic performances ($n_i$=1) and AMR reduction ($n_i$=3).

The last contribution was through economic measures ($n_i$=5) that contributed to change herd and health managements and AMU practices through financial support or incentives. These interventions generated positive impacts on animal health ($n_i$=2), technical performances ($n_i$=1) and AMR reduction ($n_i$=1).

## 4. Discussion

### 4.1. Summary of evidence

In this scoping review, we identified thirty studies addressing ToC of successful interventions to change AMU practices in livestock between 2000 and 2022. We used an impact pathway logic model as an analytic framework to guide the technical aspects of the scoping review process and to identify the complex relationships between outputs, outcomes, impacts and contextual factors. This is consistent with recent calls for greater use of "realist" and systemic approaches in evaluating programs and policies (Anderson et al., 2011; Pawson et al., n.d.). Our findings indicate a paucity of research focusing specifically on impact assessment or providing sufficient evidence to understand what is effective, how, for whom and why. To our knowledge, this is the largest review to document the impact pathways of interventions aiming to change AMU practices in livestock.

We provided evidence that these interventions are part of a complex biophysical and social environment including social, cultural, institutional and economic contextual factors. We support a previous study conducted by Baudoin et al. who demonstrated the usefulness of systemic and interdisciplinary approaches in the implementation of interventions that aim to contain AMR in livestock while considering this complexity (Baudoin et al., 2021). Baudoin et al. suggest using three fundamental questions to design interventions to mitigate AMR in livestock: who should be targeted, what change the intervention wish to target, and how to target (Baudoin et al., 2021). We agree with their approach and bring additional reflective and response elements for decision-makers. The different pathways we identified to change AMU practices are similar to the existing Van Woerkum's classification of interventions (Baudoin et al., 2021; Leeuwis and Ban, 2004) and to the R.E.S.E.T. mindset model used by Lam et al. to explore the behavioral change theory of interventions to change Dutch dairy farmers' AMU practices (Lam et al., 2017; Wessels et al., 2014). We also inductively identified pathways that could be embedded in the different types of cues to change human behavior defined in the R.E.S.E.T. mindset model; being Rules and regulations, Education and information, Social pressure, Economics, and Tools. In addition, our review allowed us to quantify their importance in the literature and our impact pathway analysis allowed us to further detail them and to better understand their complexity by including intermediate outcomes, impacts and bridges between these different elements.

We found that most of the strategies implemented to change AMU practices are the ones which targeted changes in herd and health management practices. This is in line with "the fix that fails" system archetype adapted and discussed by Baudoin et al. to represent the interconnection between AMU, therapeutic alternatives to AMs, preventive measures/improved animal health, resistances, and animal morbidity in livestock production (Baudoin et al., 2021). Our review confirms that the improvement of herd and health management practices including disease prevention is a key outcome which should be simultaneously targeted with change in AMU practices to avoid negative impacts on AMR reduction, animal health and welfare, and technical and economic performances. Change in knowledge and perception regarding AMU, AMR and herd and health management is an important intermediate outcome reached in successful interventions and knowledge and perception were identified as an important key success factor. Therefore, we think that informational or educational measures could be relevant but probably not sufficient in certain contexts as changes in beliefs and knowledge do not systematically generate changes in behavior (Chambers et al., 2020; McKernan et al., 2021; Speksnijder and Wagenaar, 2018). In this condition, targeting AMU change in normative belief by implementing norms and standards through mandatory or non-mandatory measures could be a relevant pathway (Chambers et al., 2020; Speksnijder and Wagenaar, 2018) but if they are not context-adapted there is a risk to be not accepted, leading to illegal

practices or generating negative impacts. In addition, we identified the veterinarian-farmer relationship as one of the most important key success factors. The veterinarian-farmer relationship was identified as a barrier in a previous study (Gozdzielewska et al., 2020) and improving the interaction between veterinarians and farmers could be an interesting pathway to explore if there is a trust relationship and no conflict of interest (Speksnijder and Wagenaar, 2018). The number of interventions achieving this outcome is probably underestimated in our review because it is rarely measured or reported whereas there are several strategies involving veterinarians which should have probably generated more veterinarian-farmer interactions. Finally, economic support measures could be a more direct way of generating changes in practices, but their long-term effects may be more prone to a lack of sustainability if financial resources are no longer sufficient.

There is no one-size-fits-all solution to change AMU practices but we identified semi-regularities and provided a basis for decision-makers to select strategies according to the outcomes they could plausibly reach regarding the available resources (inputs) to produce the necessary outputs and a particular context. The list of success and failure factors gives decision-makers the opportunity to identify potential levers to activate in their context or potential barriers to bypass if possible or to explain why current interventions are not successful. We identified factors influencing decision to change similar to those identified in previous studies such as knowledge and perception, economic factors, social factors including veterinarian-farmer relationship and external pressure from society and media, herd and health status related to epidemiological factors and agricultural factors (Coyne et al., 2016; Gozdzielewska et al., 2020). We also identified other factors that are more specific to the characteristics of the intervention and to be considered at the design stage of the intervention such as guidance, feasibility and compliance also described by Graells et al. (2022). The most successful interventions are herd and health management measures tailored at the farm level through participatory and bottom-up approaches that increase compliance. However, the AMR issue is embedded in a more complex agri-food system including different interconnected socio-technical levels (Adam et al., 2020; Geels and Schot, 2007). Transition pathways toward reduced AMU are also temporally embedded in medium or long-term processes. We identified the trajectory and ecosystem of change as influencing factors for the success of interventions. Therefore, a global rethinking of the overall socio-technical system through interdisciplinary and systemic approaches rather than modifications of a single element at the farm level could allow opening new windows of opportunity (Adam et al., 2020). The review showed that mainly veterinarians and farmers are targeted whereas the success of the intervention is influenced by a multitude of other major and influential actors' decisions along the food supply chain (Marsden et al., 2000). Interventions do not only affect one type of actor or sector. Based on this evidence, joining efforts from different backgrounds and perspectives by involving the food-supply chain upstream and downstream actors and other actors embedded in a larger societal system (policy domain, academics, etc.) may have bigger impacts (Baudoin et al., 2021; Graells et al., 2022). For example, researchers can involve actors through action research to design adapted strategies based on various knowledge and guide decision-makers who can make the institutional and political context more conducive to the success of intervention.

We agree with Baudoin et al. that it is important from the design of an intervention to identify what long-term impacts and outcomes the targeted actors want to reach together to select the appropriate strategies and outputs regarding available inputs and contextual factors but also to identify relevant indicators to monitor to adjust strategies and evaluate interventions. Our review indicates that few studies measure impacts and that monitoring could be a success factor. Results from the assessment can help to maintain motivation and to identify new goals and opportunities to improve outcomes or to promote actions impacting AMR (Graells et al., 2022). Monitoring of intervention mainly focused on AMU indicators but they are not always appropriate and there is a lack of consistency in the use of metrics (Collineau et al., 2017a; Ferreira, 2017). Monitoring indicators can relate to any part of the intervention's logic model and document whether outcomes (AMU practices, knowledge and perception, veterinarian-farmer relationship) or impacts (AMR, animal health, technical performance, economic performance) have been achieved or the intervention's progress based on process and output indicators (level of implementation or compliance with herd and health management strategies or educational strategies). Some programs used the S.M.A.R.T. (specific, measurable, attainable, relevant and timely) to design strong context- and objective-adapted indicators (Indicators - Program Evaluation - CDC, 2022; Pérez-Escamilla et al., 2017). We provided in the Supplementary material (S6 Table) a non-exhaustive list of indicators identified in the included references that could be used by intervention promoters in an operational way to adjust strategies as needed to generate the targeted outcomes and impacts, or by researchers in further evaluation studies to better understand the ToC underlying these interventions.

### 4.2. Limitations

Our scoping review has some limitations. To make our review more feasible, we only included references in open access and published between 2000 and 2022. It would be interesting to complete this scoping review by using the same method but without the restriction to open access references. Furthermore, only one author performed the whole study selection and data charting process. There are potential biases and subjectivity related to qualitative data analysis and interpretation (Bumbuc, 2016). Authors minimized this effect by defining, testing and validating the variables together. Our review allowed to identify what works but not to what extent. Indeed, we analyzed success of interventions through the number of interventions reporting positive, null or negative measured outcomes and impacts but a more refined meta-analysis is needed to quantify the success of interventions, taking into account the scale and not only the number and type of impacts and outcomes generated. The studies recorded changes in AMU practices but not all of them assessed intermediate outcomes, impacts and the relationships between these different elements and outputs. For this reason, the generic impact pathway is plausible but hypothetical and we made several assumptions to facilitate its understanding. We assumed that all successful interventions that implemented strategies to improve herd and health management changed the related practices. We grouped outcomes related to AMU practices and outcomes related to herd and health management practices as the same outputs and intermediate outcomes led to these two changes. We also assumed that all successful interventions that implemented educational or informational strategies generated changes in knowledge and perception or motivation and confidence to change. Nevertheless, the review was able to identify trends and gaps in the literature which could guide future interventional studies to test these assumptions and realist reviews to explore the identified impact pathways and better acknowledge interventions' complex mechanisms and interactions with the context (Pawson et al., n. d.). For example, we think that the importance of the intermediate outcomes regarding the veterinarian-farmer relationship was underestimated because this outcome was not explored or recorded whereas many strategies involved both actors and their collaboration. We proposed a generic impact pathway but it should be read and adapted by decision-makers to each context. As in previous similar reviews, no interventions implemented in low-income countries were identified (Gozdzielewska et al., 2020; Wilkinson et al., 2019) and only three dealt with the poultry sector. Screening references that are not in open access could allow to identify interventions in these countries and sector.

### 4.3. Conclusions and perspectives

The lack of evidence to support interventions that aim to change

AMU practices in livestock appears to pose a challenge to users, prescribers and decision-makers. This scoping review aimed to identify gaps in the literature and to inform decision-makers on what works, how for whom and why. The theory-based and impact pathway analysis provided a holistic view of the successful change processes. There was no one-size-fits-all solution but the review allowed to draw a generic impact pathway logic model, presenting the plausible and complex relationships between outputs, outcomes and impacts. This could guide decision-makers to select the intervention's elements and strike a balance between what is feasible, effective and acceptable regarding the available resources and context. Further studies are needed to inform with more robust evidence the underpinning ToC of successful interventions towards a better AMU. Our review supports other studies on the need to adopt systemic, interdisciplinary, socio-technical and participatory approaches to embed their complexity (Adam et al., 2020; Baudoin et al., 2021; Douthwaite et al., 2007). Based on this evidence, we recommend using participatory strategic planning approaches that consider contextual factors, a range of actors and impact pathways to design, implement and evaluate plausible and effective interventions.

## Funding

This work has been conducted as part of the ROADMAP project which was funded by the European Union's Horizon 2020 research and innovation programme under ©Grant Agreement Number 817626® (https://www.roadmap-h2020.eu/).

## Declaration of Competing Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationship that could be considered as a potential conflict of interest.

## Acknowledgements

We acknowledge Aurelle De Romémont for the methodological support on impact pathway analysis.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.106025.

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