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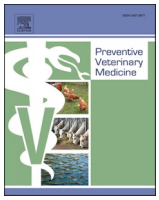

Participatory identification of the causes of antimicrobial use and how they may vary according to differences in sector structure: The case of the Flemish pork and veal sectors

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ABSTRACT

The increasing threat of antimicrobial resistance (AMR) to human health has prompted many countries to adopt national action plans to reduce antimicrobial use (AMU) in farm animals. To achieve this goal, it is necessary to gain a deeper understanding of the factors driving AMU in farm animals. While previous research has focused on gaining a better understanding of AMU from the perspective of farmers and veterinarians, less emphasis has been placed on examining the systemic and contextual factors that influence AMU from multiple viewpoints within the food supply chain. To this end, this paper describes a participatory approach involving multiple stakeholders from two distinct livestock sectors to identify the underlying drivers of AMU and explore their case-specificity. For each sector, we identified causes of AMU during four online focus groups, by co-creating a "problem tree", which resulted in the identification of over 50 technical, economic, regulatory, and sociocultural causes per sector and exploration of causal links. Following this, we analysed the focus group discussion through a content analysis and clustered causes of AMU that were related into 17 categories (i.e. main drivers of AMU), that we then classified as drivers of AMU at sector level or drivers of AMU at farm level. Finally, we compared the two sectors by assessing whether the generated categories (i.e. main drivers for AMU) had been discussed for both sectors and, if so, whether they involved the same causes and had the same implications. Through our analysis, we gained a better understanding of several main drivers of AMU at sector level, that result from systemic and/or contextual causes. As these cannot always be addressed by farmers and/or their veterinarian, we suggest that interventions should also target other actors related to these causes or consider them to help implement certain strategies. Furthermore, based on the results of our comparative analysis, we suggest that systemic structural differences, such as size and level of supply chain integration/fragmentation, may lead to differences in how animal health management is approached. This in turn may influence AMU's decision-making and the effectiveness of interventions, if they are generic and not tailored to the specificities of the sector.

1. Introduction

Over the past two decades, the threat of antimicrobial resistance (AMR) to human health has been increasingly recognized worldwide and the link between antimicrobial use (AMU) in veterinary medicine and the proliferation of resistant bacteria has become more established (European Centre for Disease et al., 2021; Tang et al., 2017). To address this problem, many countries have adopted national action plans (NAPs) to reduce the use of antimicrobials in farm animals (World Health Organization, 2018).

To achieve the goals outlined in the NAPs and develop effective interventions, it is necessary to better understand antimicrobial use in farm animals. To this end, research has focused on characterizing AMU on farms, by e.g. documenting and quantifying drug use (Khan et al., 2021; Mikecz et al., 2020; O'Neill et al., 2020; Pardon et al., 2012; Saini et al., 2012; Van Boeckel et al., 2015), assessing the prophylactic and/or metaphylactic use (Callens et al., 2012; Jorritsma et al., 2021; Mouiche et al., 2022; O'Neill et al., 2020) and comparing AMU levels between different sectors (Filippitzi et al., 2014).

In addition to characterising antimicrobials consumption, a significant amount of social sciences research has been conducted to shed light on the reasons for their use, assessing farmers' and veterinarians'

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knowledge and awareness of antimicrobials and AMR, their attitudes toward antimicrobials and AMR, and the factors and barriers that influence AMU (McKernan et al., 2021; Tompson and Chandler, 2021). Interestingly, most of these studies aimed to understand the problem from the perspective of farmers and veterinarians (Tompson and Chandler, 2021), who are also the main targets of interventions (Chandler, 2019).

While this seems legitimate, several authors have argued that the responsibility of end-users may be considered more important than it actually is, given that they operate in a food supply chain and their choices may be influenced by other actors and/or the context (Begemann et al., 2020; Chandler, 2019). Therefore, a better understanding of systemic factors (e.g. social dynamics, private standards or norms within a system, such as a farm animal pruduction sector or a food supply chain), and/or contextual factors (i.e. overarching structures such as EU policies or the world market that impact many different systems) and how these interact, may offer new opportunities for the development of AMU interventions beyond the farm level. Unfortunately, such factors, as well as their interactions, are currently under-researched since studies that explore the bigger picture of AMU in farm animals, as for example the dependencies and relationships between different actors (Caudell et al., 2020; Masud et al., 2020; Rojo-Gimeno et al., 2018), structural factors that influence animal health management (Lekagul et al., 2021; Rojo-Gimeno et al., 2018), antibiotics distribution routes (Hennessey Id et al., 2023) or the analysis of policies regarding AMU (Avraam et al., 2021) are not numerous and often deal with specific aspect of a production system (e.g. regulations or interrelationships between actors).

In this view, this paper aimed to explore the technical, economic, regulatory, and sociocultural (i.e. systemic and contextual) dimensions of AMU in farm animals, using a participatory approach with multiple stakeholders in order to answer the questions “why do we have a high antimicrobial use?”. This was done for two diverging livestock sectors and resulted in two visual representations of causes of AMU. These identified causes were then further clustered (i.e. main drivers of AMU) and classified as drivers of AMU at farm or sector level.

In addition, as it has been noted that interventions might need to be defined and developed at the local level due to the case-specificity of contextual/systemic factors (Tompson and Chandler, 2021), this paper also assessed whether the identified causes and their implications differed between the two case studies.

2. Material and Methods

2.1. Case study characteristics

For our research, we chose the Flemish pig and veal calf sectors, mainly because of their differences in terms of species, size and structure.

As such, the Belgian veal calf sector, which is almost fully located in Flanders, is a quite small sector that comprises ca. 170 000 animals distributed over ca. 270 farms (Kempeneers, 2019; Pardon et al., 2014; Statbel, 2022). These farms operate in a highly integrated system, composed of three main integrators with their own milk powder plants and slaughterhouses and some smaller integrators (Kempeneers, 2019; Pardon et al., 2014). The sector has a production value of ca. 210 million euros (Departement Landbouw en Visserij, 2023b) and that the majority of the production is exported to European countries, such as Italy, France and Germany, as reported by key informants we interviewed.

The Belgian pig sector, which is also mainly located in Flanders, is a bigger sector, that consists of ca. 3200 farms and 5,4 million animals (Statbel, 2022). In this sector, farmers operate mostly independently, as it was estimated that in 2016, 25% produced under contract, mainly with the feed industry or other pig farmers (Deuninck et al., 2017). The sector has a production value of ca. 1600 million euro (Departement Landbouw en Visserij, 2023a) and a self-sufficiency rate of ca. 240% (VLAM marketingdienst, 2022), meaning that most of the production is exported, mainly to Germany and Poland (Belgian Meat Office, 2019).

In addition to their structure, these sectors also differ in their contribution to the total AMU of Belgian animal production. The pig sector accounts for 71% of antibiotics used in nationally monitored species (i.e. pigs, broilers, laying hens, and veal calves), with a total consumption of 86,5 tonnes active substance of pharmaceuticals and medicated premixes (Belgian veterinary surveillance on antimicrobial consumption report 2021 (BELVETSAC 2021), 2022). These species are also estimated to represent more than 75% of the total AMU in Belgian livestock (estimated on the basis of data from Belgian Veterinary Surveillance of Antibacterial Consumption 2021). In contrast, the veal calf sector has, due to its size, a smaller overall AMU contribution (i.e. 14,2 tonnes), but has a large AMU per animal, with ca. three times as many days of treatment over a 100-day period (i.e. BD_{100}, the belgian unit for AMU) as pigs, namely 17,8 versus 5,5 (Belgian veterinary surveillance on antimicrobial consumption report 2021 (BELVETSAC 2021), 2022).

2.2. Participatory research: problem tree analysis

To explore the technical, structural, economic, institutional, and socio-cultural dimensions of AMU of both sectors, we relied on a commonly used technique in participatory research, namely problem tree analysis (also called situational analysis or problem analysis). This technique makes it possible to explore the direct causes of a problem and to understand how the different actors perceive it, thus obtaining a collective comprehensive vision of that problem (Chevalier and Buckles, 2008).

In practice, the problem tree analysis is a visual approach, meaning that discussions are summarized in a visual format. To achieve this, the problem is first clearly defined and the objective of the analysis is specified (Chevalier and Buckles, 2008). Next, the question of why the problem has arisen is addressed, which usually identifies five or six factors, called direct causes, that are visually placed under the main problem. These are then questioned again (e.g. why is this cause happening?), identifying indirect causes, visually placed under the corresponding direct causes. This process is repeated until all underlying causes have been addressed and the whole picture visually resembles the root system of a tree (Chevalier and Buckles, 2008). To deepen the analysis, it is also suggested that the participants’ discussions be documented to provide a detailed explanation of each cause of the problem (Chevalier and Buckles, 2008).

2.2.1. Data collection

To collect the data, we performed the following four steps between January 2020 and October 2021: (1) identification of relevant stakeholders and their invitation to an introductory meeting; (2) joint online introductory meeting; (3) organisation of 4 online focus groups for each case study; (4) validation of the co-developed output of the focus groups during a joint meeting.

2.2.2. Identification of relevant stakeholders and their invitation to an introductory meeting

For both sectors, relevant stakeholder groups, which were defined as having either an interest or an influence on animal health and antimicrobial use, were first identified through eight key informant interviews (four for each sector) and desk research (i.e. Scientific literature, (official) reports and documents and organisations’ websites). Representatives of the identified stakeholder groups of both sectors were personally invited via email or phone to participate in a joint online introductory meeting in October 2020. This was done to ensure representation of key stakeholder groups. In addition, the invitation was further disseminated through various communication channels and newsletters to enable other interested parties to participate.

2.2.3. Joint online introductory meeting

The purpose of this introductory meeting was threefold: 1) to ensure

Table 1
Overview of the participants (type and number) of the introductory meeting, focus groups and the validation meeting for each sector.

	Farmers	Veterinarians	Integration	Governmental agencies	Pharmaceutical industry	Feeding industry	Farmers'/ sectoral organisations	Veterinarians' organisations	Extension services	Retail sector	Slaughterhouses' organisations	Academia	Research institutes	Quality Labels	Total*
Introductory meeting															
Joint	4	8	0	4	7	8	3	1	6	4	1	5	6	1	54
Focus group 1															
Pig sector	1	3	0	1	6	5	1	1	6	1	1	1	2	0	25
Veal calf sector	0	4	2	2	4	2	1	0	4	1	0	0	2	0	21
Focus group 2															
Pig sector	1	2	0	2	4	3	1	1	3	1	1	0	1	2	19
Veal calf sector	0	4	2	2	5	3	0	0	2	1	1	0	2	0	21
Focus group 3															
Pig sector	2	4	0	3	3	4	1	1	2	1	1	0	2	2	22
Veal calf sector	0	4	1	2	3	0	1	0	3	1	1	0	4	0	20
Focus group 4															
Pig sector	1	2	0	2	4	3	1	0	3	1	0	0	2	1	19
Veal calf sector	0	4	1	1	4	3	0	0	2	1	0	0	2	0	17
Feedback meeting															
Joint	4	5	0	1	7	5	4	0	5	1	0	5	4	2	38

* The total number of participants does not always equal the sum of the number of participants per stakeholder category since some stakeholders had dual roles

that all the important stakeholder groups had been identified and contacted, 2) to recruit participants for the focus groups by presenting the study and the method used, and 3) to identify the expectations of those who wish to participate. In total, 54 participants, from 44 organizations, participated in the joint online introductory meeting organized via "Microsoft Teams" (see Table 1), a situation forced by COVID-19 restrictions. We opened the meeting with a presentation of the study and the method, as well as our initial stakeholder analysis. To validate this analysis and give participants an idea of what would be discussed during the focus groups and how it would be done online, we invited participants to (anonymously) join the online "Mural" app (Mural online visual collaboration app; Tactivos inc, 2020–2021), which enables visual collaboration. Once participants had joined the shared template in the app, they were asked to validate our initial stakeholder analysis by first identifying the most important actors in the animal health system (each participant could select up to five actors from a list). Next, a poll was used to ask participants if their organization or other important stakeholders had been omitted from our initial stakeholder analysis. If this was the case, participants could specify the names of the missing organizations through the chat. Finally, we asked participants to place their organization in an interest-influence matrix. Following the validation of the stakeholder analysis, we asked participants which actions they had already taken towards a more responsible AMU. They could simultaneously share their answers by creating virtual post-its on the shared template, resulting in many responses that were also discussed briefly. The same approach was used to ask participants what regulatory, social, economic and political barriers they had encountered to responsible AMU as well as what they felt was important to actively participate in the focus groups. Finally, we ended the meeting by asking participants if they would be willing to participate in focus groups to identify the causes of antimicrobial use in the pig or veal calf sector. Approximately 65% of the participants responded affirmatively. Results of this meeting will not be presented here.

2.2.4. Four online focus groups for each case study

Subsequently, four online meetings of 1,5 h were organized through "Microsoft Teams" for each case study between December 2020 and March 2021. The number of focus groups was not determined in advance, as it was not known how much time would be needed to create the full problem tree. As such, focus groups were held until participants felt that all of the reasons for the AMU had been addressed, which was the case after four meetings.

Regarding the short, monthly format of the focus groups, the stakeholders chose this approach rather than one single but much longer focus group session, partly because of the digital nature of the meetings, a situation forced by COVID-19 restrictions. However, given our collaboration with busy agricultural and governmental actors, we deemed the online format suitable, as research showed that online focus groups made it easier for participants to combine their participation with work/personal obligations ((Zwaanswijk and Van Dulmen, 2014). Regarding the quality of the data, several studies also demonstrated that online focus groups are able to elicit an equivalent quality of data to face to face focus groups (Abrams et al., 2015; Woodyatt et al., 2016).

To moderate the focus groups, we relied on two veterinarians working for a Belgian organization called "Diergezondheid Vlaanderen", which provides extension services, amongst other things. For the pig sector, the discussions were moderated by the veterinarian specialized in pig health, while for the veal calf sector, this task was undertaken by the veterinarian specializing in cattle health. Meanwhile, the problem tree was built by the first author, in collaboration with the participants.

During the first focus group, the "problem-tree" approach was introduced to the participants. Once it was clear that all participants had understood the approach, we proceeded with the construction of the problem tree, starting from the question "Why do we have a high AMU". Once participants had named a direct cause (verbally or using the chat function), the moderators further asked if other elements underlay that

Table 2
Overview of the different types of stakeholders and their roles.

Stakeholder	Role
Farmers	Breed animals
Veterinarians	Provide advice and assesses health status on farms. Veterinarians can also sell medicines to farmers.
Integrations	Companies that own several segments of the value chain (e.g. feed mills, farms, slaughterhouse, etc.).
Governmental agencies	**Federal Agency for Medicines and Health Products** The agency is responsible for the quality, safety and efficacy of medicines and health products. The agency also coordinates the antibiotic use data collections BelVet-SAC (antimicrobial sales for food-producing and companion animals) and SANITEL-MED (antimicrobial consumption in food-producing and companion animals). **Federal Agency for the Safety of the Food Chain** Guards the safety and quality of food in order to protect the health of humans, animals and plants.
Pharmaceutical industry	Develop & sell medicines. Some companies also provide extension services. In such cases, they collaborate with the veterinarians, not the farmers.
Feeding industry	Provide feed and advice to farmers. Sometimes, farmers can be integrated by feed mills. Different types of contract exist for this.
Farmers'/ sectoral organisations	Represent the interest of the farmers but also diffuse knowledge and take part to research projects.
Veterinarians' organisations	Represent the interest of the veterinarians.
Extension services	Services that provide "third line" animal health services, organise workshops and training and sometimes take part in research projects.
Retail sector	Markets the meat.
Slaughterhouses' organisations	Represent the interests of slaughterhouses, cutting plants and wholesalers.
Academia	Perform research, create and diffuse knowledge. Ghent University (UGENT) is also contributing to the Belgian veterinary surveillance of antimicrobial consumption.
Research institutes	Contribute to knowledge development through research projects.
Quality Labels	Promote the quality of Belgian meat in a sustainable manner through the management of quality systems and integrated chain management. For the pigs, some quality labels made the monitoring of ABU mandatory, send benchmarking reports to the participating farmers and request high users to be coached.

reason. This resulted in the identification of indirect causes, third-order causes, fourth-order causes, and so on. The tree was constructed from the terms that were mentioned by the participants and in the order in which they were named. Participants could see the tree being built through the "Mural" app, meaning they could see how the virtual post-its were placed on a shared virtual board and could also comment on how the different elements should be linked together. Five minutes before the end of the meeting, the moderators ended the discussions, thanked people for their participation and defined a time for the following focus group.

Every subsequent focus group was then started with a brief recap of what had been achieved in the previous focus group, before continuing the building of the problem tree. Once the discussions among the participants yielded no new information, it was considered that data saturation had been achieved, meaning that in this setting, no new data would being collected (Saunders et al., 2018). When this point was reached and participants felt that all of the reasons for the AMU had been addressed, it was collectively decided to stop the focus groups.

2.2.5. External feedback on the co-developed output of the focus groups during a joint meeting

Upon completion of the problem tree, an online event was organized through "Microsoft Teams" in October 2021 to present the results of the eight focus groups. Participants of the introductory meeting who had requested to be kept informed of this study were personally invited by e-mail. In addition, the event was also advertised through newsletters. During the meeting, the project, method and results were presented to the 38 participants, who could also comment (verbally or through the chat function) on the developed problem tree. During the meeting, notes were taken to document feedback from external participants. These comments were not used to adapt the tree, as they did not dispute the causes identified, but rather pointed out that certain branches and sub-branches of the tree could have been developed further. However, these comments were taken into account when performing the analysis.

2.3. Data analysis

To analyse the data, we first transcribed and coded the data of the focus groups, before conducting a content analysis.

2.3.1. Data preparation

To deepen the analysis and properly describe the identified causes, we followed Chevalier and Buckles suggestion to document the process (2008) and recorded the online focus groups via the "Microsoft teams" app. We informed participants of this fact orally and through an information form sent by e-mail, as well as of the fact that they could end their participation at any time and that they could also request that their data be deleted from the study. In addition, we also asked participants to submit an informed consent form and reminded them at the beginning of each focus group that the sessions were being recorded and that they were free to leave the session at any time. After the focus groups, the recordings were saved on a secure internal server in order to be transcribed and anonymized, upon which they were deleted.

2.3.2. Content analysis

To organise the data, the first author used the causes that had been discussed with the participants (i.e. all the items listed in the problem tree) to code the anonymized transcripts in the NVIVO 12 plus software (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12 plus, 2018). This means that for every cause identified by the participants, all texts in the transcripts that were related to that specific cause were manually labeled using the cause as a "code" and filed together in the program. The use of this "codebook approach" was driven by our desire to reflect the participants' perspectives as objectively as possible, by using the terms they collectively agreed on to represent a certain aspect of the problem. This was important as this paper relied on a post-positivist approach that aimed to represent the "reality" as best as possible (Santiago-Delefosse et al., 2015), through consolidated views from different stakeholders in the food supply chain.

To further organize the data into a concise summary, the first author clustered related causes in categories, that were in turn classified as "drivers of AMU at farm level", that mainly comprised causes that were primarily tied to the farmer or veterinarian, and "drivers of AMU at sector level", that mainly comprised causes of AMU that relate to other actors and/or systemic structures/situations that cannot be changed by the farmer/veterinarian. As the aim was to structure and report the data, but not to interpret it, most of the categories represented parts of the problem tree, except for two categories that were generated by identifying similar codes across different branches of the problem. Moreover, we didn't perform the next level of data abstraction that can be

performed in a content analysis, which is the identification of themes (Erlingsson and Brysiewicz, 2017).

Finally, the first author compared the results of both sectors in order to determine whether the identified categories had been discussed in for both sectors, and whether they had been discussed in the same way (i.e. had the same underlying causes be named for a certain category).

3. Results

3.1. Identification of underlying causes of AMU (problem-tree analysis)

For the pig sector, the participants of the focus groups identified six direct causes for a high antibiotic use: a poor animal gut health (blue box in Fig. 1a), poor biosecurity (light grey box in Fig. 1a), poor farm management (dark grey box in Fig. 1a), poor stall climate (orange box in Fig. 1a), economic reasons (yellow box in Fig. 1b) and societal pressure (purple box in Fig. 1b). We further discussed these direct causes, which formed the starting points of the four branches of the tree (see Figs. 1a and 1b), and identified 52 underlying causes (16 indirect causes, 21 causes of the 3rd order, nine causes of the 4th order, five causes of the 5th order and one cause of the 6th order).

For the veal calf sector, the participants of the focus groups identified seven direct causes for a high antibiotic use: high cross-contamination rate in calf fattening farms (blue box in Fig. 2a), a poor biosecurity (dark grey box in Fig. 2a), infrastructural problems (light grey box in Fig. 2a), business blindness (yellow box in Fig. 2a), a lack of preventive management (purple box in Fig. 2b), a lack of incentives (orange box in Fig. 2b), and the way antibiotics are used (brown box in Fig. 2b). As with the pig sector, we further examined these direct causes and identified 52 underlying causes (17 indirect causes, 22 causes of the 3rd order, nine of the 4th order, three of the 5th order and one of the 6th order).

A complete description of both problem trees can be found in the supplementary materials.

3.2. Classification of the causes and comparison of both sectors (content analysis)

For the content analysis, the first author clustered related causes in 17 categories that explained why antimicrobials were used in both sectors (see Fig. 3). Following this, six categories were classified as "drivers of AMU at farm-level" (i.e. causes that are primarily tied to the farmer or veterinarian), while the 11 others were classified as drivers of AMU at sector level (i.e. causes that relate to other actors and/or systemic structures/situations that cannot be changed by the farmer/veterinarian themselves).

3.2.1. Drivers of AMU at farm-level

Of the six generated categories, three were solely discussed for the pig sector (poor gut health of pigs, lack of control of farm parameters, antibiotics are used out of fear for change), while the remaining were solely discussed for the veal calf sector (group vs. individual treatment, poor stall climate (infrastructural issues), and business blindness).

a) *Poor gut health of pigs*

Participants identified a poor animal gut health (see blue branch in Fig. 1a) as a direct cause for a high AMU in the pig sector, which occurs primarily in weaned piglets (ca. 28-day-old pigs), the category of pigs with the highest AMU consumption in Belgium. To further explain this, participants identified four indirect causes: the transmission of pathogens from sows to piglets, poor quality of raw materials, poor feed intake after weaning and animal genetics (see blue branch in Fig. 1a). Regarding the former, participants noted that infections such as hemolytic *Escherichia coli* and Salmonella strains, combined with stress at weaning, could be difficult to treat without antibiotics and could recur over several rounds. For the poor quality of raw materials such as feed, participants noted that, unlike in the "old days", raw material deficiencies could no longer be compensated by the systematic use of antibiotics. The intake after weaning, which was thought to have an effect on gut health, was mentioned but not further discussed, as opposed to the role of genetics, for which participants explained that some rounds would be naturally more prone to health problems than others under equivalent conditions and despite the best efforts of the breeder, farmer and veterinarian.

b) *Lack of monitoring of parameters in pig farms*

When discussing poor farm management (i.e. direct cause for high AMU in the pig sector, see dark grey box in Fig. 1a), participants identified the lack of monitoring of parameters in pig farms as an indirect cause (see dark grey branch in Fig. 1a) and explained that important indicators such as carcass gain per kg of feed intake (i.e., the amount of feed consumed per unit of weight gain of the pig) are often not known and when they are, it is often on an annual basis. Participants thought that this lack of data makes it difficult to assess the impact and the return on investment of interventions such as vaccination or changes in nutrition. They therefore suggested that pig farmers should be convinced of the usefulness of monitored parameters - such as pig weights at different times, barn temperatures, water and feed consumption - to detect underlying problems and evaluate the impact of interventions. Although several monitoring devises already exist, participants noted that their integration or, when present, their actual use, remains rare as farmers tend to rely more on visual signs. Reasons for this were a lack of time and digital applications to collect data, but especially to analyze them (e.g., weighing all the animals takes time and so does processing the data), as well as the large investments required by some equipment (e.g., scales).

c) *Use of antibiotics out of fear for change*

For the pig sector, participants reported that farmers fear to do things differently, mainly due to the fact that antibiotics delivered immediate results (see dark grey branch in Fig. 1a), thus securing the financial margins.

d) *Group treatment* vs. *individual treatment of veal calves*

Regarding the importance of group treatments (see brown branch in Fig. 2b), which was specifically discussed for the veal calf sector, participants explained that while veterinarians do their best to use as many individual treatments as possible, this is not always the most effective approach, as in some cases, the disease has already spread through the herd and a group treatment will inevitably be needed at a later stage, resulting in a higher AMU. However, it is important to note that this was discussed in the context of a hypothetical situation where clinical symptoms would have been detected, and not as a disease prevention approach.

e) *Infrastructural problems in veal calf farms*

In terms of infrastructural problems (i.e. direct cause for AMU in veal calf sector, see grey branch in Fig. 2a), participants of the veal calf focus groups stated that although biosecurity on fattening farms is generally quite good, some stables may have a poor ventilation, contaminated water pipes, or lack a hygiene sas or compartmentalization. In addition, there are different interpretations of what a sickbay is. Regarding ventilation, participants noted a general lack of knowledge and know-how in the sector. They also considered that farmers needed more guidance in this area. As the knowledge of veterinarians was considered to be rather limited, they suggested that veterinarians request an external audit, especially since the solutions proposed to improve ventilation are not always expensive or sophisticated. With regard to sickbays, participants described that all farms actually had them, but that there were different interpretations: while on some farms sick or lagging animals are completely isolated from the rest, in others they are kept in a specific area of a stable. This simpler design and the abandonment of compartmentalization are due to the fact that sorting calves into different compartments is quite labor intensive, as farmers must

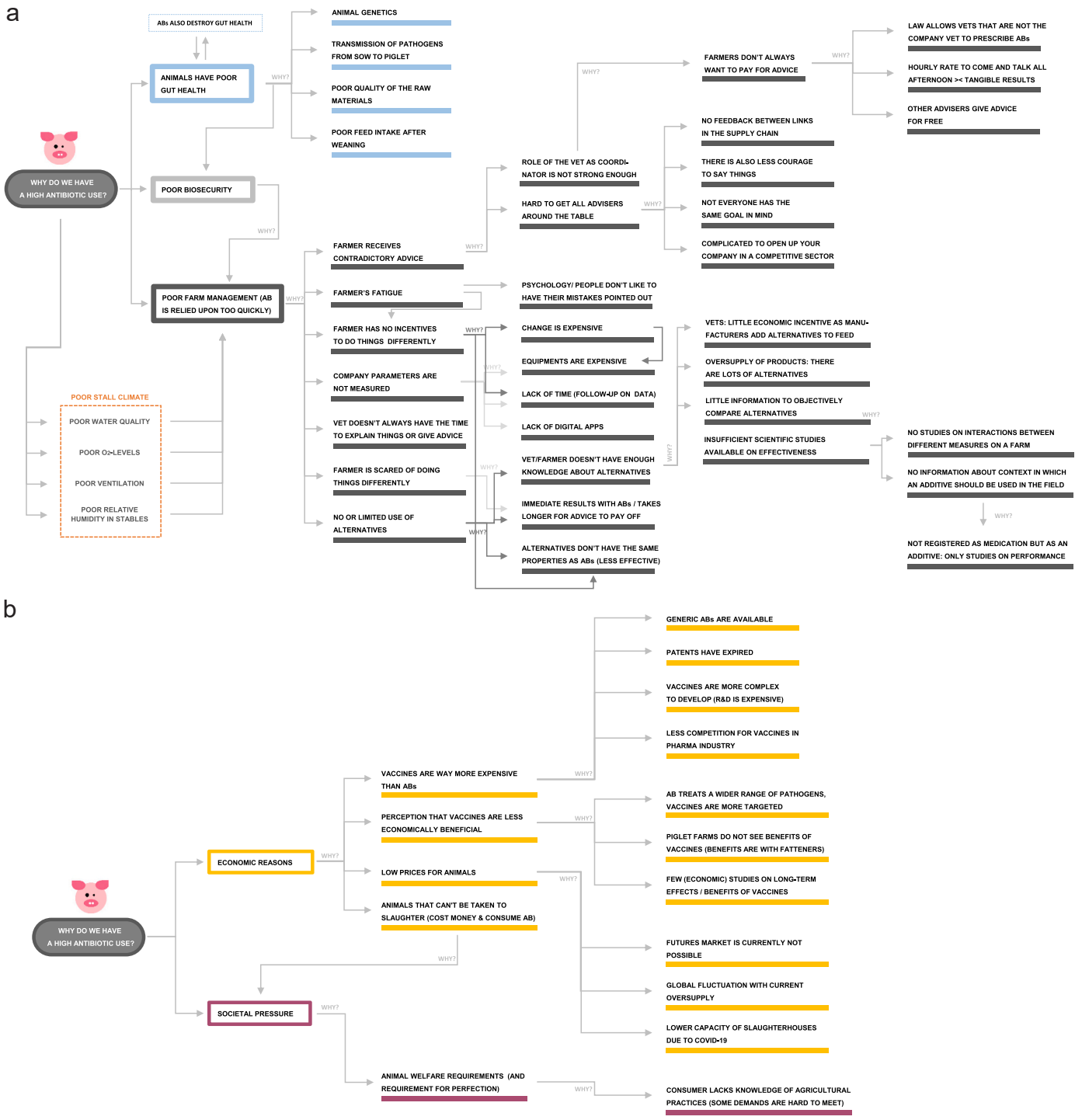

Fig. 1. Problem tree developed with stakeholders of the Flemish pig sector. Six direct causes for a high antibiotic use were identified (see coloured boxes in Figs. 1a and 1b). For every direct cause, underlying reasons were identified, resulting in four tree branches. Fig. 1*a*: Four direct causes for a high antibiotic use: a poor animal gut health (blue box), poor biosecurity (light grey box), poor farm management (dark grey box), poor stall climate (orange box). These are the starting points of two branches (blue and dark grey branches).Fig. 1*b*: Two direct causes for a high antibiotic use: economic reasons (yellow box) and societal pressure (purple box). These are the starting points of two branches (yellow and purple branches).

carefully observe the animals to select and isolate the stragglers. However, although this step represents a lot of work at one point, participants also agreed that it was more beneficial in the long run than systematically screening the animals in order to isolate the sick ones.

f) *Business blindness in veal calf farms*

For the veal calf sector, participants explained that farmers were so focused on delivering as many healthy and strong calves as possible that they tended to pay more attention to the health of their animals than to their environment (see yellow branch in Fig. 2a). In addition, farmers were said to be used to doing things a certain way and were not always aware that small changes in housing could improve their results with regard to animal health. However, participants stressed that this was not due to a lack of motivation but rather to a lack of awareness about how (small) housing deficiencies can affect animal health.

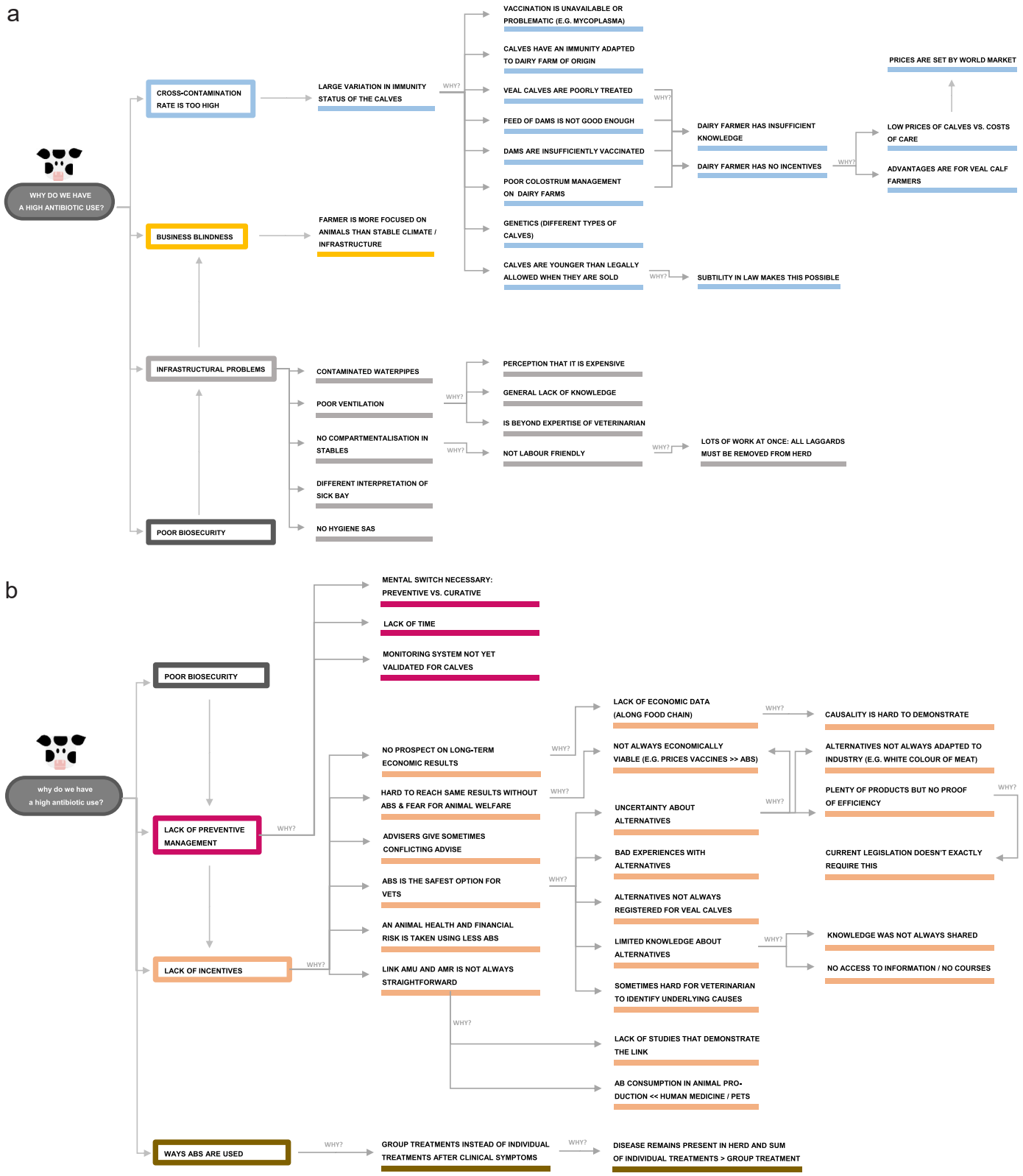

Fig. 2. Problem tree developed with stakeholders of the Flemish veal calf sector. Six direct causes for a high antibiotic use were identified (see coloured boxes in Figs. 2a and 2b). For every direct cause, underlying reasons were identified, resulting in six tree branches. Fig. 2*a*: Four direct causes for a high antibiotic use: a high cross-contamination rate in calf fattening farms (blue box), business blindness (yellow box), infrastructural problems (light grey box) and a poor biosecurity (dark grey box). These are the starting points of three branches (blue, yellow and grey branches).Fig. 2*b*: Two direct causes for a high antibiotic use: a lack of preventive management (orange box) and the way antibiotics are used (brown box). These are the starting points of three branches (orange and brown branches).

Codes Causes of AMU	Categories Main drivers of AMU	Typology
Animal genetics Transmission of pathogens from sow to piglets Poor quality of raw materials Poor feed intake after weaning	Poor gut health of pigs	AMU drivers at farm level
Equipment are expensive Lack of time (follow-up data) Lack of digital apps	Lack of monitoring of parameters in pig farms	
Farmer is scared of doing things differently Immediate results with ABs / takes longer for advice to pay off	Antibiotics are used out of fear for change	
Group treatments instead of individual treatments after clinical symptoms **Disease remains present in herd and sum of individual treatments > group treatment**	Group treatment vs. individual treatment of veal calves	
Contaminated waterpipes **Poor ventilation** **Perception it's expensive** **General lack of knowledge** **Beyond expertise of veterinarian** **No compartmentalisation in stables** **Not labour friendly** **Lots of work at once: all laggards must be removed from herd** **Different interpretation of sick bay** **No hygiene sas**	Infrastructural problems in veal calf farms	
Farmer is more focused on animals than stable climate /infrastructure **Business Blindness**	Business blindness in veal calf farms**	
Role of the vet as (advice-) coordinator is not strong enough Farmers don't always want to pay for advice Law allow vets that are not the company vet to prescribe ABs Hourly rate to come and talk all afternoon >< tangible results Other advisers give advice for free	Advisory role of veterinarian is hard to establish	AMU drivers at sector level
Hard to get all advisers around the table Not everyone has the same goal in mind Complicated to open up your company in a competitive sector There is less courage to say things **Advisors sometimes give conflicting advice**	Conflicting advice due to a lack of consultation	
Animal welfare requirements (and requirement for perfection) Consumer lacks knowledge of agricultural practices (some demands are hard to meet)	Societal pressure / request for perfect animals in the pig sector	
Large variation in immunity status of the calves **Vaccination is unavailable or problematic (e.g. mycoplasma)** **Calves have an immunity adapted to dairy farm of origin** **Veal calves are poorly treated** **Feed of dams is not good enough** **Dairy farmer has insufficient knowledge** **Dairy farmer has no incentives** **Advantages are for veal calf farmers** **Low prices of calves vs. costs of care** **Prices are set by world market** **Dams are insufficiently vaccinated** **Poor colostrum management on dairy farms** **Genetics (different types of calves)** **Calves are younger than legally allowed when they are sold** **Subtility in law makes this possible**	High cross contamination rate among animals (veal calf sector)	
Link AMU and AMR is not always straightforward **AB consumption in animal production << human medicine / pets** **Lack of studies that demonstrate the link**	Hard to establish link between AMU and AMR (veal calf sector)	
Monitoring system not yet validated for calves	Lack of sector-specific tools and knowledge in the veal calf sector *	
Alternatives not always adapted to industry (e.g. white colour of meat **General Lack of knowledge**		
Alternatives don't have the same properties as abs (less efficient) Immediate results with abs / takes longer for advice to pay off Vet/farmer doesn't have enough knowledge about alternatives	Limited use of alternatives: limited knowledge and registration	
Vets: little economic incentive as manufacturers add alternatives to feed Over-supply of products: there are lots of alternatives Little information to objectively compare opportunities Insufficient scientific studies available on effectiveness No studies on interactions between different measures on a farm No information about context in which an additive should be used in the field Not registered as medication but as an additive: only studies on performance **ABs is the safest option for vets** **Uncertainty about alternatives** **Plenty of products but no proof of efficiency** **Alternatives not always adapted to industry (e.g. white colour of meat)** **Current legislation doesn't exactly require this** **Bad experiences with alternatives** **Alternatives not always registered for veal calves** **Limited knowledge about alternatives** **Knowledge was not always shared** **No access to information / no courses** **Sometimes hard for veterinarian to identify underlying causes**		
Low prices for animals Futures market is currently not possible Global fluctuation with current oversupply Lower capacity of slaughterhouses due to covid-19 An animal health and financial risk is taken using less ABs **Low prices of calves vs. costs of care** **Prices are set by world market** **Not always economically viable (e.g. prices vaccines >> abs)**	Limited capacity to invest	
Vaccines are way more expensive than ABs Generic abs are available Patents have expired Vaccines are more complex to develop (R&D is expensive) Less competition for vaccines in pharma industry **Not always economically viable (e.g. prices vaccines >> abs)**	Price differences between antibiotics and vaccines	
Perception that vaccines are less economically beneficial AB treats a wider range of pathogens, vaccines are more targeted Few (economic) studies on long-term effects / benefits of vaccines **No prospect on long-term economic results** **Hard to reach same results without abs & fear for animal welfare** **Lack of economic data (along food chain)** **Causality is hard to demonstrate**	Economic benefit of interventions are unknown	
Piglet farms do not see benefits of vaccines (benefits are with fatteners) No feedback between links in the supply chain **Veal calves are poorly treated** **Dairy farmer has no incentives** **Advantages are for veal calf farmers**	Diverging interest of animal suppliers and buyers *	

(caption on next page)

Fig. 3. Overview of the generated categories (i.e. main AMU drivers) through a content analysis of the focus group transcripts, as well as their classification according to their typology. The codes in bold are the codes that were used to structure data from the veal calf focus groups, while the others were used to structure data from the pig focus groups. Most of the categories represent parts of the problem tree, except for the categories marked with an asterisk* , as these were generated by identifying similar codes across the branches of the problem tree. Business blindness was marked with two asterisks* * as for the pig sector, the term was mentioned once by a participant, but not further discussed.

3.2.2. Drivers of AMU at sector-level

Of the 11 drivers for AMU at sector-level, we identified two drivers that were only discussed for the pig sector (advisory role of veterinarian is hard to establish and societal pressure/request for perfect animals), four for the veal calf sector (high cross contamination rate amongst young calves, hard to establish link between AMU and AMR, lack of sector-specific tools and knowledge, f)Antibiotics are the safest option in the veal calf sector) and seven that were discussed for both sectors (limited use of alternatives, demonstrated economic benefit/status quo of interventions, limited capacity to invest, price differences between antibiotics and vaccines, conflicting advice from advisers to farmer and diverging interests of animal suppliers and buyers).

a) *Advisory role of veterinarian is hard to establish in the pig sector*

The difficulty for veterinarians to establish themselves as consultants and be compensated accordingly was only discussed for the pig sector. There, participants identified this as one of the causes for which pig farmers sometimes receive conflicting advice (indirect cause for high AMU, see gray branch in Fig. 1a). While participants agreed that the farm veterinarian[1] (21 JULI 2016 - Koninklijk besluit betreffende de voorwaarden voor het gebruik van geneesmiddelen door de dierenartsen en door de verantwoordelijken van de dieren, 2016) was the most qualified person to bring the various advisers together, streamline advice, and monitor and evaluate the implementation of advice/interventions, they also agreed that it is currently difficult due to the fact that it is not common for them to charge an hourly fee and that farmers often prefer to pay for something tangible such as medicine. Moreover, "free" advice is provided by advisers from feed mills and other suppliers, with the result that some farmers prefer to seek advice there. In addition, participants also discussed the fact that farmers could easily ask another veterinarian to dispense drugs on their farm when they disagree with the advice given by the farm veterinarian. However, participants also stated that these practices were becoming rare as veterinary prescriptions are officially monitored and it is known who is dispensing drugs on a farm. They also stressed the importance of continuing to legally authorize another veterinarian to dispense medication on a farm in the event of an emergency, in order to ensure the health and welfare of the animals.

b) *Societal pressure / request for perfect animals in the pig sector*

Another topic that was only discussed for the pig sector was the societal pressure regarding animal welfare and the request for perfect animals (see pink branch in Fig. 1b). For this, participants explained that animals with small defects (e.g. bitten tail) are not accepted by the slaughterhouses anymore. These animals are then often treated with antibiotics on the farms in the hope that they will become fit enough to be sold and go to slaughter. In reality, this is rarely the case, and such animals end up being euthanized. Participants described this problem as an indirect consequence of the general public's unfamiliarity with agricultural practices, which results in requirements that are difficult to combine with current production models and can have unexpected results. Another discussed example is the general public's confusion regarding antibiotic use and antibiotic residues in meat.

c) *High cross contamination rate among animals (veal calf sector)*

As opposed to the previous topics, the high rate of cross-contamination among young animals was only discussed for the veal calf sector (see blue box in Fig. 2a). Participants explained that this high rate is mainly due to the fact that veal calves are collected from several farms, transported to sorting centers and finally sent to fattening farms. This process usually takes place during the period of immune deficiency of the calves, i.e. when the passive immunity, acquired through colostrum, slowly decreases and the adaptive immunity starts to develop, which means that the calves are then very susceptible to infections. In addition, calves have an immunity tailored to the dairy farm of origin, making them susceptible to other pathogens when in contact with calves from other dairy farms.

d) *Hard to establish link between AMU and AMR (veal calf sector)*

Another point that was only discussed during the veal calf focus groups is the link between AMR and AMU (see orange branch in Fig. 2b), with some participants pointing out that it is not always straightforward as, for some antibiotics, resistance rates are still quite high even though these antibiotics are not used anymore (e.g. chloramphenicol). In addition, the contribution of animal production to global AMR versus human medicine was also questioned and some participants felt that there is a perception that animal production is the largest contributor to drug resistance when in fact it is human medicine.

e) *Lack of sector-specific tools and knowledge in the veal calf sector*

Additionally, participants of the veal calf focus groups repeatedly pointed to the lack of industry-specific tools and knowledge. For example, veterinarians reported that the action of some supplements was incompatible with the expected characteristics of white veal (e.g., some supplements can color the meat red, see orange branch in Fig. 2b). They also indicated that alternative products were not always approved for veal calves because of the small market (see orange branch in Fig. 2b). In addition, when discussing early detection systems, they indicated that, to their knowledge, no algorithms have yet been developed for veal calves (see orange branch in Fig. 2b). A lack of general knowledge was also reported regarding ventilation, which participants said led to infrastructural problems and poor biosecurity (see grey branch in Fig. 2a).

f) *Antibiotics are the safest option in the veal calf sector*

For the veal calf sector, participants explained that antibiotics were often the safest option for veterinarians (see orange branch in Fig. 2b), who are mainly responsible for the proper running of a production cycle, since it was hard for them to identify underlying causes for disease as well as to sometimes use alternatives. In addition, participants also noted that it was hard to reach the same results without antibiotics, both regarding productivity and animal health, given the high cross-contamination rate amongst calves.

g) *Limited use of alternatives in both sector: limited knowledge and registration requirements*

Participants of both the pig and veal calf focus groups reported that there was a limited use of alternatives, such as feed additives like probiotics, prebiotics, organic acids, essential oils, etc. A commonly identified cause for this is the limited knowledge of veterinarians regarding these products as a result of an oversupply of such products as well as the limited amount of independent scientific

[1] In Belgium, farmers are legally obliged to have a farm veterinarian, with whom they have a registered agreement, in order to keep a stock of medicines on their farm.

knowledge on the efficiency and influence on animal health. This last point is also related to the fact that additives are not registered as medicines, which implies companies that market them are only required to demonstrate their performance. This is of limited value to veterinarians, who are more interested in the impact on animal health. Additionally, participants of the pig focus groups noted a lack of information to compare these products (e.g. type and amount of active compound, in what situation a product should be used) (see dark grey branch in Fig. 1a), while the participants of the veal calf groups explained that trainings regarding alternatives had only recently become available and that alternatives were often not registered for veal calves or even incompatible with request regarding the quality of the meat that has to remain white (see orange branch in Fig. 2b). Participants of both sectors also indicated that in general, they were not very optimistic about the results they obtained when using alternatives such as probiotics, prebiotics, organic acids, essential oils, etc.

h) *Limited capacity to invest in both sectors*

For both sectors, participants explained that choices must be made with limited financial resources, meaning that it is sometimes financially difficult to invest in major changes and adopt more preventive approaches.

For the pig sector, participants explained that this investment capacity was limited due to low animal prices, which are based on the world market (see yellow branch in Fig. 1b). In such periods of low prices, participants indicated that some farmers try to reduce certain costs (e.g., vaccines). However, it is interesting to note that in times of high prices, participants reported that preventive animal health management temporarily becomes less important because the focus is on good production, which means that both low and high prices can lead to an increase in AMU. In addition to animal selling prices, participants also explained that it is currently not possible to sell animals in the future market because producers are not willing to sell at low prices, as opposed to buyers who wait until prices drop to make a purchase (see yellow branch in Fig. 1b).

For the veal calf sector, participants explained that prices were set by the global market and that this also influenced the margin for investment in preventive approaches (see orange branch in Fig. 2b), improving the stable environment, but also the prices for calves purchased from dairy farmers (see blue branch in Fig. 2a).

i) *Price differences between antibiotics and vaccines in both sectors*

Related to the previous, participants also discussed the fact that antibiotics are way cheaper than vaccines. Participants of the pig sector also identified reasons for this, being that many patents for antibiotics have expired and that since a lot of generics are available, the prices of antibiotics must be competitive (see yellow branch in Fig. 1b). Vaccines, on the other hand, are newer and more specific products for which fewer substitutes are available and for which differences in quality can be noted, resulting in higher prices. This is further exacerbated by the fact that the needed investments to research and develop vaccines are larger than for antibiotics. While participants of the pig focus groups agreed that taxes on antibiotics were really low, participants of the veal calf focus groups stated that they were sufficient. There, discussions regarding the differences in price related more to the capacity to invest (see orange branch in Fig. 2b), as previously reported.

j) *Demonstrated economic benefit of interventions in both sectors*

Participants reported that there were few studies that demonstrated the economic benefits of interventions. For the pig sector, participants discussed this in the context of vaccines, noting that there were few (economic) studies on the long-term effects or benefits of vaccines (see yellow branch in Fig. 1b). For the veal calf sector, participants identified this as an underlying cause for a lack of incentives (see orange branch in Fig. 2b). Some participants also explained this was the case because it was quite difficult to collect economic data along the food supply chain and to demonstrate causality (see orange branch in Fig. 2b).

k) *Conflicting advice from advisers to farmer in both sectors*

For the pig sector, participants extensively discussed the issue of conflicting advice, which they identified as one of the causes of poor farm management (see dark grey branch in Fig. 1a). They noted that, although it is becoming increasingly common to bring advisers together to discuss farm-specific issues and provide consolidated advice, this task is sometimes not easy to accomplish, especially when some farm suppliers are (in)direct competitors. This competition among suppliers was also seen as contributing to some extent to conflicting advice, since solving a farm-specific problem may be an opportunity for a firm to acquire a new client. For the veal calf sector, this issue was only briefly addressed by participants and was more about better coordination of advisers working primarily for an integrator (e.g., technicians, veterinarians, nutritionists, etc.), who sometimes have different ways of achieving the same goal and therefore face different trade-offs (see orange branch in Fig. 2b).

l) *Diverging interest of animal suppliers and buyers in both sectors*

In both sectors, participants reported diverging interests between animal suppliers and buyers. In the pig sector, participants indicated that when health problems arise in feeder-to-finish pig farms, it might be worthwhile to involve the supplying farmers (i.e. farrow-to-feeder farms), since the problems might actually originate there. However, the complication is that farmers who sell their piglets do not always feel the benefits of certain interventions, such as vaccination, because they do not become apparent until later in the pig production process (see yellow branch in Fig. 1b). For the veal calf sector, participants reported a similar but greater sectoral problem between dairy farmers and veal fatteners, with dairy farmers limiting the time and resources they invest in the calves. More specifically, participants explained that the robustness of the young calves greatly vary if they have not received enough colostrum, have been improperly treated, and/or have received poor quality colostrum due to improper feeding, stress, or lack of vaccination of the dams (see blue branch in Fig. 2a). This robustness can be even lower if calves are transported at a younger age than legally allowed (i.e. 14 days) which sometimes happens as dairy farmers have a 7-day window to report the birth of a calf. Participants further attributed the poor care of some calves to a lack of knowledge, but mostly to a lack of financial incentive for dairy farmers, as veal calves are not very valuable. In the veal calf sector, this problem thus appears to be of bigger importance than in the pig sector, as it affects all fattening operations, compared to a subset of the pig farms.

4. Discussion

In this paper, we used a multi-stakeholder participatory approach to explore technical, economic, regulatory, and sociocultural dimensions of AMU. While multi-stakeholder approaches have become more common to qualitatively study antimicrobial use in livestock (Arnold et al., 2021; Begemann et al., 2020; Caudell et al., 2020; Poupaud et al., 2021), the combination with a participatory approach has, to our knowledge, only been used to develop solutions such as an antimicrobial stewardship leadership plan for animal health in Canada (Otto et al., 2018) as well as innovative strategies towards improved AMU in the French pig and poultry sectors (Guenin et al., 2022). In our case, the advantage of combining the two approaches was mainly that it enabled us to explore the complexity of the main issues, by exploring their technical, economic, regulatory and socio-cultural dimensions, which was facilitated by combining the perspectives of the different stakeholders. In addition,

as we explored the causal links, we were also able to see how these dimensions were interconnected, gaining a more comprehensive understanding of the main causes of AMU. As such, although most of the causes we identified had already been identified in previous literature (McKernan et al., 2021), our contribution lied more in the better understanding of how they were interrelated.

Although the method proved useful, the way it was implemented also had its limitations. As such, it should first be noted that the pig focus groups included few pig farmers and that no calf fatteners participated in the veal calf focus group discussions. Although, we believe that in this study the lack of farmers was compensated for by the active participation of other stakeholders (e.g., veterinarians), who are very involved in the production process and have a very good view of the problems at the farm level, we cannot guarantee that the underrepresentation of the farmers didn't influence the results, especially regarding the level of detail in which we discussed causes related to farmers.

Second, given the fact that participants joined the focus groups on a voluntary basis, there was a "voluntary bias", as all the participants were interested in the topic. In addition, we think there might have been a strategic bias (Hajkowicz, 2012), with some participants putting more or less emphasis on some causes, due to their own perspectives and/or interests regarding the matter. For example, when designing the problem tree, there was an instance where we had to be very careful with some of the wording chosen, as some participants feared that the results might be interpreted in certain ways by policymakers and potentially influence future policies. To address this situation, the moderator actively questioned other participants, in order to gather other points of view and reach a more nuanced agreement on how to word things. Another example, includes the fact that some causes were not discussed during the focus group, as pointed out during the feedback meeting. There, external participants pointed out that difference between group treatment versus individual treatment and oral treatments versus parenteral treatments were not on the "problem tree" of the pig sector. They also thought that for the pig sector, the branch related to economics and societal problem should be more developed. However, we can't determine whether these gaps were the result of a strategic bias, groupthink bias, or simply the fact that the participants were so used to certain things, that they no longer questioned them.

Concerning the results, the problem tree analysis of the Flemish pig and veal calf sectors identified an important amount of technical, economic, regulatory, and sociocultural factors that influence farmers' and veterinarians' decisions regarding AMU. Although participants sometimes indicated that some elements were of lesser importance, we did not ask them to rate the relative importance of the direct causes of AMU. Furthermore, while we explored causal links between causes of AMU, we did not assess the possible interconnections between the identified indirect causes, as this was not part of the used method and beyond the scope of this study. Nevertheless, gaining understanding in these could help identify feedback loops (i.e. processes that reinforce or balance themselves over time), identify leverage points for change and also better estimate the impact of an intervention over time. We therefore suggest that further research should also focus on the dynamic interactions among factors that influence AMU.

Regarding the cluster analysis, the clustering of the identified causes of AMU showed that most of the categories we generated (i.e. drivers of AMU) were composed of several dimensions (i.e. technical, economic, regulatory, and/or sociocultural), showing their complexity and highlighting the value of studying them from different angles. In addition, our results also support the idea that the context in which end users operate influences their decisions regarding AMU, as we identified several drivers of AMU at sector level, who typically involved other actors than the end-users. Examples include company advisers that may give free or conflicting advice, which had also been reported by Rojo-Gimeno et al. for Flanders (Rojo-Gimeno et al., 2018); European institutions and governmental bodies that regulate feed additives, consumers who are not well informed (e.g. differences between AMR and AMU residues in meat) and upstream suppliers (e.g. dairy farmers) who have diverging interests. Similar results regarding the diversity of stakeholders were also obtained by Guénin et al., when building ex ante impact pathways towards a prudent use of antimicrobials in the French pig and poultry sectors (Guenin et al., 2022). Therefore, when designing interventions, actors other than the end-users could also be the target (e.g. awareness campaign for consumers about antibiotic residues or new standards regarding calf care for dairy farmers) or even be encouraged to implement interventions themselves (e.g. new private standards regarding animal health and welfare).

When comparing the two sectors, it appeared that the main drivers of AMU differed, as we identified 11 sector specific drivers of AMU and six common drivers of AMU, of which one had different implications for both sectors. We hypothesize that some drivers of AMU could partly be explained by structural differences between the two sectors, something that has also been suggested by Di Martino et al. (Di Martino et al., 2019) in a comparative study among Italian turkey and rabbit. For example, in the vertically integrated veal calf sector, farmers mainly work under contract with integrators and are responsible for fattening the integrator's calves with feed and medication provided by the integrator (Kempeneers, 2019). In doing so, they also benefit from the support and visits of animal health experts employed by the integrator. In difference to this, pig farmers, who operate in a mainly fragmented food supply chain, generally own their animals and buy feed and medication. As such, they are potential customers for various upstream actors in the supply chain, which means that diverging interests can lead to conflicting advice. By considering these two different contexts, it can be hypothesized that coordination between animal health experts can be influenced by the way the supply chain is organized, with in this case a stronger collaboration and coordination in the vertically integrated sector. This could have further implications regarding the development of interventions that would aim to enhance this coordination, such as for example the coaching of farmers, as there is a possibility that this would be more effective in the pig sector than in the veal calf sector. In the same vein, interventions aimed at regulating veterinary services, such as for example legally defining the frequency of veterinary visits, would possibly be more effective in pig sector.

However, further quantitative research is needed in other to confirm whether differences between the two sectors are indeed the result of structural systemic differences. This is all the more important for causes related to stakeholders attitudes, as the results could be influenced by the composition of the focus groups. If we consider for example the observation that the "hard-to-establish link between AMU and AMR" was only addressed for the veal calf sector. At this stage, it is impossible to determine whether this is the result of differing attitudes within in the sectors, or whether participants in the pig focus group simply did not consider this issue to be important. To further study this, a quantitative survey could be used, in order to complement the results obtained via the qualitative approach.

5. Conclusion

For both case studies, this multi-stakeholder participatory approach provided a wide range of opinions and experiences of different stakeholders with respect to AMU and allowed for discussion of issues related to the entire supply chain, not just the farm. Given that we have identified several drivers of AMU at sector level, and that these involve a variety of agricultural actors, we suggest that interventions should also target actors outside the farms and/or that they may be best placed to help implement certain strategies. In addition, based on the results of our comparative analysis, we suggest that structural differences between sectors may influence some processes or factors that have an impact on

AMU. This further implies that interventions designed for a specific sector may not be appropriate for another sector or might not have the same effectiveness.

CRediT authorship contribution statement

Wauters Erwin: Validation, Funding acquisition, Conceptualization. **Hogeveen Henk:** Validation, Conceptualization. **Baudoin Fanny:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known conflict of interest that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.106099.

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