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European Partnership on Animal Health and Welfare – Strategic Research and Innovation Agenda

(draft of the index)

Highlights on objectives, actions and related research needs

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Introduction

Safeguarding animal health (AH) and ensuring animal welfare (AW) is central for supporting the health, wellbeing and sustainability of livestock farming and related activities, such as protection of public health, food security and safety, rural economies and environmental health. Furthermore, the sector contributes substantially to the EU economy through employment and trade of products.

The ever-changing environment that surrounds the AH and AW sectors, such as the significant and far-ranging changes in climate, social needs, technology, economics and politics, increase the need for continuous research and innovation.

This Strategic Research and Innovation Agenda (SRIA) captures the long-term vision of animal health and welfare research and innovation. It aims to create an integrated approach toward AH and AW and put its users in the position to achieve shared objectives and reach common goals and results.

This SRIA will guide European research funders to prioritize areas for investment and collaboration, as well as to assist researchers and research managers to focus their research activities and stakeholders invest their own resources and knowledge.

The SRIA is a joint strategic document for the future co-funded European Partnership on Animal Health and Welfare (EUP AH&W) and for the ERA-NET on International Coordination of Research on Infectious Animal Diseases (ICRAD). It also provides an update of the agendas produced under the SCAR Collaborative Working Group on Animal Health and Welfare (CWG AHW) in recent years and aims to provide suggested priorities for R&I within Horizon Europe, EUP AH&W and any future transnational call on animal health and welfare.

The SRIA has been developed in collaboration with the ICRAD WP6 team, the core group of EUP AH&W, CWG AHW members and its experts' community. In addition, it involved extensive and broad consultation of experts and academics in scientific areas related to veterinary sciences with a One Health (OH) approach, industry representatives, trade associations and breeders and aligns with the objectives laid down in the Animal Health Law and its principle of "prevent is better than cure"[1] and in the Green Deal, in particular as regards the relationship/connection "from Farm to Fork"[2].

The process received support in the dossier created to outline the future EUP AH&W and in the scope and calls realised within the ERA-NET ICRAD as part of the additional activities included in its WP6.
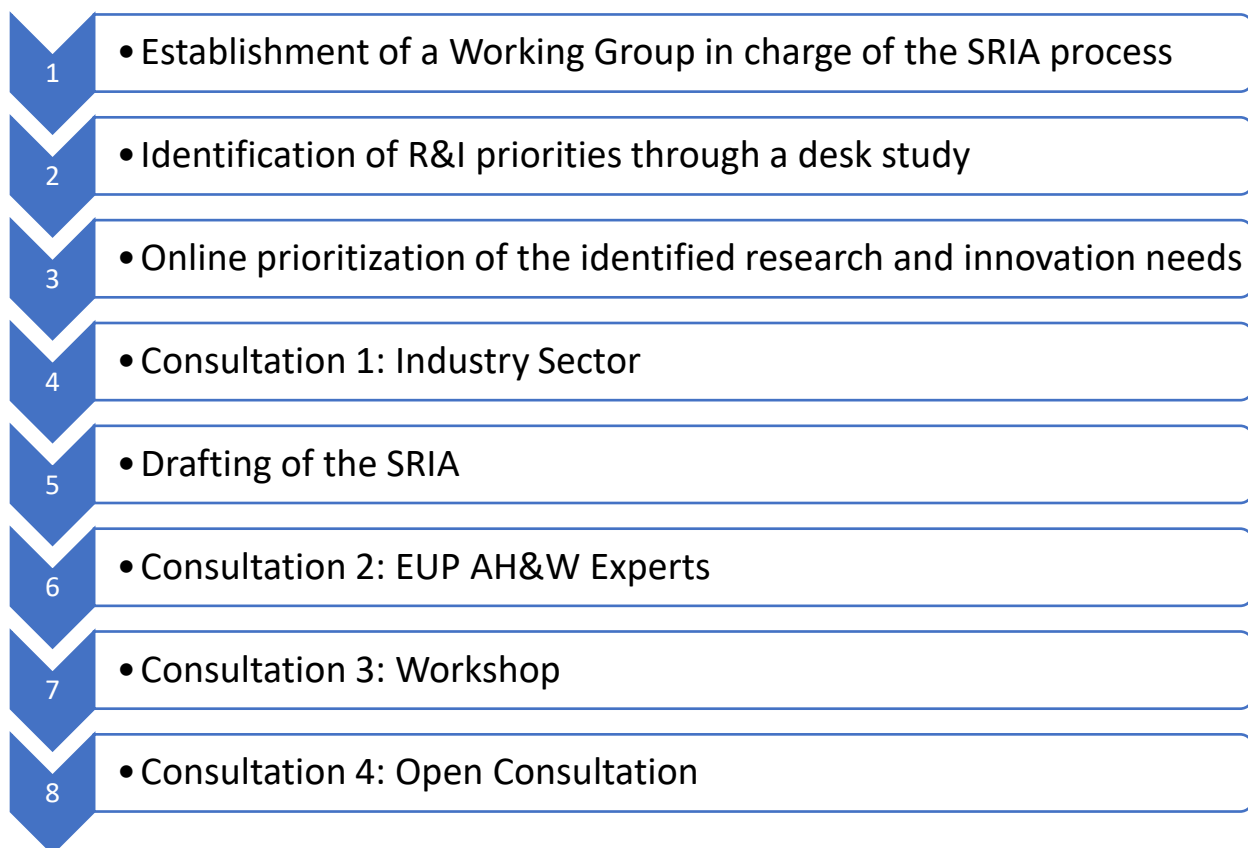
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[1] Animal Health Law | Food Safety (europa.eu)
[2] Farm to Fork Strategy | Food Safety (europa.eu)

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Methodology

The SRIA has been developed by Work Package 6 (WP6) of the International Coordination of Research on Infectious Animal Diseases (ICRAD ERA-Net, Grant Agreement 862605), in close collaboration with the EU Partnership of Animal Health and Welfare and comprised of the following steps:

1. • Establishment of a Working Group in charge of the SRIA process

2. • Identification of R&I priorities through a desk study

3. • Online prioritization of the identified research and innovation needs

4. • Consultation 1: Industry Sector

5. • Drafting of the SRIA

6. • Consultation 2: EUP AH&W Experts

7. • Consultation 3: Workshop

8. • Consultation 4: Open Consultation

The detailed Methodology is in Annex 1 including research need survey and analysis. Briefly it included

Step 1: Establishment of a Working Group in charge of the SRIA process
A Working Group (WG), comprising of representatives from the ICRAD WP6 leaders and other main contributors of the task was established. The WG served, in close consultation with the EUP AH&W core group defined the methodology, delivery plan and timeframe by devising an Action Plan, then proceeded to implement the tasks within the Plan before drafting the SRIA document.

Step 2: Identification of R&I priorities through a desk study
An extensive desk study, performed by the WG, collected and identified animal health and welfare research and innovation (R&I) needs and priorities from the existing European and global strategic documents. This step was a key component in the analysis of the policy,

research and innovation context for the Partnership. The desk study was carried out in three phases:

- Compilation of existing strategic documents on animal health and welfare
- Literature review and identification of research and innovation needs
- Validation of research and innovation priorities

Step 3: Online prioritization of the identified research and innovation needs
An online survey was generated and consulted with animal health and welfare researchers from European and international scientific centers, higher education institutions, industry/professional associations, research funding organizations, government ministries, community groups / NGOs, private sector companies, veterinary practitioners and independent public agencies. The consultees were invited to   rank animal health and animal welfare research needs based on 'urgency' and 'importance'.

Step 4: Consultation 1: Industry Sector
To develop the SRIA in an open and participatory manner, the WG planned to consult a broad set of stakeholders to make the agenda more responsive to their needs and ensure their interest and commitment. As the majority of respondents to the survey were researchers form academia and research centers, so during the next step it was fundamental to seek input from industries (high tech, diagnostics industry, vet industry, vaccine and treatment) and EU associations (farmers associations, livestock associations, animal welfare associations and NGOs). The discussion was focused on:
- Sharing the prioritization of research needs identified by the survey of experts from academia/research institutes;
- Taking into account the perspectives of industry and associations, the prioritization was reviewed regarding importance and urgency and potential uptake within the framework of EUP AH&W;
- Investigating/soliciting interest in possible partnership cooperation and joint working in the areas of mutual interest.

Step 5: Drafting of the SRIA

Step 6: Consultation 2: EUP AH&W Experts

Step 7: Consultation 3: Workshop

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SRIA Results Section
Combined Survey and Focus Group Results

The research needs and related actions are aligned to the operational objectives (OO) identified in the EUP AH&W dossier submitted to and validated by DG Research and Innovation (https://research-and-innovation.ec.europa.eu/system/files/2022-04/ec_rtd_he-partnership-pahw.pdf). The summary tables for each OO contain both the needs/actions identified in the EUP AH&W dossier as well as needs identified during the SRIA development process (desk study, survey and focus groups).

In general, the stakeholders (industry, livestock sector and research communities) agreed with the results from the survey and expressed interest for both competitive and pre-competitive research activities. Industry representatives preferred identifying unambiguous, concrete, direct research needs whereas other stakeholders, such as authors of various Strategic Research Agendas, preferred a conceptually wider framing of topics. Thus, some research needs from the survey were developed further through the focus groups to clearer outline what is needed through future calls in the EUP AH&W.

Each research and innovation need, identified by the consultation process, was rated and ratified as either 'important' (scored out of 6) and 'urgent' (scored out of 3). These are captured in the Annex 1.

The tables below summarise prioritisation of research and innovation needs in short (1-2 years)-, medium (3-5 years)- and long (5+)-term. Also, included are additional research needs identified by stakeholders for each operational objective, these research needs will be developed and added into the tables. It is important to note that research needs are also the basis for the non-research activities that are planned under the EUP AH&W.

The "**Additional suggestions from the experts**" below will either be integrated in the summary table or, if they are too detailed, will be kept for possible future developments/actions.

Animal Health & Welfare - Surveillance and Monitoring systems

OO1. To design and harmonize surveillance and monitoring systems for animal health and welfare

At a time when the world is facing an unprecedented pandemic, the importance of surveillance for animal diseases is crucial. Surveillance systems and networks designed and built-in recent years have an essential role in the management of new tools to safeguard the health and welfare of animals, to minimise animal production loss due to disease, to ensure quality assurance for trade in animals and animal products, and to safeguard human health. With increased cross-species transmission and disease impact, there is an urgent need to strengthen

preparedness to prevent and respond to animal infectious diseases (AID), AMR and zoonoses through cross-sector research collaboration both in animal health, including wildlife, and animal welfare in a conceptual framework of One Health surveillance system. **A successful multisectoral surveillance system** based on high-quality data will help to support national and EU policy development on animal health and welfare, to foster the standardisation of methods and the harmonisation of their implementation where relevant, to reduce wasteful duplications, to enable synergies and maintenance at the European level.

Research activities corresponding to each action are described below in the table.

In summary, in the near-term for both animal health and welfare actions 1, 3, 5 and 6 referred to in the Table 1 of this Operational Objective are priority including following research needs:

- **Improved preparedness and predicition methods** including understanding of transmission sources of pathogens (including from wildlife) and impact of climate change and ecosystem changes and trade
- **Development of tools and methods** for efficient surveillance systems with harmonized collection and timely data sharing and it's evaluation
- Need for **better use and reuse of data** using bioinformatics and artificial intelligence tools
- Development of **animal welfare surveillance** and its evaluation
- Development of **platforms to support farmers and veterinarians** in collecting and sharing primary data on animal welfare'

With regards to these research needs, focus group participants noted that the potential impacts of these new monitoring technologies on farmers is not captured here and that there will be differences in burden on small farms compared to bigger farms. The social science aspect of acceptance (or not) of these new surveillance systems by farmers is also not captured.

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Table 1: Summary table for OO1 activities indicating urgency

Action	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Optimize and extend to other countries current surveillance systems for animal health, AMR and zoonotic infections and to develop new ones, where needed	Improvement of preparedness for emerging and exotic diseases through syndromic surveillance	Increase investigations at the human-animal-environment interface of diseases and by increase engagement in networking (One Health approach)	Develop models and tools to identify the most effective and efficient control methods and control points to protect society from new diseases, also including considerations on socio-economics, climate effects and biodiversity
	Identify transmission sources and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...) through passive and active surveillance	Integrate various surveillance methods and ensure transparency between geographies	Develop animal identification technologies and systems for traceability of animals and their products for disease prevention, control and emergency management
	Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission	Integrate animal health surveillance systems of different sources	Elaborate alternative systems to compensate for downsizing of surveillance/detection systems
	Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases)	Control on introduction of exotic arthropods which are potentially vectors of AID (in point of entry and in the field)	
	Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	Develop ranking, prioritization tools based on risk and impact assessments to support decision makers in control of these new pathogens.	
	Develop terrestrial and aquatic wildlife disease surveillance and reporting systems, including methods, systems and harmonisation for assessment of wildlife populations and demography		
	Progress alternative methods to control vectors: integrated pest management, biological control, genetically modified insects/improving networking with the human and environment sectors		
	Creation of standardized Next Generation Sequences protocols to run surveillance systems in particular for emerging diseases		
Action 2. Set up a European wildlife network (both terrestrial and aquatic	Identify transmission sources and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...)	Increase investigations at the human-animal-environment interface of diseases and by increase engagement in networking (One Health approach) and identify stakeholders and vulnerable groups	Improved understanding of the role of wildlife-livestock interactions including risk populations. Building partnerships with collaborators to reduce the risks.

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animals), based on existing wildlife disease surveillance and reporting systems, to coordinate and expand their activities, to analyse wildlife populations in Europe, and to analyse what specific data with reference to potential threat to animals and humans are needed.	Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	Animal health and welfare risk-assessment related data sharing and networking among research centres	Develop optimised terrestrial and aquatic wildlife disease surveillance and reporting systems, including methods, systems and harmonisation for assessment of wildlife populations and demography
		Study the role of wildlife host/reservoirs for a number of diseases which might impact on human and animal health (transmission parameters study, effect of biosecurity measures, wildlife-livestock interactions, physical barriers etc.)	Need for assessment of impact of human interventions on wildlife: hunting, trade, translocation of wildlife
		Build a European wildlife network (both terrestrial and aquatic animals) based on existing network and wildlife disease surveillance and reporting systems	
		Development of tools to assess risk to people and domesticated animals from wildlife considering both health and welfare risks.	
Action 3. Create networks that bring together bio-informatics and epidemiology, to harmonise metagenomic data and data collection methods, to integrate genomic, clinical and epidemiological data, applicable to both livestock/aquaculture and wildlife.	Managing Big data, GIS, NGS; progress bioinformatics, improve sharing data integration and better use of existing data	Progress analysis tools that integrate genomic, clinical and epidemiological data into risk assessment, early detection and disease spread models, including creation of network that bring together bio-informatics and epidemiology applicable to both livestock /aquaculture and wildlife	Develop syndromic surveillance tools and systems to interpret data and support decision making by risk managers and society.
	Integration and better use of existing data and data analysing techniques for animal health and welfare to inform future initiative	Development of novel big data, bioinformatics and Artificaila Intelligence tools for animal welfare	Research on machine learning based methods for exploring the ontologies of catalogues' values to integrate and network surveillance systems
	Progress artificial intelligence and machine learning techniques that support identification of new pathogens and earlier detection of known pathogens from sequencing and proteomic data	Improve cost effectiveness of real-time data collection	Broader surveillance informing transmission chain during epidemics or pandemics
	Development of platforms to support farmers in collecting and sharing primary data on animal welfare	Data mining as a potential tool for AW syndromic surveillance/early warning systems	
Action 4. Monitor pathogens of veterinary importance (that are not covered	Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts	Understanding of AMR incidence, prevalence, range across pathogens including study of resistance circulation within	Need for accurate estimates of the impact of AMR on routine treatment success (poultry, swine, cattle, fish) that drive an exceptionally substantial proportion of use of AM

in One Health calls) and their antimicrobial resistance profiles.	AMR surveillance in connection with measuring animal health and welfare indicators	Increase ability to rapidly characterise newly emerged resistance in microorganisms and elucidate the underlying mechanisms to support selection of correct antimicrobial the first time and avoid repeated treatments	Need for standardized metadata on AMR and AMU
	Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	AMR surveillance in a broader sense, e.g. anthelmintics and fungicides	AMR surveillance in a broader sense, e.g. anthelmintics and fungicides
	Development of tools to convert apparent to true prevalences, to enable fit-for-purpose monitoring	Development of harmonized cut-off point for clinically relevant resistance in animal pathogens	
Action 5. Build networks, develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal health and welfare issues, and to develop a hazard monitoring and early warning service.	Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases)	Increase investigations at the human-animal interface of diseases and by increase engagement in networking (One Health approach)	Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal health issues, and to develop a hazard monitoring and early warning service
	Managing Big data, GIS; progress bioinformatics, improve sharing data integration and better use of existing data	Friendly use of platforms supporting farmers and veterinarians in collecting and sharing primary data on animal health. Networks building to develop a hazard monitoring and early warning service	Develop tools and systems for syndromic surveillance
	Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences	Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning and other welfare indicators (e.g. tail docking pigs, lameness or cachexia cattle) at the slaughterhouses	Research on machine learning based methods for exploring the ontologies of catalogues' values to integrate and network surveillance systems
	Development of quantifiable positive animal welfare indicators	Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal welfare issues, and to develop a hazard monitoring and early warning service	Development of indicators and markers for understanding mental experiences of animals
	Integration and better use of existing data and data analysing techniques for animal welfare	Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	Progress on guidance and application of alternatives to animal experiments (e.g. organoid or in vitro models)
	Design of the data-driven surveillance tools that are useful for the farmer but also provide surveillance information on regional or national level	Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal welfare issues, and to develop a hazard monitoring and early warning service	Development of novel big data and bioinformatics techniques for animal welfare
	validate and use telemetry data (livestock precision farming) in relation to animal's behaviour, fitness and longevity, stress and physiological parrameters		Applications of sensors in animal welfare for real-time monitoring

Action 6. Create a platform on animal welfare in the EU with the objective to provide scientific and technical support to all stakeholders, in particular related to data necessary for the monitoring of animal welfare; develop animal welfare surveillance systems and their evaluation.	Development of platforms (where possible integrated in a meaniful way into exisiting operational networks) to support farmers and veterinarians in collecting and sharing primary data on animal welfare without making it an administrative burden.	Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	Applications of sensors in animal welfare for real-time monitoring
	Develop animal welfare surveillance including epidemiology and its evaluation	Animal welfare risk-assessment related data sharing and networking among research centres	Research on animal cognition (e.g. preferences and motivation to obtain rewards)
	Need for early warning of Animal Welfare	Development of novel big data and bioinformatics techniques for animal welfare	Precision Livestock Farming technologies and artificial intelligence for welfare
	Validation of those variables that most closely and reliably reflect the animals' affective state and thus their welfare before using these as indicators in automatically collected data	Go FAIR (**F**indable-**A**ccessible-**I**nteroperable-**R**eusable): long-term stewardship, assess ability, legal interoperability and timeliness of sharing of data" and "support research communities to adopt and coordinate data standards and mechanisms for FAIR sharing	Develop novel animal identification technologies (e.g. non-invasive biometric identification) for animal welfare monitoring
		The animal welfare surveillance systems should be shifted towards Animal based measures (ABMs) rather than resource-based measures. Need for surveillance/monitoring on AW will support risk assessments on AW	Deepen knowledge between the interaction of animal physical health and animal mental state and emotion

Additional suggestions from the experts

Fundamental research for surveillance	Biome and Pathobiome analyses in different species and their compartments
	Investigation of the role of intraspecific genetic diversity of animals on the likelihood of emergence of AID
	Pathogenesis of emerging and re-emerging AID
	Study of the effects of biodiversity loss on human and animal health
	Studying of drivers and monitoring of trends in wildlife population health applying holistic approach
	Combining slaughterhouse disease reports and welfare biomarkers in large populations (i.e. pig, poultry, aquaculture) to define the correlations between AW issues and disease onset
	Studies on Animal Health - Animal Welfare interaction
	Validation of those variables that most closely and reliably reflect the animals' affective state and thus their welfare before using these as indicators in automatically collected data
Development of new tools and technologies	Development of computerised vision systems at post-mortem to detect findings of relevance for animal health and welfare as well as food safety/quality including digital pathology algorithms for histopathology

	Means of disinfection that are both effective and respectful of ecosystems
	Increase the collection of reliable field data (e.g. distribution of vector species) through the organized sampling at European scale
	Establishing monitoring systems to better understand the mechanisms by which pathogens cross species barriers
	Development of diagnostics and decision support tools, integrated into farm management software, for monitoring of endemic production diseases in livestock
	Development of tools to monitor the progress of on-farm disease control of endemic infectious diseases
	Development of new methods of arthropod vectors containment
	Development of tools to measure and record positive welfare states
	Ensure good coordination between early warning systems across geographical areas and activation of response measures
	Monitoring of wildlife endemic pathogens in livestock - subclinical effects in wildlife systems are widespread, and if present in livestock but undetected may be having impacts on yield and profitability
	Use and standardization of GIS approaches to manage animal disease zones
	Creation of standardized Next Generation Sequences protocols to run surveillance systems in particular for emerging diseases and issues
	Application of surveillance e monitoring system to pet trade
New procedures and strategies	Coordination and interoperability of datasets for efficient and useful animal health information systems 3
	Facilitation of data exchanges between organisations in charge of detection and data collection with research bodies so that they can benefit promptly from field samples.
	Integrating human health surveillance with animal health surveillance (One Heath Surveillance)
	Environmental monitoring within disease surveillance (One Heath Surveillance)
	Risk-based approach to surveillance and monitoring systems
	The increase of European research and infrastructure funding in pathogen biology in the framework of One Health
	Development of innovative methods to promote the effectiveness of operators' training
	Cross-sectorial research collaborations

Animal Health - Diagnostic procedures, methodologies and tools

OO2. To develop diagnostic procedures, methodologies and tools to support the monitoring of animal health

Diagnostics are often the first step in any medical process, both regarding individual patients (human and animal) and public health. Any control measure should be tailored to the specific issue and circumstance. Reliable diagnostic tests are crucial that can distinguish between healthy and infected individuals, especially when some individuals can be asymptomatic carriers of the disease. Diagnostic tests should be able to detect new diseases (or new variants) to prevent public health or economic crises.

New methodologies and technologies are made available by the scientific advances, and many tools still need to be developed further to be used for the early detection of AIDs. While the adoption of optimised tools in the surveillance programme belongs to the OO1, many other tools need to be perfected, in order to increase their sensibility and specificity, their suitability in field conditions and to reduce their invasiveness. Better diagnostics can improve our understanding of disease and allow the improvement of control measures.

Research activities corresponding to each action are described below in the table.

In summary in the near-term it is urgent to focus on developing deep understanding of **host-pathogen-microbiome interactions and novel diagnostics tools** that will enable early detection and are easy to use. The need for **high throughput technologies and novel sampling methods** are key consideration for developing novel diagnostics. Developing diagnostics for wild-life, DIVA and inter-species pathogen transmission was identified at medium-term priority.

In the short-, medium- and long-term focus needs to be on actions 1, 2 and 5.

Table 2: Summary table for OO2 activities indicating urgency

Action	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Gain knowledge on priority pathogens (i.e. bacteria, parasites, viruses, fungi, prions including resistance patterns) responsible for important economic losses or high risk of transmission to humans and their detection	Deepen understanding of host-pathogen-microbiome interactions in animals: mechanisms by which emerging pathogens transgress species barriers	Foster basic research and translational studies to support the development of new diagnostic tools (immunology, microbiology, virology, pathology)	Develop sensitive biomarkers for early detection of diseases paired with artificial intelligence and remote detection tools
	Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools		Expand nanotechnology in animal disease diagnosis
			Identify bio-, genetic and predicitive markers of a healthy (innate) immune system in relation to feed efficiency, disease prophylaxis, pathogenesis and animal welfare

methods, including metagenomics approaches, molecular markers of interest, etc.			Identify stage-specific antigens in helminths that can be used in immune tests
			Develop new diagnostic tests for helminths detection, including rapid systems for parasitic egg/larvae isolation from fecal and environmental samples, which provide reliable and representative data on e.g. environmental contamination, anthelmintic resistance
Action 2. Development, optimisation and standardisation of reliable, faster, potentially automatable and/or scalable direct antigen/genome amplification/detection and indirect detection/immune response assessment tools/technologies; tools for the rapid detection of drug-resistant bacteria, viruses, fungi or parasites; on-farm, pen-site diagnostics for pathogens and antimicrobial resistance; focus on priority pathogens and those that do not have EURL.	Develop new, cheap, accurate, rapid and easy to use field diagnostic tests and diagnostic techniques, including pen-side diagnostics for the early detection of pathogens	Tools to study inter-species (including wild animals) circulation of pathogens or resistant variants	
	Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts	Develop new screening test for wildlife infectious agents	
	Progress rapid, accurate, tests for AMR diagnosis (e.g. LAMP, AST estimation through MALDI-TOF and fluorescence coloration of RNA biomarkers)	Accredited AST alternatives for fastidious re-emerging bacteria, e.g. Brucella and Coxiella	
	Develop routine use of high-throughput technologies (metagenomics, sequencing, machine learning and bioinformatics) for multi-target and quantitative diagnostics		
	Development of alternative models especially biologically relevant (species-specific) cell culture models that are still lacking for drug screening/testing approaches		
Action 3. Development, optimisation and standardisation of tools to distinguish between (i) infected and vaccinated individuals (DIVA) as well as (ii) dead and infectious pathogens for the study of pathogens survival in the environment or in effluents and (iii) to study of inter-species (including wild animals) circulation of pathogens or resistant variants.	Improved competitive vaccines, particularly for economically devastating diseases such as weaning diarrhoea in piglets and coccidiosis in broiler and turkeys	Develop DIVA vaccines and corresponsing serological tests for HPAI and ASF	Develop sensitive biomarkers for early detection of diseases paired with artificial intelligence and remote detection tools
	Harmonization of lab tests and result communication		Tools that distinguish between dead and infectious pathogens for the study of pathogens survival in the environment or in effluents (e.g., mRNA marker)

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Action 4. Development of quantitative and multi-target diagnostics to identify infection levels and silent microorganisms that can interfere with animal production for informed treatment/prevention measures decisions in enzootic production diseases in animals.	Development of multi-pathogen diagnostic tool to optimize the surveillance systems able to identify at once bacteria and viruses	Develop quantitative and multi-target diagnostics to identify infection levels and silent microorganisms for enzootic production diseases in animals	
Action 5. Development of non or less invasive and more convenient sample collection methods, including new matrices as well as transport, storage, treatment strategies and corresponding diagnostic tools, also suitable for the detection of diseases in free-ranging or wild animals.	Develop new sampling methodologies and strategies, incl. widening of the range of biological, also for drug screening/testing approaches samples	Develop non or less invasive and more convenient sample collection methods, including new matrices	Progress alternatives to animal experiments such as organoid or models in vitro models
			Optimise sampling, transport, storage, treatment strategies suitable for the detection of diseases in free-ranging or wild animals
Action 6. Application of new methodologies, i.e., research focusing on application of new detection and characterisation methodologies, on in vitro models; study host-pathogen-environment interactions, i.e. focusing on drivers and markers, on characterisation of microbial ecosystems, on drivers of resistance.	Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools	Tools to study inter-species (including wild animals) circulation of pathogens or resistant variants	
	Development of digital toolboxes that centralize all diagnostic data coming from local laboratories in real time and directly send the information to responsible authorities at a national level and international level and linked to human diagnostic system.		

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Additional suggestions from the experts

Fundamental research for diagnostics	*A posteriori* identification of the host species used by vectors
	Study on receptor in order to develop resistant animal strains
	Veterinary immunology, microbiology, virology
New tools and technologies	Development of diagnostic methods that can be used for samples from both humans and animals
	Development of cheap and accessible diagnostic screening tests for non-infectious diseases (e.g. biotoxins)
	Development of rapid assays to identify mutations of significance in genomes
	Development of quantitative diagnostics and interpretation of results in relation to the usage of antimicrobials
	DNA diagnostic techniques
	Research on high throughput diagnosis methodologies and multiplexing diagnostic tools.
	Development of multi-pathogen diagnostic tool to optimize the surveillance systems able to identify at once bacteria and viruses.
	Development of multi-pathogen diagnostic tool able to identify minor variants of a given pathogen in sample rich in microorganisms.
	Develop accurate point of care (POCT) tests for the main pathologies
	Rapid assays to identify significant mutations in genomes
	Digital PCR for quantification of pathogens and health status e.g. microbiome signatures
	Develop new screening test for wildlife infectious agents and circulation of zoonotic pathogens.
	Test for the biomolecular identification of potential arthropod vectors of diseases
	Development of diagnostics tests using recombinant antigens and monoclonal antibodies
	Development of diagnostics and decision support tools, integrated into farm management software, for monitoring of endemic production diseases in livestock
	Define criteria to strengthen laboratory analysis to distinguish virulent pathogens, from biological bystanders.
	Development of methodology and molecular tools to assess infectivity of pathogens detection in surveillance methods
New procedures and strategies	*In situ* detection of viable versus non-viable pathogens
	Development of new methodology to sample invasive species
	Development of strategies combining cheap point of care tests (POCT) with matrices easy to manipulate (as for example fluids)
	Fostering the collection of quality samples (representativeness of species, geographies, forms of infection) and the sharing of characterized and informed samples
	Improvement the standardization of diagnostic methodologies and techniques
	Develop more reliable in situ techniques for diagnosing infectious diseases and educate more diplomates in diagnostic pathology

Animal Welfare - Diagnostic procedures, methodologies and tools

OO3. To develop procedures, methodologies, and tools to support the monitoring of animal Welfare

The conditions under which animal production takes place and the level of animal welfare should be improved, in the first place for ethical reasons, but also to increase health standards. Obtaining a full understanding of baseline data and effects of interventions are key factors in the cycle of improvement, and the development of procedures, methodologies and tools for monitoring animal welfare will directly contribute towards its continued improvement. This will decrease needs for veterinary drugs and slow down the development of antimicrobial resistance in microorganisms in addition to improving food safety and quality. Over the long term, this form of research has potential to aid the genetic selection of more resilient livestock breeds with superior protective immune and metabolic responses.

The research needs against each action is summarised in Table 3. There are several topics which both the survey and the focus groups identified as being priorities relevant to this research area. These include:

- Development of **tools for measuring animal stress**
- Refinement of **animal-based measures of welfare**
- **Work on design of slaughter facilities** in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase
- **Integration and better use of existing data** and data analysing techniques for animal welfare

The focus group participants did not have any specific comments with regards to research needs focused on monitoring of animal welfare.

Considering the results of the survey and the focus group, Actions 2 and 4 for this Operational Objective have been highlighted as most critical. The focus of research in the next 1-2 years should prioritise development of tools to measure animal stress and refinement of animal-based measures of welfare.

Table 3: OO3 Research needs in relation to Actions and urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +

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Action 1. Focus on positive welfare (positive emotions), identification of behavioural, endocrine and neurological indicators of positive welfare: research focusing on animal cognition, preferences and motivation to obtain rewards.	Understand stockperson care/management practices and their welfare implications	Understanding consequences of social interactions/hierarchies and the impact these have on welfare	Understanding social/group dynamics (for social species)
		Development of positive animal welfare indicators and markers for understanding mental experiences of animals including playing behaviour	Deepen knowledge between the interaction of animal physical health and animal mental state and emotions including understanding individual animal variability
			Research on animal cognition (e.g. preferences and motivation to obtain rewards
Action 2. Development of <u>technologies on the slaughter line</u> to assess animal welfare (on farm and/or during transport). Identification of suitable animal-based measures (ABM) with appropriate level of validity, sensitivity and specificity; development of in-line sensors, large scale data collection.	Development of tools for measuring animal stress	Identify indicators and to develop systems to assess the state of consciousness and death	Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning at the slaughterhouses
	Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences	Development of positive animal welfare indicators and markers for understanding mental experiences of animals	
Action 3. Animal <u>welfare at slaughter</u>: i) consciousness and death: development of technologies, procedures and/or protocols to increase the reliability of methods to assess consciousness and death at the slaughter line; ii) improve stunning and killing methods; iii) work on design of slaughter facilities in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase; related staff training.	Work on design of slaughter facilities in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase	Understanding pain recognition and how it varies across species and across generation	Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning at the slaughterhouses
	Work on design of pre-slaughter phase including stunning methods	Identify positive animal welfare indicators and to develop systems to assess the state of consciousness and death	
	Research on humane methods for on-site killing of large groups of animals i.e. farm depopulation in case of disease outbreak	Development of AI systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	

Action 4. Development of <u>physiological indicators to measure acute and chronic negative animal welfare consequences on farm</u>. The indicators should identify stress, pain, fear, discomfort, etc. at individual and group levels: measure of physiological stress, impact on immune response and omics (e.g. transcriptomics and metabolomics). Integration of these to metadata welfare tools.	Development of tools for measuring animal stress	Understanding pain recognition and how it varies across species	Modelling for the natural behaviour and basic physiological data for different species in different farming systems
	Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences	Studies to further understand infection mechanisms to improve health and welfare	Investigations in integration of data originating from transcriptomics, proteomics and metabolomics methods in animal risk assessment
Action 5. Development <u>of digitally assisted monitoring technologies on farms for increasingly enabling precision management of animal (health and) welfare</u>. Technology includes recording visual and auditory signals related to animal-based measures for welfare, analysing records with deep learning technology, data processing techniques and decision support systems.	Integration and better use of existing data and data analysing techniques for animal welfare	Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal welfare issues, and to develop a hazard monitoring and early warning service	Develop novel animal identification technologies (e.g. non-invasive biometric identification) for animal welfare monitoring
	Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare	Development of novel big data and bioinformatics techniques for animal welfare	Produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal welfare
	Develop animal welfare surveillance and its evaluation	Development of AI systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	
	Precision Livestock Farming technologies and artificial intelligence for welfare linking to genomic selection data	Precision farming enhanced by developments in information and communication technology (ICT), GPS-based and sensor technologies for animal welfare	
	Data mining of syndromic surveillance/ early warning systems to allow for AW evaluation	Develop Precision Livestock Farming (PLF) tools and Farm Management Information Systems	

		(FMIS) (data collection, processing and decision making)	
Action 6. Development of technologies to assess <u>animal welfare during transport</u>. Affordable and reliable solutions to prevent serious welfare problems through early detection of signals before and whilst in transit, e.g. lameness, lesions, heat stress, aggression, thirst or hunger, exhaustion, etc. Development of sensor technology, data analysis tools, data collection and integration platforms, decision support for the driver; related staff training.	Studies on the impact of transport on animal welfare across species including aquatic animal concerns - e.g. oxygenation levels, starving protocols etc	Development of AI systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	Applications of sensors in animal welfare for real-time monitoring
	Precision Livestock Farming technologies and artificial intelligence for welfare	Precision farming enhanced by developments in information and communication technology (ICT), GPS-based and sensor technologies for animal welfare	

Additional suggestions from the experts

Fundamental research for surveillance	Studies on Animal Health - Animal Welfare interaction
Development of new tools and technologies	Validation of those variables that most closely and reliably reflect the animals' affective state and thus their welfare before using these as indicators in automatically collected data
New procedures and strategies	Application of surveillance e monitoring system to pet trade
	Development of tools to measure and record positive welfare states
	Combining slaughterhouse disease reports and welfare biomarkers in large populations (i.e. pig, poultry, aquaculture, pisciculture) to define the correlations between AW issues and disease onset
	Increasing awareness of animal welfare
	One Welfare approach to research
	More funding for Animal Welfare and animal ethology research is required due to scarce scientific knowledge in those areas

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	More research in fish welfare is required

Animal Health & Welfare - Risk assessment and alert communication

OO4. To adapt risk assessment and alert communication to the new needs in animal health and welfare

Great importance is given to risk assessment and communication in the public discussion regarding animal health and welfare. The movement of animal, goods and people around the world increases the transmission rate of diseases and consequently the need for rapid, accountable communication between health stakeholders, from local health units to governments and international agencies. In order to deliver data in a sufficiently detailed way, new platforms and tools are necessary. Strong research coordination, both on animal health, including wildlife, on animal welfare and on cross-sector collaborations, will help strengthen preparedness to prevent and respond to AID, support national and EU policy development on animal welfare, standardise methods and harmonise their implementation where relevant, reduce wasteful duplication, ensure joint efforts, enable synergies and maintenance of a knowledge at the European level.

The animal welfare research needs relevant to OO4 which both the online survey and focus groups agreed were most relevant in the short term are:

- Refinement of **Animal-based measures of welfare**
- Develop **animal welfare surveillance** and its evaluation
- Develop thresholds for intervention based on **animal welfare risk assessment data**

One item that was raised by the AW focus group in relevance to these research areas was that there is likely to be significant variation here in terms of species-specific knowledge and also that it is important to ensure a distinction between stress and welfare.

In light of these priortised research needs, Action 6 of this OO has been highlighted as most critical to address in near-term.

Table 4: OO4 Research needs in relation to Actions and urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Enhance rapid risk and consequence assessment	Develop thresholds for interventions based on animal welfare risk assessment data	Animal health and welfare risk-assessment related data sharing and networking among research centres	Investigations in integration of data originating from transcriptomics, proteomics and

methodologies, to assess the economic, social, environmental and cross sectoral consequences of animal health and welfare issues.			metabolomics methods in animal risk assessment
	Investigations into possible application of science-based animal health and welfare risk assessment criteria in real life and under different husbandry conditions including introducing new husbandry systems/technologies	Develop a dynamic risk assessment system and assess methodologies to evaluate the economic, social, environmental and cross sectoral consequences of animal health and welfare issues	Produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal health and welfare
	Research on determination and monitoring of socio-economic factors that can increase farm susceptibility to infectious diseases, with the aim to detect less resilient holdings/areas/regions		
Action 2: Study and assess epidemiologucal associations between human interventions such as hunting, trade, transport, rewilding and transloctions of wildlife and disease spereas, in order to propose harmonised tools to support alert system			
Action 3: Adapt existing or develop new methodologies to integrate genomic surveillance data in risk assessment guidelines for the integrated use of epidemiological and denomic data			

Action 4: Assess the risk of spread of resistant animal pathogens clones and genes encoding resistance	Integrated risk analysis based on farms data on management, animal welfare, antimicrobial resistance, drug consumption, vaccination strategies, biosecurity, and health data	Study of impact of antimicrobial use (AMU), and the role of companion animals (CA) in AMR transmission: 1. estimate the AMR burden associated with CA 2. Investigate transmission dynamics between CA and humans, the environment and farm animals 3. evaluate AMU and drivers of prescription in CA 4. identify how to reduce AMU and prudent use in CA	
Action 5; Build or further map and coordinate emergency networks for scientists and communities, to increase risk knowledge by systematically collecting data and undertaking risk assessments			
Action 6. Develop animal welfare surveillance and its evaluation, develop indicators and alarm levels, produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal welfare.	Develop animal welfare surveillance and its evaluation	Development of AI systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	Applications of sensors in animal welfare for real-time monitoring
	Development of welfare surveillance systems	Development of indicators and markers for understanding mental experiences of animals	Develop novel animal identification technologies (e.g. non-invasive biometric identification) for animal welfare monitoring
	Development of tools for measuring animal stress addressing specifically farrowing crates and piglet castration		Develop tools/strategies for effective monitoring of air quality to maintain high animal welfare
	Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences		

Additional suggestions from the experts

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Fundamental research for risk assessment	*Ex-vivo* and *in vitro* studies for risk assessment of pathogens
	Assess the link between climate change, environmental pollutants, pathogens, AMR
	Standardization of risk assessments
	Multidisciplinary study in ecological vectors diseases
	Relationship between media and experts
	Risk assessment of species jump
	Research on determination and monitoring of socio-economic factors that can increase farm susceptibility to infectious diseases, with the aim to detect less resilient holdings/areas/regions
	Application of slaughterhouse waste as organic fertilizer
	Link between animal health and animal welfare
New tools and technologies	Scientific evaluation of animal based welfare indicators before wider use
New procedures and strategies	Guidelines for helping health managers to implement preliminary measures against unknown hazards
	Improve communication across sectors
	Develop strategies to improve risk perception
	Training activities to improve awareness on infectious animal diseases
	Sharing information by networking
	Integrated risk analysis based on farms data on management, animal welfare, antimicrobial resistance, drug consumption, vaccination strategies, biosecurity, and health data observed at the slaughterhouse
	Application of effective risk assessment methodologies to pet breeding
	Scientific evaluation of animal based welfare indicators before wider use

Animal Health & Welfare - Farm management preventive tools

OO5. To develop guidelines and preventive tools to fight against animal infectious diseases on farm and during transport

Good farm management and comprehensive biosecurity measures will reduce the development of animal disease and minimise the animal distress. Farm management encompasses all practices animals have to undergo from birth to slaughter. Various factors must be taken into account e.g., ethology, production sustainability, biosecurity, nutrition and many others.

There was less of alignment of research needs prioritizations and urgency ranking between survey and focus group. For example, 'Develop strategies to reduce antimicrobial and anthelminthic use (incl. feed additives/nutrition) and/or to encourage their prudent use' was ranked as the highest priority research need from any thematic area by the survey (6.2 importance score) whilst it was only ranked the third most important research need in the 'Feeding and understanding the microbiome to improve animal welfare' thematic area by the focus group.

The focus group commented that pre-natal stress, epigenetics and reproduction have influences on on-farm welfare that aren't reflected here.

The AMR based research needs also gathered some interest from focus group participants. It was noted that this research need in reverse could also be relevant. For example, what impacts improved animal welfare could have on AMR.

Overall, there was a trend towards Action 4 of this OO having a greater number of higher priority research needs associated with it and therefore it should be prioritised as the most critical.

Table 5: OO5 Research needs in relation to Actions and urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years+
Action 1. Establish a multidisciplinary network of experts with focus on biosecurity measures to prevent and control AID on farm and during transport, and draft foresight and priority studies on animal health, public health, pandemics and the role of biodiversity, the changing climate, emerging vectors and	Studies on the impact of transport on animal welfare and infectious disease	Identify biosecurity risks associated with free-range organic farming	Resilience farming - Set up relevant networks
	Improved understanding of climate change and its impact on welfare and on current and new animal diseases as well as the role it may play in an epidemic situation	Identify economic and realistic interventions that may improve health and welfare adapted to climate change, extreme weather, CO2	Improved understanding of the role of wildlife-livestock interaction

vector-borne diseases, bird and fish migrations, epidemiology/ modelling, bioinformatics, etc. for all animal species, including minority species and aquaculture.		emmission, biodiversity and new husbandry systems and technologies	
	Develop disease and welfare models that include climate change, biodiversity, changing vector habitats to assess impact including CO2 emissions and socio-economic impacts to develop decision support for improving welfare and animal health		Improved understanding and identification of optimal control points
			Efficient and safe management of manure and animal by-products for improved of animal welfare and reduced risk of disease spread
Action 2: Reduce the entrance and spread of AID by reinforcing external and internal biosecurity in both terrestrial and aquatice animals, while limiting antimicrobiak use, setup innovative systems and models with focus on biosecurity and integrated management			
Action 3: Perform research on prudent use of antimicorbials: research on treatment conceptsfor antimicrobial and antiparasitic usage, on alternatice to antimicrobials including feed additives/nutrition, studying improved vaccination strategies etc.; develpment of best practices for administration/application of Veterinary Medicine Products (VMP)			
Action 4. Reinforce animal resilience/resistance (the natural ability of animals to withstand pathogens), through feeding and breeding; establish a pan-European network of experts in genetics (breeding), feed additives including pre- , post- and probiotics and leading experts in immunology to produce foresight and priority reports; both fundamental and applied	Deepen understanding of host-pathogen-microbiome interactions	Develop/Improve reproductive/breeding technologies to select for high welfare traits or improve performance and welfare	Understanding of the Intestinal microbiota and their role in immunity, health, and welfare and across the life course
	Develop strategies to reduce antimicrobial and anthelmintic use (incl. feed additives/nutrition) and/or to encourage their prudent use	Research to improve animal welfare through feeding strategies	Deepen knowledge of microbial ecosystems on farms
	Evaluate the interaction between feed, the development of immunity and increased	Advance genetic selection for animal health resilience, promote the use of	Increase knowledge of systems at the level of the transcriptome, proteome and metabolome that

research supporting animal resilience will be set up.	resistance of animals to pathogens especially for young animals (piglets, chicken)	local and more resistant breeds, increasing natural disease resistance or tolerance	contribute to understanding the links between the genome and the traits of interest
	Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators	Improve breeding technologies: e.g. integration of molecular technologies into breeding programs, gene editing and genetic engineering especially for low heritability traits and traits associated with health and pathogen resistance	Advance precision genetic modification using homologous recombination in appropriate stem cells, use of zinc-finger nucleases and RNAi-based gene knockdown
		Understanding how alternative protein sources (incl. insects) affect animal health (risks/benefits)	Social science on acceptance of genetic improvement
			Increase understanding of how genetic engineering in farm animals affects disease resistance
			Develop novel antimicrobial molecules e.g. antiseptics, antimicrobial peptides (bacteriophages), immunomodulatory specific agonists or antagonists and bioactive plants or alternative specialty feed ingredients such as plant extracts (essential oils, tannins, etc.)
			Conduct studies in vivo/ in vitro/ in silico to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life

Additional suggestions from the experts

Fundamental research for farm management preventive tools	Livestock sustainability and animal health
	Study effect on better feed on gut microbiota to avoid weaning diarrhoea
	Research on how to preserve health rather than treatment

	Alternative proteins such as insect for feed security
	Assess the potential human and animal health risks of circular farming systems and alternative farming systems (e.g. insects)
	Prioritization of emerging pathogens linked with organic farming and new farming practices
	Organic livestock and animal health
New tools and technologies	Safe use of bone meal for food producing animals. Safe use of manure and offal for feed to insects in animal feed production.
	Development of diagnostics and decision support tools, integrated into farm management software, for monitoring of endemic production diseases in livestock
New procedures and strategies	Improve biosecurity and biosafety of all animal keeping, including e.g. petting zoos
	How to enhance UPTAKE of biosecurity and vaccines needs research
	Improve collaboration between veterinary and human science regarding antimicrobial usage
	Focus on the big picture
	Encourage farmers to use antibiotics cautiously
	Advice to farmers with livestock raised outdoors - how to improve biosecurity?

Animal Welfare - Farm management preventive tools

OO6. To develop guidelines and prototype solutions that advance animal welfare on farm, during transport and at the end of life

Mitigating or removing animal welfare challenges on farm, during transport and at the end of life addresses societal concerns, increases resilience to diseases that impair productivity, and deepens the understanding of the links between animal health and welfare. Research on these aspects of animal welfare will accompany the implementation and further development of the new animal welfare legislation and contribute to increase the interest of food chain actors and consumers in improved animal welfare. Finally, a One Welfare approach to farming practices, animal transport and end of life will strengthen both human wellbeing and animal welfare and facilitate sustainable livestock production and aquaculture. There are three research needs which the survey rated highly on importance and urgency and which the focus group also noted as their greatest priority. These include:

- Development **of platforms to support farmers and veterinarians in collecting and sharing primary data** on animal welfare
- Improved **understanding of the trade-offs between sustainability and animal welfare**
- Develop and set appropriate **breeding goals that consider welfare implications** (not solely focused on production)

The participants of the focus group noted that there are many factors that impact welfare during transport across species and that there is already lots of research in this area. However, there is a lack of more practical, applied research. Secondly, it was noted that what is currently lacking is an ability to assess the transport of animals - what arethe correct indicators and measures? Finally, it was noted that there may need to be trade-offs between welfare and sustainability and these must be considered.

Overall, Actions 1 and 2 for this Operational Objective has been highlighted as most critical when considering the results of the survey and focus group. Research Needs pertinent to Action 5 are relevant in long-term.

Table 6: OO6 Research needs in relation to Actions and urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Establish a multidisciplinary network of experts to draft foresight and priority studies with focus on sustainability aspects related to non-cage systems, indoor and outdoor systems for livestock, flow though, pond or RAS for aquaculture animal transportation and slaughter, killing on farm, in slaughterhouses or at sea, and focussing on ending mutilations, including aquaculture production systems.	Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare.	Studies which demonstrate alternative solutions to reduce animal mutilations	
	Investigations into possible application of science-based animal welfare risk assessment criteria in real life and under different husbandry conditions	Develop pain free and feasible new methods for on-farm	
	Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators	Animal welfare risk-assessment-related data sharing and networking among research centres	
Action 2. Perform research on how to improve animal welfare while maintaining or increasing farm economic and environmental sustainability. Involves animal cognitive capacities and emotions adapted to each species' needs, opportunities for pain relief, and environmental enrichments technologies. Aims to develop innovative housing systems and addresses the opportunities and consequences of reducing the use of cages in a sustainable way, in terms of economic and environmental impacts.	Establish social science studies along the production chain to monitor behaviour towards maintaining and improving animal welfare, including consumers' willingness to pay for improvements; incentives and barriers to adopting innovations and practices such as welfare labelling schemes	Understanding the role of environmental enrichment on animal welfare	
	Improved understanding of stocking density and its welfare implications and economic trade-offs	Understanding animal housing - welfare and cost implications	
	Improved understanding of the trade-offs between sustainability and animal welfare	Understanding the impact of behavioural restriction/inability to express behaviour on welfare	
	Improved understanding of impacts of extensive farming on animal welfare and how it effect environmentally positive way	Develop a dynamic risk assessment system and assess methodologies to evaluate the economic, social, environmental and cross sectoral consequences of animal welfare issues	
Action 3. Perform background science to identify indicators and to develop systems to assess the state of consciousness and death, develop appropriate Precision Livestock/fish Farming and killing technologies to limit pain and	Development of tools for measuring animal stress	Understanding pain recognition and how it varies across species	Progress alternatives to animal experiments (e.g. organoid or in vitro models)
	Refinement of Animal-based measures of welfare	Development of AI systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	

reduce stress, alert systems for poor welfare during transport, etc.; develop innovative systems in livestock/fish transport and slaughter.	Precision Livestock Farming technologies and artificial intelligence for welfare	Precision farming enhanced by developments in information and communication technology (ICT), GPS-based and sensor technologies for animal welfare	
Action 4. Improve animal welfare through feeding and breeding strategies.	Welfare considerations for new methods of rearing	Develop/Improve reproductive/breeding technologies to select for high welfare traits or improve performance and welfare	Understanding of the Intestinal microbiota and their role in immunity, health, and welfare and across the life course
	Develop and set appropriate breeding goals that consider welfare implications (not solely focused on production)	Advance genetic selection for animal health resilience, promote the use of local and more resistant breeds, increasing natural disease resistance or tolerance	Develop seasonal diets for appropriate nutrition (especially dairy cows and sows) to improve animal welfare
	Research to improve animal welfare through feeding and breeding strategies	Understanding how alternative protein sources (incl. insects) affect animal health and welfare (risks/benefits)	
	Improve breeding technologies for animal health: e.g. integration of molecular technologies into breeding programs, especially for low heritability traits and traits associated with health and pathogen resistance		
	Increase understanding of how genetic engineering in farm animals affects zoonotic disease resistance		
	Understanding welfare consideration for breeding of companion animals and welfare risks related to those?		
Action 5. Evaluate the need and possibility to set up a pan-European network of experimental farms.			Resilience farming - Set up relevant networks
			Deepen knowledge of microbial ecosystems on farms

Additional suggestions from the experts

Fundamental research for surveillance	Research in management practices regarding cross-fostering of piglets in highly proliferative sows - impact on health, diseases, immunity, productivity and welfare during whole growth phase - especially focusing on farms/breeds with low birthweight
	Methods to improve animal welfare and animal health in a sustainable system to influence climate change and risk of zoonoses
	Understanding the social environment for animal welfare in intensive farming
	Research on animal welfare indicator for all common species in the European Union.
Development of new tools and technologies	-
New procedures and strategies	Stunning before slaughter should be obligated and the state should regularly and strictly control whether stunning in slaughterhouses is done within the framework of animal welfare.
	Aquaculture: the air-quality question translates to water-quality here
	One Welfare approach to research
	Improvement of training of the operators
	Improving animal handling practices
	Integrating animal welfare assessment into measurement of environmental, economic and social/ethical sustainability of farming systems
	Improving breeding strategy in pet animals
	Improving animal welfare, economic sustainability and environmental sustainability of farming systems
	State-mandated training to train qualified stunners

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Animal Health & Welfare - New interventions and treatments

OO7. To develop new interventions and treatments, or improve existing ones, against specific priority animal infectious disease

In order to maintain the health and welfare of animals, control interventions including treatments (for example antimicrobials/antibiotics/antiparasitic/antihelminth) are required if an animal is infected with an infectious disease. Suitable treatments require basic research understanding of host – pathogen interactions to target the infection mechanisms and harness an effective immune response. The emergence of antimicrobial resistance has hampered the effective use of such treatments and it is now paramount that tools are developed to understand the mechanisms of resistance and enhance efficacy and safety testing to improve these treatments. Working closely with industry new or improved interventions and treatments can be tested through proof of concept/early/pre-clinical studies.

Research activities corresponding to each action are described in the table below.

In summary, in the near-term basic research and development of tools is urgently needed to:

- Understand **interactions between pathogens, host and its microbiome**, and to understand the host immunity
- Understand the **molecular and cellular basis of antibiotic and antiparasitic resistance**; reducing antimicrobial resistance and its impact on welfare; the impact of reducing antimicrobials and antibiotic free productions have on animal welfare including evaluating the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals.
- Develop a **range of novel interventions including antimicrobial molecules, immunomodulators**, novel therapeutics to control parasitic diseases and animal-free models for vaccine development.

Actions 1 and 2 need to be prioritised through the short, medium and long term whilst action 3 builds on the previous actions into the medium and long term.

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Table 7: Summary table for OO7 activities indicating urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Perform basic research (TRL 1-2) to study interactions between pathogens and host microbiome, focussing on the immune system (e.g. pathobiome), and direct or indirect interactions between pathogens (e.g. co-infections), antimicrobial and antiparasitic drugs and host microbiome, mechanisms of anti-microbial (antibiotic and antiparasitic) resistance; trained immunity.	Improved understanding of direct or indirect interactions between pathogens (e.g. co-infections) and between pathogen and host and its microbiome	Better underpinning understanding of health ecology and connections between microbial communities, animal health & welfare	Better understanding of direct or indirect interactions between antimicrobial and antiparasitic drugs and host microbiome
	Better understanding of host immunity	Synergy between pharmacological solutions to disease outbreaks and vaccination	Piloting animal ecosystems to reduce pathogen shedding in the environment
	Better understanding of the molecular and cellular basis of antibiotic resistance	Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools	Studies to further understand infection mechanisms to improve health and welfare
	Investigation of the impact of the reduction of antimicrobials and antibiotic free productions on animal welfare	Better understanding of anthelmintic resistance (e.g., mechanisms of resistance, genetics, ecology) and markers of resistance addressing particularly bacterial resistance to anthelmintics	
	Reducing antimicrobial resistance and its impact on welfare		
	Evaluate the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals (piglets, chicken)		
Action 2. Develop tools such as (i) experimental farm approaches; (ii) in vivo, in vitro and in silico infection models for testing efficacy and safety of new drugs with reduced need for animal testing, new drug-delivery devices, therapeutics including leads for new antimicrobials; and (iii) bioinformatic pipelines for analysis of microbiome and pathogen data; this will be done in collaboration with industry, where appropriate.	Develop novel antimicrobial molecules e.g. antiseptics, antimicrobial peptides (bacteriophages), immunomodulatory specific agonists or antagonists and bioactive plants or alternative specialty feed ingredients such as plant extracts (essential oils, tannins, etc.)	Studies on antibiotic effectiveness and availability and development of rapid accredited alternatives to classical antimicrobial susceptibility (AST)	Conduct studies on animals to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life
	Develop novel immunomodulators and antivirals	Conduct in vitro/in silico studies on pre and probiotics, immuno-stimulants, phages and synthetic microbial communities	Utilize reverse genetics studies for new intervention and treatment research
	Develop novel therapeutics/ strategies to control parasitic diseases	Develop bioinformatic pipelines for analysis of microbiome and pathogen data	Utilise genomics and Integrated Biology studies for new intervention and treatment research *In vivo* pre-treatments for animals infected with MDR bacteria to re-sensitise them and

			rendering the bacteria susceptible to Class C and D antibiotics, e.g. plasmid-curing CRISPR-cas9
	Develop animal-free models for vaccine development, such as organoids	Develop in vivo, in vitro and in silico infection models for testing efficacy and safety of new drugs with reduced need for animal testing, new drug-delivery devices, therapeutics including leads for new antimicrobials	Conduct safety and residue studies to expand availability of therapeutics into the minor use/minor species areas
	Reducing antimicrobial resistance and its impact on welfare	Develop pharmacokinetic studies to reduce animal experimentation and provide effective dosing schedules to reduce incidence of resistance and maximise efficacy	Utilise synthetic biology studies for new intervention and treatment research
	In order to reduce AMR more research on treatment strategies that reduce both length and dose of the antimicrobial used		Develop nanotechnology in animal health for new interventions and treatments
			Valid, reliable and feasible welfare indicators for monitoring drug delivery
			Progress alternatives to animal experiments (e.g. organoid or in vitro models)
Action 3. Build on the results of Action 1&2 to develop or improve interventions and treatments and deliver first proof of concept, where appropriate, in collaboration with industry: demonstration of immunogenicity and efficacy in target species; representative (small scale) animal (challenge) model (TRL 3-4)	To foster the research to find new treatments (drugs or protocols) for fish and shellfish which are extremely limited	Conduct studies on animals including field trials to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life	Conduct safety and residue studies to expand availability of therapeutics into the minor use/minor species areas
		Studies on antibiotic effectiveness and availability	Studies to investigate side effects of treatments and their welfare impacts
		Develop novel therapeutics/ strategies to control parasitic diseases	
Action 4. In collaboration with industry: bring outputs to higher TRL in early/pre-clinical development (GMP-material; TRL 5-6); **(i) for non-food animals:**		Develop novel therapeutics/ strategies to control parasitic diseases	

demonstration of efficacy and field safety at large scale in representative animal models or approved alternative methods; (ii)for food animals: lab-scale assessment of animal safety and initiation of environmental safety, user safety, and (if needed) microbiological safety assessments; absence of toxicity/side effects; carcinogenicity studies initiated if needed, and demonstration of efficacy and field safety at large scale in a representative animal model and toxicology studies. Work on TRL 7 to 9 (late/clinical development, marketing authorisation and lifecycle management) will be performed by industry itself.		Studies on antibiotic effectiveness and availability	

Additional suggestions from the experts

Fundamental research for new interventions and treatments	Address the impact of new intervention and treatments on pathogens' evolution, virulence and transmissibility (host-shift)
	Research on Interactions with antimicrobials and environmental pollutants
	Studies to investigate the effect of methane reducing feed additives on dairy cow welfare
Development of new tools and technologies	Studies on the effectiveness and use of bacteriotherapy
	Research on biological control for animal health
	Rediscover ethnoveterinary therapeutic practices to reduce antimicrobial uses

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New procedures and strategies	
	In order to reduce AMR more research on treatment strategies that reduce both length and dose of the antimicrobial used
	To strive to avoid medication (or apply prudent medication) by selection of good genes, offering healthy environment and healthy feed (example: Norwegian landbased animal production)
	Focus on interventions and treatments which are sustainable
	Treatments against poorly controlled diseases should not suffer from the global drive to reduce chemical inputs. It is therefore necessary to continue the research that has proven its effectiveness in the past whenever necessary.
	There is a need in strategic direction for novel interventions and treatment development
	More funding for animal welfare research and ethology
	Apply fish health and welfare consideration also for lab animals used as replacement for mammal studies

Animal Health & Welfare - Vaccines, adjuvants and immune modulators

OO8. To develop new vaccines or improve existing vaccines, including adjuvants and immune-modulators

Vaccination of animals is often the most cost-efficient measure to prevent and control the spread of AID and can be an important tool to reduce the burden of diseases and reduce the use of antimicrobials. With modern technologies (cfr. mRNA vaccine technology or multimeric scaffold particles) the efficacy of existing vaccines may be further improved. Production of new vaccines and improvement of existing ones will require significant scientific advances, such as new approaches to antigen selection and production, antigen delivery, improved adjuvants, vaccine administration, and new insights immune system function before products can be commercialised.

In the AH focus group, the majority of the stakeholders agreed with the prioritisation resulting from the online survey. Indeed, the results from the survey and the FG were similar. There was only one research need relevant to OO8 which was considered a priority for both the survey and the animal welfare, breeding, feeding and precision livestock farming focus group. This was **'Develop animal-free models for vaccine development, such as organoids'**.

The AH focus group attendees expressed concern regarding the timeline of highly desirable vaccines for a market-ready production. This issue is critical for economically devastating diseases such as weaning diarrhoea in piglets. The animal welfare focus group members did not have any further comments in relation to vaccines.

The stakeholders unanimously asked for a vaccine platform and a smarter regulatory system. The platform should foster the development, manufacture and authorisation of new vaccines. The process is recognised to be already in motion, thanks to the new veterinary regulation and guidance from EMA. A single market for vaccines and other VMPs is considered very important in terms of cooperation. The market should comprehend at least EU/EFTA countries and hopefully North America Countries.

The stakeholders asked for the inclusion of the following topics, which were not initially included in the proposed research topics:

- Environmental risk assessment to vaccine development
- Novel adjuvants
- Mucosal immunity

The suggestions from both the focus groups align well with the research needs prioritsed in the survey. Vaccine development in general was considered an important topic and so each of the actions in the summary table below should be considered a priority.

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Table 8: Summary table for OO8 activities indicating urgency

Actions	Research Needs: 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1. Study the role of the immune system of farm animals, including the innate immune capacity of new-born animals; the mechanisms that elicit protective immunity at the entry site, factors affecting immune response to vaccines, mode of action of adjuvants (basic research; TRL 1-2).	Better understanding of pathogen biology for better targeting of vaccines and therapeutics, including mucosal immunity	Study the role of the immune system of farm animals, including the innate immune capacity of new-born animals; the mechanisms that elicit protective immunity at the entry site	Utilise systems vaccinology to identify immune correlates and surrogates of protection including repertoire signatures and response to adjuvants
Action 2. Develop tools such as vaccine platforms and expression systems, immunological toolboxes (cell lines, reagents, etc.) and delivery systems, etc.; this will be done in collaboration with industry, where appropriate	Develop and improve research and translation of new vaccines (e.g. DIVA, recombinants) including new genetically engineered vaccines	Establish a pipeline of vaccine platform technologies, expression systems, immunological toolboxes (cell lines, reagents, etc.) and delivery systems, etc.	Develop animal-free models for vaccine development, such as organoids
	Development of novel adjuvants	Utilise bioinformatics and mathematical modelling to study efficacy of new treatments and vaccines including the animal individual genetic variability of responses to vaccines	Valid, reliable and feasible welfare indicators for monitoring drug delivery
	Develop animal-free models for vaccine development, such as organoids	Studies to investigate side effects of treatments and their welfare impacts	
Action 3. Build on the results of Anction 1 &2 to develop or improve vaccine and immune-modulators abd deliver proof of concept: demonstration of immunogenicity and efficacy in target species; representative (small scale) animal (challenge) model (TRL 3-4) or approved alternative methods; this will be done in collaboration with Industry, where appropriate; this will be done in collaboration with industry, where appropriate			
Action 4. In collaboration with industry: bring outputs to higher TRL in early/pre-clinical development (GMP-material; TRL 5-6); (i) demonstration of animal safety in target and non-target species; and demonstration of efficacy in a representative and validated target animal challenge model.	Environmental risk assessment to vaccine development Improved competitive vaccines, particularly for economically devastating diseases such as weaning		

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Work on TRL 7 to 9 (late/clinical development, marketing authorisation and lifecycle management) will be performed by industry itself.	diarrhoea in piglets and coccidiosis in broiler and turkeys		

Additional suggestions from the experts

Fundamental research for new interventions and treatments	Address the impact of new intervention and treatments on pathogens' evolution, virulence and transmissibility (host-shift)
	Research on Interactions with antimicrobials and environmental pollutants
	Studies to investigate the effect of methane reducing feed additives on animal welfare
Development of new tools and technologies	Studies on the effectiveness and use of bacteriotherapy
	Research on biological control for animal health
	Rediscover ethnoveterinary therapeutic practices to reduce antimicrobial uses
New procedures and strategies	To foster the research to find new treatments (drugs or protocols) for fish and shellfish which are extremely limited
	In order to reduce AMR more research on treatment strategies that reduce both length and dose of the antimicrobial used
	To strive to avoid medication (or apply prudent medication) by selection of good genes, offering healthy environment and healthy feed (example: Norwegian landbased animal production)
	Focus on interventions and treatments which are sustainable
	Treatments against poorly controlled diseases should not suffer from the global drive to reduce chemical inputs. It is therefore necessary to continue the research that has proven its effectiveness in the past whenever necessary.
	There is a need in strategic direction for novel interventions and treatment development
	More funding for animal welfare research and ethology
	Apply fish health and welfare consideration also for lab animals used as replacement for mammal studies

Animal Health & Welfare: Access to interventions

OO9. To increase access to veterinary vaccines, interventions and treatments and uptake of said vaccine interventions and treatments in the field

To progress toward this operational objective the following Actions are:

Action 1. Monitor the results of the EUP AH&W projects and evaluate if they can be the basis of new patent applications.

Action 2. Manage intellectual property (IP) and further development of the deliverables towards European Innovation Council (EIC) or similar programmes and industrial partners.

Action 3. Prepare the regulatory process for novel and innovative vaccines and treatments developed by the PAHW, with implementation of regulatory experts (for each of the projects in the implementation phase), interaction with national regulators and with EMA, taking into account its recently published paper (Regulatory Science Research Needs78).

Action 4. Develop methods and procedures for comparative evaluation of clinical efficacy of veterinary antimicrobials to feed into antimicrobial guidelines and policies.

This OO focuses on regulation and policy. It was not included in consultation with the research community but would be discussed as a part of the second stakeholder consultation

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Animal Health & Welfare - Socio-economic aspects

OO10. To develop an integrated approach on animal health and welfare including socio-economic aspects of animal health and animal welfare

Animal husbandry is a complex human activity, involving not only production factors and direct contact with animals, but a wide range of relationships. Animal health and welfare is a particularly emotive subject for the general public and this can have an impact on consumer choice and demand. Animal diseases (including those with zoonotic potential) have a great impact on consumer behaviour and public health, this is effected by cultural and societal norms. Farmers react to challenges and regulatory requirements depending on the risk communication they are exposed. Incentives (not only economic) are often necessary for the reinforcement of control measures.

This Operational Objective received a spread of high scoring research needs from both the survey and the animal welfare, feeding, breeding and precision livestock farming focus group. The top research needs are listed below:

- Improved **understanding of the trade-offs between sustainability and animal welfare**
- **Establish social science studies along the production chain** to understand incentives and barriers to adopting innovations and practices such as vaccination and welfare labelling schemes
- Study the **integration of animal infectious disease mitigation and improved animal welfare in the overall context of sustainable livestock** production and aquaculture in the EU
- Improved understanding of trade-offs between farming (production and practices) and welfare

These research needs were equally spread across both of the Operational Objective actions and so both Actions 3 and 4 are recommended for prioritisation.

Table 10: OO10 Research needs in relation to Actions and urgency

Actions	Research Needs : 1-2 years	Research Needs: 3-5 years	Research Needs: 5 years +
Action 1: Assess the burden of selected priority diseases (including resistant pathogens, including their control (e.g. cost-benefit of different surveillance	Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators	Improve the data collection and data quality in animal health economics	cost-benefit analyses of active and targeted surveillance in livestock for a selection of high-impact pathogens in the EU

components and risk mitigation options)		Develop models and collaborations to carry out comparative burden of disease assessment between different diseases	
Action 2: Set up social science studies among veterinarians, farmers, consumers and other actors along the production chain on their behaviour (also in relation to AM use) to maintain and <u>improve animal health</u>, including consumers' <u>willingness to pay for improvements; incentives and barriers to adopt innovations and practices</u>	Identify obstacles for acceptance of bioengineered vaccines	Study the social strategy to improve acceptance of insect use as a source of protein	Research on determination and monitoring of socio-economic factors that can increase farm susceptibility to infectious diseases, with the aim to detect less resilient holdings/areas/regions and to feed precise risk assessments
	How to enhance UPTAKE of biosecurity and vaccines needs research	Elucidate trade offs between animal health and animal welfare in modern og new production systems and technologies	
Action 3. Set up social science studies among veterinarians, farmers, consumers and other actors along the production chain on their behaviour to maintain and improve <u>animal welfare</u>, including consumers' willingness to pay for improvements; incentives and barriers to adopt innovations and practices, including welfare labelling schemes.	Establish social science studies along the production chain to understand incentives and barriers to adopting innovations and practices such as welfare labelling schemes	Social science studies to assess the acceptability of new technologies aimed at improving of animal health and welfare	
	Improved understanding of the trade-offs between sustainability and animal welfare	Investments in philosophical and ethical research on animal welfare issues	
Action 4. Study the integration of AID mitigation and improved animal welfare in the overall context of sustainable livestock production and aquaculture in the EU.	Study the integration of animal infectious disease mitigation and improved animal welfare in the overall context of sustainable livestock production and aquaculture in the EU	Identify biosecurity risks associated with organic farming	
		New economic methods are needed to take into account the trade impacts in case of outbreaks, implementation of specific	

		interventions, voluntary measures. The question is how these influence the trading behaviour between countries.	
	Improved understanding of the trade-offs between sustainability and animal welfare		
	Improve epidemiological knowledge to quantify the risks of culling versus vaccination (all epizootic and notifiable diseases)		
	Improved understanding of trade-offs between farming (production and practices) and welfare		
Action 5: Develop integrated strategies for the control and prevention of diseases, including emergency situations, taking into account relevant criteria, e.g. epidemiological situation, cost-benfit etc. in order to support decision making by national and international risk managers and other relevant stokeholders.	Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators	Studies on methods of communication to better inform consumers and citizens about health and welfare issues in a balanced way	
	Improve epidemiological knowledge to quantify the risks of culling versus vaccination (all epizootic and notifiable diseases)	Multidisciplenary projects to develop harmonized methodologies to assess beneifts and disadvantages for society of different interventions from multifascetted perspectives such as economy, climate impact, food security and welfare	
	Develop cost-benefit analyses of active and targeted surveillance in livestock for a selection of high-impact pathogens in the EU		

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Additional suggestions from the experts

Fundamental research for socio-economic aspects	
	Integration of studies in the human and social sciences (socio-anthropological surveys) in order to describe the perception of health risks and improve dialogue and collective governance of the management of crisis situations in a process of health democracy
	Research in animal welfare of pets
	Study of impact of antimicrobial use (AMU), and the role of companion animals (CA) in AMR transmission: 1. estimate the AMR burden associated with CA 2. Investigate transmission dynamics between CA and humans, the environment and farm animals 3. evaluate AMU and drivers of prescription in CA 4. identify how to reduce AMU and prudent use in CA

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Thematic Area Prioritisation and missing research needs - AW

Although not related to Operational Objectives the focus group participants were asked to rank several thematic areas related to animal welfare, feeding, breeding and precision livestock farming in order to gather more general results and to help with the structure of the focus group. The highest ranked thematic area in terms of importance to address research an innovation gaps was **'Understanding and measures stress, pain and behaviour'** with **'Improved and understanding welfare'** ranked second and **'Sustainability/ climate change and animal welfare'** ranked second and third.

The two least important thematic areas according to the focus group participants were **'Feeding and understanding the microbiome'** and **'Alternatives to animal experiments and societal animal welfare issues'**.

Participants noted that the thematic areas which were ranked higher tended to be broader, perhaps as they had a wider range of applications and impacts than the more specific areas which were ranked lower.

In the survey and also in the focus group, participants were asked whether they felt that there was any research needs missing. Below are common research needs that were missing and should be addressed within the framework of this SRIA:

- Positive welfare
- One welfare
- Links between animal health and welfare
- Fish/aquaculture health and welfare
- Sustainability and farming practices
- Inclusion of more social science – including economics
- Focus on the animal-human interaction e.g., more training
- Companion animal welfare
- Animal welfare indicators

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Monitoring Framework

Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Deliverables	Indicators
Improvement of **preparedness** for emerging and exotic diseases through syndromic surveillance Identify **transmission sources** and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...) through passive and active surveillance Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases) Develop methods/tools for the design of efficient surveillance systems for early warning, early	Foster basic research and translational studies to support the development of new diagnostic tools (immunology, microbiology, virology, pathology) **Networking** Increase the multidisciplinary networking including a One Health approach through organisation of transnational research calls EU network of laboratories monitoring AMR in animal pathogens Link as appropriate with existing reports from human and zoonotic pathogens Create a network of farmers to allow collaboration Increase cross-sectorial networking/Platforms	Coordinated response to animal health and welfare issues with greater cooperation Increased investments in research and innovation, infrastructures, education and training and serviced in animal health and welfare Increased Networking between farmers, veterinarians and researchers to develop coordinated response to animal health and welfare issues Improved science-based understanding of virulence and transmission dynamics (within and between herds) of pathogens affecting animal health that leads to better surveillance, improved laboratory tests for diagnosis and characterisation and more performant risk assessment models and studies.	Multidisciplinary network(s) (in Europe) with a One Health approach both for animal health and welfare Early warning of (re)-emerging diseases DB for Big data implemented and easy access to and sharing of data Recommendations to CAs for progress in regulatory aspect VMP administration protocols validated and approved for use in livestock /aquaculture farming by regulatory agency Methods/procedures for comparative evaluation of clinical efficacy of veterinary antimicrobials and alternatives to antibiotics to inform antimicrobial guidelines and policies	Scientific production on the related science. Database of networks and participants in the networks Data sharing agreements within the networks* People trained on Big Data management/Db software Scientific production on the related science No. of guidelines /reports produced No. of trained stakeholders or courses VMP protocols finalized No. of pilot farms Database of networks and participants in the networks

Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
detection, monitoring of pathogen diversity, frequency and animal health implications

Develop terrestrial and aquatic wildlife disease surveillance and reporting systems, including methods, systems and harmonisation for assessment of wildlife populations and demography

Identify transmission sources and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...)

Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications

Managing Big data, GIS, NGS; progress bioinformatics, improve sharing data integration and better use of existing data

Integration and better use of existing data and data analysing techniques for animal welfare

Progress artificial intelligence and machine learning techniques that support identification of new pathogens and earlier detection of known | Increase cross-sectorial networking

Creation of new networks that bring together bioinformatics and epidemiology applicable to both livestock/aquaculture and wildlife

Map and create an inventory of existing networks and standardized EU risk assessment platforms and notification systems and possibilities for their interoperability

Network diagnostic facilities and centres, enable sharing of data, protocols, specimen, technical expertise; build skills and capacities where lacking

Data and Bioinformatics and AI
Reuse of data: Increase and optimize the Big data management in relation to identification of new pathogens and on climate and other environmental conditions

Create systematic collection of animal welfare data | Improved informing decisions on prioritization of targeted (which pathogen or pathogens) risk assessment and -management or control strategies

Better preparedness for potential new epidemics/pandemics (reword: Better prediction strategies and control measures to respond to potential new epidemics/pandemics)

Improved response for emerging and exotic diseases, enabling precisely targeted disease management

Better preparedness (contingency planning, training...) for potential new epidemics/pandemics
Improved early detection and control (emerging/re-emerging pathogens)

Better source attribution, better understanding of sources, transmission, and spread

Improved outbreak response of higher accuracy of tracing activities and real time understanding of transmission risks | Methods/procedures for registration of alternatives to antibiotics

Timely training activity of stakeholder in new developed therapeutic strategies

Input for modelling and prediction

Report on needs and barriers for appropriate us of AM

Advice/recommendations on actions on clever use of AM

Report on socio-economic impact of changes in practice on use of AM

Foresight reports on animal health and welfare (One per year over the lifespan of EUP AH&W)

New concepts and knowledge produced by EUP AH&W and endorsed by stakeholders (breeding companies, policy makers etc)

Novel drugs, immune-modulators, and other alternatives to reduce antibiotics use on farm

New markers for host response/vaccine efficacy etc | |

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
pathogens from sequencing and proteomic data

Development of platforms to support farmers in collecting and sharing primary data on animal welfare

Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts

AMR surveillance in connection with measuring animal health and welfare indicators

Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications

Development of tools to convert apparent to true prevalences, to enable fit-for-purpose monitoring

Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases) | Invest in multidisciplinary research combining bioinformatics, machine learning and big data technologies and animal welfare and health

Develop bioinformatic and mathematical modelling to study efficacy of new treatment

Create a data sharing culture that farmers and relevant stakeholders have trust in

Coordination and interoperability of datasets

Bioinformatics and mathematical modelling for the assessment of vaccines efficacy

Adapt existing or develop new methodologies to integrate genomic surveillance data in risk assessment.

AMR

Develop diagnosis technologies that can be used to rapidly detect AMR on farm without the need for lab

Develop alternatives to antibiotics and anthelmintics | Early detection/early warning, monitoring of pathogen diversity, knowledge about disease frequency and animal health implications

More accurate identification or prediction of hotspots of emergence and disease transmission

Science based prioritization of targeted control strategies

Increased identification of outbreaks and decreased number of false alerts

Improved sustainability of treatments (reword: new molecules or therapeutics for potential use in veterinary medicine are available)

Deep understanding of economic and social consequences of novel therapeutic strategies

Realistic insight in the socio-economic opportunities, challenges and barriers to | X number of new and improved validated and harmonised diagnostics procedures

New non-animal models/assays/procedures for testing efficacy and safety of novel therapeutics

X number of new and improved vaccines and delivery systems for current and emerging diseases

X number of new animal welfare labelling scheme initiated by MS and/or Industry | |

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Deliverables	Indicators
Managing Big data, GIS; progress bioinformatics, improve sharing data integration and better use of existing data

Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences

Development of tools for measuring animal stress

Integration and better use of existing data and data analysing techniques for animal welfare

Development of quantifiable positive animal welfare indicators

Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare

Develop animal welfare surveillance including epidemiology and its evaluation

Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare

Need for early warning of Animal Welfare | Basic research on molecular and cellular studies to better understand resistance e.g. resistant traits, genes etc.

Research to understand how antibiotic free production effects animal welfare e.g. what are the trade-offs and how do alternatives effect animal welfare.

Basic and applied research on the development of ATAs.

Basic and applied research on the development of ATAs.

Policies
Develop novel therapeutics administration strategies

Development of methods to measure the efficacy of AID control programs

Develop novel therapeutics administration strategies

Improve feedback systems along the food supply chain to translate RA in policy or control measures

Develop procedures to measure the environmental effect of pharmaceuticals on farm and if this can have an effect within the | develop new antimicrobials in some European areas

Effective, evidence-based communication and risk strategies

Scientific basis for new legislation and regulatory framework (reword: new evidence-based applications for existing therapeutics)_

Science-based understanding of virulence and transmission dynamics and recommendations to improve surveillance, laboratory work, risk assessment and -management.

Science-based understanding of virulence and transmission dynamics (within and between herds) of pathogens.

Understand situations and environments that lead to increased stress responses and negative welfare states

Develop health parameters and ethograms of species-specific behaviour that relate to increased stress responses and negative welfare states | | |

Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Deepen understanding of host-pathogen-microbiome interactions: mechanisms by which emerging pathogens transgress species barriers Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools Develop new, cheap, accurate, rapid and easy to use field diagnostic tests and diagnostic techniques, including pen-side diagnostics for the early detection of pathogens Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts Progress rapid, accurate, tests for AMR diagnosis (e.g. LAMP, AST estimation through MALDI-TOF and fluorescence coloration of RNA biomarkers) Develop routine use of high-throughput technologies (metagenomics, sequencing, machine learning and bioinformatics) for multi-target and Diagnostics	environment or ecosystem outside of the farming environment. **Foresight and Horizon Scanning** Foresight approach to identify challenge and barriers for the • development of new AM • sustainability of livestock sector/application of OH approach **Tools and Technology** Create cost-effective technology for use on-farm and during transport and slaughter Scientific studies looking at different technologies to monitor stress in different species and at different life stages Optimise sampling, transport, storage, treatment strategies suitable for the detection of diseases in free-ranging or wild animals **Animal Welfare** Deepen understanding of animal health and behaviour that can link to welfare and stress responses	Improved slaughter conditions that minimise pain and suffering during killing Improved animal husbandry methods that reduce stress and promote positive welfare Diagnostic tools to rapidly detect AMR and AHR on farms and within the environment. Reduction in the use of antibiotics, anthelmintics and antivirals. Improved understanding of underlying mechanisms of resistance to allow more applied research to have specific targets to focus future research efforts. Deepened understanding of how animal emotional state is affected by the presence/absence of antimicrobials, anthelmintics and antivirals. Improved uptake of ATAs. Increased understanding of parasitic diseases and sustainable methods of reduction and treatment. Increased understanding of weather patterns and conditions that lead to increased vector numbers and disease spread.		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Development of alternative models especially biologically relevant (species-specific) cell culture models that are still lacking for drug screening/testing approaches Harmonization of lab tests and result communication Develop new sampling methodologies and strategies, incl. widening of the range of biological, also for drug screening/testing approaches samples Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools Development of digital toolboxes that centralize all diagnostic data coming from local laboratories in real time and directly send the information to responsible authorities at a national level and international level and linked to human diagnostic system. Understand stockperson care/management practices and their welfare implications Development of tools for measuring animal stress Refinement of animal-based measures for fit-for-purpose	Continuously monitor and review guidelines for slaughter conditions and standards for all relevant species Deepen understanding of what constitutes as poor welfare and what can encourage positive welfare on-farm, during transport and at slaughter to minimise stress and poor welfare conditions Understand optimal housing conditions for all livestock species (including fish) to minimise poor welfare conditions and maximise positive welfare experiences Develop indicators of negative/positive welfare for different farm animal species. Study weather pattern and climate and the effect this has on different farm animal species both on farm and during transport Design and carry out studies that monitor sustainable farming and the animal welfare response to that change. Ensure that research studies involving sustainable livestock production take into account the	Deepened understanding of behaviours and physiological parameters that indicate negative/positive welfare states in different farmed animal species. Deepened understanding of heat stress tolerances of different farmed animal species and optimal temperature and climate patterns for those species. Greater awareness of the environmental effects of pharmaceuticals on the environment (both within and external to the farming environment) Increased understanding of effects of sustainable livestock production on animal welfare and the balance that needs to be created. New genetic breeds with improved robustness Breeding programs adapted to alternative production systems Improved uptake of new or improved breeding technologies Improved knowledge on immune memory mechanisms		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Deliverables	Indicators
assessment of animal welfare consequences Work on design of slaughter facilities in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase Work on design of pre-slaughter phase including stunning methods Research on humane methods for on-site killing of large groups of animals i.e. farm depopulation in case of disease outbreak Development of tools for measuring animal stress Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences Integration and better use of existing data and data analysing techniques for animal welfare Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare Develop animal welfare surveillance and its evaluation	welfare of the farm animal species under study before sustainability measures are put into place. **Vaccines and Vaccinology** To establish a pipeline of vaccine platform technologies, and immunological toolboxes **Risk Assessment** Risk assessment on human and animal health related to circular and/or alternative farming systems Draft risk assessment guidelines for the integrated use of epidemiological and genomic data **Surveillance** Integrate, optimise and extend surveillance methods to other countries and develop new ones where needed Develop better surveillance tools to monitor weather, vector and disease spread.	Improved knowledge on computational systems Scientific basis for new legislation and regulatory framework Improved knowledge on the ecology and interaction between wildlife/aquatic life and farm animal Improved knowledge on the heredity of resilience traits Improved early detection of pathogens and/or the presence of vectors Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission Better risk communication and increased trust between institutions, authorities, stakeholder and the public on risk information and management Reduced impact of diseases Better understanding of AMR incidence, prevalence, range across pathogens including study of resistance circulation within and between humans and		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Precision Livestock Farming technologies and artificial intelligence for welfare		animals and through food, water and the environment		
Data mining of syndromic surveillance/ early warning systems to allow for AW evaluation		Uptake of dashboards with DATA, WARNINGS and MESSAGES that allow informed decisions. These dashboards should be governed and 'gardened'		
Studies on the impact of transport on animal welfare across species		Novel biomarkers (pathogen, host response/vaccine efficacy, drug resistance/efficacy, variants, zoonotic potential, infectivity/virulence, vectors, environment)		
Precision Livestock Farming technologies and artificial intelligence for welfare				
Develop thresholds for intervention based on animal welfare risk assessment data		Better understanding of infectious agents circulating through populations and the environment, particularly wildlife and of interactions between host, pathogen and environment		
Investigations into possible application of science-based animal welfare risk assessment criteria in real life and under different husbandry conditions		Better intervention against helminths		
Develop animal welfare surveillance and its evaluation		Easier and more effective sample collection and processing		
Development of tools for measuring animal stress addressing specifically farrowing crates and piglet castration		Reduced use of animal experiments by alternative and appropriate *in-vitro* and *in-silico* models		
Refinement of animal-based measures for fit-for-purpose assessment of animal welfare consequences		Multi-criteria decision-support for policy, agreed among relevant stakeholders		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Studies on the impact of transport on animal welfare across species Improved understanding of climate change and its impact on welfare Deepen understanding of host-pathogen-microbiome interactions Develop strategies to reduce antimicrobial and anthelmintic use (incl. feed additives/nutrition) and/or to encourage their prudent use Evaluate the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals (piglets, chicken) Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare Investigations into possible application of science-based		Proportionate epidemic control interventions with reduced economic loss and least societal adverse impacts Implementation of proportionate and cost-efficient surveillance programmes based on optimal benefit per risk-reduction unit Improved collaboration between animal disease specialists, risk assessors, economists and social scientists in animal health epidemics Better understanding of the effect of weather extremes and ecosystem changes on vector-borne diseases occurrence and transmission Improved welfare by measuring/monitoring and implementing surveillance will also have positive economic effects (market value of e.g., meat quality) Better support for risk assessments on animal welfare in many housing/husbandry systems in the EU and consequently result in better and sound decisions/advice on the status of animal welfare at farm level and at animal level and by consequence also to economic		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
animal welfare risk assessment criteria in real life and under different husbandry conditions Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators Establish social science studies along the production chain to monitor behaviour towards maintaining and improving animal welfare, including consumers' willingness to pay for improvements; incentives and barriers to adopting innovations and practices such as welfare labelling schemes Improved understanding of stocking density and its welfare implications and economic trade-offs Improved understanding of the trade-offs between sustainability and animal welfare Development of tools for measuring animal stress Refinement of Animal-based measures of welfare		value (labelling on Animal welfare) Reduced spending on on-farm welfare inspections and checks Understanding of AMR incidence, prevalence, range across pathogens including resistance circulation within and between humans and animals and through food, water and the environment (One Health) Improved knowledge on different production systems with improved external biosecurity measures that reduce the spread of new and emerging diseases. (For some aquatic production systems, there is no distinction between external and internal biosecurity) Sustainable cross-sectorial and multidisciplinary networks on biosecurity established New/improved efficient methods for killing and destruction of animals in an outbreak situation with focus on prevention/control and animal welfare Streamlined process for development of biosecurity plans for farms (livestock and aquaculture, fostering translation of innovations and technological		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Precision Livestock Farming technologies and artificial intelligence for welfare Welfare considerations for new methods of rearing Develop and set appropriate breeding goals that consider welfare implications (not solely focused on production) Research to improve animal welfare through feeding and breeding strategies Improve breeding technologies for animal health: e.g. integration of molecular technologies into breeding programs, especially for low heritability traits and traits associated with health and pathogen resistance Increase understanding of how genetic engineering in farm animals affects zoonotic disease resistance Improved understanding of direct or indirect interactions between pathogens (e.g. co-infections) and between pathogen and host and its microbiome Better understanding of host immunity		advances in farm management procedures		

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Better understanding of the molecular and cellular basis of antibiotic resistance				
Investigation of the impact of the reduction of antimicrobials and antibiotic free productions on animal welfare				
Reducing antimicrobial resistance and its impact on welfare				
Evaluate the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals (piglets, chicken)				
Develop novel antimicrobial molecules e.g. antiseptics, antimicrobial peptides (bacteriophages), immunomodulatory specific agonists or antagonists and bioactive plants or alternative specialty feed ingredients such as plant extracts (essential oils, tannins, etc.)				
Develop novel immunomodulators and antivirals				
Develop novel therapeutics/ strategies to control parasitic diseases				

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Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Develop animal-free models for vaccine development, such as organoids				
Reducing antimicrobial resistance and its impact on welfare				
Better understanding of pathogen biology for better targeting of vaccines and therapeutics, including mucosal immunity				
evelop and improve research and translation of new vaccines (e.g. DIVA, recombinants) including new genetically engineered vaccines				
Development of novel adjuvants				
Develop animal-free models for vaccine development, such as organoids				
Environmental risk assessment to vaccine development				
Improved competitive vaccines, particularly for economically devastating diseases such as weaning diarrhoea in piglets and coccidiosis in broiler and turkeys				
Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge				

THIS IS A WORKING DRAFT

Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
and technology transfer to end users/operators				
Identify obstacles for acceptance of bioengineered vaccines				
Establish social science studies along the production chain to understand incentives and barriers to adopting innovations and practices such as welfare labelling schemes				
Improved understanding of the trade-offs between sustainability and animal welfare				
Study the integration of animal infectious disease mitigation and improved animal welfare in the overall context of sustainable livestock production and aquaculture in the EU				
Improved understanding of the trade-offs between sustainability and animal welfare				
Improve epidemiological knowledge to quantify the risks of culling versus vaccination (all epizootic and notifiable diseases)				
Improved understanding of trade-offs between farming (production and practices) and welfare				

Research and Innovation Needs (1-2 years)	Actions and Strategies	Outcomes	Delivarables	Indicators
Deepeining the understanding the role of veterinarians in prevention of disease and improving welfare – knowledge and technology transfer to end users/operators				

Survey results: identified R&I needs aligned with EUP AHW&W's Operational Objectives

The operational Objects from the EUP AH&W dossier have been mapped to the research needs from the survey and focus groups. Below is an explanation of the OOs.

Animal Health & Welfare - Surveillance and Monitoring systems

OO1. To design and harmonise surveillance and monitoring systems for animal health and welfare

Actions	Research Needs	Importance score	Urgency Score
Action 1. Optimize and extend to other countries current surveillance systems for animal health and zoonotic infections and to develop new ones where needed	**Fundamental Research for Surveillance** - Increase investigations at the human-animal interface of diseases and by increase engagement in networking (One Health approach)	5,97	2,39
	Fundamental Research for Surveillance - Improvement of preparedness for emerging and exotic diseases	5,95	2,54
	Fundamental Research for Surveillance - Identify transmission sources and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...)	5,89	2,43
	Fundamental Research for Surveillance - Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission	5,73	2,51
	Development of new tools and technologies - Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	5,98	2,50

Actions	Research Needs	Importance score	Urgency Score
	Development of new tools and technologies - Develop optimised terrestrial and aquatic wildlife disease surveillance and reporting systems, including methods, systems and harmonisation for assessment of wildlife populations and demography	5,36	2,11
	Development of new tools and technologies - Progress alternative methods to control vectors: integrated pest management, biological control, genetically modified insects/improving networking with the human and environment sectors	5,15	2,10
	Development of new tools and technologies - Develop animal identification technologies and systems for traceability of animals and their products for disease prevention, control and emergency management	4,93	1,99
	Development of new tools and technologies - Elaborate alternative systems to compensate for downsizing of surveillance/detection systems	4,51	1,73
	Communication - Integrate various surveillance methods and ensure transparency between geographies	5,78	2,33
	Communication- Integrate animal health surveillance systems of different sources	5,78	2,35
Action 2. Set up a European wildlife network (both terrestrial and aquatic animals), based on existing wildlife disease surveillance and reporting systems, to coordinate and expand their activities, to analyse wildlife populations in Europe, and to analyse what specific	**Fundamental Research for Surveillance** - Increase investigations at the human-animal interface of diseases and by increase engagement in networking (One Health approach)	5,97	2,39
	Fundamental Research for Surveillance - Identify transmission sources and/or sentinels for animal diseases (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...)	5,89	2,43
	Fundamental Research for Surveillance - Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission	5,73	2,51

Actions	Research Needs	Importance score	Urgency Score
data with reference to potential threat to animals and humans are needed.	**Fundamental Research for Surveillance** - Study the role of wildlife reservoirs for a number of diseases which might impact on human and animal health (transmission parameters study, effect of biosecurity measures, wildlife-livestock interactions, physical barriers etc.)	5,48	2,20
	Development of new tools and technologies - Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	5,98	2,50
	Development of new tools and technologies - Develop optimised terrestrial and aquatic wildlife disease surveillance and reporting systems, including methods, systems and harmonisation for assessment of wildlife populations and demography	5,36	2,11
	Development of new tools and technologies - Progress alternative methods to control vectors: integrated pest management, biological control, genetically modified insects/improving networking with the human and environment sectors	5,15	2,10
	Communication - Integrate animal health surveillance systems of different sources	5,78	2,35
	Communication - Build a European wildlife network (both terrestrial and aquatic animals) based on existing wildlife disease surveillance and reporting systems	5,57	2,28
	Animal welfare on farm, during transport and at the end of life – Improved understanding of the role of wildlife-livestock interaction	4,90	1,71
	Welfare, sustainable production systems and Biosecurity - Improved understanding of climate change and its impact on welfare	5,35	2,13
Action 3. Create networks that bring together bio-informatics and	**Fundamental Research for Surveillance** - Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to	5,80	2,44

Actions	Research Needs	Importance score	Urgency Score
epidemiology, to harmonise metagenomic data and data collection methods, to integrate genomic, clinical and epidemiological data, applicable to both livestock/aquaculture and wildlife.	international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases)		
	Development of new tools and technologies - Progress analysis tools that integrate genomic, clinical and epidemiological data into risk assessment, early detection and disease spread models, including creation of network that bring together bio-informatics and epidemiology applicable to both livestock /aquaculture and wildlife	5,91	2,34
	Development of new tools and technologies - Managing Big data, GIS; progress bioinformatics, improve sharing data integration and better use of existing data	5,89	2,45
	Development of new tools and technologies - Progress artificial intelligence and machine learning techniques that support identification of new pathogens and earlier detection of known pathogens from sequencing and proteomic data	5,37	2,18
	Development of new tools and technologies - Develop tools and systems for syndromic surveillance	4,92	1,91
	Development of new tools and technologies - Research on machine learning based methods for exploring the ontologies of catalogues' values to integrate and network surveillance systems	4,80	1,84
Action 4. Monitor pathogens of veterinary importance (that are not covered in One Health calls) and their antimicrobial resistance profiles.	**Fundamental Research for Surveillance** - Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts	6,03	2,55
	Fundamental Research for Surveillance - Better understanding of the effect of extreme weather and ecosystem changes on vector-borne diseases occurrence and transmission	5,73	2,51

Actions	Research Needs	Importance score	Urgency Score
	Fundamental Research for Surveillance - Understanding of AMR incidence, prevalence, range across pathogens including study of resistance circulation within and between humans and animals and through food, water and the environment	5,65	2,33
	Development of new tools and technologies- Develop methods/tools for the design of efficient surveillance systems for early warning, early detection, monitoring of pathogen diversity, frequency and animal health implications	5,98	2,50
	Development of new tools and technologies - Increase ability to rapidly characterise newly emerged resistance in microorganisms and elucidate the underlying mechanisms	5,53	2,27
Action 5. Build networks, develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal health and welfare issues, and to develop a hazard monitoring and early warning service.	**Fundamental Research for Surveillance** - Increase investigations at the human-animal interface of diseases and by increase engagement in networking (One Health approach)	5,97	2,39
	Fundamental Research for Surveillance - Progress prediction methods to identify new and emerging diseases and when they may become a threat to Europe in relation to international trade, global warming and climate change (e.g. new diseases, transboundary and vector borne diseases)	5,80	2,44
	Development of new tools and technologies - Managing Big data, GIS; progress bioinformatics, improve sharing data integration and better use of existing data	5,89	2,45
	Development of new tools and technologies - Friendly use of platforms supporting farmers and veterinarians in collecting and sharing primary data on animal health. Networks building to develop a hazard monitoring and early warning service	5,56	2,24

Actions	Research Needs	Importance score	Urgency Score
	Development of new tools and technologies - Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal health issues, and to develop a hazard monitoring and early warning service	5,17	2,08
	Development of new tools and technologies - Develop tools and systems for syndromic surveillance	4,92	1,91
	Development of new tools and technologies - Research on machine learning based methods for exploring the ontologies of catalogues' values to integrate and network surveillance systems	4,80	1,84
	Fundamental Research for Surveillance - Refinement of Animal-based measures of welfare	5,74	2,43
	Fundamental Research for Surveillance - Development of **indicators and markers for understanding mental experiences of animals**	5,25	2,04
	Fundamental Research for Surveillance - Deepen knowledge between the interaction of animal physical health and animal mental state and emotion	5,20	2,04
	Fundamental Research for Surveillance - Research on animal cognition (e.g. preferences and motivation to obtain rewards)	5,02	1,94
	Development of new tools and technologies - Development of tools for measuring animal stress	5,98	2,41
	Development of new tools and technologies - Integration and better use of existing data and data analysing techniques for animal welfare	5,85	2,43

Actions	Research Needs	Importance score	Urgency Score
	Development of new tools and technologies - Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning at the slaughterhouses	5,50	2,22
	Development of new tools and technologies - Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal welfare issues, and to develop a hazard monitoring and early warning service	5,39	2,18
	Development of new tools and technologies - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25
	Development of new tools and technologies - Progress alternatives to animal experiments (e.g. organoid or in vitro models)	5,27	2,16
	Development of new tools and technologies - Precision Livestock Farming technologies and artificial intelligence for welfare	5,27	2,14
	Development of new tools and technologies - Development of novel big data and bioinformatics techniques for animal welfare	5,04	2,10
Action 6. Create a platform on animal welfare in the EU with the objective to provide scientific and technical support to all stakeholders, in particular related to data necessary for the monitoring of animal welfare; develop animal welfare surveillance systems and their evaluation.	**Development of new tools and technologies -** Development of welfare surveillance systems	5,82	2,52
	Development of new tools and technologies - Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare	5,62	2,31
	Development of new tools and technologies - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25

Animal Health - Diagnostic procedures, methodologies and tools

OO2. To develop diagnostic procedures, methodologies and tools to support the monitoring of animal health

Diagnostics are often the first step in any medical process, both regarding individual patients (human and animal) and public health. Any control measure should be tailored to the specific issue and circumstance. Reliable diagnostic tests are crucial that can distinguish between healthy and infected individuals, especially when some individuals can be asymptomatic carriers of the disease. Diagnostic tests should be able to detect new diseases (or new variants) to prevent public health or economic crises.

New methodologies and technologies are made available by the scientific advances, and many tools still need to be developed further to be used for the early detection of AIDs. While the adoption of optimised tools in the surveillance programme belongs to the OO1, many other tools need to be perfected, in order to increase their sensibility and specificity, their suitability in field conditions and to reduce their invasiveness. Better diagnostics can improve our understanding of disease and allow the improvement of control measures.

To progress toward this operational objective the following Actions are:

Action	Research needs	Importance score	Urgency score
Action 1. Gain knowledge on priority pathogens (i.e. bacteria, parasites, viruses, fungi, prions including resistance patterns) responsible for important economic losses or high risk of transmission to humans and their detection methods, including	**Fundamental research** - Deepen understanding of host-pathogen-microbiome interactions: mechanisms by which emerging pathogens transgress species barriers	5,80	2,27
	Fundamental research - Foster basic research and translational studies to support the development of new diagnostic tools (immunology, microbiology, virology, pathology)	5,63	2,13
	Fundamental research - Develop sensitive biomarkers for early detection of diseases paired with artificial intelligence and remote detection tools	5,40	2,09

Action	Research needs	Importance score	Urgency score
metagenomics approaches, molecular markers of interest, etc.	**Fundamental research** - Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools	5,30	2,11
	Fundamental research - Expand nanotechnology in animal disease diagnosis	5,19	1,95
	Fundamental research - Identify biomarkers of a healthy (innate) immune system in relation to feed efficiency, disease prophylaxis, pathogenesis and animal welfare	5,19	1,95
	Fundamental research - Identify stage-specific antigens in helminths that can be used in immune tests	4,30	1,65
	Development of new tools and technologies - Develop new diagnostic tests for helminths detection, including rapid systems for parasitic egg/larvae isolation from fecal and environmental samples, which provide reliable and representative data on e.g. environmental contamination, anthelmintic resistance	4,75	1,84
Action 2. Development, optimisation and standardisation of reliable, faster, potentially automatable and/or scalable direct antigen/genome amplification/detection and indirect detection/immune response assessment tools/technologies; tools for the rapid detection of drug-resistant bacteria, viruses, fungi or parasites; on-farm, pen-site diagnostics for pathogens and antimicrobial resistance; focus on priority pathogens and those that do not have EURL.	**Development of new tools and technologies** - Develop new, cheap, accurate, rapid and easy to use field diagnostic tests and diagnostic techniques, including pen-side diagnostics for the early detection of pathogens	5,98	2,44
	Development of new tools and technologies - Develop diagnostic tools enabling the early detection and reliable monitoring of infections, in both vectors and vertebrate hosts	5,86	2,46
	Development of new tools and technologies - Progress rapid, accurate, pen-side tests for AMR diagnosis	5,69	2,33
	Development of new tools and technologies - Develop routine use of high-throughput technologies (metagenomics, sequencing and bioinformatics) for multi-target and quantitative diagnostics	5,64	2,22

Action	Research needs	Importance score	Urgency score
	Development of new tools and technologies - Tools to study inter-species (including wild animals) circulation of pathogens or resistant variants	5,60	2,22
	Development of new tools and technologies - Develop new screening test for wildlife infectious agents	5,25	2,14
Action 3. Development, optimisation and standardisation of tools to distinguish between (i) infected and vaccinated individuals (DIVA) as well as (ii) dead and infectious pathogens for the study of pathogens survival in the environment or in effluents and (iii) to study of inter-species (including wild animals) circulation of pathogens or resistant variants.	**Fundamental research** - Develop sensitive biomarkers for early detection of diseases paired with artificial intelligence and remote detection tools	5,40	2,09
	Development of new tools and technologies - Develop DIVA tests	5,67	2,26
	Development of new tools and technologies - Tools that distinguish between dead and infectious pathogens for the study of pathogens survival in the environment or in effluents	5,12	1,99
Action 4. Development of quantitative and multi-target diagnostics to identify infection levels and silent microorganisms that can interfere with animal production for informed treatment/prevention measures decisions in enzootic production diseases in animals.	**Development of new tools and technologies** - Develop quantitative and multi-target diagnostics to identify infection levels and silent microorganisms for enzootic production diseases in animals	5,61	2,20

Action	Research needs	Importance score	Urgency score
Action 5. Development of non or less invasive and more convenient sample collection methods, including new matrices as well as transport, storage, treatment strategies and corresponding diagnostic tools, also suitable for the detection of diseases in free-ranging or wild animals.	**Fundamental research** - Deepen understanding of host-pathogen-microbiome interactions: mechanisms by which emerging pathogens transgress species barriers	5,80	2,27
	Fundamental research - Progress alternatives to animal experiments such as organoid or models in vitro models	5,43	2,21
	New procedures and strategies - Develop non or less invasive and more convenient sample collection methods, including new matrices	5,39	2,10
	New procedures and strategies - Optimise sampling, transport, storage, treatment strategies suitable for the detection of diseases in free-ranging or wild animals	5,16	1,96
	New procedures and strategies - Develop new sampling methodologies and strategies, incl. widening of the range of biological samples	5,08	1,97
Action 6. Application of new methodologies, i.e., research focusing on application of new detection and characterisation methodologies, on in vitro models; study host-pathogen-environment interactions, i.e. focusing on drivers and markers, on characterisation of microbial ecosystems, on drivers of resistance.	**Fundamental research** - Deepen understanding of the host-pathogen-microbiome interactions that serves the development of diagnostic tools	5,30	2,11
	Development of new tools and technologies - Tools to study inter-species (including wild animals) circulation of pathogens or resistant variants	5,60	2,22

Animal Welfare - Diagnostic procedures, methodologies and tools

OO3. To develop procedures, methodologies and tools to support the monitoring of animal welfare

Actions	Research Needs	Importance score	Urgency score
Action 1. Focus on positive welfare (positive emotions), identification of behavioral, endocrine and neurological indicators of positive welfare: research focusing on animal cognition, preferences and motivation to obtain rewards.	**Animal welfare on farm, during transport and at the end of life** - Understanding social/group dynamics (for social species)	5,52	2,08
	Animal welfare on farm, during transport and at the end of life - Understanding consequences of social interactions/hierarchies and the impact these have on welfare	5,29	2,12
	Procedures/Methodologies/Tools - Deepen knowledge between the interaction of animal physical health and animal mental state and emotion – Importance	5,20	2,04
	Procedures/Methodologies/Tools - Research on animal cognition (e.g. preferences and motivation to obtain rewards	5,02	1,94
	Surveillance and monitoring - Development of indicators and markers for understanding mental experiences of animals	5,25	2,04
	Resilience farming - Understand stockperson care/management practices and their welfare implications	5,80	2,32
Action 2. Development of <u>technologies on the slaughter line</u> to assess animal welfare (on farm and/or during transport). Identification of suitable animal-based measures (ABM) with appropriate level of validity, sensitivity and specificity; development of in-line sensors, large scale data collection.	**Animal welfare on farm, during transport and at the end of life** - Identify indicators and to develop systems to assess the state of consciousness and death	5,64	2,19
	Diagnostics - Development of tools for measuring animal stress	5,98	2,41
	Diagnostics - Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning at the slaughterhouses	5,50	2,22
	Surveillance and monitoring - Refinement of Animal-based measures of welfare	5,74	2,43
	Surveillance and monitoring - Development of indicators and markers for understanding mental experiences of animals	5,25	2,04

Actions	Research Needs	Importance score	Urgency score
Action 3. Animal <u>welfare at slaughter</u>**: i) consciousness and death: development of technologies, procedures and/or protocols to increase the reliability of methods to assess consciousness and death at the slaughter line; ii) improve stunning and killing methods; iii) work on design of slaughter facilities in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase; related staff training.**	**Animal welfare on farm, during transport and at the end of life** - Work on design of slaughter facilities in order to avoid welfare issues like stress, fear and pain at pre-slaughter phase	5,94	2,47
	Animal welfare on farm, during transport and at the end of life - Understanding pain recognition and how it varies across species	5,86	2,24
	Animal welfare on farm, during transport and at the end of life - Identify indicators and to develop systems to assess the state of consciousness and death	5,64	2,19
	Diagnostics - Validation of diagnostic tests (EEG, artificial intelligence) to assess effective correct stunning at the slaughterhouses	5,50	2,22
	Surveillance and monitoring - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25
Action 4. Development of <u>physiological indicators to measure acute and chronic negative animal</u> **welfare consequences on farm. The indicators should identify stress, pain, fear, discomfort, etc. at individual and group levels: measure of physiological stress, impact on immune response and omics (e.g. transcriptomics and metabolomics). Integration of these to metadata welfare tools.**	**Animal welfare on farm, during transport and at the end of life** - Understanding pain recognition and how it varies across species	5,86	2,24
	Diagnostics - Development of tools for measuring animal stress	5,98	2,41
	New interventions and treatments - Studies to further understand infection mechanisms to improve health and welfare	4,87	2,02
	Risk assessment and alert communication - Modelling for the natural behaviour and basic physiological data for different species in different farming systems	5,13	1,89
	Risk assessment and alert communication - Investigations in integration of data originating from transcriptomics, proteomics and metabolomics methods in animal risk assessment	4,67	1,76
	Surveillance and monitoring - Refinement of Animal-based measures of welfare	5,74	2,43
Action 5. Development of digitally assisted monitoring technologies on farms for increasingly enabling precision management of animal (health and)	**Procedures/Methodologies/Tools** - Integration and better use of existing data and data analysing techniques for animal welfare.	5,85	2,40
	Procedures/Methodologies/Tools - Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare.	5,62	2,31

Actions	Research Needs	Importance score	Urgency score
welfare. Technology includes recording visual and auditory signals related to animal-based measures for welfare, analysing records with deep learning technology, data processing techniques and decision support systems.	**Procedures/Methodologies/Tools** - Develop FAIR data and implement FAIR principles for the monitoring of (re)emerging animal welfare issues, and to develop a hazard monitoring and early warning service. – Importance	5,39	2,18
	Procedures/Methodologies/Tools - Development of novel big data and bioinformatics techniques for animal welfare – Importance	5,04	2,10
	Resilience farming - Develop novel animal identification technologies (e.g. non-invasive biometric identification) for animal welfare monitoring	5,16	2,08
	Risk assessment and alert communication - Develop animal welfare surveillance and its evaluation	6,16	2,49
	Risk assessment and alert communication - Develop thresholds for intervention based on animal welfare risk assessment data	5,58	2,21
	Risk assessment and alert communication - Produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal welfare	5,25	2,04
	Surveillance and monitoring - Development of welfare surveillance systems -	5,82	2,52
	Surveillance and monitoring - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25
	Surveillance and monitoring - Precision Livestock Farming technologies and artificial intelligence for welfare	5,27	2,14
	Sustainable production systems and Biosecurity - Precision farming enhanced by developments in (information and communication technology) ICT, GPS-based and sensor technologies for animal welfare	5,54	2,28
Action 6. Development of technologies to assess animal welfare during transport. Affordable and reliable solutions to prevent serious welfare	**Animal welfare on farm, during transport and at the end of** life - Studies on the impact of transport on animal welfare across species	5,92	2,39
	Risk assessment and alert communication - Applications of sensors in animal welfare for real-time monitoring.	5,37	2,18

Actions	Research Needs	Importance score	Urgency score
problems through early detection of signals before and whilst in transit, e.g. lameness, lesions, heat stress, aggression, thirst or hunger, exhaustion, etc. Development of sensor technology, data analysis tools, data collection and integration platforms, decision support for the driver; related staff training.	**Surveillance and monitoring** - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25
	Surveillance and monitoring - Precision Livestock Farming technologies and artificial intelligence for welfare	5,27	2,14
	Sustainable production systems and Biosecurity - Precision farming enhanced by developments in (information and communication technology) ICT, GPS-based and sensor technologies for animal welfare	5,54	2,28

Animal Health & Welfare - Risk assessment and alert communication

OO4. To adapt risk assessment and alert communication to the new needs in animal health and welfare

Action	Research needs	Importance score	Urgency score
Action 1. Enhance rapid risk and consequence assessment methodologies, to assess the economic, social, environmental and cross sectoral consequences of animal health and welfare issues.	**New approaches for risk assessment** - Develop a dynamic risk assessment system and assess methodologies to evaluate the economic, social, environmental and cross sectoral consequences of animal health issues	5,51	2,18
	New approaches for risk assessment - Improve feedback systems between the actors of the food chain to translate outcomes from risk assessment in policy or control measures	5,23	1,99
	Data collection and management - Develop real-time traceability in food systems to achieve rapid animal health/public health actions and early warning.	5,72	2,20
	Data collection and management - Increase risk knowledge by systematically collecting data and undertaking dynamic risk assessments (availability of risk maps and data, knowledge on hazards and vulnerabilities)	5,68	2,32

Action	Research needs	Importance score	Urgency score
	Data collection and management - Develop new or innovative methods/approaches for incorporating machine learning and artificial intelligence in big data-based risk assessment systems.	5,44	2,13
	Data collection and management - Improve epidemiological knowledge to quantify the risks of culling versus vaccination (all epizootic and notifiable diseases)	5,23	2,01
	Risk communication - Develop risk perception research to inform policy and improve communication over measures	5,41	2,10
	Risk communication - Investigate and define a method to quantify how the various risk communication strategies are influencing the behaviour of people and, eventually, the occurrence/impact of the diseases	5,37	2,08
	Risk assessment and alert communication - Develop a dynamic risk assessment system and assess methodologies to evaluate the economic, social, environmental and cross sectoral consequences of animal welfare issues	5,31	2,04
Action 2. Study and assess epidemiological associations between human interventions such as hunting, trade, transport, rewilding and translocations of wildlife and disease spread, in order to propose harmonized tools to support alert systems.	**New approaches for risk assessment** - Assess epidemiological associations between human interventions such as hunting, trade, transport, rewilding and translocations of wildlife and disease spread, in order to propose harmonized tools to support alert systems	5,34	2,15
	New approaches for risk assessment - Improve feedback systems between the actors of the food chain to translate outcomes from risk assessment in policy or control measures	5,23	1,99
	Data collection and management - Develop real-time traceability in food systems to achieve rapid animal health/public health actions and early warning.	5,72	2,20

Action	Research needs	Importance score	Urgency score
Action 3. Adapt existing, or develop new methodologies to integrate genomic surveillance data in risk assessment and to draft risk assessment guidelines for the integrated use of epidemiological and genomic data.	**New approaches for risk assessment** - Draft risk assessment guidelines for the integrated use of epidemiological and genomic data	5,35	2,10
	New approaches for risk assessment - Develop new methodologies to integrate the data originating from transcriptomics, proteomics and metabolomics tools in animal health risk assessment	5,02	1,95
	Data collection and management - Develop new or innovative methods/approaches for incorporating machine learning and artificial intelligence in big data-based risk assessment systems.	5,44	2,13
	Data collection and management - Applications of sensors in animal health for real-time monitoring	5,34	1,99
	Risk assessment and alert communication - Investigations in integration of data originating from transcriptomics, proteomics and metabolomics methods in animal risk assessment	4,67	1,76
Action 4. Assess the risk of spread of resistant animal pathogen clones and genes encoding resistance.	**New approaches for risk assessment** - Asses the risk of spread of multi resistant animal pathogen improving understanding on the patterns of transmission of clones or resistant genes	5,56	2,27
	New approaches for risk assessment - Molecular profiling of the immune system of the different livestock species and investigations into possibilities of reaching trained immunity over the life cycle of the animals	4,88	1,90
Action 5. Build or further map and coordinate emergency networks for scientists and communities, to increase risk knowledge by systematically collecting data and	**New approaches for risk assessment** - Animal health risk-assessment-related data sharing and networking among research centres	5,67	2,18
	Data collection and management - Map existing, standardized EU risk assessment platforms and notification systems and possibilities for their interoperability.	5,38	2,19

Action	Research needs	Importance score	Urgency score
undertaking risk assessments (availability of risk maps and data, knowledge on hazards and vulnerabilities).	**Risk communication** - Develop risk perception research to inform policy and improve communication over measures	5,41	2,10
	Risk communication - Boost risk communication and social research to inform and promote disease management and prevention, at all target levels	5,40	2,13
	Risk assessment and alert communication- Animal welfare risk-assessment-related data sharing and networking among research centres	5,28	2,04
	Risk assessment and alert communication - Produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal welfare	5,25	2,04
Action 6. Develop animal welfare surveillance and its evaluation, develop indicators and alarm levels, produce factsheets and any relevant digital infrastructure that enable risk assessment of any breach in animal welfare.	**Risk assessment and alert communication** - Develop animal welfare surveillance and its evaluation	6,16	2,49
	Risk assessment and alert communication - Investigations into possible application of science-based animal welfare risk assessment criteria in real life and under different husbandry conditions	5,81	2,23
	Risk assessment and alert communication - Develop thresholds for intervention based on animal welfare risk assessment data	5,58	2,21
	Risk assessment and alert communication - Applications of sensors in animal welfare for real-time monitoring.	5,37	2,18
	Risk assessment and alert communication - Modelling for the natural behaviour and basic physiological data for different species in different farming systems	5,13	1,89

Animal Health - Farm management preventive tools

OO5. To develop guidelines and preventive tools to fight against animal infectious diseases on farm and during transport

Action	Research needs	Importance score	Urgency score
Action 1. Establish a multidisciplinary network of experts with focus on biosecurity measures to prevent and control AID on farm and during transport, and draft foresight and priority studies on animal health, public health, pandemics and the role of biodiversity, the changing climate, emerging vectors and vector-borne diseases, bird and fish migrations, epidemiology/ modelling, bioinformatics, etc. for all animal species, including minority species and aquaculture.	**New technologies and data**- Foster sharing of information and uptake of innovation by networking	5,39	2,03
	Biosecurity - Establish a multidisciplinary network of experts with focus on biosecurity measures to prevent and control animal infectious diseases on farm and during transport	5,30	2,17
Action 2. Reduce the entrance and spread of AID by reinforcing external and internal biosecurity in both terrestrial and aquatic animals, while limiting antimicrobial use, set up innovative systems and models with	**New technologies and data** - Improve traceability technologies of farmed animals and registration systems for disease prevention, control and emergency management	5,47	2,21
	Biosecurity - Improve biosecurity methods to control the spread of diseases and technology for inactivation of pathogens	6,10	2,41
	Biosecurity - Develop biosecurity strategies on all levels	5,78	2,37

Action	Research needs	Importance score	Urgency score
focus on biosecurity and integrated management.	**Biosecurity** - Improve efficient and safe management of manure, animal by-products, slurries and water recycle systems	5,72	2,28
	Biosecurity - Identify biosecurity risks associated with organic farming	5,42	2,20
Action 3. Perform research on prudent use of antimicrobials: research on treatment concepts for antimicrobial and antiparasitic usage, on alternatives to antimicrobials including feed additives/nutrition, studying improved vaccination strategies, etc.; development of best practices for administration/application of Veterinary Medicine Products (VMP) in livestock and aquaculture production systems.	**Health, treatments, vaccines and feeding** - Develop strategies to reduce antimicrobial and anti-helminthic use (incl. feed additives/nutrition) and/or to encourage their prudent use	6,20	2,64
	Health, treatments, vaccines and feeding - Development of best practices for administration/application of veterinary medicine products in livestock and aquaculture production systems	5,67	2,39
	Health, treatments, vaccines and feeding - Study on improved vaccination strategies	6,13	2,56
	Sustainability - Study environmental impact of treatments	5,80	2,34
Action 4. Reinforce animal resilience/resistance (the natural ability of animals to withstand pathogens), through feeding and breeding; establish a pan-European network of experts in genetics (breeding), feed additives including pre- and probiotics and leading experts in immunology to	**New technologies and data** - Develop Precision Livestock Farming (PLF) tools and Farm Management Information Systems (FMIS) (data collection, processing and decision making)	5,46	2,19
	New technologies and data - Improve breeding technologies: e.g. integration of molecular technologies into breeding programs, especially for low heritability traits and traits associated with health and pathogen resistance	4,86	1,95
	Sustainability - Advance climate change mitigation and adaptation strategies	6,07	2,52

Action	Research needs	Importance score	Urgency score
produce foresight and priority reports; both fundamental and applied research supporting animal resilience will be set up.	**Sustainability** - Develop new production systems and study on their sustainability (both terrestrial and aquatic)	5,74	2,26
	Genomics and Genetics- Advance genetic selection for animal health resilience, promote the use of local and more resistant breeds, increasing natural disease resistance or tolerance	5,35	2,09
	Genomics and Genetics - Improve genetic evaluations for animal health	4,98	1,88
	Genomics and Genetics - Increase knowledge of systems at the level of the transcriptome, proteome and metabolome that contribute to understanding the links between the genome and the traits of interest.	4,85	1,87
	Genomics and Genetics - Increase understanding of how genetic engineering in farm animals affects zoonotic disease resistance	4,84	1,85
	Genomics and Genetics - Advance precision genetic modification using homologous recombination in appropriate stem cells, use of zinc-finger nucleases and RNAi-based gene knockdown.	4,02	1,61
	Health, treatments, vaccines and feeding - Understanding how alternative protein sources (incl. insects) affect animal health (risks/benefits)	5,06	2,04
	Health, treatments, vaccines and feeding - Study on technopathies of terrestrial and aquatic animals	4,73	1,77
	Health, treatments, vaccines and feeding - Advance phenomics – the physical and biochemical traits of organisms	4,58	1,70

Animal Welfare - Farm management preventive tools

OO6. To develop guidelines and prototype solutions that advance animal welfare on farm, during transport and at the end of life

Actions	Research Needs	Importance score	Urgency score
Action 1. Establish a multidisciplinary network of experts to draft foresight and priority studies with focus on sustainability aspects related to non-cage systems, indoor and outdoor systems for livestock, animal transportation and slaughter, killing on farm, in slaughterhouses or at sea, and focussing on ending mutilations, including aquaculture production systems.	**Animal welfare on farm, during transport and at the end of life** - Studies which demonstrate alternative solutions to reduce animal mutilations	6,09	2,52
	Animal welfare on farm, during transport and at the end of life - Develop Pain free and feasible new methods for on-farm	5,60	2,24
	Procedures/Methodologies/Tools - Development of platforms to support farmers and veterinarians in collecting and sharing primary data on animal welfare.	5,62	2,31
	Risk assessment and alert communication - Investigations into possible application of science-based animal welfare risk assessment criteria in real life and under different husbandry conditions	5,81	2,23
	Risk assessment and alert communication - Animal welfare risk-assessment-related data sharing and networking among research centres	5,28	2,04
Action 2. Perform research on how to improve animal welfare while maintaining or increasing farm economic and environmental sustainability. Involves animal cognitive capacities and emotions	**Animal welfare on farm, during transport and at the end of life** - Understanding the role of environmental enrichment on animal welfare	5,79	2,21
	Animal welfare on farm, during transport and at the end of life - Understanding animal housing - welfare and cost implications	5,73	2,24
	Animal welfare on farm, during transport and at the end of life - Understanding the impact of behavioural restriction/inability to express behaviour on welfare	5,71	2,24

Actions	Research Needs	Importance score	Urgency score
adapted to each species' needs, opportunities for pain relief, and environmental enrichments technologies. Aims to develop innovative housing systems and addresses the opportunities and consequences of reducing the use of cages in a sustainable way, in terms of economic and environmental impacts.	**Risk assessment and alert communication** - Develop a dynamic risk assessment system and assess methodologies to evaluate the economic, social, environmental and cross sectoral consequences of animal welfare issues	5,31	2,04
	Socio-economic - Establish social science studies along the production chain to monitor behaviour towards maintaining and improving animal welfare, including consumers' willingness to pay for improvements; incentives and barriers to adopting innovations and practices such as welfare labelling schemes	6,02	2,46
	Sustainable production systems and Biosecurity - Improved understanding of stocking density and its welfare implications and economic trade-offs	6,00	2,28
	Sustainable production systems and Biosecurity - Improved understanding of the trade-offs between sustainability and animal welfare	5,96	2,38
	Sustainable production systems and Biosecurity - Improved understanding of trade-offs between farming (production and practices) and welfare	5,54	2,31
	Sustainable production systems and Biosecurity - Develop tools/strategies for effective monitoring of air quality to maintain high animal welfare	5,19	2,11
	Sustainable production systems and Biosecurity - Efficient and safe management of manure and animal by-products for improved of animal welfare	4,43	1,64
Action 3. Perform background science to identify indicators and to develop systems to assess the state of consciousness and death, develop appropriate Precision Livestock/fish Farming and killing technologies to limit pain and reduce stress, alert systems for poor welfare during transport, etc.; develop innovative systems in livestock/fish transport and slaughter.	**Animal welfare on farm, during transport and at the end of life** - Understanding pain recognition and how it varies across species	5,86	2,24
	Diagnostics - Development of tools for measuring animal stress	5,98	2,41
	Procedures/Methodologies/Tools - Progress alternatives to animal experiments (e.g. organoid or in vitro models) – Importance	5,27	2,16
	Surveillance and monitoring - Development of welfare surveillance systems	5,82	2,52
	Surveillance and monitoring - Refinement of Animal-based measures of welfare	5,74	2,43
	Surveillance and monitoring - Development of artificial intelligence systems for animal welfare for automated scoring welfare issues across farms, transportation, and slaughterhouses	5,32	2,25

Actions	Research Needs	Importance score	Urgency score
	Surveillance and monitoring - Precision Livestock Farming technologies and artificial intelligence for welfare	5,27	2,14
	Sustainable production systems and Biosecurity - Precision farming enhanced by developments in (information and communication technology) ICT, GPS-based and sensor technologies for animal welfare	5,54	2,28
	Vaccines, adjuvants and immune modulators - Develop animal-free models for vaccine development, such as organoids	5,51	2,24
Action 4. Improve animal welfare through feeding and breeding strategies.	**Animal welfare on farm, during transport and at the end of life** - Welfare considerations for new methods of rearing	5,69	2,24
	Animal welfare on farm, during transport and at the end of life - Understanding of the Intestinal microbiota and their role in immunity, health, and welfare and across the lifecourse	4,86	1,79
	Resilience farming - Develop and set appropriate breeding goals that consider welfare implications (not solely focused on production)	5,73	2,24
	Resilience farming - Research to improve animal welfare through feeding and breeding strategies	5,29	2,14
	Resilience farming - Develop/Improve reproductive/breeding technologies to select for high welfare traits or improve performance and welfare	5,22	2,22
	Sustainable production systems and Biosecurity - Develop seasonal diets for appropriate nutrition (especially dairy cows and sows) to improve animal welfare	4,79	1,85
Action 5. Evaluate the need and possibility to set up a pan-European network of experimental farms.	**Resilience farming** - Set up relevant networks	4,91	1,96
	Sustainable production systems and Biosecurity - Deepen knowledge of microbial ecosystems on farms	4,70	1,87

Animal Health & Welfare - New interventions and treatments

OO7. To develop new interventions and treatments, or improve existing ones, against specific priority animal infectious disease

Actions	Research Needs	Importance score	Urgency score
Action 1. Perform basic research (TRL 1-2) to study interactions between pathogens and host microbiome, focussing on the immune system (e.g. pathobiome), and direct or indirect interactions between pathogens (e.g. co-infections), antimicrobial and antiparasitic drugs and host microbiome, mechanisms of anti-microbial (antibiotic and antiparasitic) resistance; trained immunity.	**Understanding of immunology and environment for new interventions and treatments** - Improved understanding of direct or indirect interactions between pathogens (e.g. co-infections) and between pathogen and host and its microbiome	5,87	2,25
	Understanding of immunology and environment for new interventions and treatments - Better understanding of host immunity	5,67	2,20
	Understanding of immunology and environment for new interventions and treatments - Evaluate the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals (piglets, chicken)	5,64	2,20
	Understanding of immunology and environment for new interventions and treatments - Better underpinning understanding of health ecology and connections between microbial communities, animal health & welfare	5,51	2,21
	Understanding of immunology and environment for new interventions and treatments - Synergy between pharmacological solutions to disease outbreaks and vaccination	5,49	2,11

Actions	Research Needs	Importance score	Urgency score
	Understanding of immunology and environment for new interventions and treatments - Better understanding of direct or indirect interactions between antimicrobial and antiparasitic drugs and host microbiome	5,44	2,04
	Understanding of immunology and environment for new interventions and treatments - Piloting animal ecosystems to reduce pathogen shedding in the environment	5,01	1,89
	Understanding of immunology and environment for new interventions and treatments -Studies to further understand infection mechanisms to improve health and welfare	4,87	
	Antimicrobials and alternatives to antibiotics - Better understanding of the molecular and cellular basis of antibiotic resistance	5,59	2,21
	Antimicrobials and alternatives to antibiotics - Better understanding of anthelmintic resistance (e.g., mechanisms of resistance, genetics, ecology) and markers of resistance	5,25	2,07
	Antimicrobials and alternatives to antibiotics - Investigation of the impact of the reduction of antimicrobials and antibiotic free productions on animal welfare	5,52	2,37
	Antimicrobials and alternatives to antibiotics - Reducing antimicrobial resistance and its impact on welfare	5,42	2,24
Action 2. Develop tools such as 1. experimental farm approaches; 2. in vivo, in vitro and in silico infection models for testing	**Antimicrobials and alternatives to antibiotics** - Develop novel antimicrobial molecules e.g. antiseptics, antimicrobial peptides (bacteriophages), immunomodulatory specific agonists or antagonists and bioactive plants or alternative specialty feed ingredients such as plant extracts (essential oils, tannins, etc.)	6,34	2,64

Actions	Research Needs	Importance score	Urgency score
3. efficacy and safety of new drugs with reduced need for animal testing, new drug-delivery devices, therapeutics including leads for new antimicrobials; and bioinformatic pipelines for analysis of microbiome and pathogen data; this will be done in collaboration with industry, where appropriate.	**Antimicrobials and alternatives to antibioticsv**- Conduct studies on animals to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life	5,31	2,16
	Antimicrobials and alternatives to antibiotics - Studies on antibiotic effectiveness and availability	5,27	2,11
	Antimicrobials and alternatives to antibiotics - Conduct in vitro/in silico studies on pre and probiotics, immuno-stimulants, phages and synthetic microbial communities	5,20	2,15
	Tools and Technologies for novel interventions and treatment - Develop novel immunomodulators and antivirals	5,71	2,28
	Tools and Technologies for novel interventions and treatment - Develop bioinformatic pipelines for analysis of microbiome and pathogen data	5,54	2,14
	Tools and Technologies for novel interventions and treatment - Develop novel therapeutics/ strategies to control parasitic diseases	5,49	2,19
	Tools and Technologies for novel interventions and treatment - Utilize Reverse genetics studies for new intervention and treatment research	5,23	2,06
	Tools and Technologies for novel interventions and treatment - Utilise Genomics and Integrated Biology studies for new intervention and treatment research	5,23	2,01
	Tools and Technologies for novel interventions and treatment - Conduct safety and residue studies to expand availability of therapeutics into the minor use/minor species areas	5,19	2,04
	Tools and Technologies for novel interventions and treatment - Utilise synthetic biology studies for new intervention and treatment research	5,14	1,84

Actions	Research Needs	Importance score	Urgency score
	Tools and Technologies for novel interventions and treatment- Develop nanotechnology in animal health for new interventions and treatments	4,80	1,93
	Tools and Technologies for novel interventions and treatment -Develop in vivo, in vitro and in silico infection models for testing efficacy and safety of new drugs with reduced need for animal testing, new drug-delivery devices, therapeutics including leads for new antimicrobials	5,42	2,26
	Tools and Technologies for novel interventions and treatment -Develop pharmacokinetic studies to reduce animal experimentation and provide effective dosing schedules to reduce incidence of resistance and maximise efficacy	5,16	2,14
	Tools and Technologies for novel interventions and treatment - Valid, reliable and feasible welfare indicators for monitoring drug delivery	4,70	1,83
Action 3. Build on the results of Action 1&2 to develop or improve interventions and treatments and deliver first proof of concept, where appropriate, in collaboration with industry: demonstration of immunogenicity and efficacy (minimum immunizing dose) in target species; representative (small scale) animal (challenge) model (TRL 3-4)	**Antimicrobials and alternatives to antibioticsv**- Conduct studies on animals to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life	5,31	2,16
	Antimicrobials and alternatives to antibiotics - Studies on antibiotic effectiveness and availability	5,27	2,11
	Tools and Technologies for novel interventions and treatment - Develop novel therapeutics/ strategies to control parasitic diseases	5,49	2,19
	Tools and Technologies for novel interventions and treatment - Conduct safety and residue studies to expand availability of therapeutics into the minor use/minor species areas	5,19	2,04

Actions	Research Needs	Importance score	Urgency score
Action 4. In collaboration with industry: bring outputs to higher TRL in early/pre-clinical development (GMP-material; TRL 5-6); 1. for non-food animals: demonstration of efficacy and field safety at large scale in representative animal models or approved alternative methods; 2. for food animals: lab-scale assessment of animal safety and initiation of environmental safety, user safety, and (if needed) microbiological safety assessments; absence of toxicity/side effects; carcinogenicity studies initiated if needed, and demonstration of efficacy and field safety at large scale in a representative animal model and toxicology studies. Work on TRL 7 to 9 (late/clinical development, marketing authorisation and lifecycle management) will be performed by industry itself.	**Antimicrobials and alternatives to antibiotics**- Conduct studies on animals to evaluate the effect of pre and probiotics, immuno-stimulants, phages and synthetic microbial communities at different stages of life	5,31	2,16
	Antimicrobials and alternatives to antibiotics - Studies on antibiotic effectiveness and availability	5,27	2,11
	Tools and Technologies for novel interventions and treatment - Develop novel therapeutics/ strategies to control parasitic diseases	5,49	2,19
	Tools and Technologies for novel interventions and treatment - Conduct safety and residue studies to expand availability of therapeutics into the minor use/minor species areas	5,19	2,04
	Tools and Technologies for novel interventions and treatment - Studies to investigate side effects of treatments and their welfare impacts	5,23	1,98

Actions	Research Needs	Importance score	Urgency score
Possible new action on relation between Animal Welfare and New interventions and treatments	**New interventions and treatments** - Investigation of the impact of the reduction of antimicrobials and antibiotic free productions on animal welfare	5,52	2,37
	New interventions and treatments - Develop in vivo, in vitro and in silico infection models for testing efficacy and safety of new drugs with reduced need for animal testing, new drug-delivery devices, therapeutics including leads for new antimicrobials	5,42	2,26
	New interventions and treatments - Reducing antimicrobial resistance and its impact on welfare	5,42	2,24
	New interventions and treatments - Studies to investigate side effects of treatments and their welfare impacts	5,23	1,98
	New interventions and treatments - Develop pharmacokinetic studies to reduce animal experimentation and provide effective dosing schedules to reduce incidence of resistance and maximise efficacy	5,16	2,14
	New interventions and treatments - Valid, reliable and feasible welfare indicators for monitoring drug delivery	4,70	1,83

Animal Health & Welfare - Vaccines, adjuvants and immune modulators

OO8. To develop new vaccines or improve existing vaccines, including adjuvants and immune-modulators

Actions	Research Needs	Importance score	Urgency score
Action 1. Study the role of the immune system of farm animals, including the innate immune capacity of new-born animals; the mechanisms that elicit protective immunity at the entry site, factors affecting immune response to vaccines, mode of action of adjuvants (basic research; TRL 1-2).	Understanding immunology and pathogen biology for vaccine development- Better understanding of pathogen biology for better targeting of vaccines and therapeutics	5,91	2,36
	Understanding immunology and pathogen biology for vaccine development- Utilise systems vaccinology to identify immune correlates and surrogates of protection including repertoire signatures and response to adjuvants	5,64	2,19
	Understanding immunology and pathogen biology for vaccine development- Study the role of the immune system of farm animals, including the innate immune capacity of new-born animals; the mechanisms that elicit protective immunity at the entry site	5,56	2,22
Action 2. Develop tools such as vaccine platforms and expression systems, immunological toolboxes (cell lines, reagents, etc.) and delivery systems, etc.; this will be done in collaboration with industry, where appropriate	**Tools and technologies for vaccine development** - Develop and improve research and translation of new vaccines (e.g. DIVA, recombinants) including new genetically engineered vaccines	6,12	2,54
	Tools and technologies for vaccine development - Establish a pipeline of vaccine platform technologies, expression systems, immunological toolboxes (cell lines, reagents, etc.) and delivery systems, etc.	5,64	2,27
	Tools and technologies for vaccine development - Utilise bioinformatics and mathematical modelling to study efficacy of new treatments and vaccine	5,54	2,20

Actions	Research Needs	Importance score	Urgency score
	Tools and technologies for vaccine development - Develop animal-free models for vaccine development, such as organoids	5,51	2,24

Animal Health & Welfare: Access to interventions

OO9. To increase access to veterinary vaccines, interventions and treatments and uptake of said vaccine interventions and treatments in the field

Animal Health & Welfare - Socio-economic aspects

OO10. To develop and integrated approach on animal health and welfare including socio-economic aspects of animal health and animal welfare

Action	Research needs	Importance score	Urgency score
Action 1. Assess the burden of selected priority diseases (including resistant pathogens), including their control (e.g. cost-benefit of	**Animal health** - Improve the assessment of the burden of selected priority diseases, including their control measures (e.g. cost-benefit of different surveillance components and risk mitigation options)	5,59	2,22

Action	Research needs	Importance score	Urgency score
different surveillance components and risk mitigation options).	**Animal health** - Develop models to assess the cost of antimicrobial resistance and the costs and benefits of intervention plans	5,38	2,08
Action 2. Set up social science studies among farmers, veterinarians, consumers and other actors along the production chain on their behaviour (also in relation to AM use) to maintain and improve animal health, including consumers' willingness to pay for improvements; incentives and barriers to adopt innovations and practices.	**Animal health** - Social science studies among stakeholders along the production chain on their behaviour to maintain and improve animal health, including consumers' willingness to pay for improvements; incentives and barriers to adopt innovations and practices	5,63	2,24
	Animal health - Interventions to improve awareness on infectious animal diseases	5,45	2,16
	Animal health - Social science on acceptance of genetic improvement	4,42	1,59
Action 3. Set up social science studies among farmers, veterinarians consumers and other actors along the production chain on their behaviour to maintain and improve animal welfare, including consumers' willingness to pay for improvements; incentives and barriers to adopt innovations and practices, including welfare labelling schemes.	**Animal welfare** - Establish social science studies along the production chain to monitor behaviour towards maintaining and improving animal welfare, including consumers' willingness to pay for improvements; incentives and barriers to adopting innovations and practices such as welfare labelling schemes	6,02	2,46
	Animal welfare - Study the integration of animal infectious disease mitigation and improved animal welfare in the overall context of sustainable livestock production and aquaculture in the EU	5,77	2,25
	Animal welfare Understanding the role of veterinarians in improving welfare – knowledge and technology transfer to end users	5,64	2,20
	Animal welfare - Social science studies to assess the acceptability of new technologies aimed at improving of animal health and welfare	5,44	2,00
	Animal welfare - Improve cost effectiveness of realtime data collection	5,24	1,92

Action	Research needs	Importance score	Urgency score
Action 4. Study the integration of AID mitigation and <mark>improved animal welfare</mark> in the overall context of sustainable livestock production and aquaculture in the EU.	**Animal health** - Improve cost effectiveness of data/Realtime collection	5,13	2,07
Action 5. Develop integrated strategies for the control of diseases, including emergency situations, taking into account relevant criteria, e.g. epidemiological situation, cost-benefit, etc. in order to support decision making by national and international risk managers and other relevant stakeholders.	**Animal health** - Develop integrated strategies for the control of diseases, including emergency situations, taking into account relevant criteria, e.g. epidemiological situation, cost-benefit, etc. in order to support decision making by national and international risk managers and other relevant stakeholders	5,84	2,34
	Animal health - Interventions to improve awareness on infectious animal diseases	5,45	2,16