GLOBAL AMR R&D HUB

Using the Dynamic Dashboard to identify gaps and opportunities for the development of veterinary vaccines in an effort to reduce antibiotic use

August 2021

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1. Introduction

Antimicrobial resistance (AMR) poses a global threat to public health and also has severe implications for the health and welfare of animal populations as well as the safety and security of global food systems[1]. While antibiotics are needed to ensure animal health and welfare, they have been over- and misused in animal production, thereby contributing to the development of AMR. Increased restrictions on the use of antibiotics in animal production has emphasised the need for responsible and prudent antibiotic use and invigorated the development of efficacious alternatives to antibiotics, including vaccines[2].

Vaccines have been identified as promising tools to prevent animal diseases and could therefore contribute to reduce the need for antibiotic use[3]. However, there are significant scientific and technical challenges for veterinary vaccines and their development requires considerable resources and investments. Public and private sector funding for research on antibiotic alternatives in animal production[4] is scarce and guidance on prioritization of research needs is crucial to target areas of greatest impact. In this context, the World Organisation for Animal Health (OIE) convened an *ad hoc* Group of relevant experts and provided a priority list of diseases and syndromes with highest impact on antimicrobial use to help guide the prioritization of investments in animal vaccines that may reduce the need for antimicrobial use[5].

Here, we used the OIE priority vaccine list to conduct an analysis of the public and philanthropic funding supporting animal health vaccine development based on the information captured in the Investment Gallery of the Dynamic Dashboard[6]. Although viral and parasitic diseases are included in the OIE priority list and remain important in the fight against AMR, this report is focused on bacterial diseases. This is due to more data being available and because the effect of viral and parasitic diseases on AMR is largely indirect by contributing to secondary bacterial infections.

The overall aim of the report is to support the identification of potential gaps and opportunities for funding research and development (R&D) relevant for animal health vaccines.

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[1] IACG report (2019): 'No Time to Wait: Securing The Future From Drug-Resistant Infections', IACG Report Link

[2] Jim O'Neill (2015): Antimicrobials in Agriculture and the Environment: Reducing Unnecessary Use and Waste, Report Link

[3] Hoelzer et al. Vet Res (2018): Vaccines as alternatives to antibiotics for food producing animals. Part 1: challenges and needs.

[4] US Department of Health and Human Services: Development of Vaccines, Diagnostics, and Therapeutics to Combat Antibiotic Resistance (2017), PACCARB Link

[5] OIE ad hoc Group on 'Prioritization of Diseases for which Vaccines Could Reduce Antimicrobial Use in Animals', 2015: Chicken, Swine, Fish and 2018: Cattle, Sheep, Goats

[6] Dynamic Dashboard – Global AMR R&D Hub (globalamrhub.org)

2. Results

2.1 Overview of funding presented in the Dynamic Dashboard

The investment gallery of the Dynamic Dashboard presents public and philanthropic investments in AMR R&D that were initiated from 1st January 2017 (Dashboard link). At the cut-off date 16 March 2021, only investments related to human and animal health as well as projects where the sector was not specified were captured and considered for this analysis – projects related to plants and environment were published on 29 April 2021[7].

Overall, the majority of the total investment in AMR R&D was related to human health projects (~90%/7.7 billion USD, 10355 projects), as shown in **Table 1** and **Figure 1**. The remaining 10% (728 million USD, 1222 projects) targeted animal health-related R&D, of which two thirds addressed the research areas 'Operational & Implementation', 'Basic Research' and 'Capacity Building'[8] (35%/254 million USD, 18%/133 million USD and 13%/95 million USD, respectively, **Figure 2**).

Interestingly, human health product-related R&D (therapeutics, vaccines, diagnostics), focused on the development of therapeutics and received 60% (1.7 billion USD) of the total funding, whereas vaccines and diagnostics received about 20% each (570 million USD and 542 million USD, respectively). In contrast, the majority of product-related R&D in animal health was for the development of vaccines (43%/68 million USD), followed by diagnostics (35%/55 million USD) and therapeutics (23%/36 million USD). This may be a result of the different priority settings for R&D within the different health sectors, and may also indicate an underappreciated role of vaccines in the evaluation of AMR strategies, particularly in human health.

[7] Special Newsletter: Advancing the One Health response to AMR
[8] Link: Definitions Dynamic Dashboard

Research Area	Total		Animal Health		% Animal Health of total	
	Investments (million USD)	Number of projects	Investments (million USD)	Number of projects	Investments (million USD)	Number of projects
Basic Research	2339	5439	133	316	6	6
Therapeutics	1734	1263	36	68	2	5
Operational	1529	2046	254	369	17	18
Vaccines	638	399	68	111	11	28
Diagnostic	597	769	55	100	9	13
Capacity Building	530	422	95	96	18	23
Other Products	179	456	18	54	10	12
Preventives Other	71	89	25	48	35	54
Policy	67	112	7	20	10	18
Promotants	44	45	37	40	84	89
Total	**7,728**	**10,355**	**728**	**1,222**	**9**	**12**

Table 1: Overall investment for AMR R&D between 1 January 2017 and 16 March 2021 captured in the Dynamic Dashboard.

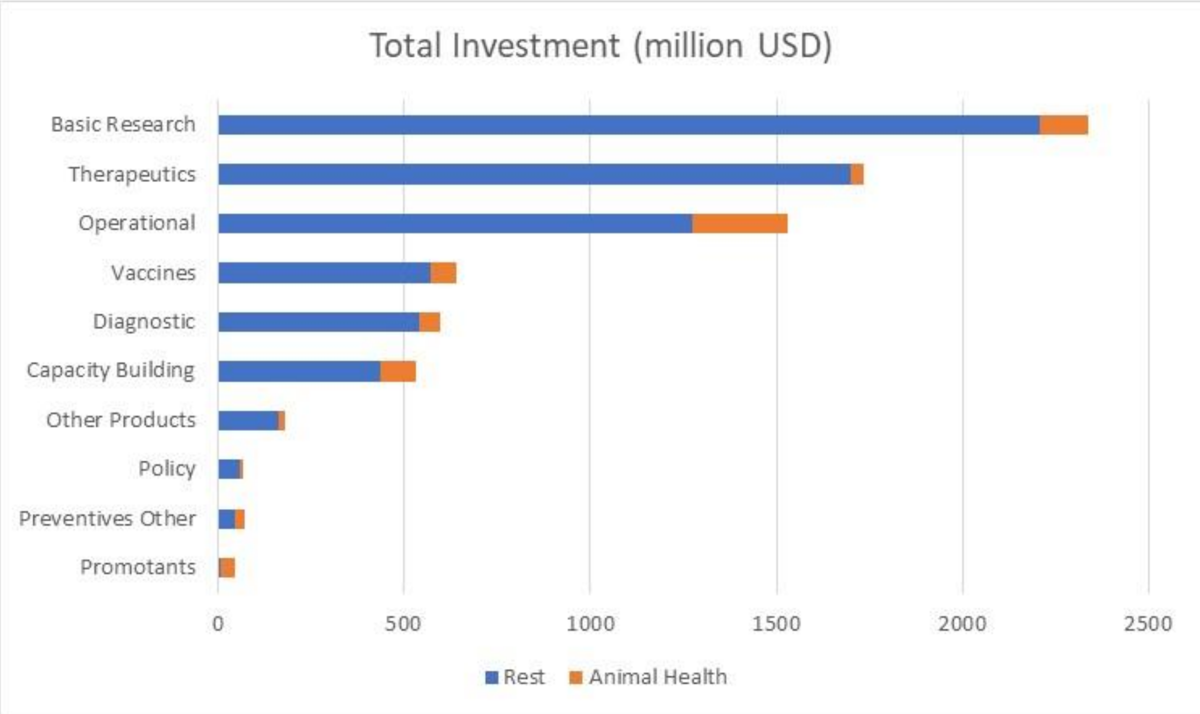

Figure 1: Overall investment for AMR R&D between 1 January 2017 and 16 March 2021 captured in the Dynamic Dashboard. 'Rest' indicates investments related to human health or where the sector is not specified.

2.2 Investments supporting vaccine development in animal health

Of the total investments into animal health, 9% (68 million USD, 111 projects) was directed towards vaccine development, the majority coming from public-government entities (50 million USD or 73% of total vaccine budget, **Figure 2**). Here, nearly 80% (54 million USD, 53 projects) was provided by funders from the United Kingdom, the United States and the European Union (19 million USD, 18 million USD and 16 million USD respectively, **Figure 3a**). Universities and Public Research Institutions each received about one third of the funding for vaccine development (23 million USD and 22 million USD respectively), Public Bodies received 19% (13 million USD) and the remaining 15% (11 million USD) went towards Industry, Private Research Institutions and other entities (**Figure 3b**).

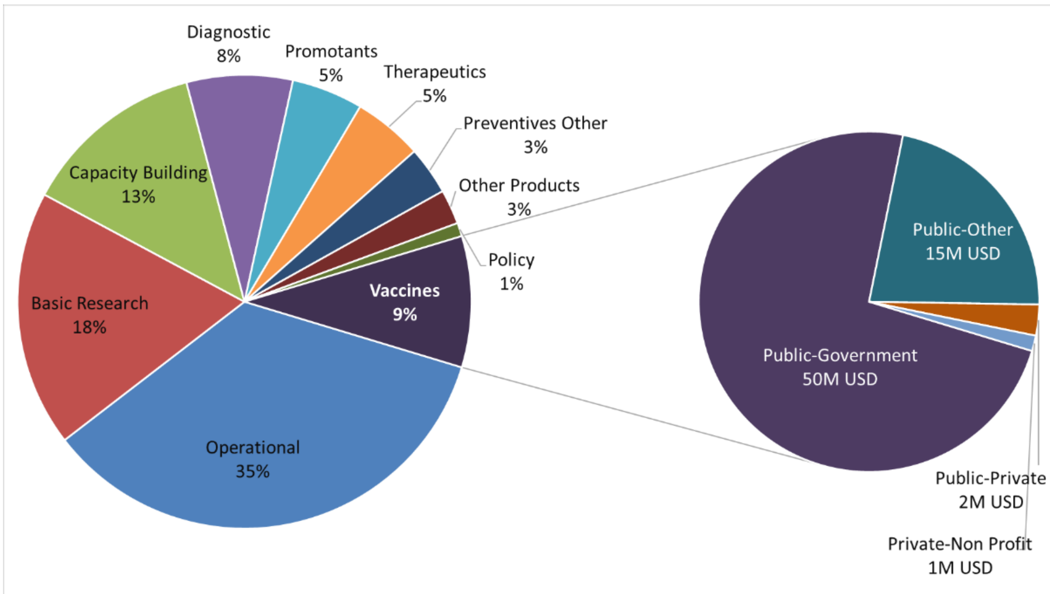

Figure 2: Investment in animal health by research area in percentage (left) and vaccine development by type of funders in million USD (right).

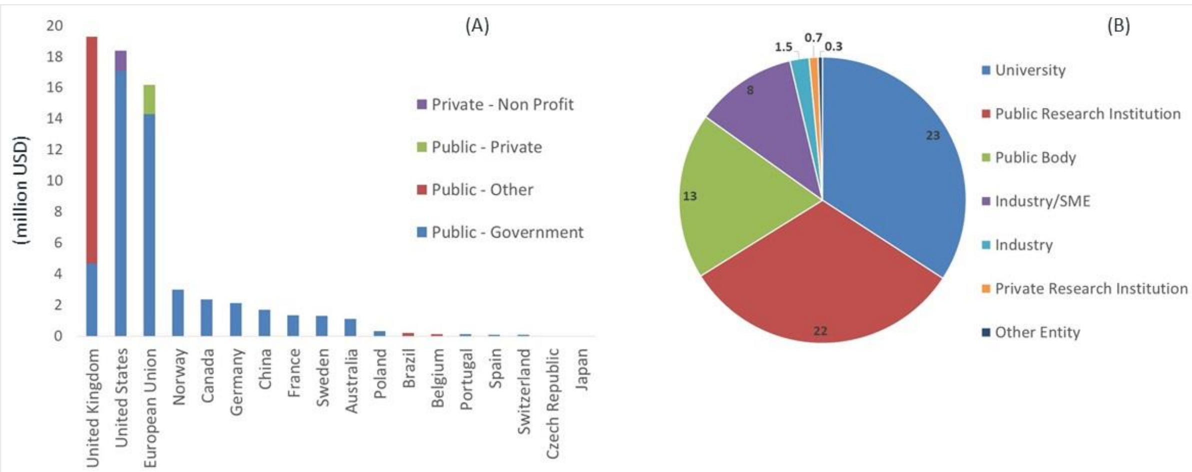

Figure 3: Investment in animal health vaccine development by (A) Country of Funders and (B) Research Organizations in million USD.

2.3 Investments into overall animal vaccine R&D – OIE-prioritized bacterial diseases

Vaccines are currently the most promising alternative to antibiotics in animal health and are widely used to prevent bacterial and other infectious diseases in terrestrial and aquatic animals. However, research resources are scarce and prioritization of research needs is required to ensure that public and philanthropic resources are targeting the most promising approaches and areas of greatest impact. Therefore, in support of these prioritization efforts, OIE with help from the OIE *ad hoc* Group, provided a prioritization list of diseases for which vaccines could reduce antimicrobial use for chicken, pigs, fish, cattle and small ruminants[9]. A number of key principles were adopted to facilitate prioritization based on identifying the most prevalent and important bacterial and non-bacterial infections associated with antibiotic use, patterns of antibiotic use in response to syndromic indication or diagnosed disease, the availability of vaccines and their effectiveness and the potential for new or improved vaccines to reduce the need for antimicrobial treatment. Investments relevant to viral and parasitic diseases were also considered as they often are the underlying cause for secondary bacterial infections driving increased antibiotic use and remain important in tackling AMR.

The majority of funding captured in the Investment Gallery of the Dynamic Dashboard between 1 January 2017 and 16 March 2021 addressing vaccine development targets bacterial infections (> 60%, 42 million USD, 83 projects), with more limited funding directed towards parasitic (18%, 12 million USD) and viral (15%, 19 million USD) infectious diseases (**Figure 4**, **Table 2**). This is likely a reflection of the prioritised research focus and key search terms used that primarily target AMR-relevant bacterial pathogens. As a result, we focused our in-depth analysis of vaccine R&D on bacterial diseases that drive high antibiotic use in animals based on the OIE priority vaccine lists[8] (adapted list shown in **Appendix Table 1**).

[9] The OIE ad hoc Group on 'Prioritization of Diseases for which Vaccines Could Reduce Antimicrobial Use in Animals', 2015: Chicken, Swine, Fish and 2018: Cattle, Sheep, Goats

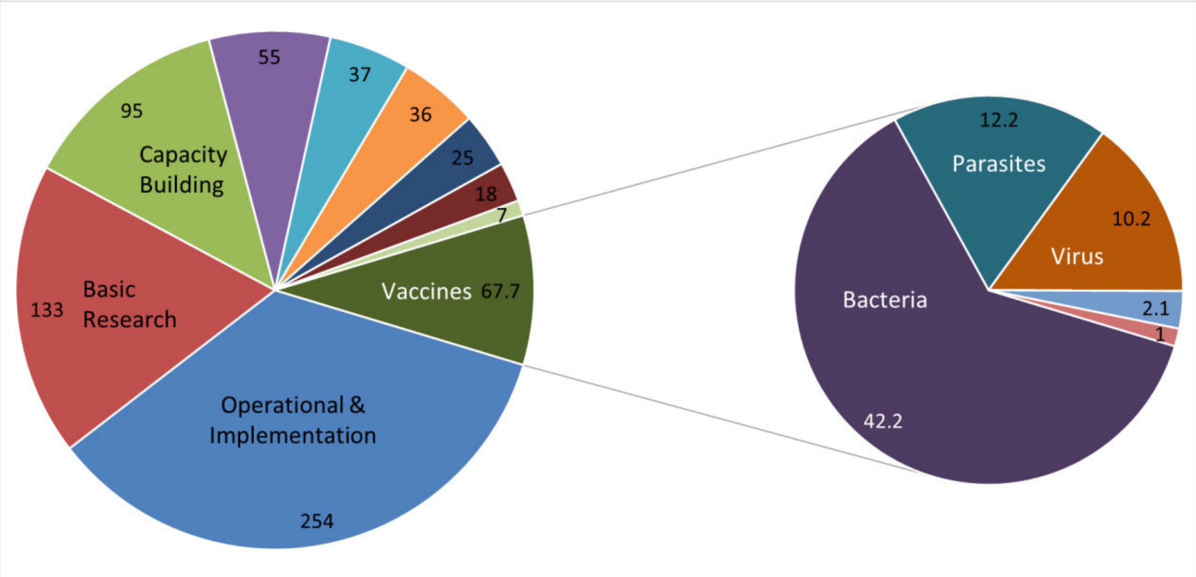

Figure 4: Investment in animal vaccine development by infectious agent (million USD).

Infectious Agent		Investments (million USD)	Number of projetcs	% of total Vaccine Investment (AH)
All pathogens		68	111	100
Bacteria	**All**	**42**	**83**	**62**
	OIE vaccine priority	22	65	32
	Other	14	8	21
	Not specified	7	10	10
Non-bacteria	**All**	**26**	**37**	**38**
	Virus	10	28	15
	Parasites	12	8	18
	Fungus	2	1	3
	Not Specified	1	2	1

Table 2: Investment in animal vaccine development by infectious agent (million USD) and percentage total animal vaccine investment.

We observed that of the total investment in vaccine development, 32% (22 million USD, 65 projects) targeted the OIE-prioritized bacterial infectious agents (**Table 2**). Here, the majority addressed bacterial diseases in pigs (38%/8.2 million USD, 19 projects, 14 of which are unique) followed by poultry (28%/6.1 million USD, 7 projects, 6 of which are unique) and cattle (26%/5.6 million USD, 21 projects, 15 of which are unique). Less funding was provided for vaccine R&D targeting bacterial diseases of fish (6%/1.2 million USD, 8 projects) and small ruminants (3%/0.6 million USD, 10 projects, 3 of which are unique) (**Figure 5**, **Table 3**).

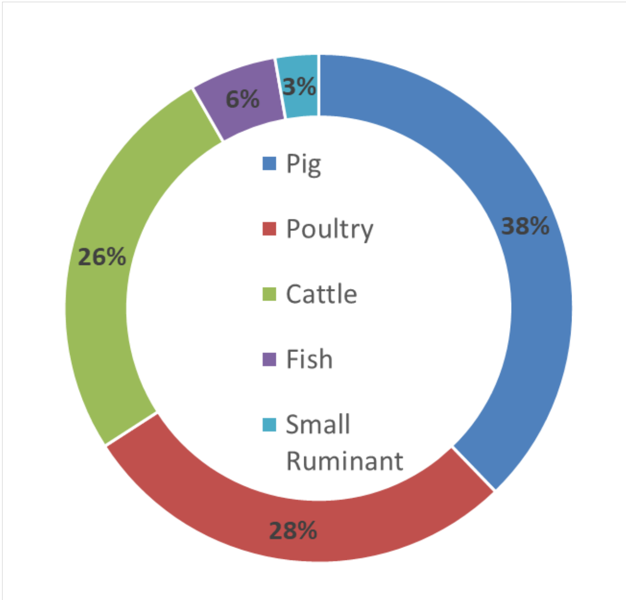

Figure 5: Investment in vaccine development of the OIE prioritized bacterial infections by animal groups shown as percentage of the total investment in the OIE-prioritized bacterial infections.

Animal Group	Investment Vaccines in million USD (bacteria)	Investments OIE prioritized Vaccines (bacteria)		
		million USD	# Projects	% of OIE priority
Pig	11.8	8.2	19	38
Poultry	11.7	6.1	7	28
Cattle	6.2	5.6	21	26
Fish	1.2	1.2	8	6
Small Ruminant	2.7	0.6	10	3
Other	2.3	NA	NA	NA
Total	35.9	21.7	65	100

Table 3: Investment in vaccine development targeting bacterial infections by animal groups shown as total investment (million USD) with focus on the OIE-prioritized bacterial infections (million USD, number of projects and percentage).

2.4 Vaccine R&D investments by animal group and individual OIE-prioritized bacterial pathogens

For the purpose of gaining more insight into potential gaps and opportunities for funding animal vaccine R&D, the investments were analysed according to individual bacterial diseases within the key animal groups and displayed by genus level (see list in **Appendix Table 1** for individual bacterial species).

2.4.1 The OIE-prioritized bacterial diseases in pigs

Within the overall investment in animal health vaccines, 17% targeted bacterial infections in pigs (11.8 million USD, 26 projects) - about 70% addressed the OIE-prioritized bacterial diseases (8.2 million USD, 19 projects, **Table 3**). However, funding for only five of the eight prioritized bacterial pathogens was provided. Here, the majority of funding went towards projects targeting bacteria within the genus *Streptococcus* (80%, 6.6M USD, 14 projects), followed by *Actinobacillus*, *Haemophilus* and *Mycoplasma* (**Figure 6**, **Table 4**).

Even though there was no investment captured in the Dynamic Dashboard against three pathogens (*Escherichia coli*, *Lawsonia* and *Pasteurella*), the animal health pharmaceutical industry reported investments into the development of alternatives to antibiotics (ATA), including vaccines, against *Pasteurella* and *Lawsonia* (pers. comm. Health for Animals[10]).

The remaining 30% of the investments (3.6 million USD, 6 projects, not shown) targeted five additional bacterial pathogens (genus *Campylobacter, Salmonella, Staphylococcus, Clostridium and Clostridioides)* relevant for pigs but not prioritized by the OIE for vaccine development for which new or improved vaccines would significantly reduce the need for antibiotic use.

[10] https://healthforanimals.org/; Health for Animals is member of the Global AMR R&D Hub's Stakeholder Group

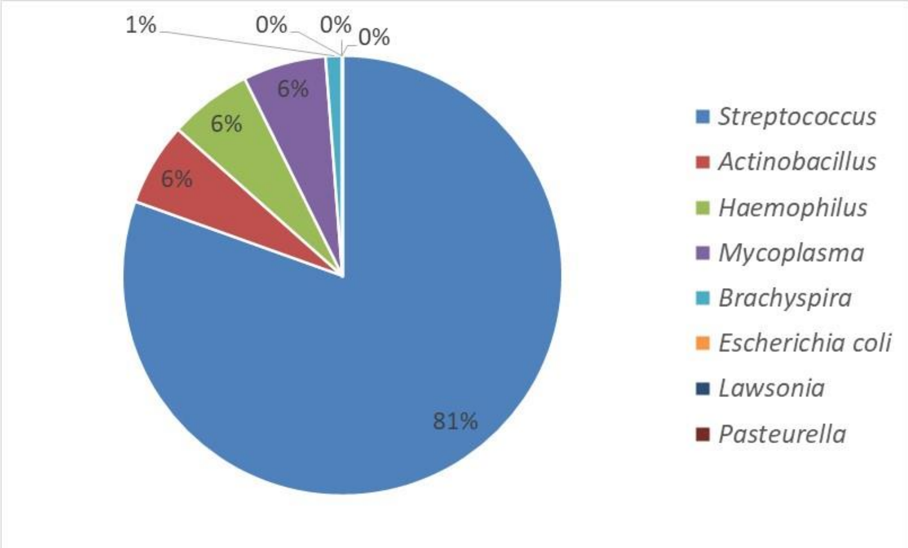

Figure 6: Vaccine R&D investment in pigs by the OIE bacterial priority pathogens (percent investment of total OIE-prioritized bacterial pathogens in pigs).

OIE Vaccine Priority in Pigs	No of Projects	Investment (million USD)	% of total vaccine investment in pigs	% of total OIE priority vaccine investment in pigs
Streptococcus	14	6.6	56	80
Actinobacillus	2	0.5	5	6
Haemophilus	1	0.5	4	6
Mycoplasma	1	0.5	4	6
Brachyspira	1	0.1	1	1
Escherichia coli	0	0	0	0
Lawsonia	0	0	0	0
Pasteurella	0	0	0	0
Total	18	8.2	70	100

Table 4: Vaccine R&D investments in pigs by the OIE bacterial priority pathogens (number of projects, total investment in million USD, percentage of total investment, percentage of the OIE-prioritized bacterial pathogens in pig).

2.4.2 The OIE-prioritized bacterial infections in poultry

Development of vaccines against bacterial infections in poultry (mostly chicken) received similar funding as pigs, namely 17% of the overall animal vaccine R&D funding (11.7 million USD, 26 projects, **Table 3**). About half (53%, 6.1 million USD, 7 projects) of the investment targeted the two OIE-prioritized bacterial pathogens (*E. coli, Clostridium*) - 61% of the funding was allocated to projects investigating *E. coli* and 39% towards *Clostridium* (3.7 million USD, 4 projects and 2.4 million USD, 4 projects, respectively, **Table 5**, **Figure 7**).

The remaining 47% of investments (5.6 million USD, 8 projects) targeted three additional bacterial pathogens that are relevant in poultry but not prioritized by the OIE for vaccine development as they did not meet the criteria that vaccines would significantly reduce the need for antibiotic use. Both OIE-prioritized bacterial pathogens as well as *Salmonella* – a relevant zoonotic foodborne pathogen – are addressed by the animal health pharmaceutical industry (pers. comm. Health for Animals).

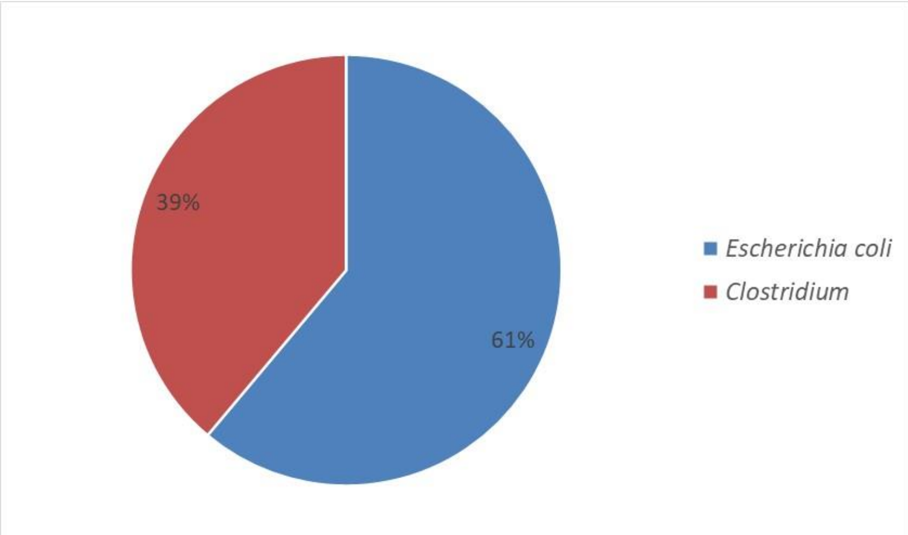

Figure 7: Vaccine R&D investment in poultry by OIE bacterial priority pathogens (percent investment of total OIE-prioritized bacterial pathogens in poultry).

OIE Vaccine Priority in Poultry	No of Projects	Investment (million USD)	% of total vaccine investment in poultry	% of total OIE priority vaccine investment in poultry
Escherichia coli	4	3.7	32	61
Clostridium	4	2.4	21	39
Total	7	6.1	53	100

Table 5: Vaccine R&D investments in poultry by the OIE bacterial priority pathogens (number of projects, total investment in million USD, percentage of total investment, percentage of the OIE-prioritized bacterial pathogens in poultry).

2.4.3 The OIE-prioritized bacterial infections in cattle

Less than 10% (6.2 million USD, 21 projects, **Table 3**) of the overall investment in animal health vaccine development focused on bacterial infections in cattle. The majority (90%, 5.6 million USD, 21 projects) of the investments targeted only four of the 14 bacterial pathogens prioritized by OIE for vaccine R&D (**Figure 8**, **Table 6**). Here, funding largely went towards *Mycobacterium* (80%, 4 million USD, 10 projects) and to a lesser extent towards *Staphylococcus*, *Mycoplasma* and *Pasteurella* (12%, 8% and <1%, respectively). For the remaining ten OIE priority bacterial pathogens, there was no investment captured in the Dynamic Dashboard. It should be noted that prioritization of relevant diseases in cattle were not listed according to dairy and meat cattle, but listed as a whole group. The same applies to small ruminants (see below). Also, four of the six projects targeting *Staphylococcus spp.* addressed vaccine R&D against mastitis (0.5 million USD).

However, the animal health pharmaceutical industry reported investments for vaccine development and other ATAs into seven of these ten pathogens (*Bacillus, E. coli, Histophilus, Leptospira, Mannheimia, Salmonella and Streptococcus*). Based on the information shown in the Dynamic Dashboard, there were no investments into the remaining three bacterial infectious agents (*Dermatophilus, Fusobacterium and Trueperella*) within the reported time period.

The remaining 10% of the investments (0.6 million USD, 2 projects, not shown) targeted two additional bacterial pathogens (*Campylobacter and Clostridium*) that are relevant pathogens in cattle but not prioritized by the OIE for vaccine development as they did not meet the criteria. Both pathogens are not considered to trigger high antibiotic use and therefore, vaccines would not significantly reduce the need for antibiotic use.

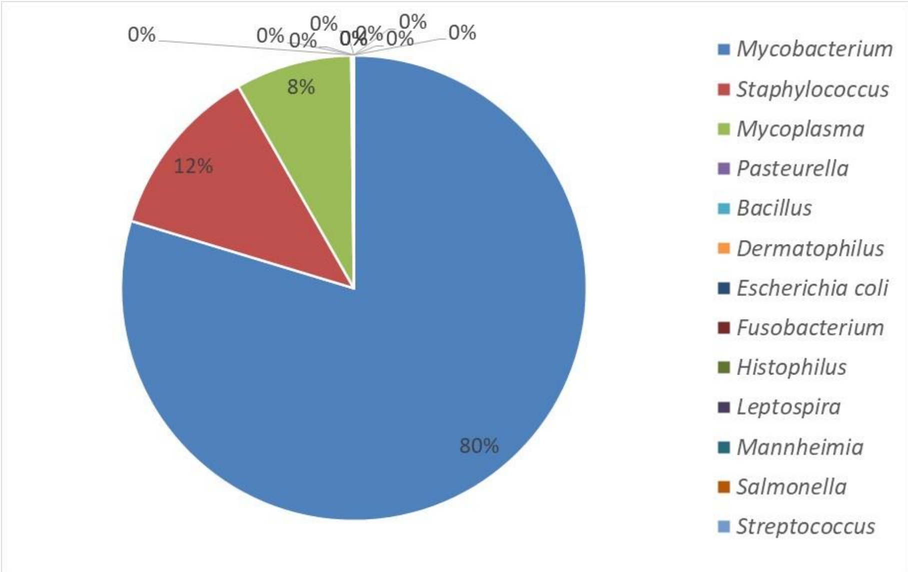

Figure 8: Vaccine R&D investment in cattle by the OIE bacterial priority pathogens (percent investment of total OIE-prioritized bacterial pathogens in cattle).

OIE Vaccine Priority in Cattle	No of Projects	Investment (million USD)	% of total vaccine investment in cattle	% of total OIE priority vaccine investment in cattle
Mycobacterium	10	4	71	80
Staphylococcus	6	0.7	11	12
Mycoplasma	1	0.5	7	8
Pasteurella	6	0.01	0	0
Bacillus	0	0	0	0
Dermatophilus	0	0	0	0
Escherichia coli	0	0	0	0
Fusobacterium	0	0	0	0
Histophilus	0	0	0	0
Leptospira	0	0	0	0
Mannheimia	0	0	0	0
Salmonella	0	0	0	0
Streptococcus	0	0	0	0
Trueperella	0	0	0	0
Total	21	5.6	90	100

Table 6: Vaccine R&D investments in cattle by the OIE bacterial priority pathogens (number of projects, total investment in million USD, percentage of total investment, percentage of the OIE-prioritized bacterial pathogens in cattle).

2.4.4 The OIE-prioritized bacterial infections in small ruminants

About 3% (2.7 million USD, 16 projects, **Table 3**) of the overall vaccine investment in animal health went towards bacterial infections in small ruminants. However, only about 20% (0.6 million USD, ten projects, 3 of which are unique) of the investment targeted the OIE-prioritized bacterial pathogens and here only three of the 13 bacterial pathogens (**Figure 9**, **Table 7**). The majority of funding went towards vaccine development against *Mycobacterium* and *Staphylococcus* (11% and 10%, 0.3 million USD each, 4 & 2 projects, respectively), while funding targeting *Pasteurella* was negligible (10,000 USD, 6 projects). For ten pathogens there was no investment captured in the Dynamic Dashboard, and of those only *Mycoplasma* was addressed by the animal health pharmaceutical industry.

The remaining 79% of the total investments (2.1 million USD, 4 projects, not shown) targeted two additional bacterial pathogens (*Brucella* and *Ehrlichia*; 1.6 million USD/3 projects and 0.5 million USD/1 project, respectively) that are relevant pathogens in small ruminants but not prioritized by the OIE for vaccine development as they did not meet the criteria that vaccines would significantly reduce the need for antibiotic use.

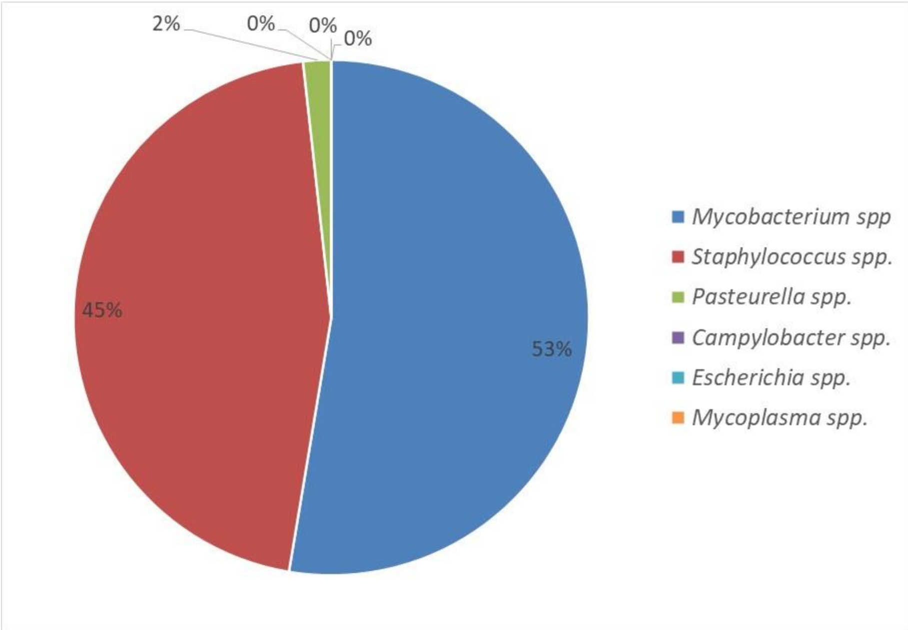

Figure 9: Vaccine R&D investment in small ruminants by the OIE bacterial priority pathogens (percent investment of total OIE-prioritized bacterial pathogens in small ruminants).

OIE Vaccine Priority in small Ruminants	No of Projects	Investment (million USD)	% of total vaccine investment in smallR	% of total OIE priority vaccine investment in smallR
Mycobacterium spp	4	0.3	11	53
Staphylococcus spp.	2	0.3	10	46
Pasteurella spp.	6	0.01	0	2
Campylobacter spp.	0	0	0	0
Escherichia spp.	0	0	0	0
Mycoplasma spp.	0	0	0	0
Bibersteinia	0	0	0	0
Chlamydophila	0	0	0	0
Corynebacterium	0	0	0	0
Dichelobacter	0	0	0	0
Fusobacterium	0	0	0	0
Mannheimia	0	0	0	0
Trueperella	0	0	0	0
Total	10	0.6	21	100

Table 7: Vaccine R&D investments in small ruminants by the OIE bacterial priority pathogens (number of projects, total investment in million USD, percentage of total investment, percentage of the OIE-prioritized bacterial pathogens in small ruminants).

2.4.5 The OIE-prioritized bacterial infections in fish

All the investment into vaccine development for fish targeted bacterial infections prioritized by the OIE (1.8% of total animal health vaccine investment, 1.2 million USD, 8 projects). However, only three of the nine prioritized bacterial pathogens received funding. Here, half of the funding went towards vaccine development against *Aeromonas* (52%/0.6 million USD, 5 projects), followed by *Edwardsiella* and *Streptococcus* (27%/0.3 million USD, 2 projects and 21%/0.3 million USD, 5 projects, respectively; **Figure 10**, **Table 8**). There was no investment captured in the Dynamic Dashboard for six pathogens and information from the animal health pharmaceutical industry was not collected.

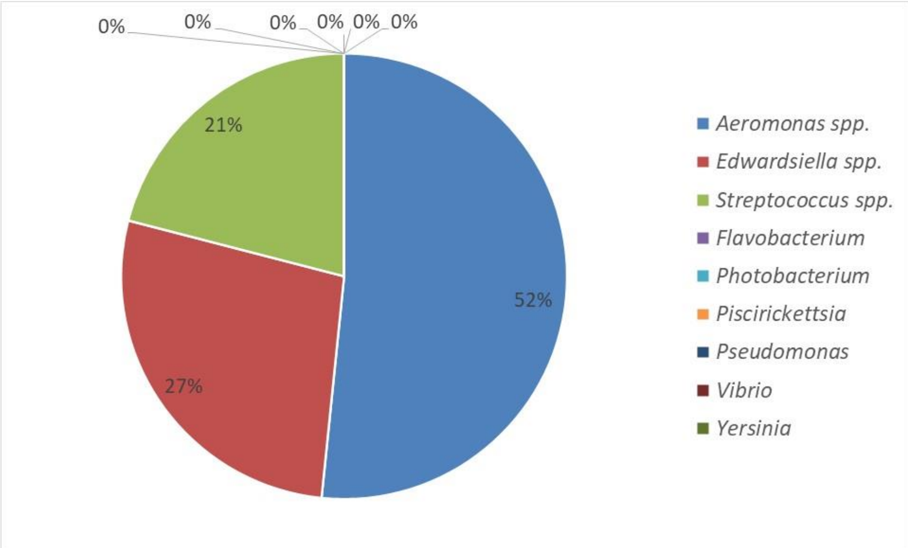

Figure 10: Vaccine R&D investment in fish by OIE bacterial priority pathogens (percent investment of total OIE-prioritized bacterial pathogens in fish).

OIE Vaccine Priority in Fish	No of Projects	Investment (million USD)	% of total vaccine investment in fish	% of total OIE priority vaccine investment in fish
Aeromonas spp.	5	0.6	52	52
Edwardsiella spp.	2	0.3	27	27
Streptococcus spp.	5	0.3	21	21
Flavobacterium	0	0	0	0
Photobacterium	0	0	0	0
Piscirickettsia	0	0	0	0
Pseudomonas	0	0	0	0
Vibrio	0	0	0	0
Yersinia	0	0	0	0
Total	8	1.2	100	100

Table 8: Vaccine R&D investments in fish by the OIE bacterial priority pathogens (number of projects, total investment in million USD, percentage of total investment, percentage of the OIE-prioritized bacterial pathogens in fish).

3. Conclusions

Tackling AMR requires a concerted global effort to fill gaps in the current knowledge and evidence base, maximise existing resources and identify the most appropriate areas for further investment. Even though animal health faces similar pressure as human health in combating AMR, it receives only a small fraction of the public investment, as also shown in this report based on the data collected in the Dynamic Dashboard (https://dashboard.globalamrhub.org/).

Vaccines represent a cost-effective, preventive, medical countermeasure that can be used to confront the threat of AMR and is a key strategic priority in animal health for reducing antibiotic use in animal production[11]. Here, we conducted an analysis of investments for vaccine development against the OIE-prioritized bacterial infectious agents with the aim to help provide guidance to policy and decision makers regarding investments in vaccine research and development for livestock, poultry and fish. It should be noted that viral and other infectious diseases remain important in tackling AMR as they can cause secondary bacterial infections, but were not analysed in this report.

This report shows that about half of the overall public and philanthropic funding for vaccine development against animal bacterial infections target the OIE-prioritized bacterial infections in pig, poultry, cattle and fish for which new or improved vaccines would significantly reduce the need for antibiotic use. However, funding for vaccine development does not address all bacterial pathogens within the individual animal groups, even when considering investments into vaccines and other ATAs reported by the animal health pharmaceutical industry. Particularly in cattle, funding for vaccine R&D is lacking for the majority of the bacterial infectious agents.

[11] Hoelzer et al. Vet Res (2018): Vaccines as alternatives to antibiotics for food producing animals. Part 1: challenges and needs.

4. Methodology

Details of the methodology regarding the development of the Dynamic Dashboard and the first annual analysis has been provided previously and can be found in the Dynamic Dashboard Library here.

Briefly, the three galleries of the Global AMR R&D Hub's Dynamic Dashboard[12] capture components of the research context supporting the effort to understand and combat the threat from AMR. The investments in AMR R&D gallery of the Dynamic Dashboard reports on basic and applied research projects and investments from public and philanthropic funders starting on 1 January 2017. As information is continually updated in all three galleries, this report is based on a snapshot of the information taken from the Investment Gallery on 16 March 2021. At this timepoint only information on human and animal health related R&D was captured. Information on plant- and environment-relevant investments was launched on 29 April 2021[13].

For conducting an analysis on animal vaccine development relevant for AMR R&D, we used the information published by the OIE that provides a priority list of diseases and syndromes with highest impact on antimicrobial consumption to help guide the prioritization of investments in animal vaccines that may reduce the need for antimicrobial use[14]. Given the bias in the AMR field towards bacterial diseases, e.g., in human health and key search terms, we focused our analysis and report on the bacterial diseases in major animal species including fish. Here, data was collected and categorized according to the species listed in **Appendix Table 1**. For the categorization process and easiness of representation, only the bacterial genus level was used and displayed in the tables.

Projects that received funding from more than one source and/or where more than one recipient received funding were listed and counted as multiple projects, each with unique ID numbers in order to capture all funders and recipient information. The budget was split according to the number of funders and recipient, unless the exact amount was provided.

[12] https://dashboard.globalamrhub.org/

[13] Special Newsletter: Advancing the One Health response to AMR

[14] OIE ad hoc Group on 'Prioritization of Diseases for which Vaccines Could Reduce Antimicrobial Use in Animals', 2015: Chicken, Swine, Fish and 2018: Cattle, Sheep, Goats

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For questions or enquiries please contact the Global AMR R&D Hub (globalamrhub@dzif.de).

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6. Appendix

Genus	Primary pathogen(s)	Antimicrobial Use	Commercial vaccine exists	Vaccine Research Priority
Cattle (n=14)				
Bacillus	*Bacillus anthracis*	Medium	Yes	Low
Dermatophilus	*Dermatophilus congolensis*	Medium	No	Medium
Escherichia coli	*Escherichia coli*	High	Yes	Low
Fusobacterium	*Fusobacterium spp.*	High	No	High
Histophilus	*Histophilus somni*	High	Yes	Medium
Leptospira	*Leptospira spp.*	Medium	Yes	Medium
Mannheimia	*Mannheimia haemolytica*	High	Yes	High
Mycobacterium	*Mycobacterium avium subspecies paratuberculosis*	Medium	Yes	Medium
Mycoplasma	*Mycoplasma mycoides, Mycoplasma bovis*	High, Medium	Yes	High
Pasteurella	*Pasteurella multocida*	High	Yes	High, low
Salmonella	*Salmonella enterica*	High	Yes	Medium
Staphylococcus	*Staphylococcus aureus*	High	Yes	High
Streptococcus	*Streptococcus agalactiae, Streptococcus uberis*	High	Yes	High
Trueperella	*Trueperella pyogenes*	High	No	High
Pig (n=8)				
Actinobacillus	*Actinobacillus pleuropneumoniae*	High	Yes	High
Haemophilus	*Haemophilus parasuis*	Medium	Yes	Medium
Pasteurella	*Pasteurella multocida*	High	No	High
Escherichia coli	*Escherichia coli*	High	Yes	High
Brachyspira	*Brachyspira spp B. hyodysenteriae, B. pilosicoli*	Medium-High	No	High
Lawsonia	*Lawsonia intracellularis*	High	Yes	Low
Mycoplasma	*Mycoplasma hyopneumoniae*	High	Yes	Low
Streptococcus	*Streptococcus suis*	High	Yes	High
Small Ruminants (n=13)				
Bibersteinia	*Bibersteinia trehalosi*	Medium	Yes	Medium
Mannheimia	*Mannheimia haemolytica, Mannheimia capricolum*	High	Yes	High
Pasteurella	*Pasteurella multocida*	High-Medium	Yes	High-Medium
Escherichia coli	*Escherichia coli*	High	Yes	Low
Campylobacter	*Campylobacter jejuni*	Medium	Yes	Medium
Chlamydophila	*Chlamydophila spp.*	Medium	Yes	Medium-Low
Corynebacterium	*Corynebacterium pseudotuberculosis, C. spp.*	High-Medium	Yes	Medium
Dichelobacter	*Dichelobacter nodosus*	High	Yes	High
Fusobacterium	*Fusobacterium spp.*	High	No	High
Mycobacterium	*Mycobacterium avium subspecies paratuberculosis*	Medium	Yes	Medium
Mycoplasma	*M.a agalactiae, M. capricolum, M. hyopneumoniae, M. mycoides, M. ovipneumoniae, M. putrefaciens*	High-Medium	No/Yes	High-Medium
Staphylococcus	*Staphylococcus aureus*	Medium	Yes	Low
Trueperella	*Trueperella pyogenes*	Medium	No	Medium
Chicken (n=2)				
Escherichia coli	*Escherichia coli*	High	Yes	High
Clostridium	*Clostridium perfringens, type A*	High	Yes	High
Fish (n=9)				
Aeromonas	*Aeromonas spp.*	High to medium (de	No	High to Low
Edwardsiella	*E. tarda, E. ictaluri, E. piscicida*	Medium	Yes	High
Flavobacterium	*F. columnare, F. psychrophilum*	Medium	Yes	Low
Photobacterium	*Photobacterium spp.*	Medium	Yes	High
Piscirickettsia	*Piscirickettsia salmonis*	Medium	Yes	Unknown
Pseudomonas	*Pseudomonas spp*	High	No	High
Streptococcus	*Streptococcus spp.*	Medium	Yes	High/Medium
Vibrio	*Vibrio spp., Vibrio anguillarum*	Medium	Yes	High to Low
Yersinia	*Yersinia rukerii*	Medium	Yes	Low

Appendix Table 1: List for bacterial infections in cattle, pig, small ruminant, chicken and fish considered in this report and adapted from the OIE Priority Vaccine documents[15]*. Also shown, antimicrobial use, existence of commercial vaccine and level of vaccine research priority as identified by the* OIE *ad hoc* Group *and taken from the OIE Priority Vaccine documents.*

[15] The OIE ad hoc Group on 'Prioritization of Diseases for which Vaccines Could Reduce Antimicrobial Use in Animals', 2015: Chicken, Swine, Fish and 2018: Cattle, Sheep, Goats

CONTACT
+49 30 403 677 76
globalamrhub@dzif.de

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GLOBAL AMR R&D HUB
c/o Unicorn Workspaces
Schlüterstr. 39
10629 Berlin, Germany

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