atf animal task force

A European Public-Private Platform

A strategic research and innovation agenda for a sustainable livestock sector in Europe

Suggested priorities for research for Horizon Europe
to enhance innovation and sustainability in the livestock production sector
of Europe's food supply chains

Third White Paper of the Animal Task Force

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Core Team

Presidents: Jean-Louis Peyraud - INRAE (France), Frank O'Mara - Teagasc (Ireland)

Vice Presidents: Vivi Hunnicke Nielsen - Aarhus University (Denmark), Ana Granados - FABRE-TP, Mia Eeckhout - Ghent University (Belgium), Ana Sofia Santos - FeedInov CoLab (Portugal)

Secretariat: Florence Macherez & Susana De Magalhaes, Idele (France)

This paper was prepared by ATF members and engaged partners.

Our members and engaged partners are research providers from 19 countries, including Member States of the EU (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Spain, Sweden, United Kingdom), plus Norway, Serbia and Switzerland, industry representative bodies that support the interests of Europe's livestock industries (AnimalHealthEurope, FABRE-TP, FEFAC, FEFANA) and farmers innovation groups (ECIP, EU-PiG).

About the Animal Task Force (ATF)

ATF is a European Public-Private Partnership and a leading body of expertise linking European industry and research providers for developing innovation in the livestock sector.

We work together to identify actions that are needed to foster knowledge development and innovation for a resource efficient, sustainable, competitive and safe livestock production sector in Europe fostering more sustainable food systems.

Contents

Abbreviations and networks

Cofund ERA-NET SusAn Sustainable Animal Production

COP 21

DG Agri - Directorate General for Agriculture and Rural Development

DG RTD – Directorate General for Research and Innovation

DG Envi – Directorate General for Environment

DG Clima – Directorate General for Climate Action

DG Connect – Directorate General for Communication Networks, Content and Technology

DG Sante - Directorate General for Health and Food Safety

EC DGs - European Commission Directorates Generals

ETP Plants for the Future European Technology Platform

TP Organics – European Technology Platform for Organic food and farming

FoodForLife ETP – Food for Life European Technology Platform

EATiP ETP – European Aquaculture Technology and Innovation Platform

FACCE-JPI – Joint Programming Initiative on Agriculture, Food Security and Climate Change

FAO – Food and Agriculture Organization of the United Nations

GHG – Greenhouse Gases

GASL - Global Agenda for Sustainable Livestock

GRA GHG - Global Research Alliance on agricultural greenhouse gases

HDHL JPI – Healthy Diet for Healthy Life Joint Programming Initiative

ICT technologies – Information, communication technologies

IoT – Internet of Things

R&I – Research & Innovation

LCA – Life Cycle Assessment

RRI – Responsible Research and Innovation

SCAR – Standing Committee on Agricultural Research

SCAR Strategic Working Group AKIS - SCAR Agriculture Knowledge and Innovation Systems

SCAR CWG-SAP – SCAR Collaborative Working Group on Sustainable Animal Production

UN SDGs – Sustainable Development Goals of the United Nations

SRIA – Strategic Research and Innovation Agenda

AMR – Antimicrobial Resistance

Introduction

As a contribution to Horizon 2020, the Animal Task Force presented a White Paper with key areas and priority-topics for European research support to the livestock sector in April 2013 and an addendum in November 2014, then a Second ATF White Paper in 2016 developed for the Horizon 2020 2018-2020 Work Programme.

Towards Horizon Europe, ATF has issued a Position Paper[1] in March 2018. In February 2019, ATF published a "**Vision paper towards European Research and Innovation for a sustainable and competitive livestock production sector in Europe – Framework for suggested priorities for R&I within Horizon Europe[2]"**. This Vision Paper provided an overview of the role of R&I in up-scaling the contribution of a diversity of European livestock farming systems towards sustainable agri-food systems and to the delivery of services to society.

This Strategic Research and Innovation Agenda (SRIA) derives largely from the ATF Vision Paper and aims to provide suggested priorities for R&I within Horizon Europe towards a resource efficient, sustainable, competitive and safe livestock production sector in Europe fostering more sustainable food systems. It was developed by the ATF Presidency and Secretariat in consultation with ATF members in 2019 and 2020 and based on the outcomes of the ATF meetings, workshops and events[3] and aligns with the objectives laid down in the Green Deal, in particular as regards the communications on the Farm to Fork and the Biodiversity strategies.

Some topics were developed in collaboration with European Technology Platforms (ETPs) notably, Plants for the Future[4], TP Organics, Food for Life, and discussed with EATiP to allow for a more systemic and holistic approach of the contribution of animal production to more sustainable food systems. This SRIA was also inspired by the strategic approach to EU agricultural Research & innovation (European Commission), ATF participation in the FACCE-JPI stakeholder and HDHL-JPI events, exchanges of views with EC DGs (namely DG Agri, DG RTD, DG Envi, DG Clima, DG Connect, DG Sante), European Parliament members and FAO representatives. A large range of European and national state stakeholders were also consulted (see table 1) from the industry, farmers organisations, branch or value chain organisations, NGOs, think tanks, international organisations, etc.

[1] http://animaltaskforce.eu/Portals/0/ATF/2018/ATF_Position Paper towards FP9_final.pdf
[2] http://animaltaskforce.eu/Portals/0/ATF_Vision_Paper_2019.pdf
[3] ATF annual events: 2012: "Resource use efficiency"; 2013: "Responsible farming systems"; 2014: "Putting the i in livestock: innovation for a productive and sustainable livestock farming"; 2015: "A transatlantic perspective on visions and strategic research agenda for animal productions in Europe and the USA" and "Precision livestock farming"; 2016: "Livestock, the key in a circular Bioeconomy"; 2017: "Food integrity in the food chain: How can the animal production sector contribute?"; 2018: "Balance Production/Consumption: Animal farming for Humans' well-being and planetary health"; 2019: "Towards a climate smart European livestock farming"; 2020: "What livestock has to offer to biodiversity & healthy soils"
[4] ATF-Plants for the Future Position Paper (http://animaltaskforce.eu/Portals/0/ATF/Downloads/ATF_PlantETP_joint-paper_Sept2019.pdf), September 2019. ATF-Plants for the Future Policy Brief (http://animaltaskforce.eu/Portals/0/ATF/Downloads/ATF-PlantETP_Policy_brief_April2020.pdf) May 2020.

Scope

This SRIA presents key areas and suggested priorities for research and innovation and their overall expected impacts. The scope of the Strategic Research and Innovation Agenda is European terrestrial livestock, including herbivores (ruminants, horses, rabbits) and monogastrics (pigs, poultry). Blue Growth and aquaculture (addressed by the European Aquaculture Technology and Innovation Platform, EATiP), fisheries, game, companion animals and bees for honey are not considered. However, we fully acknowledge that interrelations between green and blue economies should be carefully considered to achieve a sustainable European food and farming. Insect breeding and production for feed is addressed in the context of the circular economy.

Stakeholders met from 2018 to 2021

European Technology Platforms & research: EATiP - European Aquaculture Technology and Innovation Platform, Food for Life, Plants for the Future, TP Organics, EIT Food, FACCE JPI, HDHL JPI, ERFP - European Regional Focal Point for Animal Genetic Resources, GreenChem, BFA - Belgian Feed Association, Vrije Universiteit Brussels, BAMST - Belgian Association of Meat Science and Technology, EurSafe - European Society for Agricultural and Food Ethics

Farmers: CEJA - European Council of Young Farmers, Copa Cogeca, ERPA - European Rural Poultry Association, EURAF - European Agroforestry Federation, FESASS - European Federation for animal health and health safety, FIL-IDF - International Dairy Federation, Nordic Savory Hub, EU PiG, ECIP

Industry: Fur Europe, IPIFF - International Platform of Insects for Food and Feed, AVEC Poultry, CLITRAVI - Liaison Centre for the Meat Processing Industry in the European Union, EDA - European Dairy Association, EFPRA - European Fat Processors and renderers Association, European Meat Network, Global Coalition for Animal Welfare, Eurocommerce - European Association of Retail and wholesale in Europe, AnimalHealthEurope, CEMA - European Agricultural Machinery Association, ELANCO, FEFAC - European Feed Manufacturers' Federation, FEFANA - EU Association of Specialty Feed Ingredients and their Mixtures, FVE - Federation of Veterinarians of Europe, COTANCE - Confederation of National Associations of Tanners and Dressers of the European Community, UECBV - European Livestock and Meat Trades Union

European Commission & European Parliament: Cabinet of Commissioner Stella Kyriakides, Cabinet of Commissioner Frans Timmermans, Commission Hogan, Commissioner Janusz Wojciechowski, DG Agri, DG Clima, DG Envi, DG RTD, DG Santé, DG Connect, EIP Agri service point; MEPs: Alexander Bernhuber, Annie Schreijer-Pierik, Benoit Biteau, Francisco Guerreiro, Isabel Carvalhais, Jérémy Decerle, Julie Girling, Norbert Lins, Ulrike Mueller, Zdzisław Krasnodębski, Fredrick Federley, Bas Eickhout

NGOs: BEUC - European Consumers' Organisation, FERN, Greenpeace, ProTerra Foundation, Eurogroup for Animals, WWF - World Wide Fund for Nature, EEB - European Environmental Bureau, BirdLife Europe, Youth Food Movement, EPHA - European Public Health Alliance, CIWF - Compassion in World Farming, EuroCoop - European Community of Consumer Co-operatives

Think Tanks: EFF - European Food Forum, Farm Europe, Friends of Europe, IDDRI - Institut du développement durable et des relations internationales, IEEP - Institute for European Environmental

Policy, IPES Food - International Panel of Experts on Sustainable Food Systems, RISE Foundation, True Animal Protein Price Coalition

International organisations: EAAP - European Federation of Animal Science, FAO - Food and Agriculture Organisation of the United Nations, GAIN - Global Alliance for Improved Nutrition, ICAR - International Committee for Animal Recording, OIE - World Organisation for Animal Health, EUFIC - European Food Information Council, World Bank

A. Challenges and expected R&I outcomes

1. Challenges

The livestock sector contributes substantially to the European economy and the value of livestock production represents 40% of the total agricultural activity[5]. Beyond its contribution to the European food and nutrition security, the EU-28 agricultural sector generated 10% of the region's total GHG emissions[6] and further emissions arise outside the EU as a result of EU agricultural activity, through the production of inputs such as feed and fertilisers. The livestock sector is responsible for 81-86% [7] of the agricultural GHG emissions. More than 80% of the nitrogen of agricultural origin present in all European aquatic environments is linked to livestock farming activities[8] and the livestock sector accounts for 90%[9] of ammonia emission of the agricultural sector when considering emissions linked to the fertilisers used to produce feed. The role of livestock on the environment, on deforestation is highly debated like animal welfare and animal diseases and antibiotic resistance can threaten human health[10]. However, livestock farming provides very high quality protein foods and provides other important nutrients and micronutrients in greater amounts or better availability than plant proteins. Well managed livestock systems provide several ecosystem services notably via the maintenance of grassland[11], the management of marginal areas, the recycling of manure and their essential contribution to the livelihood of many European regions[12]. Livestock recycle biomass and protein of plant origin that are not directly usable for human food to produce food of high nutritional quality[13] that fits with balanced diets. Animal-based foods are a unique source and/or are very rich in several micronutrients (vit B12, A, B3, B6 and D, zinc, selenium, calcium, phosphorus and heme iron) and various bioactive components that can offer nutritional benefits including development of cognitive functions[14].

The European Green Deal launched in December 2019[15] draws the general framework for the whole EU. Its application to farming and food systems is detailed in the Farm to Fork Strategy[16] and the Biodiversity Strategy[17] for 2030. Ambitious sustainability goals for agriculture are proposed, i.e.: moving towards a carbon neutral Europe by 2050, reducing the use of pesticides and antibiotics by

[5] European Commission, 2018. Agricultural and farm income. European Commission, Brussels, DG Agriculture and Rural Development, 27 p.
[6] European Environment Agency, 2019. Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, 27 May 2019, EEA/PUBL/2019/051, 962 p.
[7] Leip A., Weiss F., Wassenaar T., Perez I., Fellmann T., Loudjani P., Tubiello F., Grandgirard D., Monni S., Biala K. 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) final report: European Commission, Joint Research Centre, 323 p. http://ec.europa.eu/agriculture/analysis/external/ livestock-gas/
[8] Westhoek H., Lesschen J.P., Leip A., Rood T., Wagner S., De Marco A., Murphy-Bokern D., Pallière C., Howard C.M., Oenema O., Sutton M.A. 2015. Nitrogen on the table: The influence of food choices on nitrogen emissions and the European environment. European Nitrogen Assessment Special Report on Nitrogen and Food, Centre for Ecology & Hydrology, Edinburgh, UK, 70 p.
[9] European Environment Agency, 2018. Air quality in Europe - 2018 report. EEA, Copenhagen, 88 p.
[10] http://www.euro.who.int/fr/health-topics/disease-prevention/antimicrobial-resistance/antibiotic-resistance
[11] SUPER-G https://cordis.europa.eu/project/id/774124 - Multisward https://cordis.europa.eu/project/id/244983 - Inno4Grass https://cordis.europa.eu/project/id/727368
[12] Dumont B, Ryschawy J, Duru M, Benoit M, Chatellier V, Delaby L, Donnars C, Dupraz P, Lemauviel-Lavenant S, Méda B, Vollet D, Sabatier R 2019. Review: Association among goods, impacts and ecosystem services provided by livestock farming. Animal. 13, 1773-1784
[13] Mottet A., de Haan C., Falcucci A., Tempio G., Opio C., Gerber P. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*, 14, 1-18.
[14] Leroy F., Cofnans N. 2019. Should dietary guidelines recommend low red meat intake?, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2019.1657063
[15] Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal COM/2019/640 final
[16] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final. 20 May 2020
[17] Communication from the European Commission to the European Parliament, the Council, the European Economic and Social Committee of the Regions. EU Biodiversity Strategy for 2030 Bringing nature back into our lives. COM/2020/380 final

50% and nutrient losses by at least 50% by 2030 (with a 20% reduction in fertiliser use), restoring ecosystems and biodiversity, developing deforestation-free value chain, reaching 25% of land areas devoted to organic farming, 10% of land areas with high diversity and agroecological infrastructures. Simultaneously, the Farm to Fork strategy sets ambitious targets towards increased resilience in food systems to anticipate climatic, environmental, and health shocks. Animal welfare is becoming a priority with the EU promising to consider options for animal welfare, sustainability and nutrition labelling. In addition to the United Nations Sustainable Developments Goals and the COP21 commitments, these European policies open the way towards a rejuvenated agriculture that stays within the planetary boundaries and improving the socio-economical role of agriculture. The goal is to arrive at multi-performing, climate smart, resource efficient European agri-food systems that provide safe and nutritious foods along with a wide range of goods and services such as healthy soils, restoration of the quality of ecosystems and biodiversity, attractive landscapes, etc. and that provide fair livelihoods for livestock farmers.

In this context, European livestock farming is at a crossroads. It should significantly evolve in order to drastically reduce its negative environmental impacts while at the same time tackling health and animal welfare issues, and aim to provide a fair livelihood for livestock farmers. Climate, better use of resources, one health and welfare should be placed at the heart of innovations across the vast diversity of livestock systems. Livestock farming has a major role to play towards more environmentally friendly, healthy and fair food systems. As recyclers by nature, livestock can contribute to circularity and to a more efficient and better use of resources by utilising non-edible biomass, local feed products and new innovative sources of feed and by providing organic fertilisers. Livestock farming is also more than just food production. An important number of activities (bioenergies, clothing, human medicine...) find their raw material in the livestock sector. In addition, re-integration of livestock and cropping systems offers new opportunities to manage resources in a more efficient and safer way, balance nitrogen and phosphorus cycles, mitigate GHG emissions, maximise soil carbon storage, contribute to biodiversity remediation and restore associated ecosystems functions including soil fertility, pollination, pest control and reducing pest pressure (*Figure 1*). Well-managed livestock systems can also support the achievement of many of the Sustainable Development Goals and notably contribute to the vitality of numerous regions in Europe. To do so, the sector should continue widening its goals beyond producing commodities. The conditions under which a reduction of livestock impacts is achieved and the

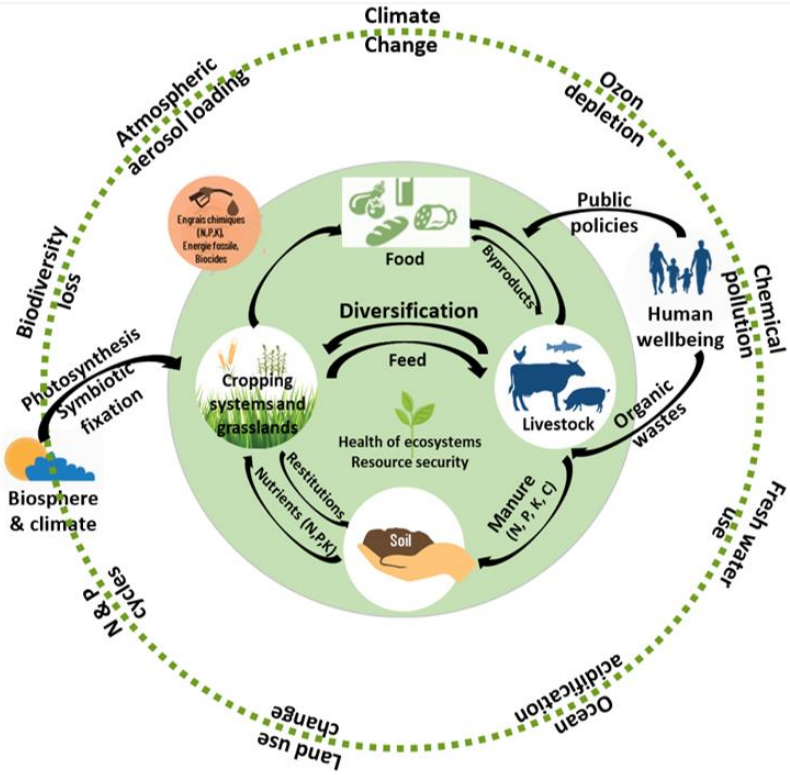
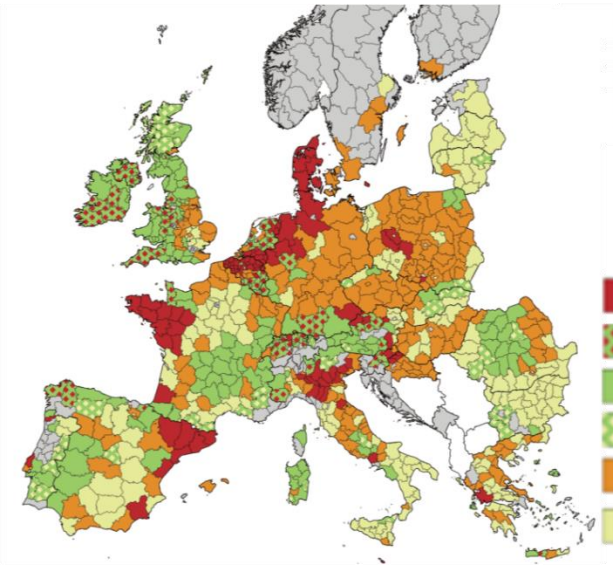


Figure 1. Role of livestock farming in sustainable agri-food systems

services provided by livestock are maximised should be better defined.

We propose a smart and coordinated approach based on: (i) innovations and science-based solutions; and (ii) transition to more sustainable systems and value chains supported by fair, inclusive and innovative governance. These should be implemented concurrently as avenues for sustainability improvement and not considered as each taken in isolation. Systemic approaches should avoid trade-offs. As an example, even combined with measures towards consumption, advocating a sharp reduction of animal production would most probably displace production and impacts to other parts of the world, while the European agriculture has the potential to offer resource efficient, environmentally sustainable, safe and nutritional food production with a high level of animal welfare. Innovations alone are not sufficient, they need support from policy legislation offering clarity on progressively realistic rising standards and new business models rewarding more sustainable practices.

Livestock are a key component of the vitality of many European territories. They are present in almost all regions of Europe across a wide diversity of production systems (*Figure 2*) and local economic, geographical & sociological contexts, reflected in different local conditions and available resources within a territory, heritage, farmers and suppliers' skills. The diversity of production systems gives resilience to the entire European production sector and may satisfy a wide range of consumer demands. Progress towards greater sustainability lies in the intensification of the use of ecological processes in some areas, up to multifunctional extensification in other areas, notably in marginal zones, to allow improved agricultural resilience and efficiency, ensure food security, contribute further to local development and offer a diversity of animal-based products fulfilling demands of consumers from low price products to niche markets. This diversity precludes "one size fit all" solutions.



	Agricultural area million ha	% total	Livestock population million LU	% total	Stocking rate (LU/ha)
	18.9	10.5	40.8	29.5	2.15
	12.0	6.7	20.1	14.6	1.70
	34.7	19.3	25.6	18.5	0.75
	12.2	6.8	2.9	2.1	0.25
	56.8	31.6	36.8	26.6	1.20
	44.9	25.0	11.9	8.6	0.30

Figure 2. Diversity of livestock systems in Europe (Dumont et al, 2019) (LU= Land use)

2. Expected R&I outcomes

The scale of the challenges outlined above is big, but so too is the opportunity for Europe to take the lead in sustainable livestock production. Research and innovation (R&I) have played a huge role in the development of our modern livestock systems and undoubtedly will play a critical role in shaping future systems of livestock production. This SRIA sets out R&I priorities for the future.

At a high level, the expected outcomes of suggested priorities for R&I aim to foster:

- **More sustainable livestock farming systems with the following attributes**,
    - Low impacts on the climate and resilience to climate change,
    - Low impacts on water quality (groundwater, wetlands and coastal areas) and air,
    - High standards of animal health and welfare and responsible use of antimicrobials,
    - Efficient use of resource (land, soil, water, workload) and resource security,
    - Reduced dependency on imported proteins and use of "deforestation free" proteins;
- **A diversity of livestock farming systems contributing to:**
    - Competitive and sustainable circular agri-food systems,
    - Food and nutrition security with high quality diets at an affordable price,
    - Restoration of soil health and fertility, biodiversity and the quality of ecosystems;
- **A stronger European research and innovation in animal production in Europe** and research on transformational changes.

B. The importance of supporting research and innovation for sustainability and competitiveness in Europe's livestock sector

Research and innovation have contributed substantially to the competitive, balanced and efficient nature of the current Europe livestock industry. Continued support for research and innovation in the livestock sector will be fundamental to meet impending challenges and to support the adoption of these innovations in agri-food systems. These challenges include as a priority to continue the supply of nutritious, safe and healthy animal products. This should be achieved within planetary boundaries by making efficient use of resources, contributing to a viable bio-economy, restoring biodiversity, reducing environmental impacts but also respecting animal integrity and rural communities and contributing to human and animal health and welfare. Interacting with citizens and consumers and meeting their needs will continue to be central and should evolve. The overall objective should be to improve all systems of production, and improve the sustainability of the current European intensive systems, as well as promoting the growth of low input including organic and agroecological based production systems.

This requires coordinated and integrated interdisciplinary research and effective, proactive translation into practice and policymaking. We recommend horizontal joint activities between different Horizon Europe clusters and pillars and vertical alignment between the EU and national/regional fundings. This will help avoid gaps and overlaps, ensure synergies and facilitate the wider agenda to support skills, innovation and research infrastructures.

The Animal Task Force promotes interdisciplinary research bringing together research groups with complementary expertise (e.g. animal nutrition and feed management strategies, grassland production and management, impact evaluation, animal breeding and genetics, reproductive physiology, welfare and health, ICT technologies, food evaluation, feed processing, construction and engineering, emission measurements, modelling, economics, sociology, multi-criteria evaluation). The Animal Task Force supports involving stakeholders of agri-food and agri-non-food systems (farmers, agro-supply industry, machinery and robotics, dairy, meat and eggs industry, non-food industries and consumers) and of the territories. Several areas of research are particularly suited for interregional and international cooperation.

The Animal Task Force also encourages future development of livestock production systems in line with the provision of ecosystem services together with holistic agriculture approaches. A greater integration between livestock and plant based agricultural systems may allow the better use and regeneration of agro-ecosystems and the maximisation of the use of biomass of both plant and animal origin through strategic recycling and harnessing of the cascade approach. These holistic agriculture approaches also need to encompass the agroecological domain and circular bioeconomy and need to be consistent with the One Health-One Welfare concepts.

The Animal Task Force supports research policies that assure and value the diversity of the livestock production systems that are considered the European treasure. To do that, it is also fundamental that researchers and research institutions in all European countries can be involved in production innovations and in proposing new solutions and advancements that are needed to support the diversity.

C. Key areas for research and innovation in the livestock sector that merit support under Horizon Europe

We summarised the main challenges facing the European livestock sector into four interdependent sustainability domains (*Figure 3*) consistent with the Global Forum on Agriculture[18].

These are key objectives for a just transition of European livestock food and farming systems that merit support from European research and innovation funding:

1. **Climate, biodiversity and natural resources**. Objectives are to maximise the potential of the livestock sector to mitigate GHG emissions and sequester soil carbon, maximise resource use efficiency and quality and minimise nutrient losses to water bodies and ammonia emissions while maximising utilisation of forage and new sources of feed, minimising direct competition for arable resources between livestock and humans, exploiting manure nutrient content and other organic waste from the agri-food sector. Another ambition is to contribute to the restoration of biodiversity, fostering high natural value farmlands in different ecological and economical contexts. This includes enhancing the roles of livestock in the emergence of circular approaches and finding new interplays with cropping to improve livestock feed/nutrient efficiency and reduce GHG emissions.
2. **Animal health and welfare.** Objectives are to design and implement integrated management of animal health and welfare to engage further on a prudent and responsible use of veterinary medicines in European livestock farming, preventing and building resilience to pandemics. Respecting animal welfare and integrity will comprise a reduction of mutilation practices and the development of practices at farm, transport and slaughter, favourable to the expression of positive welfare, including the relationship between physical and mental health.
3. **Food and nutrition security**. Objective is to understand how and to what extent livestock systems and animal-based food will contribute to the emergence of sustainable and healthy food systems taking advantage of the multi-functionality of livestock, nutritional density and intrinsic quality of animal-based food.
4. **Livelihood and economic growth:** Objective is to contribute to improve livelihoods and economic growth by creating attractive employment opportunities in economically viable livestock systems. This will require the design of public policies and regulations to guide and support efforts for transitions, renewed organisation and coordination between stakeholders to change the socio-technical system required for the development of a sustainable circular economy. Increasing resilience of farming systems to face climate, health and economic hazards is another important issue.

In addition, the ATF SRIA focuses on two cross-cutting issues:

5. **Animal as a system**: New challenges renew the paradigm of research at the animal level. The search for more efficient animals capable of coping with variable production conditions without compromising product quality implies a new approach in animal biology. This requires to move from a short-term vision of the animal to the integration of time-windows on the same individual and across generations. This will make it possible to understand the animal's capacity to manage disturbances, resource allocation between production and live functions in relation to resilience

[18] https://www.gffa-berlin.de/en/gffa-kommunique-2018/

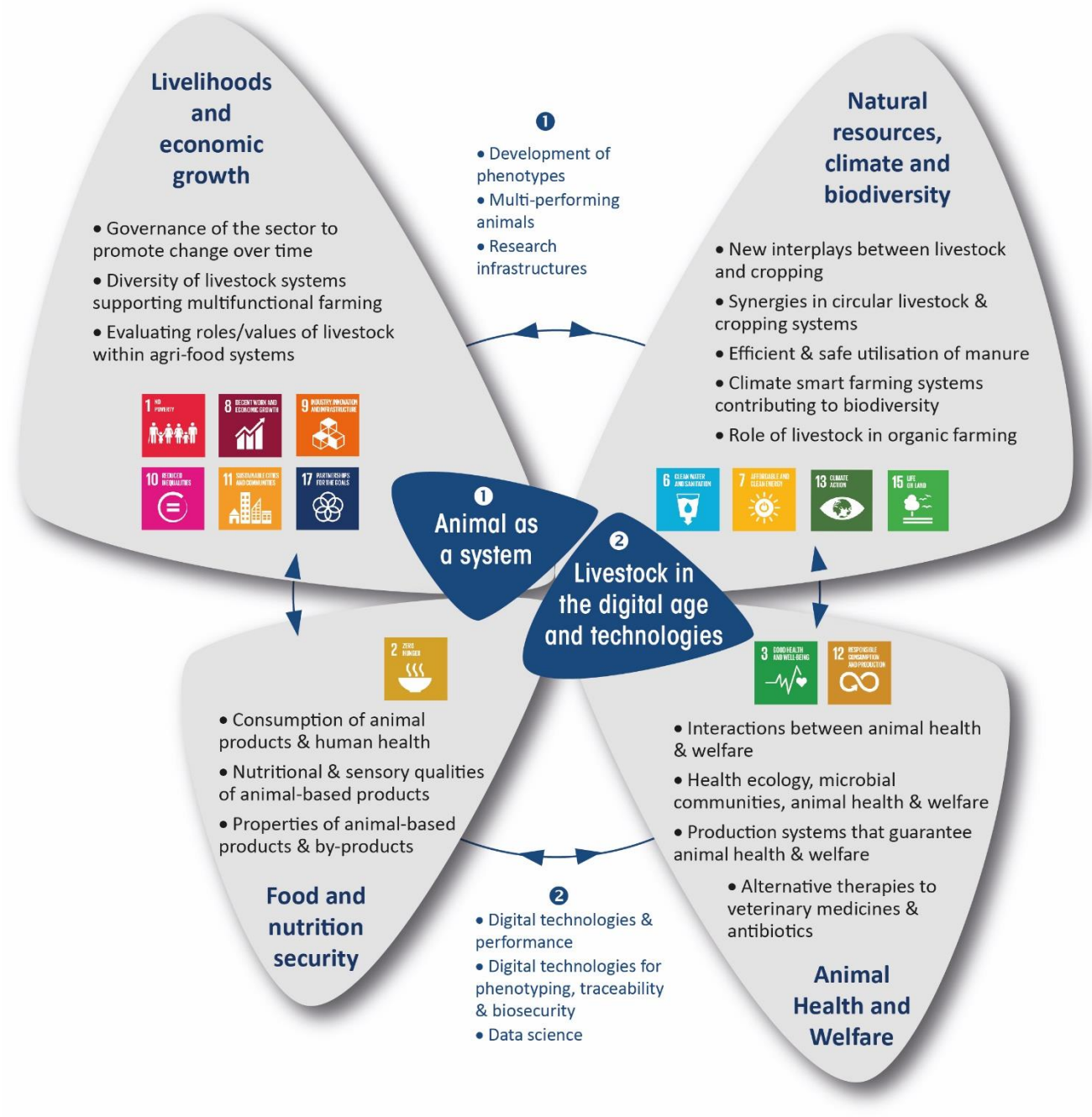
and efficiency over the course of life, and finally to renew breeding objectives considering genotype-environment interactions in predicting the reproductive values of individuals.

6. **Livestock farming in the digital age and technologies:** sensors, robotics, Internet of Things, artificial intelligence and data science, and block-chain provide innovative tools and concepts for livestock management through the continuous, automated and real-time monitoring of a growing number of parameters on the animal and its environment. Beyond the farm, large-scale data acquisition on phenotypes of interest at different levels (internal or intermediate, final or external or whole animal phenotypes) combined with genomic selection should make it possible to improve the accuracy of animal breeding. Continuous and automated processing of a huge amount of data offers new possibilities for product quality management and a basis for certification and increased transparency in relations between companies and consumers.

Suggested priorities do not cover all topics of interest for livestock systems but focuses on themes where the approach at the European level brings a real added value compared to national approaches. This concerns subjects relating to issues of common interest (such as environment or animal health and welfare) or topics related to analytical research situated at a pre-competitive level that the stakeholders/countries can then use to develop their own strategies (such as understanding the functioning of animal-related microbial ecosystems). This also concerns research requiring scientific expertise and/or a diversity of local conditions or research infrastructures that can only be brought together by the mobilisation of several countries (such as resilience of livestock system, research on animal biology). This SRIA is consistent with the One Health approach and seeks to simultaneously improve the health of animals, humans and ecosystems that are interconnected by appropriate management of livestock farming. We consider both nutritional aspects and the reduction of exposure to risk factors.

This paper considers past and on-going projects that are closely related to research and innovation suggested priorities but do not fully address the issues mentioned. As a reference, and for information, we have highlighted some on-going collaborative projects supported by H2020.

Figure 3. Four sustainability domains and two cross-cutting issues to improve European livestock farming systems



Topics list[19]

Suggested priorities are listed below for R&I that may support a transition of the livestock agri-food sector towards a greater contribution to sustainable circular agri-food systems, increased efficiency of production, better preservation of the quality of the resources while still producing healthy nutritious food at an affordable price, with fair livelihoods for livestock farmers.

1. Natural resources, climate and biodiversity

1.1. Design and support concepts for new interplays between livestock and cropping*

1.2. Optimising synergies in circular livestock and cropping systems*

1.3. Efficient and safe utilisation of manure

1.4. Development of climate smart farming systems contributing to biodiversity restoration*

1.5. Support the role of livestock in organic farming**

2. Animal Health and Welfare

2.1. Interactions between animal health and welfare

2.2. Health ecology and connections between microbial communities, animal health & welfare

2.3. Towards production systems that guarantee animal health and welfare

2.4. Development of alternative therapies to veterinary medicines and antibiotics

3. Food and nutrition security

3.1. Improving insights into consumption of animal products and human health***

3.2. Management of nutritional and sensory qualities of animal-based products***

3.3. Functional and bioactive properties of animal-based products and by-products***

4. Livelihoods and economic growth

4.1. Drivers of evolution and governance of the sector to promote change over time

4.2. Diversity of livestock farming systems supporting multifunctional farming

4.3. Evaluating the roles/values of livestock (products) within agri-food systems

5. Cross-cutting issue: The animal as a system

5.1. Early development of phenotypes

5.2. Multi-performing animals

5.3. Improving research methods and infrastructures towards innovation

6. Cross-cutting issue: Livestock in the digital age and technologies

6.1. Use of digital technologies in livestock farming to improve performance

6.2. Use of digital technologies to develop high throughput phenotyping and to improve traceability & biosecurity

6.3. Data science

[19] Topics marked "*" were developed in collaboration with Plants for the Future ETP through a multi-actor approach (see also ATF-Plants for the Future Position Paper, September 2019 and ATF-Plants for the Future Policy Brief, April 2020).

Topics marked "**" were developed in collaboration with TP Organics through experts' consultation.

Topics marked "***" were developed in collaboration with Food for Life ETP through experts' consultation.

1. Natural resources, climate and biodiversity

Challenges

During the green revolution, livestock and crop productions became more intensive, specialised and spatially separated. This allowed huge gains in efficiency but also a lot of environmental burdens notably depletion of non-renewable resources, degradation of ecosystems, challenge of protein autonomy, and contribution to climate change. Facing these challenges, priorities for European agriculture are: reduction of GHG emission and fertilizers inputs, limitation of nutrients losses to the environment, increase protein autonomy, reduction of pest pressure and pesticides inputs, enhancement of agro-biodiversity, increase of resilience of food systems to climate change and increase of soil organic matter and associated fertility (4p1000 initiative).

The crop-livestock association is a lever for the development of a thrifty style agriculture ensuring simultaneously food security and resource sufficiency while supporting the remediation of healthy ecosystems producing recognized services, including soil carbon sequestration and biodiversity restoration. Crop and livestock systems should become more integrated at multiple scales, e.g. on farm with arable and livestock rotations or at a regional/national scale through exchange of by-products and manures/slurries between livestock and arable farms.

Livestock farming has a major role to play in a rejuvenated agriculture, mainly in two ways. Firstly, it has a unique ability to valorise a broad range of biomass from the food chain that cannot be used directly for human consumption, thus supporting a diversification of crop rotations with notably N-fixing plants, honey plants and grasslands. Secondly, it provides manure, the use of which can be optimised as fertiliser (short-term nutrient supply to the soil, slurries) and amendment (long-term supply of organic matter to the soil, that can be valorised through innovative values chains.

All these developments call for science-based innovations. Agroecological and circular agriculture calls for approaching the food system as a whole and from all dimensions. This implies to shift from focusing on the efficiency of a single part of the system towards looking at efficiency of the whole system, therefore seeking the best compromises between tailoring products to customer needs, improving production, using natural and local resources and minimising climate and environmental impacts. The crop-livestock association also raises issues around new economic models, organisational innovations (see part 4) and food safety management. Circularity should be considered at local level and the diversity of situations should be considered in order to generate generic knowledge and propose locally well-suited solutions. Coordinated European research must make it possible to achieve this.

R&I priorities

R&I priorities aim to make use of the unique ability of livestock to convert biomass (particularly human inedible) into high quality human edible food and other ancillary products, while closing nutrient cycles and restoring the quality of ecosystems.

1.1. Design and support conception for new interplays between livestock and cropping*

- **Development of a masterplan enabling an integrated approach to crop and livestock production**, offering environmental advantage and a sound economic alternative for farmers and food chains. The proposal is to assess combinations of crops and livestock genetics that are best grown in certain regions/locations considering soil type, environmental and climatic factors, [Genetics X Environment] interactions, non-arable land, co-product strategies and circular approaches leveraging the potential of livestock to improve soil health and close nutrients cycles in relation to crop rotations. Knowledge should be developed around advantages and limitations of different local or at larger scale strategies, such as promoting exchange of best-suited manure between regions, and alternatively to evaluate conditions for reintroducing livestock in cropping areas.
- **Supporting efficient organisation of stakeholders and innovative public policies** to change the socio-technical system while ensuring business continuity. Priorities are exploration and demonstration of new business models to integrate innovation into local circularity approaches, analysis of novel study cases to identify factors of success and coordination challenges arising from the combination between individual initiatives and collective approaches. For the design of new public policies, information is required to develop specific measures to "protect innovation niches" during the experimental period, to define the most appropriate policy tools towards a transition (payment for environmental services, other incentives, taxes and regulations), assess the consequences of new policies in terms of production, income, trade, health and environmental services. Optimal traceability should be developed to increase transparency. To enable agri-food systems players, policy makers and researchers to assess the sustainability of current and future practices and products, Life Cycle Analysis should improve to capture interactions between crop and livestock in a circular economy, be applicable to production systems, territories and diets and allow for proper evaluation of biodiversity, economic and social performances of value chains (see key area 4).

1.2. Optimising synergies in circular livestock and cropping systems*

- **Identification and development of cropping systems adapted to local contexts**. In a cascading approach, food production has priority over feed production. As a consequence, crop plants and cropping systems should be adapted so that the plants can be used as a priority for food. Secondarily, non-edible parts could be used for feed. Research should identify avenues for breeding, production systems, feed processing and formulation to optimize the multiple use of plants for different environmental and economic situations. Special attention should be paid to locally produced legumes as legume imports disconnect regional agro-ecological cycles. We also need to develop a diversity of crops in terms of cultivation requirements as well as the introduction of green forages (grasses, legumes) in crop rotations as a promising protein source. Value of cover crops and crop residues as animal feeds must be evaluated. This requires the development of new or undersown crop species and cultivars of existing crops, (improved) varieties with environmental and nutritional advantages for animal feed. The effects of the introduction of trees/agroforestry in grasslands and croplands also needs to be elucidated with regards to productivity, feed resource, protection of animals against daily and extreme weather conditions, storage of carbon in soil,

regulation of N fluxes and adaptation to climate change. Research should also focus on policy designs that support closer coupling of feed production and use of organic fertilizer (see below).

- **New (protein rich) sources of biomass valuable for feed use:** by-products from agro-food industries or green chemistry, former foodstuffs and alternative protein sources (incl. insects, other invertebrates, yeast, bacteria/single cell proteins…) must be mobilized as feed. Apart from insects that are highly studied, the production of earthworms is potentially of interest, in particular for poultry farming as a source of natural protein making use of organic waste. The potential use of algae and micro-algae as lipid supplements rich in poly-unsaturated fatty acids with benefits for the nutritional quality of animal products and as biocontrol products for animal health should be further explored.
- **Identification, testing and development of biorefineries approaches in support to circularity**. Processing green biomass and new protein-rich sources has potential to improve their edibility and nutritional value and to isolate plant secondary compounds having beneficial effects on animal health. Detoxification of feed from anti-nutritional compounds, contaminants and pathogens is another important area since some of these novel feeds may contain anti-nutritional factors (i.e. mycotoxins) or chemical residues or contaminants at low levels.
- **Using the ability of livestock to utilise a diverse range of inedible biomass.** It is necessary to breed livestock varieties that can thrive on European feedstuff, European legumes and non-edible crop parts and that perform well with less traditional feed which are often of a lower quality. In addition, new feed resources will often be very variable in location, time and quality, which raises specific questions for livestock production. Physiological and genetic determinants of animal feed efficiency must be redesigned with resources of lower quality and more diversified, which could exacerbate inter-individual differences[20]**.** It will also require better knowledge of animal adaptation and ex-ante prediction of animal performance in response to a diet. The optimisation of use of diverse feed resources requires precision feeding techniques to assist farmers and novel information systems to assess availability and price, considering competitions of use (feed, energy, green fertiliser) and local contexts (agronomy, economic, transport, organisation between farms), feed safety.
- **Evaluation of the novel feeding options.** Multicriteria evaluation of sustainability benefits of these new circular food chains that imply progress in LCA methodology (see part 4). Evaluation of risks of novel feeds that may contain anti-nutritional factors or chemical residues or contaminants at low levels (thus implying development of detoxification techniques). Evaluation of animal-based product quality (e.g. food safety, nutrition, shelf length and sensory attributes) is also part of the assessment. Finally, guidelines for processes and policies for improved resource use must anticipate social concerns (as some practices may not appeal as socially acceptable).

A full achievement of circularity requires precompetitive research on plant genetics, notably legumes but this is not part of this SRIA. Precompetitive research on livestock breeding with due consideration on efficiency and resilience is described in part 5.

[20] FeedAGene https://www.feed-a-gene.eu/

1.3. Efficient and safe utilisation of manure

Despite previous studies, there is still a lot to be done in a new context to make former waste a valuable resource.

- **Supporting a more efficient use of manure** by minimising nutrient losses (notably ammonia) from slurries through the understanding of emissions, mineralisation and diffusion mechanisms of C, N and P. This requires to integrate all stages of the management chain, from animal nutrition to land application, including in buildings (litter, aeration, early phase separation), processing, storage and their integration into cropping systems and manure additives to reduce emissions. Modelling makes it possible to understand and predict the dynamics along the chain. In the case of composting with an aim to make manure safe, and reduce odours as a source of organic matter input to soil, the effects on the dynamics of C and N in soils need to be assessed precisely and the volatilisation of NH_3 reduced. Consequences of manure application on soil biodiversity (invertebrates, microbial population) and biological functions should be evaluated. Based on knowledge, new practices must be evaluated (i.e. removal facilitation, separation of faeces and urine for a more efficient use, spreading). Research must also highlight to which condition legislation can help to better manage manure.
- **Ensuring a safe use of manure and organic waste.** Livestock manure can convey biological (pathogens, antibiotic resistance genes), organic (pharmaceutical residues) and inorganic (Cu, Zn) contaminants. There is a need for a better understanding of the impacts of land application of manure with regards to contaminants (dissipation vs. accumulation, transfer into the food chain) as well as impacts on health, environment and soil biology. In addition to the work on livestock management to reduce drugs use and the presence of residue in effluents (see axis 2), the effects of management methods and spreading practices to limit the risks must be studied.
- **Innovative manure refinery technologies within a circular economy**. The development of biofuels raises issues around the balance between biogas production and the agronomic quality of digestates, notably their effects on soil carbon stock and N use efficiency, like a reverse engineering to adapt digestates to the needs of agriculture. Effects of insertion of a biogas digester in a territory on the functioning of agriculture (change of cropping systems), interactions between farms (logistics), on governance and social acceptability are important questions. To support new value chains, many opportunities reside on the valorisation of manures: extraction of organic acids for chemical industries, ligno-cellulosic compounds for the production of fibers, proteins and other nutrients for insects, algae and bio-fertiliser production. New processes have to be developed and the balance between the extraction of molecules and the agronomic valorisation of the by-products should be evaluated.

1.4. Development of climate smart farming systems contributing to biodiversity restoration*

Facing Green Deal priorities, we need to strengthen holistic approaches to mitigate GHG emissions while finding win-win strategies and avoiding trade-offs with biodiversity.

- **GHG mitigation innovation.** Research, fine-tuning, testing, validation, demonstration and monitoring of a wide range of innovations used simultaneously at different scales in different systems. At farm gate, key issues lie in feed systems, notably with the use of legumes, exploiting livestock-crop synergies (see 1.2), smart use of manure (see 1.3), improved feed efficiency by genetic selection, increased soil carbon sequestration and energy production. For ruminants, a reduction of methane emissions can be obtained by exploitation of the potential of feed additives (antioxidants, methyl donors, minerals) and genetic selection but the challenge is to avoid a reduction of cellulose digestion in low emitting animals and to determine methods to include these progresses within national inventory methodologies. Optimizing beef production within the dairy cattle industry is an interesting perspective (dual-purpose breeds, sexed semen, crossbreeding). At larger scale, it is necessary to explore options between monogastric production (less emitting while in competition with human food), and ruminant production (valorises cellulose and grassland but produces methane), considering avenues for improvement achievable in these production systems. Solutions should consider that mitigating methane emissions will have a rapid and important effect on climate change while the mitigation of N_2O is crucial on the medium term and far less investigated. It is important to analyse the possible trade-off between animal welfare and GHG emission mitigation.
- **Adaptation of livestock systems to global warming and water scarcity.** The frequency of hot weather and water scarcity may endanger certain livestock farming systems. The aim is to design more resilient feeding systems that optimise the use of water when it is limited: new plant, forage species and associations, agroforestry, development of off-season grazing. A better understanding of the mechanisms of animals' adaption to heat waves (or combination of heat and humidity) is required to propose new genotypes. Exploitation of the potential of feed additives (antioxidants, methyl donors, minerals) and the use of new technologies to detect the most sensitive animals on which action should be taken are other relevant avenues for improvement. Much progress can also be expected from livestock buildings whose specifications must be established from observation of animal behaviour. We also need to design production systems of the future in terms of fodder security and changing climate conditions. Adoption requires co-innovation for the development of alternative farming systems in the different climatic zones looking at livestock health and welfare challenges.
- **Contribution to biodiversity management and restoration.** To evaluate the contribution of livestock farming systems to biodiversity and monitor the best achievable balance between production efficiency, GHG mitigation and biodiversity, we need to develop relevant and understandable biodiversity indicators considering local and global scales, looking at agro/domestic biodiversity (plant and animal species, genetic diversity), soil biodiversity and habitat changes that also affect wild biodiversity. Quantitative assessments integrating various aspects like crop and animal productivity, land use, animal density, new cropping and animal husbandry systems, manure vs mineral N applications, grazing and agroecological infrastructures are required. It is also important to understand how a full integration of biodiversity and environmental schemes in the sourcing of livestock raw materials can deliver value for farmers and consumers. New strategies should be developed to characterise, multiply and ensure the *in situ* and *ex situ* conservation of genetic resources and promotion of the use of animal genetic resources diversity in commercial

breeding programmes for various objectives. A better understanding and mastering of the services to be provided by microbial biodiversity and wild plants on livestock farming should be developed.

1.5. Support the role of livestock in organic farming**

In organic farming, integrating livestock and crops at local level provides organic fertilisers for crops and feed for livestock. Organic farming together with local production are well regarded by consumers but on the other hand, organic animal husbandry raises some specific issues.

- **Achieving a circular economy** in organic farming requires gains in efficiency and resilience, breeding strategies and methods towards increased genetic diversity allowing adaptation to local conditions, ability to use a diversity of crops/biomass, resistance to diseases, tolerance to various stresses and high vitality of young animals. Feed production should look at the inclusion of new and old species and varieties targeted to local production and innovative grassland-based ruminants and horses systems balancing dietary needs through a diversity of roughage sources. There is a potential to improve animal health through management strategies and housing systems that prevent infections, illness and mortality, and feeding and breeding strategies that support animal robustness towards infections and diseases. In animal health, improvements are expected from the use of plant bioactive compounds (biorefinery, curative and preventive uses).
- **Management of soil fertility** requires better manure processing and handling (notably compost). Mixed farming (different species/breeds, livestock and crops) to increase resilience and feed efficiency needs to be assessed. Development of networks between organic farmers will facilitate organisation of (knowledge) exchanges, supporting the implementation of the CAP.
- **Climate smart organic livestock production**. Better management of grassland and selection of animal genetics (ruminants and horses) to optimise grassland use. Restoration of abandoned grassland is part of the strategy. Better understanding the effects of feed diversity on animal performances will contribute to efficiency: more biodiverse grassland and forages able to stimulate foraging behaviour while providing resilience to climate hazards, more balanced feed with suitable protein and amino acids composition. Improved manure management and increased soil carbon sequestration thanks to grassland, legumes and agroforestry will further reduce net emissions, notably N_2O emissions, and energy consumption. Finally, the evaluation of organic farming systems should be finetuned, to embed environmental services and allocate better GHG emissions between food production and other services.
- **Improving sustainability of low input monogastric systems.** Resource efficiency is a key issue as both crop production and animal efficiency are relatively low. This reinforces priorities for breeding schemes for low density diets, foraging behaviour and robustness (notably piglet survival). There is a potential to improve nutrient efficiency in organic animal production by innovative production of high quality protein and amino acid feeds from green, blue and red sources and by development of innovative bio-refinery methods. The development of outdoor systems including walking areas, innovative housing is a social demand but to what extent keeping animal in a more natural environment contributes to animal health and welfare should be evaluated. Walking areas can be diverse and should provide shade (e.g. oak tree grassland for pig, orchards where poultry are able

to contribute to plant biocontrol by eating insects). Production and management of straws are a keystone both for animal welfare (litter) and the production of compost for soil fertility.

Expected impacts

- Rejuvenated agriculture encompassing circular and efficient food production systems,
- A circular agriculture with efficient resource-use at system level that reduces wastes in the feed and food chain and closes the nutrient cycles,
- Increased soil carbon sequestration and improved soil fertility,
- Increased European protein self-sufficiency and less European protein imports,
- Reduction of the use of mineral fertilisers and biocides,
- Reduced water scarcity,
- Mitigated GHG emissions, towards a carbon neutral livestock sector,
- Increased resilience of farming system with regards to climate change,
- Increased agro-biodiversity,
- Improved agronomic value of manure and innovative use of manure in circular economy,
- New local business models based on integrated cropping and livestock systems,
- Local production of a broader range of food and feed products offering new sales opportunities,
- Animal health supporting plant secondary metabolites produced,
- Improved sustainability of organic farming systems with livestock,
- A more holistic view of the impacts of animal production on the environment,
- Europe as a frontrunner in new solutions for circular approaches and climate smart agriculture.

2. Animal Health and Welfare

Challenges

Animal health and welfare are key elements towards consumers' trust in livestock farming systems. In the framework of infectious diseases, a lot of research has, so far, focussed on the improvement of animal health and the transmission of zoonotic pathogens to humans[21], but there has been little emphasis on integrated management of animal health and welfare, nor on the links with human and ecosystems health[22] or human well-being[23]. The rapid expansion of antibiotic resistance genes is a challenge in which farming plays a role, and overuse of antibiotics has shown indirect consequences on microbial ecosystems, other than the targeted pathogens. It is crucial to mitigate antibiotic resistance in a context of strong connections between animal and human health, both sharing the same pharmacopoeia. A major breakthrough in improving animal health and reducing antimicrobial use will be the introduction of ecological approaches in animal health management. Current and new knowledge can be used towards the coexistence of humans and animals with their mutual pathogens, either by developing immune capabilities of the host to contain or eliminate pathogens, or by promoting commensal microbial ecosystems of hosts that may prevent pathogenic infection and zoonoses. Finally, acurate monitoring of pathogens transmission needs encompass anthropogenic (climate change, globalisation of trade) or biotic risks linked to new animal husbandry practices (e.g. exposure to contaminants and wildlife).

According to WHO, "*Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*". Several directives reflect the recognition of animals as sentient beings based on research by ethicists and physiologists who conclude that welfare should refer to the state of the individual in its environment, including unpleasant and positive perceptions[24]. Livestock systems should strive to avoid animals' negative perceptions as well as mutilation practices (pain, fear and frustration) and favour positive perceptions and the expression of natural behaviour. Research will inform public debates with objective indicators of animal welfare based on their perceptions according to different husbandry, transport and slaughtering conditions[25].

Animal health and welfare are linked. Physiological imbalances have a strong impact on animal welfare. Conversely, exposure to outdoor environments aiming to improve animal welfare may increase the risk of infectious diseases and biosecurity measures (e.g. against African swine fever, Avian Influenza, diseases affecting wildlife) have impacts. Alternatively, animal stress has a negative effect on immunity, making the animal more sensitive to infectious diseases. However, while it is clear that animal health affects animal welfare, effects of improved welfare on health are poorly documented.

We strongly recommend integrated animal health and welfare as central strategies to the design of more sustainable livestock farming systems and animal friendly husbandry practices fostering preventive measures, animal living conditions and animal health on-farms. Research, innovation and

[21] DISCONTOOLS https://www.discontools.eu/
[22] Eco-Health https://www.ecohealthalliance.org/
[23] One-Welfare https://www.onewelfareworld.org/
[24] ANSES (2018) definition of animal welfare: "The welfare of an animal is the positive mental and physical state related to the satisfaction of its physiological and behavioural needs and expectations. This state varies according to the animal's perception of the situation".
[25] PPILOW https://cordis.europa.eu/project/id/816172; EU PIG https://cordis.europa.eu/project/id/727933 ; HENNOVATION https://cordis.europa.eu/project/id/652638

dissemination into those areas require multidisciplinary approaches and should be conducted in close partnership with end-users of innovations across a variety of livestock systems and countries. A number of projects are already under way[26] to understand and foster wide implementation of a prudent use of antibiotics in a One Health approach. They should be further deepened. ATF strongly supports the new partnerships in this domain (One Health AMR and Animal health and welfare).

R&I priorities

R&I priorities encompass:

2.1. Interactions between animal health and welfare

The aim is to understand the positive and negative interactions between welfare and health in order to propose new animal husbandry practices that ensure animal welfare and health.

- **Understanding sensory, cognitive and emotional abilities in relation to the quality of life of animals**: better characterise the perception of animals of their living environment and of their own state and understand how this perception is built during their development (see key area 5). This includes positive mental states, behavioural and physiological expression in relation to farming conditions and practices, behavioural robustness, balance between negative and positive states throughout lifespan, and analysis of the impacts of the enrichment of the environment.
- **Deepening relationship between animal health and welfare**. A key issue is the understanding of interactions, synergies and trade-offs between animal welfare, the immune system and animal health. Animal welfare as a lever towards a reduction of the use of antibiotics covers psycho-neuro-endocrine mechanisms and physiological relationships that link well-being and health, positive or negative emotions on health and elaboration of these during lifespan (see key area 5). From a practical point of view, we need to explore to which extent improving animals' welfare, namely by facilitating the induction of prolonged or repeated positive emotions, have an impact on the immune systems, the resistance to pathogen-related aggressions and finally the benefits on antibiotic use. Conversely, consideration should also be given to health problems that may arise from innovations designed to meet the behavioural needs (e.g. pigs on straw, outside access).
- **Studying links between welfare, health, efficiency and product quality**: better understanding of trade-offs/synergies between health, welfare and efficiency (feed efficiency, production, reproduction, adaptation, immunity, etc.), as well as physiology and genetics. This covers short and long terms as well as the entire life (career) of the animal, exploration of prenatal and juvenile periods, transition phases in young and adults (weaning, pregnancy...). Relationship between animal welfare and sensory quality of animal food and environmental impacts also need to be identified.
- **Knowledge integration** to assess the complementarity of different levers (e.g. genetics, nutrition, microbiomes monitoring, husbandry practices, health and welfare management, digital technologies) at animal and group levels, towards more robust animals resilient to infections and production diseases.

[26] eg. Disarm https://disarmproject.eu/ , Roadmap https://www.roadmap-h2020.eu/, NetPoulSafe

2.2. Health Ecology and connections between microbial communities, animal health & welfare

- **Regulation and function of microbial communities (microbiomes, pathobiomes)** in relation to animal health and welfare[27] in ecosystems linked to the livestock (host microbiomes) or not and their role in the preservation of animals, humans (zoonosis, etc.) and environment (wildlife, vectors, reservoirs, etc.) health. This should lead to develop new strategies towards livestock and human welfare and health, eco-health, as well as novel prophylaxis and therapies. This requires knowledge about microbial communities (structure, composition, function) that are the most beneficial at different stages of the animal's lifespan, about biotic and abiotic parameters that influence their composition, across different microbiomes (lungs, intestine, skin, reproductive system, etc.). This covers interactions between commensal and pathogenic bacteria and viruses to understand the barrier function (e.g. salmonella in poultry). In addition to the microbial fraction of microbiota, unicellular eukaryotes, bacteriophages and viruses should be considered, but this presents methodological challenges (purification, knowledge of genomes, etc.).
- **Host-pathogen-microbiome interactions**. Development of knowledge and monitoring of the relationship between gut health, the immune system and brain functions, knowledge on the relationship between host genome and microbial metagenomes will help develop innovative practices (including pre- and post-natal periods, see part 5). We also need to identify biomarkers of a healthy (innate) immune system in relation to feed efficiency, disease prophylaxis, pathogenesis and animal welfare. As 75% of emerging infectious diseases are zoonotic, there is a pressing need for better understanding mechanisms by which emerging pathogens transgress species barriers. Comparison of animal and human microbiomes would contribute to elucidation of the common principles in infections?
- **Management of microbial ecosystems**: namely beneficial commensal communities to prevent pathogenesis, monitoring of pathogens (early detection, traffic tracking and identification of transmission sources, risk management, prophylaxis, cost-benefit assessment of solutions). The aim is to define strategies and means for piloting communities and immune defense to benefit health, which includes the use of pre and probiotics, immuno-stimulants, feeding and housing strategies at different stages of life. The use of phages and synthetic microbial communities are other (more prospective) possibilities. There is also a need to better evaluate the cost-benefit of steering ecosystems on other phenotypes of interest, particularly the productive performance and qualities of livestock products and effects on the environment (i.e. release of molecules or microbes).
- **Pathogen surveillance.** Current high throughput technologies allow to increase tenfold our ability to predict the risk of infections (i.e. emergence of variants, environmental reservoirs, carriage by wildlife...). This allows us to detect pathogens before clinical signs manifest and distinguish the virulence of strains, pathovars, variants or pathobiomes. This also allows us to monitor the circulation of these pathogens and risks associated with their transmission (coupling of omics data with epidemiological data and predictive mathematical models); identify transmission sources and/or sentinels (vectors, arthropods, wildlife, domestic or wild relay hosts, animalcules...) and promote quick preventive actions.

[27] The HoloRuminant project prefigures this new approach to global health in the case of ruminants

2.3. Towards production systems that guarantee animal health and welfare

The aim is to propose solutions that jointly preserve animal and human health and welfare, while safeguarding food safety, environmental health and farm economic profitability. The search for stress perception and disease resistance of animals (see key area 5) are part of this priority.

- **Managing interactions between individuals**. In a context where animals are increasingly kept in groups and have privileged access to outdoors, we need to understand how interactions between individuals, and between individuals and their environment, impact the health and welfare of animals by considering positive emotions, microbiome flows, pathogen exchanges between animals and their environment. The effect of the social position of an individual in a social network and at group level on the susceptibility to infectious diseases or abnormal behaviours need to be explored to understand how fast a disease or an abnormal behaviour will be transmitted within the network. Finally, the development of contagious models inspired from epidemiologic studies can help analyse animal social behaviour.
- **Exploring links between human and animal welfare in animal production** ('One Welfare' concept). We need to explore the links between human and animal welfare in livestock farming to deepen what issues are driving both, how can understanding one of them improve the other. Consequence of the improvement of animal welfare on farmer well-being is an issue.
- **Development and testing of improved rearing practices and processes at farm level**. To assist in the design of new practices and systems that maximise welfare and health throughout an animal's lifespan, it is necessary to identify balance and trade-offs between health and welfare that minimise the impact of changes in practices on other performances. Developing alternatives to mutilation practices is a priority. Practices that promote the expression of positive experience and natural behaviour with positive impacts to reduce diseases are also priorities. Examples are around optimising welfare in dairy calves and dams at post-natal separation, alternatives to farrowing crates for pigs, preventing aggression in pigs and poultry, sustainability of loose housing systems for laying hens. The issue also encompasses the study of drivers and obstacles to the implementation of improved farming practices and transitions towards sustainable animal health and welfare systems and practices including work organisation and the conditions for their economic viability.
- **Development of valid, reliable and feasible indicators and Decision Support Systems** are required for a better monitoring of animal health and welfare, allowing real-time monitoring of individual or batches of animals on farm (see key area 6). This concerns the development of new indicators (of poor or positive animal welfare in a variety of species across a variety of production systems) based on an in-depth knowledge of the animal's perception of its environment. This also concerns the development of sensor technologies, automatised collection and analysis of data and development of user-friendly feedbacks to farmers regarding welfare indicators that can be collected at slaughterhouse. We also need to develop better on-line disease-diagnostic systems operated on farms offering farmers and veterinarians an optimal basis for a targeted prevention and/or treatment of sick animals. Many avenues for improvement are expected from combining and assembling data from potentially widely differing types and varied sources into meaningful indicators.

- **Host-directed therapies for management of infectious diseases in farm animals**. To replace mass culling following detection of regulated diseases, personalized veterinary medicine inspired by omics and artificial intelligence could be used to develop sensitive biomarkers for early detection of index cases, propose farm animal host-directed therapies to help animals to combat infection and pilot animal ecosystems to reduce pathogen shedding in the environment.
- **Transition towards local and value chain organisations that guarantee animals' health and welfare throughout their lifespan.** Technical and organisational innovations as well as legal, economic and institutional processes and coordination mechanisms between stakeholders need to be implemented at these levels to move towards better consideration of health and welfare issues (including when animals move from one farm to another). This concerns the effects of different forms of coordination and of globalisation of agricultural and agri-food markets, the evolution of organisational forms according to various types of systems (e.g. co-existence of confined and open-air farming systems), the strategies of stakeholders (living with or eradicating pathogens), knowledge produced on health monitoring (e.g. interaction with wildlife) and technical innovations. These changes must take into account the full diversity of farms. This issue also encompasses the design of systems aiming to monitor and manage emerging infectious diseases and behavioural disorders related to animal welfare, using new surveillance tools (e.g. precision breeding for example).

2.4. Development of alternative therapies to animal medicine and antibiotics

- **Development of new vaccines and system vaccinology**. Specific attention should be given to the development of vaccines against immunosuppressing agents (e.g. African swine fever) and against endemic pathogens that results in antibiotic use. Breakthrough in vaccine development can be achieved by using systems vaccinology to decipher early host responses to immunization and to identify immune correlates of protection including repertoire signatures and response to adjuvants. In some cases, effective vaccines are available on the market, but we lack socio-economic research to convince farmers to continue their use once the problem is solved by vaccination.
- **Search for alternatives to chemical antimicrobials and assessment of their effectiveness.** Some compounds from natural raw materials can act as alternatives to antibiotics. These may include some 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.). It is often difficult to assess their effectiveness and the toxicity as well as the environmental safety of all these substances and we must define adequate testing methods that are generic and implemented in various members states.
- **More efficient therapies**. If antibiotics are to be used, innovative pharmacology approaches including better timing of administration, taking account of physiological status or chronobiology associated with earlier detection of diseases will allow more targeted intervention, and have the potential to reduce the amount of drugs used when animal must be treated. Routine collection of immune phenotypes will allow us to determine aspects of the immune response that are suppressed prior to and during infection thus helping developing targeted intervention strategies that are not based on the use of non-targeted antibiotics.

Expected impacts

- Improved animal welfare and health in livestock production systems,
- Improved ethics and appreciation by society of livestock production systems
- Development of preventive strategies and alternative therapies and use thereof to ensure animal health & welfare
- Development of innovative health & welfare practice guidelines
- More prudent use of antimicrobial, reduction of dissemination to the environment and reduction of anti-microbial resistance
- More efficient and “country tailored” surveillance systems
- Better implementation of animal welfare and health monitoring throughout the production chain
- Rigorous assessment of animal welfare
- Emergence of new value chains and business models, increased farm revenues and resilience
- Support to the livestock industry to open up doors, build corporate responsibility and become transparent in a way society understands
- Facilitation of free trade of animals and their products throughout Europe and strengthen the European livestock sector’s position.

3. Food and nutrition security

Challenges

A paradigm shift is required for animal product quality research. It needs to address not only intrinsic qualities of products (health, nutrition, flavour, processing technologies) but also their extrinsic qualities linked to production and distribution methods to which consumers are increasingly sensitive. This brings new research questions. The first one concerns the evaluation of the role of animal products in sustainable diets. If a moderate decrease in consumption of animal-based products might be healthy, some studies conclude that the consumption of animal products needs to be drastically reduced (or even suppressed). Consequences on physical and mental health in relation to nutritional needs of categories of population, as well as economic and social development of territories remain poorly informed. Dietary implications, and more generally impacts on sustainability of alternative proteins are also largely unknown and will depend on the use of land released by livestock.

New questions also appear on the **quality of animal products throughout the chain**. One challenge is to identify levers and design systems fostering the desired (sensory, nutritional, sanitary, technological, commercial) qualities throughout the chain. Another is to evaluate how more agroecological/smaller scale production systems will impact product quality and variability and the organisation of the processing industry.

Unexplored opportunities exist to make the best use of **animal biomass in a circular bioeconomy**. A large area of research and innovation lies in the valorisation of livestock-based products for nutraceutical and non-food use with a view to reducing food waste. A growing body of scientific evidence shows that eggs, milk, meat and carcass are sources of active molecules that are of major interest for human health and different food and non-food industrial areas. These biomolecules can be an advantageous substitutes for certain synthetic chemical molecules and may address consumers' demand for more natural products.

R&I priorities

R&I priorities aim to benefit from the assets of livestock-based products in more sustainable and healthy diets. Most of the R&I priorities were jointly developed with the Food for Life European Technology Platform.

3.1. Improving insights into consumption of animal products and human health***

- **Deepening the knowledge about the effects of animal-based products on human physical and mental health.** There is a lack of data on the benefits and drawbacks of animal-based products in a diet considering the supply of micronutrients, bioactive compounds (e.g., creatine, collagen) or anti-nutrients. There is a need for further insights on dietary requirements according to different population segments as well as on the healthiness and risks associated with more or less restrictive (vegetarian, vegan or omnivorous) diets on the long term. This concerns particularly: effect of milk lipids (especially polar lipids) on the cognitive development of children, effect of a reduction of animal proteins in the elderly on a possible cognitive decline.

- **Alternatives to animal proteins.** Innovations are very rapid in this domain (e.g. plant-based substitutes, in vitro meat, insect proteins). Research is needed to compare trade-offs on the nutritional value including bioavailability and anti-nutrients, as well as on the implications of processing and on the overall impact on consumers nutritional health of alternative foods. Foresight scenarios projecting market shares of alternative products and associated land use and environment impacts are required to understand the consequences of a shift to alternative proteins sources.

3.2. Management of nutritional and sensory qualities of animal-based products***

- **Animal products to advance human health and sensory qualities.** We need to develop combined strategies (genetic, nutritional programming, regulation of gene expression, rearing) to produce animal-based foods that have recognised healthier characteristics through focusing on components that have been shown to advance human health and improve sensory qualities. In meat, it is necessary to understand the biological construction of quality at different stages of the animal's life, at slaughtering and post-mortem, to identify predictors of quality and define the most appropriate conditions ensuring simultaneously quality and social acceptability. In milk processing, innovations may focus on some ingredients and require a better understanding of the development of casein micelle structures and properties of fat globule membranes (phospholipids, protein). In egg processing, a better understanding of the genetic and biological mechanisms that control the solidity of the shell and yolk membrane is needed to propose egg rearing and storage routes that are favourable to quality. Outdoor production raises risks of contamination and of possible alterations.
- **Optimisation of nutrient efficiency across sectors**: A "One Nutrition" approach linking human, animals and plant nutrition is essential to scientifically underpin the contribution of food production systems to support a broader sustainable food system strategy promoting effectively the minimisation of nutrients leakage, the use of sustainable feed and improved biological values of the food, feed and fertilisers. We need to develop models for an optimisation of nutrient efficiency and interlinkage between the nutrition of plants, algae, micro-organisms, insects, livestock and humans, taking into account the nutritional value at each stage of the chain.
- **Technologies to increase the nutritional value of animal-derived products**. Hydrolysis of muscle proteins could make it possible to foster the assimilation of proteins and the bioavailability of essential amino acids for certain populations. This may in particular help address sarcopenia in the elderly whose protein consumption may be below requirements. Impacts of heat processing on nutrient loss (e.g heat treatment of milk, processed meat) should be further studied. There still is a need for research and innovations on mild processing with a view to preserve native properties while ensuring animal-based food safety.
- **Food systems dynamics.** Considering the diversification of animal-based food (valorisation of animal biodiversity, autochthonous species, milk from alternative species, products with geographical indications, local food, etc.), there is a need to understand how industries can adjust to a demand for more diversified, less concentrated, niche, less standardised quality, less regular production, possibly in smaller amounts. There is an issue around the capacity for the (already

under pressure) conventional production system to adapt to down-scaling and on the impact on business sustainability.

- **Tools for improved traceability along the food chain.** To ensure transparency and mitigate food fraud, tracking and tracing, e.g. block-chain technologies, may provide verifiable information regarding production processes on product labels. Also, authenticity testing with e.g. finger printing technologies isotopes, omics techniques, may help certify the origin of a meat sample in relation to geographic aspects or (outdoor) production processes.

3.3. Functional and bioactive properties of animal-based products and by-products***

- **Exploration of bioactive compounds of interest for human health.** Animal-based products contain a diversity of compounds having relevant nutraceutical properties that need to be better known and exploited. Eggs contain active molecules with antimicrobial and anti-carcinogenic activities. Milk compounds are said to have anti-allergenic properties (asthma, dermatological diseases) that need to be better known in a society where allergies are on the rise. Due to its high content of highly digestible proteins, meat is an interesting source of food for its bioactive peptides which would add value to low price pieces.
- **Non-food applications of animal product components and by-products.** The carcass represents a source of proteins such as collagen, elastin and keratin with interesting properties of resistance (tensile strength, pH, temperature, etc.) and rigidity (bone, tendons, connective tissue, etc.). An exhaustive study of their functionalities and extraction processes would enable applications in biomedicine (haemostatic dressings), biomaterials and pharmaceuticals. The acquisition of genetic, biological and physical data on various eggshell models is a prerequisite for the development of potential applications in the field of biomaterials (use of additives or "natural" inspiration molecules). Milk components can also find numerous alternative applications in the processing of biodegradable bio-plastics, textile fibers, glues.

Expected impacts

- Evaluation of the effects of animal-based product on human health,
- Evaluation of nutritional, environmental and societal value of meat substitutes,
- Improved nutritional value of animal products though innovation at farming and downstream level,
- Innovative utilisation of products of animal origin both for human nutrition, as nutraceutics and non-food applications,
- Evolution of food systems to fit more diversified demands,
- Improved products traceability and mitigation of food fraud,
- Improved consumer trust in animal-based products,
- Business models, license to operate, economic wealth.

4. Livelihoods and economic growth

Challenges

Livestock farming is at the nexus of several social and economic challenges. Dietary and environmental recommendations towards a decreased consumption of animal products have impacts on social inequalities with consumers having very different purchasing capacity. Along with an average per capita consumption that at best is stagnating, product differentiation allows adaptation to the heterogeneity of consumer preferences and incomes. Labelling and traceability are of great importance for consumers and sectoral organisation but it comes with additional commercial costs to make the differentiated qualities known to consumers. Companies have to adjust to societal demands while structural changes in the agri-food sector and trade raise many scientific and public debates. Intensive animal husbandry is highly debated, while the development of livestock in specialised regions with high animal density was initially driven by competitiveness. R&I may allow public policies to support a transition and overcome imbalances in value sharing across value chain actors.

An analysis of these interdependent issues may provide a better understanding of the socio-technical and socio-economic transformations of the livestock sector. It may offer perspective to value chain actors to overcome challenges faced by livestock farming and to policy makers for setting up relevant incentives and regulation instruments. This may also strengthen cooperation between stakeholders at local (or larger) scales for the development of circular solutions to create new shared perspectives, partnerships and business models.

To assess the sustainability of current and future systems and products, it is critical to define the baseline and to track improvements towards sustainability. Life Cycle Assessment (LCA) has gradually emerged as an internationally recognised approach. Originally developed for industrial products, LCA is a product-based approach. It has limitations with respect to measuring the interplay between products and activities. Sector-wide indicators need to move forward to take into account at least a part of the complexity of agricultural and food systems, dynamics of phenomena and services and disservices provided by agriculture.

R&I priorities

R&I priorities aim to understand socio-economic issues to highlight the future and how different farming systems can contribute to the provision of a variety of services to the society and support new pathways.

4.1. Drivers of evolution and governance of the sector to promote change over time

At the nexus of challenges around societal expectations, farm profitability, public support and environmental and social effects of farming systems, lie new research questions in which open-Innovation and co-Innovation are relevant approaches.

- **Understanding consumers' socioeconomic drivers, trends in markets**[28] to gain precise knowledge of evolutionary trajectories of the consumption of animal products in Europe and worldwide and of the underlying motivations. Focus needs to be on intergenerational differences, stratification within populations, socio-economic and cultural situations, projected trends of evolution across countries and markets, production systems and living conditions of livestock vs consumers willing to pay, changing dietary preferences. We have to study market shares for alternative products, demand for local sourced food, all-year round supply, and potential impacts on global markets in case of a reduction of animal production in the EU, i.e. increase of imports. For ethical reason it is also important to define what products can be valorised from animals having no economical value (male layer chicks, male dairy goats, Holstein or Jersey bull calves).
- **Livestock farmers' generation renewal** is a big challenge in all Member States. It is important to develop insights into farmer's perceptions of societal issues and help them design new farming systems taking into account labour, working conditions, quality of life, attractive careers and innovation. It is necessary to understand long-term causalities and how policies and market development steer farming systems.
- **Determinants of structural changes in farms and industries** and their consequences on livestock farming performance will inform scenarios of competitiveness, territorial distribution and ability to fit very diverse demands. This requires revisiting the effects of economies of scale, range and agglomeration, as well as coordination between actors, and the influence of private (e.g. industry, retail) and public action (new food standards, policies on investment, risk management and process innovation) to create and share value. Competition (or synergies) between biofuels and animal feed production also remains poorly integrated into economic analysis.
- **Designing and evaluating livestock farming blueprints.** New value chains based on business models that allow transparency, value sharing within agri-food chains, making visible and offering economic appreciation from the migration to more sustainable productions systems. This may contribute to a better repartition of livestock farming on territories and to its reintroduction where it has disappeared**.**

4.2. Diversity of livestock farming systems supporting multifunctional farming

The diversity of farming systems (including suburban and urban farming) and its evolution (diversification) has hardly been considered. Facing new challenges, it becomes central.

- **Characterisation and management of the diversity (and diversification) of livestock systems**. Farming systems diversity should be described and evaluated as a source of adaptability and resilience at farm, sector and regional scale. They also provide production efficiency and consistency, services as well as disservices. Insights on these assets (complementarities, synergies, tensions, competition, and commensality) are needed and on the management of diversity considering collective and public actions. The diversity of production systems has a role in agroecology transitions that should be better understood and highlighted, as well as farmers' motivations. The reintroduction of livestock farming in areas where it has disappeared including

[28] This topic was developed in collaboration with Food for Life ETP through experts' consultation

cooperation and skills development is a matter of great importance. We need to determine which production systems can run successfully in the same region and how to maintain and support these different production systems. Research will also identify and implement means of supporting livestock production that will contribute to maintenance of landscape heritage, enhancement of biodiversity and offer additional farming income from rural services. Technical and administrative rules must be looked at how they disproportionately affect small enterprises and could be adapted.

- **Making use of reservoirs of existing genetic resources and managing animal diversity** within farming systems. Progress will arise from a deep analysis of interests (synergies, functional complementarities) and limits (competition) of animal diversity (species, breed, genomic variability) within herds to increase resilience, diversify production and face the increasing qualitative and temporal diversity of resources. This also requires reconsidering objectives and organisation of animal breeding schemes to bridge the gap between selection on dominant and smaller breeds that may offer advantages to respond to a diversity of systems.
- **DIversification of livestock species, breeds and products.** Production of milk and meat from alternative species (e.g. donkey, goat, etc.) or breeds can supply high-quality and innovative foods, beneficial for human health and for economies whose effects need to be better assessed. They are particularly suitable to organic systems, can help maintain autochtonous breeds, to increase farm incomes and to supply nutraceutical foods increasing economic value of animal production chain. Some local European breeds may be at risk of extinction, but they might carry the potential to withstand future challenges (e.g. climate change). It is therefore relevant to investigate the genetic diversity but also phenotypic relevance of local breeds of diverse species within European countries.
- **Food systems approach to the diversification of primary production:** insights into consumers' appreciation, expectations and willingness to pay for product diversity, in the capacity and willingness of processing and retail industries to manage diversity of products. This could range from the creation of new segments by the downstream sector to the promotion of new productions to the farmers' marketing for heterogeneous products and the capacity of downstream structures to address heterogeneity.

4.3. Evaluating the roles/values of livestock within agri-food systems

- **Multi-criteria assessment of livestock production systems[29].** LCA attributional methods must be improved by developing a holistic vision of sustainability. This includes (i) time dynamics processes to integrate phenomena taking place over long periods (eg. soil fertility, C sequestration, erosion); (ii) resource efficiency considering circularity and arable vs non arable land use; (iii) performance not linked to material flows such as biodiversity; (iv) spatialisation and regionalisation of phenomena to integrate the local carrying capacity of ecosystems, (v) social and economic indicators, (vi) a food/nutritional basket approach to consider nutritional value of food. To attain a fair assessment of production systems, we need to clarify the consequences of the allocation of emissions (notably GHG) of animal foods and related ecosystems services and consider the impacts of non-biodegradable synthetic substitutes. The development of consequential LCAs offers

[29] This item was developed in collaboration with Plants for the Future and Food for Life ETP

perspectives but it is still insufficiently developed to evaluate ex-ante scenarios concerning the place of livestock in value chains.

- **Multicriteria assessment using the "package of services"** concept as a framework for research on livestock systems. The concept of package of services aims to describe livestock systems' economic, social and environmental performances, to understand the biological, technical, cultural and economic determinants and analyse synergies and antagonisms between performances. This approach will make it possible to address trade-offs between services and disservices, relationship between services and the resilience of systems, evaluate avenues around circular territorialised approaches in livestock farming, interactions between livestock and biodiversity at different scales and valuation of market and non-market services. Methodological improvements are required on: (i) extension of the concept of ecosystem services to economic vitality and the well-being of populations; (ii) systems borders and services (diversity of beneficiaries, processes, economic and political decision-making, governance structure, etc.) and (iii) development of appropriate indicators.

Expected impacts

- Better understanding of the drivers of evolution of livestock farming systems,
- Livestock farming systems creating values and addressing societal expectations,
- Development of circular bioeconomy at local level and emergence of new value chains,
- Valuing the diversity of livestock production systems,
- Provision of a diversity of animal-based products adapted to various demands and markets,
- Increased farm revenues and resilience,
- Support to a transition towards more sustainable livestock systems and agri-food chains,
- Public policies and collectives actions to facilitate transition of the livestock sector,
- LCA methods suited to system evaluation considering various interactions between livestock, plant, soil and biodiversity and able to cope with local specificities,
- Methods and tools offering a meaningful baseline against which progress can be measured,
- Improved participation of farmers, consumers and actors of the food chain in research and transition projects.

5. Cross-cutting issue: The animal as a system

Challenges

The development of agroecological and circular livestock farming systems renews the scientific priorities of animal research. We need to develop the animal's capacities to adapt to a more changing environment and challenges with regard to biological and behavioural traits, to ensure their quality of life and develop a preventive rather than a curative approach to health management. The answer to these issues **requires moving from a static vision of the animal** as it has prevailed thus far **to a dynamic vision** taking into account, in an integrated way, the different phases of development during an animal's lifetime and intergenerational factors, as well as all physiological traits to study the long-term effects of events. This include the long-term effects of experiences in early phases of life and the ability of animals to compromise and adapt to changing environments during their lifetime. This involves cross-disciplinary approaches related to the various functions studied and the different periods of the lifetime. This implies the need to strengthen collaborations between biology, biostatistics and bio-informatics for integration of heterogeneous and complex data. This holistic, multidimensional and multidisciplinary approach links biotic and abiotic environmental factors to various animal traits. The regulation through animal genetics, early programming mechanisms (epigenetics) that modulate the expression of genotypes and the function and ontogeny of microbiomes interacting with the animal's genome and epigenome are summarised in Figure 4. Research will allow the understanding of phenomena, contribute to develop new breeding programmes for more robust and adaptable animals and to develop management practices aimed at controlling the different key animal performances traits.

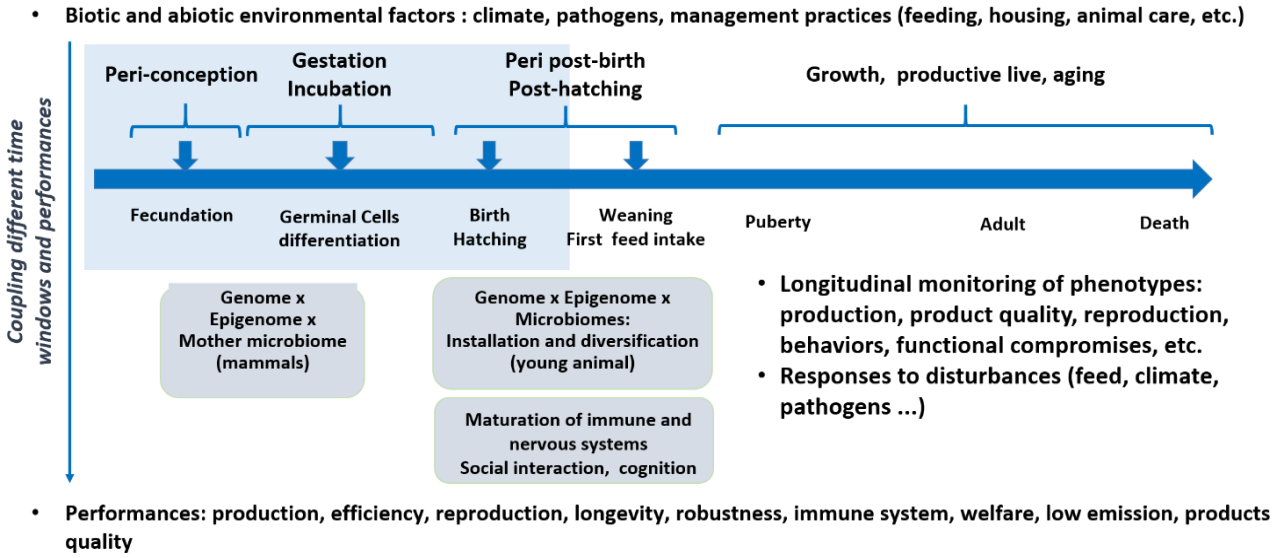


Figure 4. Early development and study of phenotypes: coupling health, welfare, reproduction, production, longevity, adaptation to heat, reduction of methane emissions, quality of products

R&I priorities

R&I priorities may support the production of a variety of more efficient and robust animals, adapted to a variety of dynamic farming conditions.

5.1. Early development of phenotypes

It is now well established that the construction of the individual's phenotype can be influenced at a very early stage of life. Periods to consider range from the periconceptional phase (chromatine organisation and first cells differentiation), the embryo-larval/foetal life (organogenesis), the neonatal period until weaning (great upheavals and first apprenticeships for young animal). The study of genome-epigenome-microbiome interactions ("holobiont" scale) is a promising area of research to decipher and use the early mechanisms of phenotype construction.

- **Microbial ecosystems and host.** The establishment of microbial ecosystems during early stages of life are decisive for animal health and production. There is a close association between microbiomes and the host immune system. We need to better understand and control the establishment of different microbiota in farm animals and to explore interaction between the immune system and microbiomes. This will enable us to identify specific sensitive biomarkers and potential therapeutic targets. One priority is to study the bidirectional "microbiome-intestine-brain" axis in relation to animal health, welfare and behaviour. New approaches have to be developed to study the effects of genetics x nutrition x digestive microbiota on the phenotype expression.
- **Cell differentiation mechanisms & development of tissues of interest**. Advances in transcriptomics have made it possible to study the cellular composition of organs and tissues in humans and mice. Similar strategies should be developed in farmed species as they are essential for understanding the mechanisms of cell differentiation during development. The reconstitution of cell lines from stem cells to differentiated cells remains a challenge for understanding development of many functions (such as sexual maturation) and organs as well as nutritional & organoleptic quality of animal products.
- **Intergenerational tracking of epigenetic deterministic traits in farmed animals:** the influence of the environment can "program" the development of organs and functions and optimise the performance of the individual (efficiency, resilience, welfare) in adulthood or even between generations. Conversely, prenatal or postnatal exposure to stress may increase the risk of disorders later in life. Monitoring epigenetically deterministic traits in farm animals throughout the animal's life and between generations should be implemented in different farm species.
- **Development of the sensory, cognitive and emotional capacities of animals.** This concerns the physiological and behavioural mechanisms of the development of the sensory, cognitive and emotional capacities of animals and their state of consciousness. A key point is the study of the neuronal network regulating functions and behaviours involved in learning and cognitive processes in the early stage of life. A particular issue is the development of new feeding and animal health strategies in early life with long term effects on health and welfare.

5.2. Multi-performing animals

- **Compromises between biological functions in various environments**: The aim is to determine whether and how animals selected in a favourable environment adapt to a changing environment; to predict the consequences of the selection of a trait like productivity on other functions like reproduction, health, behavioural robustness, longevity and adaptation to heat waves. This includes looking for new biomarkers to predict individual phenotypes under different conditions and their inheritance. It also concerns the impacts of genetic and physiological processes on products' nutritional & organoleptic qualities. Two traits are particularly important in the context of climate change: 1. adaptation to heat waves (early exposure, intergenerational transmission) and 2. antagonism between methane production and the ability of ruminants to digest cellulose, as the selection of less emitting animals should not lead to less efficient animals.
- **Characterisation and control of animal's immunity in its environment**. The mechanisms of immunity are directly related to disease resistance and the vaccine responsiveness. This includes the programming of the immune system of the neonate (immunomics) and its broad consequences on health, the genetic determination of the variability of the immune response and looking for early biomarkers to predict individual phenotypes and the factors influencing the ability of animals to return to a physiological state after a stress. Further research is needed to evaluate the interaction between feed, the development of immunity and increased resistance of animals to pathogens especially for young animals (piglets, chicken). Applied research may include the prediction of individual immune capacity through integration of immune phenotype and genetic and epigenetic identifies in interaction with rearing practices. It also concerns modelling the risk and efficacy of vaccines, revision of vaccine prophylaxis in the light of changes in rearing practices like outdoor farming according to genotype, development of effective vaccines and natural immunostimulant molecules to strengthen the immunity of young animals and the efficacy of vaccines.
- **Relations between microbial communities and animal health.** Understanding the functions of the animal's microbial communities and host–microbiota interactions will contribute to an effective control of the balance of the microbial ecosystem for the benefit of animal health and welfare as well as human health (zoonoses, antibiotic resistance) and to develop innovative prophylactic and therapeutic tools and strategies. This requires a better understanding of the most resilient/beneficial microbial assemblages at different stages of the animal's life, interrelationships between different animal microbiota (intestine, lungs, skin, reproductive system), and to include beyond microbial fractions (fungi, bacteriophages and viruses). For practical purpose, we need to develop methods to control the composition of these microbial ecosystems (feeding and rearing practices, immunostimulants, pre/pro-biotics, phages, etc.) and their consequences on other traits.
- **New individual-level disease phenotypes with -omics data:** Exploit the wealth of new phenotypes, which need to be evaluated for their usefulness for on-farm management and breeding. In combination with the -omics data available, a genetic evaluation of the applicability and implementation of the new phenotypes in breeding can be faster and more precise.
- **Animal welfare as a precursor of animal health & vice versa**: According to the WHO definition, health includes physical and mental health and therefore welfare. It is important to understand the relationship between animal welfare and health as well as the animal's awareness of its condition

and to decipher the mechanisms linking welfare and health. It is also necessary to study the effect of stress and positive emotions on health, notably on the immune system and health problems that may arise from adjustments in rearing systems design aiming to improve welfare (outdoor access, use of straw bedding, etc.). The relationship between health, welfare & efficiency and the impacts of stress during various stages of husbandry on resilience should also be considered, as well as the scale of the animal's career in order to understand multifactorial phenomena. With regard to health, research should cover livestock diseases, metabolic disorders and infectious diseases.

- **Sensory, cognitive and emotional capacities of animals.** A better understanding of the animal's awareness of its welfare and health state will help to better manage them. Addressing animal's quality of life requires to understand how does the animal perceive itself as sick or having a poor welfare, to which extend preclinical behavioural signs of disease exist and can be detected and how this perception establishes itself during development (in utero/in ovo, from birth to the end of its life) towards behavioural resilience adaptation. Ethological and multi-disciplinary studies investigating affective states will allow the characterisation of positive mental states, their behavioural and physiological expression in relation to farming conditions and practices, behavioural robustness and balance between negative and positive states throughout lifespan. This will contribute to the analysis of the effects of enrichments of the living environment and transformation of farming methods. A key issue is the development of indicators to characterise the mental states of animals and their behavioural robustness,
- **Impacts of genetic and physiological processes** on products' nutritional & organoleptic quality

5.3. Improving research methods and infrastructures towards innovation

Beyond current European research infrastructure projects (AquaExel, SmartCow, PigWeb), there are needs for networking and harmonisation of methodologies in research infrastructures to ensure that European resources are up-to-date and fit for foreseeable purposes.

- **Alternatives to animal experiments**. The development of new cellular models such as 3D cultures and organoids of the tissues of interest and organ-on-chip (multi-channel 3D microfluidic cell culture chips that simulate the activities, mechanics and physiological response of whole organs) are to be developed to limit or replace animal experiments (3R principles) and to break down and model the interactions between organs.
- **Creation of a European "large animal clinic"** where genome edited animals could be genotyped/phenotyped. Large units specialised in one species need to be identified as phenotyping platforms, to be linked to groups that are identified as specialists of a function (immune response, metabolism, reproduction, development). This would require strong networking activity and international collaboration (I3 project).
- **Adapting the concept of the digital twins** to develop *in silico* monitoring of animals in order to improve detailed knowledge of the mechanisms and processes underlying biological functions. In particular, the aim is to understand biological processes, their regulation and the way in which they interact or cooperate at different scales (from the molecule to the cell, the organ-function and the

individual), as well as to predict phenotypes in response to changes in the environment or practices at different time scales and to anticipate the emergence of new properties.

- **Support of the Functional Annotation of Animal Genomes** - FAANG international action[30].

Expected impacts

- More efficient and robust animals adapted to varied farming conditions and that are able to react quickly to changes (climate and health hazard, feed quality, etc.);
- Overall contribution to food security by supporting innovation in breeding and farming sector;
- Economically, environmentally and ethically robust and sustainable breeding and rearing blueprints for all classes of livestock
- Deep phenotyping on complex traits;
- High throughput phenotyping in commercial and experimental farms;
- Optimisation of the utilisation of European infrastructures;
- New alternatives to animal experiments
- Facilitation of knowledge dissemination and implementation;
- Different (epi-)genotypes perfectly suitable for a wide spectrum of production systems.

[30] There are currently 3 EU projects ongoing ending in 2023-2024 (SmartCow www.smartcow.eu for ruminants, Picweb for monogastrics and www.aquaexcel2020.eu for aquaculture)

6. Cross-cutting issue: Livestock in the digital age and technologies

Challenges

Technological innovations in the fields of **biotechnology**, digital technology and industrial processes can and will contribute to improve agroecological and circular economy approaches in livestock systems. This includes high-throughput genome and phenotyping knowledge that should allow for more accurate selection on socioeconomic traits and more robust, adaptable and efficient animals and improved animal products. Predicting animal adaptation and performance requires the development of new biomarkers, an important source of technological innovation. Some of the biggest challenges are around creating confidence and an environment conducive to data sharing, further development and/or promotion of models for data sharing between beneficiaries that is fair and effective.

New digital technologies (sensors, robotics, internet of things, "block-chain") provide innovative tools and concepts for livestock management, and phenotyping on large numbers for efficient genomic selection. The contribution of these new technologies lies in the possibility of having a better knowledge of the environment, the individual in the herd, the herd as a whole and the quality of the products. These technologies have potentially many areas of use: feeding strategies, welfare management, health management, management of reproduction. Genetic selection also has much to gain from this high throughput information, genotyping being much less limiting today than large-scale phenotyping of traits of husbandry interest. However a majority of technologies are dedicated to intensive farming systems and are still relatively rare in extensive farming. Continuous and automated processing of a huge amount of standardised data also opens up new possibilities for benchmarking, improvement, certification and greater transparency in business-to-consumer relations with regard to production methods. Strategic harnessing of artificial intelligence and computer learning technologies will be critical in order to fully exploit the potential of 'big data'.

Innovation in **technological biorefinery processes** must improve the nutritional value of plant co-products for animal feed, manure treatment and co-products from carcasses.

R&I priorities

R&I aim to enable changes allowed by digital technologies and big data to better support farmers and citizens' expectations

6.1. Use of digital technologies in livestock farming to improve performance

- **Determination of the gains made possible by the management of individual diversity** instead of the management of a "mean animal" based on the information available in dynamics and by combining the knowledge of genetic diversity offered by genotyping possibilities now available and phenotypic diversity of animal trajectories. It is now possible to move from management based on expected production and a calculation of associated requirements to a dynamic management based on much more varied criteria and targeted actions adapted to each individual with potential huge gain in efficiency.

- **Development of precision management technologies to improve efficiency, animal welfare and health.** These technologies allow early warning and real time management and must be applied to different targets: monitoring of feeding and resource use efficiency, animal welfare and animal health, management of reproduction. They also concern the development of indicators and/or proxies to adapt feeding and farming systems from group-based to individual-based models, management of individual animal diversity considering lifespan, scale of application and monitored performances. Feed efficiency can be improved by genotype-based management and by using temporal variation to control animal feeding. The development of new technologies and digital solutions (imaging, sensors, robotics, IoT and high-tech, artificial intelligence models) are an integrated part of this domain of research.
- **Development of structured information systems** and decision support tools to maximise the usefulness of available information for decision making. The flow of information must be organised and processed in an information system and be returned to farmers in a frugal and clear manner at optimal timing to enable farmers to integrate them as a decision support. The challenge is to move from a one sensor-/piece of information to systems capable of managing multi-input (multi-sensors or multivariable) and multi-output approaches with a coherent set of biological, behavioural, morphological, environmental information.
- **Evaluation of the return on investment of these technologies**[31] requires simulating, via the development of bio-economic models, the real interest made possible by the acquisition of new information (cost reduction, saving of working time, etc.) in relation to the upstream investment.
- **Revisiting some perceived economies of scale**: smaller units can become more viable with cost-efficient technologies displacing some elements of mechanisation or management labour.
- **Training and evolution of farmers' job** and working conditions vis-à-vis digital technologies, ensuring that end users have the knowledge and tools to focus on data that can be turned into actionable management decisions. Digital technologies make it possible to remove repetitive or painful tasks but at the same time they create new ones (maintenance/surveillance of equipment), they can be a source of stress (too many alarms), may reduce human-animal relationships and lead to less investment in basic know-how from livestock farmers. The deployment of these new technologies will also profoundly change the organisation of actors involved in consultancy and selection, and probably even the types of actors who will be involved in these fields.

6.2. Use of digital technologies to develop high throughput phenotyping and to improve traceability and biosecurity

- **Development of a multifunctional vision of an animal** to evaluate future performances for new breeding objectives. The possibility of integrating data from sensors in commercial and experimental farms makes it possible to observe large numbers of animals in very different environments and husbandry conditions to study the genetic x environmental interactions and to propose new phenotypes and development of tools for their characterisation. This will be decisive for developing selection on improved breeding qualities and for improving livestock management.

[31] This point was mentioned as a priority by the EIP-AGRI Focus Group on Precision Farming (2015)

The complementarity of macroscopic and microscopic (omics) visions is promising for a better understanding of animal physiopathology.

- **Utilisation of remote systems for improving tracking and tracing systems** for animals and diseases across countries/regions will contribute to identify and prevent the spread of animal diseases with substantial benefits for animal and human health while reducing antimicrobial use.
- **Tracing and tracking in relation to block-chain** opens up new possibilities for benchmarking, improvement, certification and greater transparency in business-to-consumer relations with regard to production methods and will contribute to develop various quality labelling systems

6.3. Data science

- **Development of "data driven" approaches** in artificial intelligence. With the development of big data and associated learning methods, prediction capabilities may no longer be based on mechanistic models simulating biological processes, but on "black box" models resulting from high-speed data analysis. Complementarities between these 2 approaches will have to be sought to make the "data driven" approaches more informative and to improve mechanistic models that suffer from the impossibility of adjusting to existing situations for lack of dynamic information on the state of the system. The applications of artificial intelligence are numerous and concern improved animal well-being, increased food safety and security, resilience against economically devastating crises, enhanced resource efficiency, reducing food losses and waste.
- **Massive data management**. The deployment of new technologies raises new questions. This concerns databases and data sharing (exchanges platforms) approaches to combine production data, molecular data and sensor data and properly harness the data available to us presently, frequency of data acquisition to provide relevant information, standardisation of data and methods promoting standard nomenclature and annotation, reliability of data. The possibility of aggregation requires the interoperability of FAIR (findable, accessible, interoperable and reusable) databases. Another issue is the scaling up of computing and data management E-infrastructures. Data security and connection between regulation and data is crucial.

Expected impacts

- Increased efficiency of livestock production systems;
- Improvement of animal health and welfare;
- Better working condition for farmers;
- Traceability of the product in a context of “connected plates”;
- Better data capture, compatibility and processing for the optimisation of inputs and yields;
- New business models for open data allow use of tools to analyse potential costs/benefits and analyse utility of applications;
- Less bureaucratic control system in the EU;
- Better understanding of the main reasons for the current lack of adoption.

Appendix 1 – Fit with the Horizon Europe structure

	Cluster 6 - Food, bioeconomy, natural resources, agriculture, environment	Public Private Partner-ships	European Institute of Innovation and technology	Mission Soil health and Food	Research infras-tructures
1. Natural resources, climate and biodiversity					
1.1. Design and support concepts for new interplays between livestock and cropping*	X	X		X	
1.2. Optimising synergies in circular livestock and cropping systems*	X	X		X	
1.3. Efficient and safe utilisation of manure	X	X		X	
1.4. Development of climate smart farming systems contributing to biodiversity restoration*	X	X		X	
1.5. Support the role of livestock in organic farming**	X	X		X	
2. Animal Health and Welfare					
2.1. Interactions between animal health and welfare	X	X			
2.2. Health ecology and connections between microbial communities, animal health & welfare	X	X			
2.3. Towards production systems that guarantee animal health and welfare	X				
2.4. Development of alternative therapies to veterinary medicines and antibiotics	X	X			
3. Food and nutrition security					
3.1. Improving insights into consumption of animal products and human health***	X				
3.2. Management of nutritional and sensory qualities of animal-based products***	X	X			
3.3. Functional and bioactive properties of animal-based products and by-products***	X	X			
4. Livelihoods and economic growth					
4.1. Drivers of evolution and governance of the sector to promote change over time	X				
4.2. Diversity of livestock farming systems supporting multifunctional farming	X				
4.3. Evaluating the roles/values of livestock (products) within agri-food systems	X				
5. Cross-cutting issue: The animal as a system					
5.1. Early development of phenotypes	X	X	X		
5.2. Multi-performing animals	X				
5.2. Improving research methods and infrastructures towards innovation	X				X
6. Cross-cutting issue: Livestock in the digital age and technologies					
6.1. Use of digital technologies in livestock farming to improve performance	X		X		
6.2. Use of digital technologies to develop high throughput phenotyping and to improve traceability & biosecurity	X		X		
6.3. Data science	X		X		

Appendix 2 – Fit with on-going or past Horizon 2020 projects

Below are listed for reference some major H2020 funded projects related to the key R&I areas suggested in this document.

ATF White paper 2021 Towards Horizon Europe	Project Short name	Project title
1.1. Design and support conception for new interplay between livestock and cropping	ALL-IN	ALfalfa for sustainable Livestock farming systems: Improve alfalfa - rhizobia symbiosis and New feeding strategy based on ecological leftovers
	Feed-a-gene	Adapting the feed, the animal and the feeding techniques to improve the efficiency and sustainability of monogastric livestock production systems
	INNO4GRASS	Shared Innovation Space for Sustainable Productivity of Grasslands in Europe
	Legumes Translated	Translating knowledge for legume-based farming for feed and food systems.
	MIX-ENABLE	MIXEd livestock farming for improved sustaiNABiLity and robustnEss of organic animal production
	SUPER-G	Developing SUstainable PERmanent Grassland systems and policies
	SUSMEATPRO	Sustainable plant ingredients for healthier meat products - proof of concepts
	SUSPIG	Sustainability of pig production through improved feed efficiency
	SUSTAINBEEF	Co-definition and evaluation of SUSTAINable BEEF farming systems based on resources non edible by humans
1.2. Optimising synergies in circular livestock and cropping systems	AgroMix	AGROforestry and MIXed farming systems - Participatory research to drive the transition to a resilient and efficient land use in Europe
	FATIMA	FArming Tools for external nutrient Inputs and water MAnagement
	FERBLEND	Fermentation-induced valorization of side stream blends from oilseed and dairy industry
	MIXED	Multi-actor and transdisciplinary development of efficient and resilient MIXED farming and agroforestry-systems
1.3 Efficient and safe utilization of manure	AgroCycle	Sustainable techno-economic solutions for the agricultural value chain
	FERTIMANURE	Innovative nutrient recovery from secondary sources – Production of high-added value FERTIlisers from animal MANURE
	RES4LIVE	Energy Smart Livestock Farming towards Zero Fossil Fuel Consumption

ATF White paper 2021 Towards Horizon Europe	Project Short name	Project title
1.4. Development of climate smart farming systems contributing to biodiversity restoration*	CCCFarming	Climate Care Cattle Farming Systems
	EcoLamb	Holistic production to reduce the ecological footprint of meat
	FarmSustainaBl	Enabling Smart Livestock Farming Technologies for Environmental Sustainability using Blockchain
	FREEWALK	Develop economic sound free walk farming systems elevating animal welfare, health and manure quality, while being appreciated by society
	GrassToGas	Grass To Gas: Strategies to mitigate GHG emissions from pasture based sheep systems
	GrASTech	Precision Livestock Farming (PLF) Technologies to Reduce Greenhouse Gas (GHG) Emissions Intensity of Pasture-based Cattle Systems
	M4Models	Manure management for methane mitigation - Improved inventory modelling to support policy actions
	MELS	Mitigating greenhouse gas emissions from livestock systems
	MilKey	Decision support system sustainable and ghg optimised milk production key European
	PEGaSus value chain	Phosphorus efficiency in Gallus gallus and Sus scrofa: Bridging the gaps in the phosphorus value chain
	SEASOLUTIONS	Seaweeds and seaweed-ingredients to reduce enteric methane emissions from pasture-based sheep, cattle and dairy cows
1.5. Support the role of livestock in organic farming**	2ORGCOWS	Towards breeding strategies based on novel traits for native dual-purpose cattle adapted to organic or low input pasture based production systems
	FreeBirds	Encouraging organic chickens and hens to be more outdoors
	GrazyDaiSy	innovative and sustainable grazing-based systems integrating cows and young stock
	MIX-ENABLE	Strategies for sustainable and robust organic mixed livestock farming
	OK-Net EcoFeed	Organic Knowledge Network on Monogastric Animal Feed
	Organic-Plus	Pathways to phase-out contentious inputs from organic agriculture in Europe
	Poultrynsect	The use of live insect larvae to improve sustainability and animal welfare of organic chickens production
	POWER	Power to strengthen welfare and resilience in organic pig production
	ProRefine	New methods for producing high quality feed locally
	ProYoungStock	Young stock and cows benefit from natural feeding systems
2. Animal Health and Welfare	DECIDE	Data-drivEn Control and prIoritisation of non-EU-regulated contagious animal DisEases
	EU PiG	EU Pig Innovation Group: Thematic Network to Support the Implementation of Innovative Practice into EU Pig Production

ATF White paper 2021 Towards Horizon Europe	Project Short name	Project title
2.3. Towards production systems that guarantee animal health and welfare	HENNOVATION	Practice-led innovation supported by science and market-driven actors in the laying hen and other livestock sectors
	PPILOW	Poultry and PIg Low-input and Organic production systems' Welfare
	CLEARFARM	Co-designed Welfare Monitoring Platform for Pig and Dairy Cattle
	EuroSheep	European Network for interactive and innovative knowledge exchange on animal health and nutrition between the sheep industry actors and stakeholders
	SHEEPNET	Sharing Expertise and Experience towards sheep Productivity through NETworking
2.4. Responsible use of antimicrobials and anti-parasitic compounds, development of alternatives and multi-solutions approach beyond curative	AVANT	Alternatives to Veterinary ANTimicrobials
	DISARM	Disseminating Innovative Solutions for Antibiotic Resistance Management
	Healthylivestock	Tackling Antimicrobial Resistance through improved livestock Health and Welfare
	NetPoulSafe	Networking European poultry actors for enhancing the compliance of biosecurity measures for a sustainable production
	ONE HEALTH EJP	Promoting One Health in Europe through joint actions on foodborne zoonoses, antimicrobial resistance and emerging microbiological hazards.
	RoADMAP	Rethinking of antimicrobial decision-systems in the management of animal production
3.2. Management of nutritional and sensory qualities of animal-based products***	HIPSTER	Deployment of high pressure and temperature food processing for sustainable, safe and nutritious foods with fresh-like quality
	INTAQT	INnovative Tools for Assessment and Authentication of chicken and beef meat, and dairy products' QualiTies
	RELACS	Replacement of Contentious Inputs in organic farming Systems
4.1. Drivers of evolution and governance of the sector to promote change over time	ANIMALFUTURE	Steering Animal Production Systems towards Sustainable Future
	CONSOLE	CONtract SOLutions for Effective and lasting delivery of agri-environmental-climate public goods by EU agriculture and forestry
	EURAKNOS	Connecting Thematic Networks as Knowledge Reservoirs: towards a European Agricultural Knowledge Innovation Open Source System
	EUREKA	European Repository for Practical Knowledge in Agriculture
	FARMWELL	Improving farmers' wellbeing through social innovation
	i2connect	Connecting advisers to boost interactive innovation in agriculture and forestry
	LIAISON	Better Rural Innovation: Linking Actors, Instruments and Policies through Networks
	NEFERTITI	Networking European Farms to Enhance Cross Fertilisation and Innovation Uptake through Demonstration
	PATHWAYS	Pathways for transitions to sustainability in livestock husbandry and food systems
	PIGSYS	Improving pig system performance through a whole system approach
	PROVIDE	PROVIding smart DElivery of public goods by EU agriculture and forestry
	SURE-FARM	Towards SUstainable and REsilient EU FARMing systems (SURE-Farm)
	SusCatt	Increasing productivity, resource efficiency and product quality to increase the economic competitiveness of forage and grazing based cattle production systems
4.1. Drivers of evolution and governance of the sector to promote change over time	SUSI	Sustainability in pork production with immunocastration
	SusPigSys	Sustainable pig production systems
	SUSSHEP	Sustainable Sheep Production
	PLAID	Peer-to-peer learning : Accessing Innovation through Demonstration (Demonstration farms and methodology)

ATF White paper 2021 Towards Horizon Europe	Project Short name	Project title
4.2. Diversity of livestock farming systems supporting multifunctional farming	BOVINE	BovINE Beef Innovation Network Europe
	EURODAIRY	A Europe-wide thematic network supporting a sustainable future for EU dairy farmers
	ReDiverse	Biodiversity within and between European dairy breeds – conservation through utilization
	R4D	Resilience for Dairy
5.1. Early development of phenotypes	Bov-Reg	Identification of functionally active genomic features relevant to phenotypic diversity and plasticity in cattle Identification of functionally active genomic features relevant to phenotypic diversity and plasticity in cattle
	GeneSwitch	The regulatory GENomE of SWine and CHicken: functional annotation during development
	GENResBridge	Joining forces for genetic resources and biodiversity management
	GENTORE	Genomic management Tools to Optimise Resilience and Efficiency
	GEroNIMO	Genome and Epigenome eNabled breedIng in Monogastrics
	iSAGE	Innovation for Sustainable Sheep and Goat Production in Europe
	RUMIGEN	Towards improvement of ruminant breeding through genomic and epigenomic approaches
	SMARTER	SMAll RuminanTs breeding for Efficiency and Resilience
	SUSTRADEOFF	Understanding trade-offs between health and efficiency to improve competitiveness and sustainability of animal production by breeding and management
	TREASURE	Diversity of local pig breeds and production systems for high quality traditional products and sustainable pork chains
5.2. Multi-performing animals	CIRCLES	Controlling mIcRobiomes CircuLations for bEtter food Systems
	HoloRuminant	Understanding microbiomes of the ruminant holobiont
	IMAGE	Innovative Management of Genetic Resources
	MASTER	Microbiome Applications for Sustainable food systems through Technologies and EnteRprise
	SAPHIR	Strenghtening animal production and health through the immune system response
	2ORGCOWS	Towards breeding strategies based on novel traits for native dual- purpose cattle adapted to organic or low input pasture-based production systems
5.3. Improving research methods and infrastructures towards innovation	SmartCow	An integrated infrastructure for increased research capability and innovation in the European cattle sector
6.1. Use of digital technologies in livestock farming to improve performance	4D4F	Data Driven Dairy Decisions 4 Farmers
	FAIRShare	Enabling the farm advisor community to prepare farmers for the digital age
	GALIRUMI	Galileo-assisted robot to tackle the weed Rumex obtusifolius and increase the profitability and sustainability of dairy farming
6.2. Use of digital technologies to develop high throughput phenotyping and to improve traceability & biosecurity	IoF2020	INTERNET of FOOD AND FARM 2020
	Sm@rt	Small Ruminant Technology - Precision Livestock Farming for small ruminants
	Tech-Care	Towards sustainable sheep farming in a wide spectrum of harsh environments: the role of precision livestock farming technologies on promoting animal welfare and environmentally friendly systems
	CATTLECHAIN 4.0	Method and system for monitoring living beings

ANIMAL TASK FORCE
Rue de Trèves 61 – BE-1040 Brussels Belgium
Website: www.animaltaskforce.eu
@AnimalTaskFrc

SECRETARIAT
149 rue de Bercy – FR-75595 Paris France
✉ info@animaltaskforce.eu
✉ mail@animaltaskforce.eu