atf

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

Suggested priorities for research
for Horizon2020 2018-2020 Work Programme
to enhance innovation and sustainability in the livestock
production sector of Europe's food supply chains

**Second White Paper of the Animal Task Force**

**December 2016**

# General introduction

## Introduction to new challenges

The livestock[1] sector contributes substantially to the European economy (€130 billion annually, 48% of the total agricultural activity) and creates employment for almost 30 million people. Animal products are essential for a healthy and balanced diet. The European demand for animal products might decrease slightly in the coming decades but the worldwide demand for animal products is predicted to double over the next decades due to population growth and increasing prosperity. This creates a huge responsibility for the European livestock sector and food chains in terms of export opportunities of animal products for a growing middle class in areas/countries with high population growth (Africa) that often are not able to produce the necessary livestock products for their own growing population. But also in terms of export opportunities of scientific knowledge and know-how enabling these countries to increase their local production capacities. European standards are extremely high compared to those from other parts of the world in term of animal welfare, safety, healthiness, environment, etc. The livestock sector is contributing substantially to the European economy in terms of national income, employment and contribution to the trade balance.

Nevertheless, the past has also highlighted the drawbacks of continuous growth of the animal sector despite huge efforts and progresses have been achieved by farmers to tackle these drawbacks. These include challenges to the environment (gaseous emissions, water and soil pollution, and ecosystem damage), animal and human health (zoonotic diseases and inappropriate use of antimicrobials and anthelmintics). There are also challenges related to the welfare of animals within the systems and the human health issues linked to the over consumption of animal products and more recently the competition between human and animal for feed resources. The livestock sector contributes to climate change. The Paris climate agreement sets a new era for climate policies. Many (109) countries have included agriculture in their Nationally Determined Contributions (NDCs) to the Paris agreement. Livestock as part of the food system is concerned and need to be part of the solution by reducing its emissions and taking part of the 4/1000 initiative. The livestock is also a victim of the climate change that will challenge the adaptive capacity of the animals and feed production systems to cope with the warming increases and record temperatures that we take every year. International cooperation on these challenges is key as Europe can benefit from the study of animal genetic resources that are present in tropical countries and that are already adapted to warm and variable environmental conditions. These resources are highly valuable e.g. in the context of climatic change and for the study of trade-offs between robustness and efficiency.

Livestock are present in almost all regions in Europe in a wide range of different production systems and inextricably linked to rural vitality. The livestock sector in Europe has to overcome cyclical crisis, and livestock farmers' income remains a tremendous problem. Any reduction of livestock farming would also affect the vitality of many European territories and the supply of high quality and safe European animal products. Food production is a major part of the bio-economic system. Scarcity of resources (fossil energy, phosphorus, land, water) has increased with the extra food that needs to be produced and rising demand for bio-energy and bio-based products in the context of climate change (4th Foresight of the Standing Committee for Agricultural Research). At the same time, environmental policies require to reduce environmental footprint of agriculture, particularly by reducing greenhouse gases, nitrate, ammonia and phosphorus emissions, loss of carbon from agricultural soils and the use of antibiotics. This will require increased resource use efficiency to mitigate the environmental footprint of agriculture. Livestock sector can positively contribute to reduce the effect of food systems on climate change and is an essential part of the various climate change adaptation and mitigation strategies.

Antimicrobial resistance is a major threat to public health. Many reports from national governments and international organisations have raised alarms and a call for action. In May 2015, the World Health Organisation adopted a global plan to combat resistance to antibiotics in the conceptual framework ''One World, One Health''.

[1] In this document, the term « livestock » includes herbivores (ruminants, horses, rabbits) and monogastrics (pigs, poultry). Aquaculture (addressed by EATIP), fisheries, game, companion animals, bees for honey and other insects produced for food are not considered.

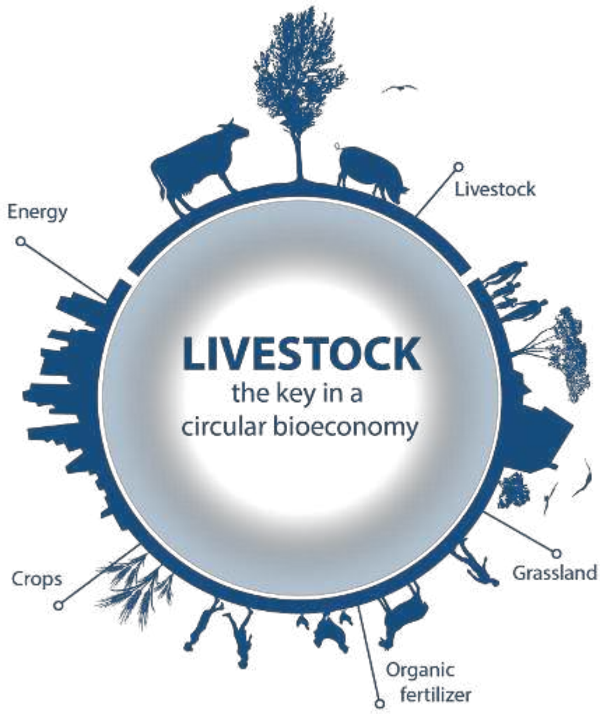
European farmers have to meet tight restrictions on the use of chemical control methods even if antimicrobial resistance is not, to date, a serious threat for the treatment of bacterial disease in animals. Furthermore, there is currently no prophylaxis and/or therapy for some diseases like Paratuberculosis in cattle, Avian Influenza and African Swine Fever in pigs. Integrated management (breeding, feeding, prevention, vaccination, organisation of actors) of animal health and welfare has to be developed based on exploitation of resistance mechanisms, optimization of gut health and innovative adaptation of livestock production systems and practices. This should include biosecurity (including integrated pest management), (better) vaccines and optimal use thereof, diagnostic tools, hygiene guidelines, management, breeding and reproduction in combination with smart farming tools, sensors and big data analyses.

The demand and consumption patterns for animal products are evolving. The consumption of meat and dairy products per capita is decreasing in most European countries, with differences according countries and species. This consumption may decrease even more as a consequence of the development of radically new technologies (e.g. cultured or vegetable "meat", vegetable "milk", insects…) as affordable alternatives and new consumption patterns (e.g. flexitarism, vegetarians, vegans…). Beyond safety issues that remain the top priority, the market will also need healthier products and products better suiting the requirements of specific populations (pregnant women, young children, seniors, people experiencing intolerances or allergies…). In addition, consumers' engagement and perceptions of food are changing and diversifying. Animal-based food contributes to healthy diets and wellbeing. Beyond the nutritional and organoleptic quality (intrinsic value of food), other criteria such as environmental footprint, animal welfare or the production of public goods (open landscape, image of naturalness…) are determining the consumption choices. This is also called the "extrinsic value of food". Besides a main stream, research should consider an increasing segmentation of the market of animal products in the context of agri-food chains.

## Livestock's role in realising a sustainable circular bio-economy for Europe

Taking active stake in Sustainable Development Goals (SDGs), the European animal production sector has a major opportunity to contribute to more sustainable food and nutrition systems. European agriculture must be competitive on the global stage, but should also lead the way in environmental stewardship and ensure socially responsible European animal productions in a changing global world. In a global circular bio-economy, livestock have many valuable roles:

- to provide sufficient protein-rich, safe and healthy food for humans with high nutritional and organoleptic values, responding to a diversifying demand, produced in a system that does not challenge human health, safety, and thus avoiding the double burden of over- and under-nutrition;
- to regulate the ecological cycles and close the nutrient loop by recycling, as much as possible, biomass from humanly inedible resources, or otherwise not suited for human consumption, derived both from marginal lands or in mountainous areas and that are not able to produce plant products for human consumption and also using manure as a bio-resource;
- to develop animal friendly rearing and production systems that meet the physiological and behavioural needs of farm animals;
- to contribute to a more efficient agriculture by valorising food-chain by-products as animal feed and nutraceutical and using new protein sources for efficient and robust animals adapted to such new European feed sources;
- to integrate new farming systems with automatic surveillance and registration of production, health and welfare of the individual animals for better management thereof, for better genetic improvement, for reduced emissions and for proper handling of manure;



- to improve soil fertility (structural stability, organic matter content and biological fertility), by the use of grassland and proper spreading of manure;
- to provide raw material for renewable energy and valuable by-products (e.g. leather);
- to provide ecosystem services linked to the vitality of diverse territories, employment in rural area, landscape and biodiversity preservation and cultural heritage.

Livestock systems would need to be discussed with the society and adapted to the diversity of regional and economic contexts. This diversity can be considered a reflection of the agricultural heritage and as such represents an asset to be protected. The society should be aware of the social and ethical value of the people working with and in these systems and the value of the individual animals living in these systems.

## The importance of supporting innovation, sustainability and competitiveness in Europe's livestock sector

Research and innovation have contributed substantially to make Europe's livestock sector as competitive, balanced and efficient as it is today. Continued support for research and innovation in the livestock sector is needed to meet the new challenges and to support the adaptation of these innovations in the corresponding farming systems. These challenges include the supply of nutritious, safe and healthy food, reducing environmental impact, making better use of resources, respecting animal integrity and contributing to human and animal health and welfare, meeting needs of consumers and contributing to a viable bio-economy in ways that are appreciated by the society.

This requires coordinated and integrated interdisciplinary research and effective, proactive translation into practice and policy making. We recommend strengthening joint activities between different Work Programmes such as 'Societal Challenge 2 - Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy', 'Societal Challenge 5 - Climate action, environment, resource efficiency and raw materials', 'Excellent Science', 'Leadership in enabling and industrial technologies' (LEIT). This will help avoid gaps and overlaps, ensure synergies and facilitate the wider agendas for skills, innovation and research infrastructures.

## The Animal Task Force's Strategic Research Agenda, Dec. 2016

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. This Second ATF White Paper (2016) is an updated view on the next steps in research developed for the Horizon2020 2018-2020 Work Programme with new key areas and priority-topics, positioning the livestock sector as a key player in a European sustainable circular bio-economy. It was developed by the ATF management board after a peer analysis of research gaps from past and on-going projects (FP6, FP7, H2020), and expanded through a consultation among ATF members.

This update was also inspired by the 4th SCAR Foresight Exercise, the strategic approach to EU agricultural Research & innovation (European Commission), the FACCE-JPI and Healthy Diet for Healthy Life-JPI, Global Agenda for Sustainable Livestock, Global Research Alliance on agricultural greenhouse gases, FAO, SCAR working group on Sustainable Animal Production, ERA-NET ANIWAH and through exchange of views with EC DGs (DG Agri, DG RTD, DG Envi, DG Clima, DG Connect, DG Sante, DG Devco…), European Parliament members and a large range of European and member states stakeholders from industry, farmers organisations, interbranch organisations, NGOs, think tanks (Farm Europe), etc. Special attention was paid to connecting with other ETPs (Plant for Future, TP Organics, Food for Life) and European Platforms (Euromontana) for cross-fertilisation for the elaboration of the Strategic Research Agendas.

The **Animal Task Force (ATF)** is a leading body of expertise linking European industry and research providers for developing innovation in the livestock sector.

Our members are research providers from 19 Member States of the EU (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Romania, Slovakia, Spain, Sweden, UK), plus Switzerland and Serbia, and industry representative bodies that support the interests of Europe's livestock industries (IFAH Europe, FEFAC, FABRE-TP).

We work together to identify actions that are needed to foster knowledge development and innovation for a sustainable and competitive livestock sector in Europe.

For more information, please visit:
**www.animaltaskforce.eu**

**The Animal Task Force promotes interdisciplinary research bringing together research groups with complementary expertise (feeding strategies, animal breeding and genetics, nutrition, physiology and health, (ICT) technology, food evaluation, modelling, economics, sociology, multi-criteria evaluation), involving actors of the agri-food chain (farmers, upstream industry, machinery and robotics, dairy and meat industry) and of the territories with the objective to improve all systems of production, including the sustainability of European intensive systems, low inputs systems, organic and agro-ecological systems. Several areas of research are particularly suited for international cooperation, especially in tropical environment.**

**The Animal Task Force also encourages future development of livestock production systems from a perspective of ecosystem services together with holistic agriculture approaches that more closely link livestock and plant to better use and protect the properties of agro-ecosystems and to maximise the use of biomasses of plant and animal origins through recycling and cascading approaches. These holistic agriculture approaches also need to encompass the agro-ecological domain and would stretch to consumers' global health by integrating from the ecosystem of a healthy soil, plants and animals in good physiological and sanitary conditions and healthy humans.**

## Stakeholder's supports

*The table lists the organisations, European and member states stakeholders from the industry, farmers' organisations, interbranch organisations, NGOs, think tanks consulted that support the 2nd White Paper of the Animal Task Force.*

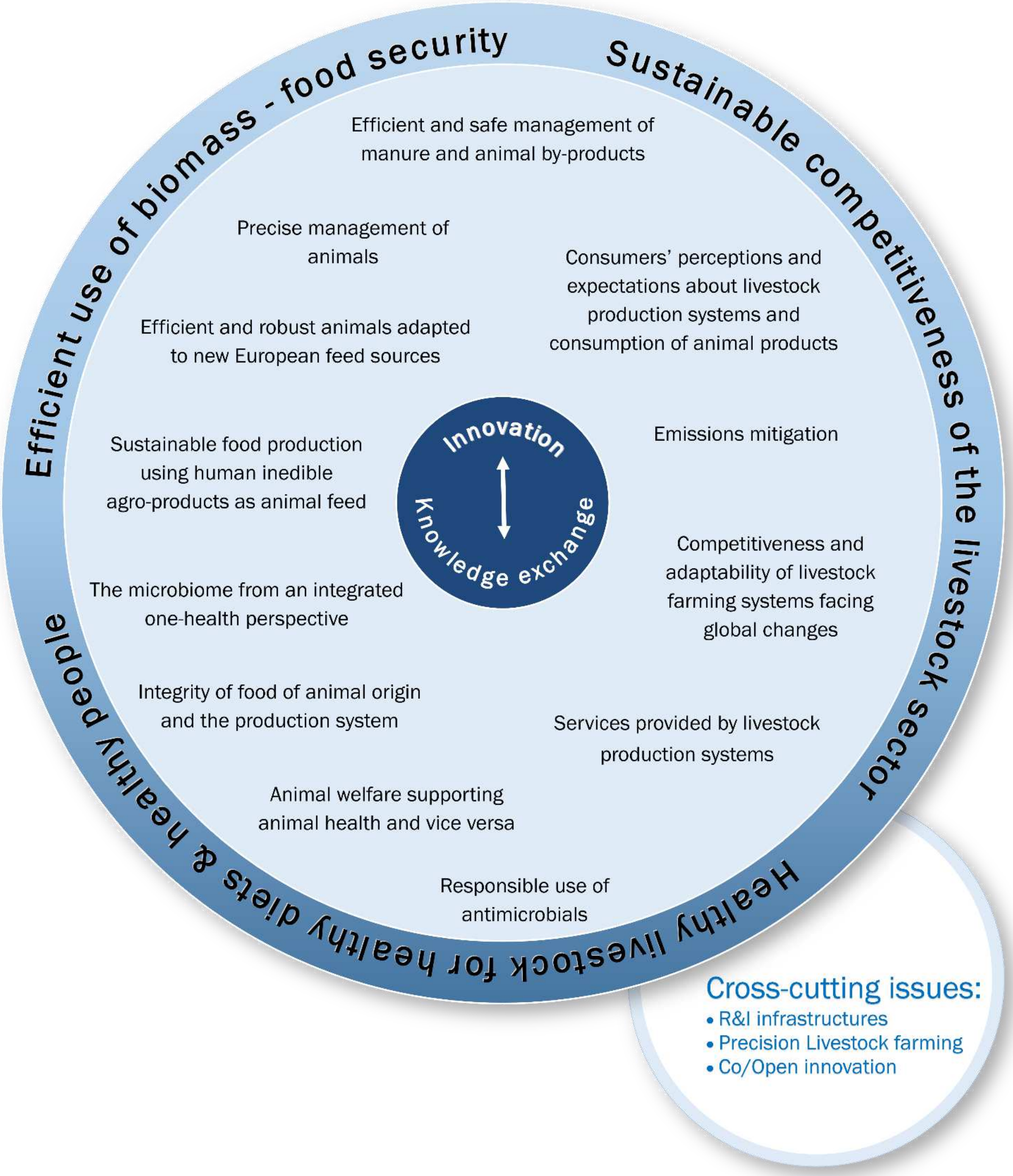
| Organisation name and Short name | Country | Type | | |
|---|---|---|---|---|
| | | Industry | Farmers' organisation | Other |
| Agriculture & Horticulture Development Board (AHDB) (levy body) | UK | X | X | |
| Agrifirm | NL | X | | |
| Alltech | IE | X | | |
| Association of Swiss Cattle Breeders (ASR) | CH | | X | |
| Association of the Swiss pig breeders (Suisseporcs) | CH | | X | |
| CEJA, European Council of Young Farmers | EU | | X | |
| CEMA, European Agricultural Machinery Industry | EU | X | | |
| CNIEL interbranch organisation | FR | X | X | |
| Confédération Nationale de l'Elevage France (CNE) | FR | | X | |
| DairyNL | NL | X | | |
| Danish Agriculture and Food Council | DK | X | X | |
| European Feed Association (EUFETEC) | EU | X | | |
| European Feed Manufacturers Federation (FEFAC) | EU | X | | |
| European Specialty feed ingredients (FEFANA) | EU | X | | |
| ELANCO | Int. | X | | |
| Glanbia | IE | X | | |
| Interbev interbranch organisation | FR | X | X | |
| McDonald's France | FR | X | | |
| Swiss Milk (SMP) | CH | X | | |
| Olmix group | FR | X | | |
| PROVIANDE (The Swiss Meat Industry Association) | CH | X | | |
| UFA AG (Union of agricultural cooperatives) | CH | | X | |

Topics related to organic and low-input farming in sections 2.3. and 2.4 are supported by TP Organics.
Topic 3.4 "Integrity of food of animal origin and the production system is supported by Food For Life ETP.

## Key areas for research and innovation in the animal production sector that merit support under Horizon2020 2018-2020 Work Programme

These suggestions are the shared view ATF members.

- Efficient use of biomass – food security;
- Sustainable competitiveness of livestock farming systems;
- Healthy livestock for healthy diets and healthy people;
- Cross-cutting issues.




*The figure illustrates the main topics and sub-topics that we suggest as prime areas for further research. All topics and sub-topics are described in this 2nd White Paper of the Animal task Force.*

## Topics list

### 1. Efficient use of biomass – food security

The main challenge is to improve livestock production's efficiency in the use of natural resources, enhance its contribution to the regulation of ecological cycles and to a sustainable circular European Bioeconomy.

*1.1. Sustainable food production using human inedible agro-products as animal feed*

- Improvement of biomass utilisation and development of alternative feeds that are not competing with human food;
- Evaluation of the novel options/technologies for feed production, evaluation and optimised utilisation;
- New feeding strategies to reduce feed versus food competition.

*1.2. Efficient and robust animals adapted to new European feed sources*

- Definition of the new sustainable breeding goals;
- Development of appropriate phenotypes and indicators for selection on efficiency and robustness;
- Genome editing: a new issue.

*1.3. Precise management of animals*

- Innovative sensors and intelligent models for monitoring resource use efficiency, animal health and animal welfare and livestock performance;
- Innovation in precision livestock farming for pastoralism and more generally for nature-based systems;
- Evaluation of social consequences of implementation of precision livestock farming.

*1.4. Efficient and safe management of manure and animal by-products*

- Evaluation of the effect of manure and organic wastes from the animal industry on soil fertility;
- Evaluation of local systems organisation to improve the efficiency of manure utilisation;
- Evaluation of the risks linked to manure and organic wastes from animal industry utilisation;
- Innovative manure refinery technologies;
- Non-food application of animal products components.

### 2. Sustainable competitiveness of the livestock sector

The main challenge is to the social, the environmental and the economic sustainability of livestock systems.

*2.1. Consumers' perceptions and expectations about livestock production systems and consumption of animal products*

- Understanding of the controversies related to livestock production systems and livestock products;
- Improvement of the transparency of animal production chains and of the confidence of consumers.

*2.2. Emissions mitigation*

- Method development for measurement of emissions;
- Avenues to further reduce emissions using win-win strategies under field conditions;
- Increasing soil organic matter and carbon storage.

*2.3. Competitiveness and adaptability of livestock farming systems facing global changes*

- Evaluation of economic competitiveness of livestock farming systems across Europe;
- Analysis of the adaptive capacities of livestock production systems;
- Using animal adaptive capacities to enhance the adaptive capacity of livestock farming systems;
- Designing livestock farming systems consistent with the farmer's will and skills.

*2.4. Services provided by livestock production systems*

- Developing metrics for measuring ecosystem and social services delivered by livestock systems;
- Understanding of trade-offs and synergies within and between benefits and costs;
- Enhancing the establishment of a highly sustainable livestock sector by multi-actor approaches.

### 3. Healthy livestock for healthy diets and healthy people

The main challenge is to implement integrated strategies for disease prevention and control. This requires multi-disciplinary and multi-stakeholder research with a systems approach, to support adaptation of agricultural production systems aligned to improved animal and human health, animal welfare and environmental concerns.

*3.1. Responsible use of Antimicrobials*

- Study of the potential for reduction of the use of antimicrobials and anthelmintics for therapy, prophylaxis and prevention
- Development of alternatives for therapy, control and prevention;
- Rethinking of innovative management of animal health and implementation thereof with stakeholders.

*3.2. The microbiome from an integrated one-health perspective*

- Study of the early life development as well as stability over time of microbiota associated with an optimal health and production;
- Microbiome and microbial metabolome and their implications for the immune system and host metabolism;
- Interaction between multiple microbiomes (soils, feeds, animals, products and humans) along the food chain in a One-health perspective;
- Creation of European network(s) to enable integration of research effort.

*3.3. Animal welfare supporting animal health and vice versa*

- Measuring and evaluating animal welfare;
- Improving animal welfare;
- Monitoring of progress of animal welfare progress at policy level, implementation in EU Member States;
- Studying the links between welfare, efficiency, sustainability and health.

*3.4. Integrity of food of animal origin and the production system*

- Evaluation of the role and impacts of animal products in a sustainable food chain;
- Evaluation of the potential of food-derived products in new food and non-food applications;
- Building up animal product quality (microbiological, nutritional, organoleptic) all along the value chain.

## 4. Cross-cutting issues

*4.1. Improving infrastructures for research and innovation*

- Creation of EU research infrastructures with large populations of farms used in combination with research herds;
- Creation of a European "large animal clinic" where genome edited animals could be genotyped/phenotyped;
- Management of generic resources for efficient multi-omics research;
- Improving animal gene bank management;
- Supporting FAANG international action;
- Establishment of an EU-wide network.

*4.2. Precision Livestock farming*

- Development of automated data sampling and analysis;
- Development of ICT/Infrastructure to promote exchange of data between stakeholders;
- Data-driven research on computer databases and data management and analysis facilities;
- Development of predictive biology approaches in PLF;
- New business models;
- Traceability within the supply chain.

*4.3. Open innovation / Co innovation*

- Analyse and compare advisory systems;
- Explore the diversification of information systems the farmers are using;
- Identify new professions that analyse and master the profusion of knowledge for livestock development (innovation brokers);
- Develop new methodologies for co-design of technological innovation;
- Explore on farm innovation and develop a framework to analyse their interest and conditions for dissemination;
- Knowledge exchange with farmers and industry towards innovation;
- Management and business models.

# Table of contents

## 1. Efficient use of biomass & Food security

Livestock are able to recycle biomass that is not directly usable for human food and grains that are not suitable for grain markets to produce food of high nutritional quality. Livestock have an important influence on the N, P and C cycles, which in turn contribute to the production of biomass. Manure should be considered as a resource rather than a waste. It contributes to soil fertility, which in turn is positive for the sustainability of plant production.

Apart from their contribution to the regulation of ecological cycles, animal production can also contribute to a sustainable circular European Bioeconomy in two ways:

- deriving value from grazed pasture and new resources such as by-products, crops residues or wastes from agro industry or bio-refineries by converting them into animal products, which may require the development of new technologies to ensure the safety of these by-products for feed use;
- bio-refinery of animal by-products as manure and wastes from slaughterhouses, hatcheries and dairy industries.

Affirmation of the role of livestock in a European sustainable Bioeconomy will require:

- better quantification of the **contribution of livestock production** to ecosystems function, to protein security (including protein quality) and supplying demand for healthy food;
- increasing the **efficiency of feed chains** with a cascading approach (food first, then feed, then bio-energy and other non-food uses);
- increasing the **efficiency and robustness of animal and herds** and closing the loops (C, N, P), mitigating GHG emissions and improving manure management.

For the 2018-2020 work programme of Horizon2020, we suggest 4 main priorities to address “Efficient use of biomass & food security” issues.

- Sustainable food production using human inedible agro-products as animal feed;
- Efficient and robust animals adapted to new European feed sources;
- Precise management of animals;
- Efficient and safe management of manure and animal by-products.

## 1.1 Sustainable food production using human inedible agro-products as animal feed

### Challenges

European livestock production is strongly dependent on protein rich feed resources that are imported and/or that can be used for human consumption directly. In the long run, this is not sustainable. In the face of growing food security uncertainty, there is a need for new initiatives in Europe. Thus, the **development of alternative protein supply strategies** that minimise reliance on imports (i.e. soybean and fishmeal) and implementing a circular economy for nutrients and biomass is of key importance. This will require better use of (alternative) protein rich raw materials produced or available in Europe.

Livestock production is absolutely necessary in the bio-economy to ensure a maximum (full) use of biomass produced in a circular economy with an **optimal utilisation of biomass components across industries.** It may be possible to produce more and better animal products with fewer edible resources and less wastage. Huge potential lies in the valorisation of organic waste streams, unused residues and new generations of by-products in the food production chain through development of novel and existing technologies. This includes the reuse of residues from bio-industries (where these have potential to yield valuable nutrients and energy) in order to optimise their utilisation across the value chain. The exploitation of various raw biomaterial resources (e.g. by-products from green biotechnologies) can be the driving force to develop new feeds. This leads to an important question: what geographical scale is needed to improve efficiency and acceptability? New opportunities can be found when **livestock and crop production are interconnected,** together with biotechnical and social sciences.

The goal is to **improve existing and/or develop novel products**, processes and logistical networks that will improve resource use for livestock production, synergistically with improved use of raw and processed materials in other industries, while not compromising quality and health aspects of animal-derived foods. Special attention must be paid to defining the risk associated with any new feed resources for animal and human health, as well as the environment and the economic viability. Research and innovation may investigate diversifying feed sources, in particular protein sources (legumes, grasses, European grown soybeans, proteins from green biomass, “blue” proteins from marine sources, insects, other invertebrates…), including industry by-products, organic waste, alternative crops, crops residues and better use of local resources. Among these alternative protein sources, invertebrates are among of the most efficient. There should be a focus on the need to secure a sustainable protein supply for animals (and thereby for human feeding). This would allow the farming sector to continue fulfilling its primary mission: production of food.

This priority requires close collaboration between animal scientists and the plant sector to develop innovative plant production systems aimed at increasing biomass production with lower inputs, and with research from the technological processes sector for creating innovative feeds from residues and wastes.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): MULTISWARD, PROTEINSECT, RAPSODY, DOCKWEEDER, GRASSBOTS, GRASSQ, ICTGRAZINGTOOLS, I-LEED, GRASSLANDSCAPE, SAFEWASTES, FEED-A-GENE, PROMINENT…*

- **Improvement of biomass utilisation and development of alternative feeds that are not competing with human food**
    - **Research and development on novel feed materials**, specifically on protein rich feed material. The new feeds include aquatic resources (algae, krill, etc), earthworms, insects (especially for poultry and aquaculture), single cell proteins and products from biorefinery of biomass (including grassland) to recover nutrients for the feed chain, or to extract bioactive-compounds for the biobased industry. This includes innovative technologies to eliminate toxic substances, produce organisms grown on manure and other humid biomass wastes (insects) and efficient uses of co-products generated by the single cell production of protein. In the field of insects, we need to investigate and select insect species with the highest potential for commercial production and address diet, feed intake, feed use efficiency as well as ensuring healthy production by implementing microbial controls for mass insect rearing and to develop new technologies for large scale production that implement cost-effective engineering solutions. There is also a need to support the development of EU legislation and industrial own control (Hazard Analysis and Critical Control Point (HACCP)) systems.
    - **Better utilisation of existing local protein** including forages, grass-based production that should aim to maximise forage intake, grain and forage legumes, cash-crops and intercrops used to design multiannual

crop rotations improving efficient use of nutrients, crop residues, agro-industrial by-products (vegetable, fruit, olive, grapevine, etc.), food left-overs and former foodstuffs (e.g. beyond the best-before date for animal feed). Beyond technical aspects, logistical organisation to improve collection and processing of products must be considered. This priority is being partly tackled by the on-going Feed-a-gene project, focused on promoting the use of by-products and protein-rich local resources like cake (of locally produced soybean and rapeseed) and protein extracted from green biomass.

  - **Novel (improved) processes enabling a more efficient use of raw materials.** These include biorefinery and extraction techniques to separate the protein fraction of feedstuffs or side streams; enzyme technologies contributing to lower emissions and upgrading feedstuffs. (The feed sector can take advantage of progress made in the use of enzymes as highly specialised catalysts in the biomaterial sector). Innovative technological treatment to improve the nutritional value of feed ingredients (e.g. protected proteins for ruminants) and reduce/eliminate antinutrients and/or contaminants.

- **Evaluation of the novel options/technologies for feed production, evaluation and optimised utilisation**
  - **Assessment of the feeds and feed chains:** this includes the development of rapid and cheap measuring techniques (NIRS, in vitro, in silico, etc.) to evaluate feed materials for their nutritional and bio-functional values for different animal species in different stages of life and production. This also includes the development of life cycle assessments to evaluate the potential above mentioned new technologies from ecological and socio-economic sustainability point of view. This also include the evaluation of risks since some of these novel feed resources may contain anti-nutritional factors (i.e. mycotoxins) or chemical residues or contaminants at low levels (thus implying development of detoxification techniques). Evaluation of product quality (e.g. food safety, nutrition, shelf length and sensory attributes) is also part of this assessment.
  - **Assessment of social acceptability of current and prospective novel options for feed production and utilisation** ahead of implementation: Develop guidelines for processes and policies for improved resource use that anticipate social concerns (as some practices may not appeal to society at large as being acceptable) and develop optimal traceability.
  - **Study drivers for change** other than economic drivers (i.e. at farmers' level).

- **New feeding strategies to reduce feed versus food competition**
  - **Development of feeding strategies for monogastrics and ruminants** to reduce reliance on human edible feed (including development of specific feed additives, e.g. enzymes to improve feed efficiency) and effects of genotype-by-environment interaction when raised on high vs. low quality feed sources.
  - **Designing integrated crop-livestock farming systems** at farm and local levels to increase the autonomy of the mixed-farming systems and analysing the ecosystem services they provide (including in the humid tropics).
  - **Genetic adaptation of animal to new feeding strategies** is a key component of the success on these new feeding strategies (see 1.2). Increased appetite and digestive capabilities can be part of this adaptation.

## Expected impact

- New unique ways of efficient resource-use at system level that reduce wastes in the feed and food chain;
- Delivery of the best strategies to develop economically viable and resilient systems with alternative protein;
- Improved protein recovery from various by-products and wastes;
- Reduced protein imports into Europe, and reduced competition between feed and food production;
- Development of SMEs for the production of new proteins;
- Optimal and efficient use of land;
- Key enabling technological developments will make Europe frontrunner in the re-use of by-products and protein-rich resources for feed.

## 1.2 Efficient and robust animals adapted to new European feed sources

### Challenges

Improving the efficiency of animals will allow to reduced resource use and will also contribute to reduce environmental impact. Efficiency is often measured by **'feed conversion rate'** (FCR: amount of feed needed to produce one unit of animal product) or the **'residual feed intake'** (RFI). These indicators are not particularly sited to lactating females, however, as they normally undergo dynamic changes in body reserves during the lactation. The FCR has already significantly decreased in the past years through successful breeding and increasing energy concentration of the diets. But today, FCR needs to go a step further when livestock have to be fed rations with lower or more variable energy (and protein) concentration. **Animal health and resilience** (incl. fertility) also play a crucial role in resource efficiency. Resource and nutrient efficiency in robust, healthy animals is higher than in animals with health problems. It is estimated by the World Organisation for Animal Health (OIE) that approximately 20% of animal production is lost due to unhealthy animals. **Resource efficiency** is thus also enhanced by reducing direct livestock losses, through, for example, clinical and sub-clinical diseases, reproductive and metabolic failures, post-natal losses, 'failure to thrive' and premature culling or exposure to critical transition periods (such as weaning in pigs, onset of lactation in dairy cattle and the early post-incubation period in poultry). These losses are also not desirable from an ethical and animal welfare point of view.

This renews the challenge for **animal breeding**, in order to identify:

- **new and reliable indicators of resource efficiency;**
- **appropriate genotypes, phenotypes and indicator traits** that reflect different ways of improving resource-use efficiency, health and resilience for lactating females;
- the genetic relationship between the different measures of efficiency to tackle some **potential trade-offs** between FCR and other phenotypes that may alter long-term selection strategies to improve lifetime efficiency (i.e. immune system including both innate and adaptive immunity, reproductive capacity).

Attention should be given to **adaptation of animals to new environmental conditions** (such as new feed sources, varying climate conditions). Animals with good performance in a diverse range of environments should be contrasted with lines adapted to specific environments. There is a need to explore innovative breeding strategies involving new management tools and crossing of breeds with different characteristics to produce robust and efficient animals for different environments. This topic is particularly suited for international cooperation as tropical countries are rich of animal genetic resources well adapted to climatic, feed sources and pathogenic constraints. There could be a mutual benefit between Europe and tropical countries to study the robustness, efficiency and their trade-offs in tropical local breeds.

The tools currently available are traditional **breeding and genomic selection** based on genome, genotype, pedigree and phenotypic data. Newer versions of genomic prediction and selection will include new sources of information from sensors or omics data (phenomics, transcriptomics, metabolomics, proteomics, genomics, epigenomics). Development of appropriate methods/techniques for transfer of traits and genes between breeds is crucial. Beyond traditional breeding techniques and genomic approaches, the potential of **New Breeding Techniques** (NBTs) like Genome Editing should be examined. NBTs open the gate to a new era of breeding allowing precise changes in specific traits, and increase in the number traits that can be considered and a resulting acceleration of genetic progress.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): NEUTRADAPT, SEQSEL, ROBUSTMILK, PROLIFIC, ECO-FCE, FEED-A-GENE, FABRE-TP, LOWINPUTBREEDS, 2-ORG-COWS, 3SR, SOLID, CLIMGEN,* ISAGE, ANIMALCHANGE, EUROPEAN NETWORK FOR PIG GENOMICS, FECUND, GENE2FARM, GENOMIC-RESOURCES, IMAGE, NEXTGEN, QUANTOMICS, SELSWEEP, GENTORE and the projects that should be funded under SFS-15-2017.

- **Definition of the new sustainable breeding goals** considering the necessity to improve simultaneously animal efficiency and robustness in the context of expected changes in the composition of animal diets in the coming decades (i.e. greater proportion of "non-edible" and lower quality feed resources). This requires determination of the use/digestion potential of those future feeds (which is part of efficiency) and greater understanding of the relationship between efficiency and robustness (efficiency is negatively correlated to robustness in the short term but positively correlated through life).

- **Development of appropriate phenotypes and indicators for selection on efficiency and robustness**
  - **Quantification of the optimal balance between efficiency and robustness.** Ability to use feed, efficiency and robustness are complex traits that require development of low-cost, easily applicable and sufficiently reliable proxies to evaluate the capability of current livestock and to develop breeding strategies. As there is no one-size-fits-all solution, quantification of the optimal balance between those traits should be evaluated in different contexts to allow locally-tailored breeding and management strategies.
  - **Exploration of combining new molecular phenotypes with new and traditional external phenotypes.** The power of genetic selection could be increased by integrating biological data from several levels (transcriptomics, proteomics, epigenomics, metabolomics, microbiota, etc.) with data from new sensor technologies and more traditional approaches. The understanding of the genetic basis of resource allocation (shift between metabolic pathways) to improve robustness and adaptation of animals in the framework of climate change (heat stress, parasitism, etc.) and nutritional challenges is an important issue.
  - **Exploiting epigenetic mechanisms to generate genotypes/phenotypes that are better adapted to environmental conditions**. In meat producing animals, we need improved understanding of the trade-offs between early-life and adult performance to allow selection for the right balance between productivity, longevity and welfare issues. In egg and milk production, we need to quantify and predict the effects of early life experiences (disease or nutritional challenges, ease of weaning, social stress, etc.) at different developmental stages (pre- or post-partum, early or late during juvenile development) on animal robustness and efficiency.
  - **Conservation, characterisation and use of genetic resources from local breeds and breeds in developing countries as a source of genetic variability, biodiversity and intrinsic value**. Better use of robustness and rusticity of autochthonous (local) breeds in selection programmes, analysing interactions between diverse species (bovine, sheep) and breed (milk/suckler) to improve technical, environmental and social performances at animal, herd and farm level. Phenotypic and genomic characterisation of tropical local breeds should be done in their local tropical environment, with also the characterization of cross-bred cattle between local and European improved breeds, that are currently performed and could be used to better assess genetic*environment interactions. Making precise use of natural biodiversity will support the future of agricultural food production in Europe and tropical countries.

- **Genome editing: a new issue**
  - **Identification of relevant targets and opportunities for Genome Editing.** The role, efficiency and added value of genome editing in the breeding scheme must be evaluated and compared to more classical technologies (progeny testing, genomic selection, line-breeding…). The priority for investment in various characteristics and traits, in different species and breeds that use diverse reproduction systems must be carefully planned. Public acceptability of the targeted character must also be assessed.
  - **Biological understanding of genes underlying complex traits** can be investigated by the use of new genetic technologies. The foreseen increased accuracy of genomic prediction will result in more effective selection on resource use efficiency, productive life and welfare traits.

## Expected impact

- More efficient and robust animals contributing to resource use efficiency (reduced resource use and resource loss);
- Lesser quantities of medicines (antibiotics, anthelmintics);
- More efficient animal production and improved animal welfare;
- Decreased risk of antibiotic-resistance in the environment and in the human population;
- Increase animal resilience to climate change.

## 1.3 Precise management of animals

### Challenges

Precision Livestock Farming (PLF) and related technologies (incl. big data and robotics) have huge potential to achieve a more efficient use of resources and a "smart" livestock farming. Several aspects need to be considered.

For **livestock management**, **sensor technologies integrated in monitoring systems** are steadily becoming more efficient, more diverse and less costly, while allowing an increasing number of parameters to be monitored. Combining phenotypic data with genetics, genomic and even metabolomic data to manage livestock is innovative and will allow a further step of progress. **Farmers and service providers** (from upstream and downstream sectors) will be able to **continuously and automatically collect and process the information needed to manage production efficiency and product quality, emissions to the environment, use of medicine and animal welfare.** They will also assure citizens that livestock production is safe, humane and environmentally sustainable, while reducing farm labour requirements. Physiological models must be developed to convert and data from sensors into useful information and decision support systems. The management interventions required in response to the sensor information received can be carried out by the farmer, but they may also and be carried out automatically thanks to enslaved robots. It is envisaged that the latter option will become commonplace in the future.

For the **breeding sector**, it is crucial to **renew predictive and systems biology approaches** and generate new knowledge for more competitive breeding and smarter farming. This will be done through bridging the knowledge gap between research and the actors of the genomic revolution ("omics tools and data") and introducing new techniques for deeper phenotyping, including transcriptomic, epi-genomic, metabolomic profiling, sensor technology, and remote sensing. These technological developments are so far evolving in two separate worlds. A main goal is to develop and share innovative pipelines dedicated to high-throughput delivery of big data generation and analysis. Computer databases and data management and analysis facilities are necessary tools for handling the huge amount of data relevant to livestock production and for simplifying the localisation, the extraction and the analyses of relevant information.

From the **animal perspective**, 'precision' or 'smart farming' technologies potentially provide solutions to the current lack of standardised data to objectively determine **animal welfare and health status** in the production chain (on farm, during transport and at slaughter), and provide a support tool for farmers to detect welfare and health problems at an early stage. Animal welfare and health assessment should be taken to the next 'level' to a) help farmers detect welfare and health problems and solve them at an early stage, b) support public policies on welfare and health and provide citizens with relevant information, c) support the industry to develop and label quality based products and d) allow value chain partners to benchmark and improve the welfare and productivity of animals in their businesses.

From a **social perspective**, precision livestock farming will change the farmer's work. It will lead to time savings but might have other undesirable effects such as introducing new tasks (maintenance and monitoring of equipment, data interpretation), disorienting the farmer with a flow of **information to manage** with the risk of misinterpretation and might lead to less investment in the practical animal management skills. All of these potential consequences must be analysed to clarify the advantages and disadvantages, and new strategies developed to reduce or eliminate the disadvantages identified. In addition, several hurdles in **sharing of (open) data** have to be overcome. Farmers are reluctant to give access to their farm management and sensor data (incl. data on variation within soil, crop and livestock). They want to be in control of who can see and use the big data. Moreover, there is a need for access to good quality public data. New business models for sharing of data and open data sources should be developed to bring PLF to the next level and benefit from big data. Recognition of ownership of data is crucial and portals to facilitate exchange of data are a prerequisite.

From a **technical perspective**, the development of PLF requires the development of **innovative technologies** such as (wireless) sensor technology, bio-sensors able to recognise molecules or microorganism in real time and to generate alerts when required, robotics, information and communication technology (ICT-infrastructure (web based, databases)), standardisation (e.g. RFID) and user-centric design methods to evaluate the value of combining data from different origins and to improve the quality of the diagnosis and support.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): BIOBUSINESS, DOCKWEEDER, GRASSBOTS, GRASSQ, ICTGRAZINGTOOLS, I-LEED, PROLIFIC, 4D4F, ALL-SMART-PIGS, AUTOGRASSMILK, BOVINOSE, CLAFIS, DAMONA, EQUISAFE, FIP, HAPPYCOW, HAPPYGOAT, HEALTHSTOCK, IPOK, LOCATION AND MONITOR LIVESTOCK OUTDOORS, PIGWISE, ROSEI, EU-PLF, BRIGHTANIMAL, MODELS4PASTURES, SILF, DAIRYICT, AWAP, IMBDATA, DRUGTRACK…*

- **Innovative sensors and intelligent models for monitoring resource use efficiency, animal health and animal welfare and livestock performance**
    - **Monitoring and management of nutrient use (in)efficiencies** by combining metabolomics, physical and biological data and taking into account the individual dynamics of biological parameters.
    - **Improved management systems for feed distribution at farm level**, related to the physiological stage of the animals and the relative nutrient requirement for optimal nutrition using the capabilities of robotic distribution of feeds and allocation of grazed grass.
    - **Development of innovative sensors and intelligent models for animal health management**. This includes identifying production, behavioural and physiological traits that can be used as reliable animal-based indicators and/or proxies for early detection of "problems". It will also be necessary to bridge the gap between early warning/diagnoses and providing a decision support tool for management intervention. The management of infections and disorders on the farm requires population models to develop gold standards datasets to allow conversion of sensor data into accurate diagnostics and decision support information.
    - **Surveillance and risk analysis by authorities**: development, application and evaluation of syndromic surveillance on regional and global level based on actual data (not assumptions), similar to those currently used by EFSA for disease monitoring purposes. This could include sentinels or 'iceberg indicators' to serve as early warning tools to competent authorities.
    - **Identification and implementation of animal-based welfare indicators**, using promising new technologies (e.g. accelerometers, imaging, positioning technology etc.) in combination to objectively and quantitatively evaluate welfare. The natural behaviour and intelligence of individual animals and groups will determine their own optimal environment (e.g. heating and cooling; lying and excreting locations), allowing design of detection/signalling systems able to inform the status of an animal (e.g. predicting or showing early stage of a welfare problem). This will also pave the way for continuous automated and standardised assessment of welfare on farms, during transport and at slaughter, providing a basis for welfare assessment and thereby accurate welfare certification and increased transparency and uniformity in welfare standards in Business to Business relationships.

- **Innovation in precision livestock farming for pastoralism and more generally for nature-based systems.** Although the majority of precision farming technologies have been adopted for housed animals, it can also provide added value for animals managed in pasture-based systems. This is relevant for both intensive and extensive grazing systems, and for animals in remote locations where there is only limited possibility for the farmer to visually monitor his/her stock and for outdoors poultry rearing systems. Recent advances in the use of satellite information, drones, and also the significant improvements in energy efficiency of monitoring technologies (improved battery performance, use of cellular processes to fuel nano-sensors, etc.) should be integrated with precision monitoring technology to allow monitoring of animals reared outdoors.

- **Evaluation of social consequences of the implementation of precision livestock farming**. This has two levels: (i) for the actors of the production chains to determine the consequences of PLF on farming management, farmer's and veterinarians' work (duration, workload, skills), intensity and sensitivity of farmer-animal bonds, work at the slaughterhouse where robotisation can also provide assistance with many tasks and on the organisation of the advisory services (relations between private and public organisations) and (ii) for **societal perception of livestock production** with PLF technologies regarding animal behaviour and sentience.

- See also part 4.2 in cross-cutting issues.

## Expected impact
- More efficient management of farmers and service providers;
- Reduction of wastes;
- Mitigation of emissions,
- Early detection of irregularities and improvement of animal welfare and health;
- Better traceability of the food;
- Strong social impact: farmers will be supported in giving care to individual animals that are part of groups, and in taking care of the circumstances in which these groups have to function;
- Further development of precision livestock farming sector in Europe.

## 1.4 Efficient and safe management of manure and animal by-products

### Challenges

Animal manure is an important source of N and P for crop production and organic matter contributing to soil fertility. In intensive livestock production systems, however, it is often seen as a residual burden rather than a valuable resource and there are significant losses. Large nutrient losses are related to manure handling both before and after spreading. For many soils the main fertility problem is deficiency of P and other micronutrients, while in other soils there be excessive P accumulation. **Effective manure management** can improve resource efficiency by using manure as a valuable resource. In particular, the **re-use of N** (replacing artificial fertilisers that have high associated energy costs) **and P** (which is a first limiting resource for all plant production and is in very limited supply globally) offers tremendous opportunities for closing the nutrient cycles, increase resource efficiency and restrict pollution and eutrophication of ground waters and soils. This will also reduce the EU's dependency on phosphorus imports. We need also to increase the efficiency of the animal industry in terms of nutrient recycling.
Manure (especially solid manure) is also a unique source of carbon, humic substance and microorganisms (bacteria, fungi) for **soils**. The role of manure in the biological life of the soil and on soil fertility, however, is yet largely unknown. The increasing biodiversity in the soils should confer resilience and higher fertility (C and N organisation). In addition, **integrated manure management** offers new solutions for on-farm or biogas plant energy production. On the other hand, manure can contain organic pollutants, residues of antibiotics, anthelmintics, biocides and others biological agents with potential risk for the environment and human health including zoonoses. For example, up to 90% of the administered antibiotics are excreted, and it is well established that manure can be a vector for several microbes (e.g. salmonellae, E Coli, Campylobacter, HEV). Anthelmintics have a direct effect on the biological life in the soil.
A holistic research approach for a **systems analysis** is needed to assess the total effects of different manure management practices. Besides technological progress, socio-economic studies are needed to create sound business models and organisational models for manure management. It is essential to develop region specific concepts that take into account local conditions and are well adapted to site specific requirements. It is also essential to develop these concepts in a multi-actor approach in order to guarantee acceptance by farmers and consumers which is a prerequisite for achieving high rates of implementation.

### Suggested scopes of research/topics

*Several studies have concerned the determination of bioavailability of nutrients in manures, the nitrate and GHG emissions from manure chains, the effects of animal nutrition on manure composition, the use of manures as fertilizers and for biogas production, in particular (Appendix 2): AGROCYCLE, BPV, DEPURGAN, ECO-LOGIC GREEN FARM, ENERBOX, NOAW: NO AGRO-WASTE, PLAGASMIC, PLASMANURE, POLYDOME, POUL-AR, PROSPARE, BAT-SUPPORT, INCOME, GLOBAL NETWORK, AQUAGRIS, NEWFERT… Although these topics are still requiring new progress and considering more holistic approach to tackle all issues simultaneously, we prioritise the following themes:*

- **Evaluation of the effect of manure and organic wastes from the animal industry on soil fertility** including chemical fertility, biological fertility and structural stability. In particular, the role of manure, which is rich in microorganisms (bacteria, fungi) on the biological life of the soil is currently not well known. New technologies (Omic's tools for soil microbiota and enzymatic activities) allow the development of more detailed studies on the effects of various types of manure application (compost, solid manure, liquid manure, various products after separation techniques), application rate and frequency of application and species origin of manure (including horses).

- **Evaluation of local systems organisation to improve the efficiency of manure utilisation** including transport after phase separation, compost production, anaerobic fermentation systems, systems to increase nutrient use efficiency of the residues as fertilizers such as improving the balance between different macro nutrients and acidification and spreading methods that prevent ammonia emissions. This includes adaptation of nutrient flows on farms and on regional levels (including slaughterhouses wastes) as well as socio-economic studies and developing business models that can be adapted to regional situations and evaluate the geographic scale that is needed for optimal effects in nutrient dispersion. Ideally, this also includes implementation and strategies to upscale successful business models to wider application. This also includes management of slaughterhouses wastes taking into account the regulation about animal by products.

- **Evaluation of the risks linked to manure and organic wastes from animal industry utilisation.** This includes analysis of the transfer and discharge of pathogens, antibiotics, anthelmintics and hormones from manure treatment plants, including a risk assessment of (i) infectious agents in manure under various uses and storage methods; (ii) nutrient runoff, leaching and retention in soil and plants; and (iii) survival and accumulation of biological agents with potential risk for human and animal health in waste water and manures from farms and processing plants. It will be necessary to develop measures to **reduce the production and distribution of medicine residuals and endotoxins** from manure in animal production facilities, resulting in reduced exposure and impact thereby contributing to improved health of animals, people working in the farm and living in the vicinity and the human population in general.

- **Innovative manure refinery technologies** to gain N, P and K products with the demanded purity in the market for fertilizers or non-agricultural markets in a competitive way compared to mineral fertilizer.

- **Non-food application of animal products components.** Antimicrobial activities of some egg white proteins are well-known but more recently some additional activities including antiviral, antioxidant, anti-adhesive, immuno-modulating, anti-hypertensive, anti-cancer or anti-inflammatory activities have been reported. Similarly, milk components also find numerous alternative applications in the non-food area such as in the manufacture of plastic materials, textile fibres, glues and in the production of ethanol or methane. With the diversity of the biological activities and physicochemical properties present in egg and milk and maybe other food or animal co-products), this research area provides a promising potential for innovations.

## Expected impact

- new unique ways of efficient resource-use at system level that reduce wastes;
- improvements in the re-use of nutrients in manure, and of energy stored in carbon connections, less negative environmental impact;
- mitigation of emissions;
- improved fertilizer value of manures;
- less use of mineral fertilizers;
- preservation of natural P resource;
- improved soil fertility by solving the problem of deficiency of micronutrients in many soils while reducing the risk of accumulation of P and other trace elements (Cu, Zn…) and residues in others soils;
- cascading utilisation of manure and development of high value-added products from manure for other industries, development of bio-based industry valorising animal by-products;
- innovative non-food utilisation of some components of products of animal origin.

## 2. Sustainable competitiveness of the livestock sector

**Livestock farming systems** generate valuable and desirable products, essential for a healthy balanced human diet and they also support the development of rural communities. They have to face challenges concerning their **environmental impact** and the **welfare of animals**. They adjust continuously to various criteria, such as competitiveness, food safety standards, climate change and environmental issues and depend on the farmer's choice of production, which is highly variable across European regions and even between neighbouring farms. Livestock production systems are contrasted in Europe due to geographical, ecological and sociological diversities. Challenges and constraints also differ significantly.

Livestock production is being scrutinised by European society, in particular the so-called "industrial" livestock production systems, which are assumed to have an adverse effect on animal welfare and on the environment. **Ethical and nutritional considerations** are developed against meat and milk production and consumption. In many areas, livestock production is recognised for its positive contributions to the society (excluding GHG emissions), but farmers have to seek alternative ways to maintain an **acceptable standard of living** and cannot compete the production in more intensive systems. Some rural and peri-urban areas are now adjusting to and benefitting from a new role of agriculture and agri-food sector in local development, based on the growing awareness of environmental dimensions, interest in rooted-PDO products or the emergence of new producers-consumers relationships (short chains) and the continuing development of organic production.

Further research is needed to **understand both the farmers and societal expectations** (at global and local level) to better identify opportunities, provide the most appropriate responses and feed into the continuous discussion between the livestock sector and society. Research based information is required for future farming systems to adjust through dialogue with society, give **social and ethical value** to people and animals, integrated in a diversity of regional and economic contexts. One major issue is the **lack of attraction that livestock farming** holds for the next generation of farmers and farm workers, arising from the poor quality of life and poor financial return compared with other career choices. An early ending of livestock farming activity (before retirement) is increasing, whilst older farmers are generally less likely to adopt innovations, especially new technologies. Generational renewal requires finding new attractive solutions. Low income, heavy workload with a servitude to animals, critics from society towards livestock farming, high level of capitalisation that holds back transmission are suggested reasons of that lack of attraction.

Multidisciplinary and holistic approaches involving socio-economic expertise and other relevant research fields will be necessary to overcome those challenges.

For the 2018-2020 work programme of Horizon2020, we suggest 4 main priorities to address this issue of "Sustainable competitiveness of the livestock sector":

- Consumers' perceptions and expectations about livestock production systems and consumption of animal products;
- Emissions mitigation;
- Competitiveness and adaptability of livestock farming systems facing global changes;
- Services provided by livestock production systems.

## 2.1 Consumers' perceptions and expectations about livestock production systems and consumption of animal products

### Challenges

Animal proteins are essential for a balanced diet to maintain good health for the general population. Consumers have generally a rather good opinion of farmers, but some of express concerns about the consumption of food of animal origin due to welfare issues and food safety reasons. **Social acceptance** of livestock production and livestock products is crucial and research is required on the evolution of acceptance and consumption of livestock products (particularly meat), with time, in different European regions and with regard to the general economic situations. It is also crucial to determine how to modulate and foresee these changes and to allow adaptation of products and production systems to the societal demands.

To identify solutions for socially acceptable animal production systems, there is a need to have a sound **analysis of the current perception of the livestock sector** and livestock products by the general public. Better social engagement and new communication and educational approaches are needed to address the critical perception of some parts of society towards modern livestock production systems. It is necessary to raise public awareness of the positive potential and indeed necessity of livestock production for global food security. It is essential to create a constructive dialogue and build consensus to secure a safe and high-quality European livestock production for European consumers and exports, based on improved social acceptability, environmental sustainability and economic competitiveness. More specifically, attention should be given to dialogue, in order to pave the way for **acceptability of new technologies** incl. biotechnologies and new breeding techniques that can contribute to improved efficiency, resilience and to reduce environmental footprint.

### Suggested scopes of research/topics

*Very few past and on-going EU research projects are related to the suggested priorities: BRIGHTANIMAL, CODE-EFABAR, ISAGE, SAFE FOODS, WELFARE QUALITY, TRACE, DIALREL, ECONWELFARE…*

- **Understanding of the controversies related to livestock production systems and livestock products**
  - **Evaluation of consumers' preferences with special attention to animal product consumption** (including milk and eggs) and to establish the reason of the decrease in meat consumption in some European countries. It is important to consider the diversity of consumer's attitudes and expectations (based on region, demographic, etc.). Understanding the social dynamics pf various movements in Europe that are anti-animal production and consumption would be useful when working for more sustainable animal production.
  - **Evaluation of the role of various actors** incl. the NGO's in the conception and development of the controversies about livestock systems and consumption of meat. **The mind-set of the farmer** is also an important factor influencing the consumer perception of livestock systems. Focus on how to develop forums for increased dialogue and understanding between producers, processors and consumers is central. This will require radically different types of expertise from anthropology, economics and animal science.
  - **Analyses of factors determining consumers' willingness to pay** a premium for a differentiated product and perspectives on the development of new value chains for traceable gourmet animal derived foods or more generally to consumers segments with different preferences regarding production systems and/or the use of new technologies. This will, in the long term, sustain European animal production, incl. its beneficial effects on rural areas. This requires integration of technological innovation, market analyses, studies of societal and consumer attitudes as well as public and private sector policy development.

- **Improvement of the transparency of animal production chains and of the confidence of consumers**
  - **Evaluation and use patterns of new IT tools** to address communication between producers and consumers about the animal production systems, animal product(s) quality and food safety and its role in a European circular Bioeconomy. Participative approaches engaging all the relevant stakeholders are needed to co-develop and implement the IT tools. Precision farming technologies, coupled with big data handling in the chain, can reliably and transparently contribute to the provision of information and harmonisation of technological developments in line with societal expectations and interests, notably with regards to welfare. This will help the sector develop corporate responsibility, improve transparency and disseminate clear, relevant and understandable communication to society at large.
  - **Evaluation and use patterns of new and sustainable packaging at low environmental impact**.

- **Evaluation of the feasibility of co-designing innovative/alternative livestock production systems,** incl. environmental and welfare NGO, farmers and other actors of the sector, including the acceptance of innovative technologies, i.e. new biotechnologies (as NBTs).

## Expected impact

- Improved future strategies of livestock production, underpinned by a better understanding of controversies, their intensity, their multi-actor dimension and the tangled subjects (animal welfare, slaughter, animal rights, environment, production model);
- Better understanding of consumer awareness, knowledge and behaviour about livestock and consumption of animal based products;
- Increased societal acceptance of animal agriculture by the society;
- Improved strategies for communicating the role of livestock in food systems;
- Re-established contacts between consumers and livestock producers;
- Development of a better shared vision among stakeholders on the future of livestock;
- Definition of a development strategy;
- Better transparency of production processes for the general public.

## 2.2 Emissions mitigation

## Challenges

The livestock sector contributes significantly to the emission of greenhouse gasses (GHG), representing 14.5% of total GHG emissions. Ruminants are the largest contributors, accounting for 60% of total livestock emissions, in particular via enteric methane, whose mitigation potential is important (FAO, 2013). There is a strong requirement to mitigate these emissions and to develop a low-carbon livestock agriculture. **Mitigation options** can be found in the production of feed, enteric methane production, manure production, energy consumption and carbon sequestration in soils. In addition, shortcomings in the management of animal production lead to other harmful emissions and losses in the nutrient cycle (Carbon, Nitrates, Phosphorus – C, N, P) with negative impacts on soil, water and air quality. Apart from GHG, air pollutants include ammonia and other nitrogen compounds (NOX), dust particles, sediments and odours. Water pollutants include Nitrate, P and pesticides. Soil pollutants include trace elements, pesticides and antibiotics residues. Improvements in managing environmental impacts will benefit farmers (economic), society and environment. These emissions should be reduced with multiple benefits for ecosystems, animal health and the farmer. Research is needed to reduce GHG emission without negative effects on other emissions (risk of pollution transfer) or on livestock productivity.

**Research on integrating adaptation and mitigation** has started in several recent research projects. Progress is still needed to mitigate GHG emissions, however, and this remains a major challenge for the livestock sector. In addition, we need a comprehensive approach integrating all emissions at farm and food chain levels and to identify effective mitigation measures considering not only GHG (methane, $N_2O$, $CO_2$), but also ammonia, dust, particles, odours, P, nitrate. The work on emission mitigation needs to cover emissions to air and water, since the trade-offs and pollution swapping issues are very important factors in the cost-benefit analysis. This approach should avoid pollution risk transfer that can always happen with one-sided approaches. Multidisciplinary research in close cooperation with stakeholders is needed to develop region-wide specific solutions that contribute to highly productive agriculture, with increased resilience and efficient resource use with reduced emissions. More efficient use of resources, decreased losses and reduced emissions need to be achieved simultaneously.

## Suggested scopes of research/topics

*Several projects have already considered emissions (*(AnimalChange-FP7, *AE-FOOTPRINT, ECO-FCE, FEED-A-GENE, MODELS4PASTURES, SILF, DAIRYICT, BAT-SUPPORT, GLOBAL NETWORK, GPLUSE, METHAGENE, SMETHANE, CLIMGEN, AQUAGRIS, PHYTOMILK, REDNEX, RUMENSTABILITY, RUMINOMICS, PRO-PIG…), but usually considering only one type of emission (GHG, nitrate, odours…) or a limited number of emission stations (rumen, manure, nitrogen fertilization…).*

- **Method development of measurement of emissions**
    - **More precise and holistic measures and modelling of emissions under field conditions**. Despite numerous studies and previous progress, there is still a need to develop usable methodology for quantification of emissions (e.g. GHG, $NH_3$, odours, particles) in free range conditions and in open barns, for measurement of water footprints in feed and animal production chains, and for evaluation of human edible protein consumption by livestock. Standardisation of methods to improve usability of recorded data is still required. Using well-equipped research farms and landscapes with the necessary equipment for capturing multiple emissions will be useful.
    - **Improvement of life cycle analysis (LCA) methods for a more holistic evaluation of livestock** performances. This includes assessing C-sequestration, impacts on soil fertility, evaluating usage of numerous by-products and marginal land, and preserving biodiversity. Coupling biotechnical and social LCA will allow consideration of impacts on employment and rural vitality. Development of consequential LCA analysis will allow evaluation of alternatives to livestock production, which is presently never undertaken. Finally, this will allow us to determine more objectively the impacts of livestock production systems on the whole food chain, considering the most appropriate level (level of product, animal, farm, area, country, world).

- **Avenues to further reduce emissions using win-win strategies**
    - **Development of holistic approaches to analyse and decrease the environmental impact of livestock farming.** Those approaches that would encompass the agro-ecological approach and would stretch until (the awareness of the farmer of the impact of each of the production steps on) consumers' global health. Mitigation processes need to be identified that also have favourable impacts on reproductive health, welfare, feed production and quality and on the phenotype of future generations. The approach need to

encompass the agro-ecological domain and would stretch until consumers' global health. This requires the promotion of optimum metabolic functions of farming systems integrating various options simultaneously to identify some synergies between various levers. **At farm gate**, this includes breeding livestock for low emissions as a permanent and cumulative mitigation strategy, considering the positive impact of animal health on efficiency of production, the impact of production level on emissions, the development of new nutritional strategies to simultaneously mitigate GHG emissions, nitrogen and phosphorus losses and to improve animal efficiency (incl. designed compounds for reduced enteric methane synthesis), development of intelligent housing for livestock for the capture and elimination of odours, ammonia and GHG emissions, innovative management of manure, cropland and grassland, not only to reduce emissions but also to maximise soil C storage and to restore soil organic matter content (4/1000 initiative) as well as interactions between these various levers. Innovative information and decision support systems will help to reach the objectives and precision farming offer new opportunities. **Beyond the farm gate**, exploring the livestock-crop synergies through collaborations between (neighbouring) farms that are specialised offers new solutions. Development of integrated models of crop-livestock systems will allow exploration of the benefits and threats and help identify brakes and levers of development of such cooperation. At both scales, development of integrated monitoring and modelling frameworks to demonstrate win-wins to support increased adaptation by the sector.

  - **Studying food production systems, incl. both production and consumption and the role of livestock in food chain**, is a new area not yet fully explored. Modelling is required to analyse goal conflicts and their solutions at different levels (farm, region, Europe, world) so that data on emissions are put in a broader context.

- **Increasing soil organic matter and carbon storage:** Techniques to be considered include utilisation of grassland (both permanent and sown grasslands), and also return of various forms of manure to the soil (composts vs liquid vs digesta of biogas production) in combination with crop rotations, with the objective of designing economically and environmentally sound models. In addition, an important issue is the evaluation of the benefits of introducing permanent cover (grassland, Lucerne) in the crop rotation and grazing cover crops on soil organic matter carbon storage, biological fertility, biodiversity, plant disease occurrence, quality of crops and financial margins including measures to avoid pollution transfer in the form of emissions of ammonia, methane or nitrous oxide due to improper management of manure. Increasing soil organic matter content will also contribute to improve resilience of livestock farming systems against climate change and improve soil fertility (see also 1.4).

## Expected impact

- Reduced GHG emissions and other emissions to air and water;
- Implementation of Paris Agreement (COP 21);
- Reduced emissions having potential negative effects on water (nitrate, P) and air (ammonia, odours…) quality;
- Increased soil C sequestration and improved soil fertility;
- Development of innovative and more holistic tools to evaluate emissions on farms;
- Develop a more holistic view of the impacts of animal production on the environment;
- Europe can take the lead by being a frontrunner in creating new solutions, and knowledge sharing around climate smart agriculture.

## 2.3 Competitiveness and adaptability of livestock farming systems facing global changes

### Challenges

Economically viable animal production systems rely on the optimised use of all available resources including natural and financial resources. In intensive systems, the mainstream commodity system favours work productivity as an essential criterion for competitiveness; the EU livestock sector needs to be productive and competitive to take advantage of the high EU production standards (environmental issues, animal welfare, high quality safe products, resource efficiency) for exports.
Some collective actions and chain operators have chosen a different path of development, with a differentiation founded on the high quality or the origin of the product supported by a list of specifications (niche product) or low inputs (e.g. organic systems). These **alternative systems** are of particular importance for less-favoured areas that are not able to compete with more favourable regions on a standard market. In addition, in these regions, competition for land between livestock and crops is very limited. Even in intensive and urbanised regions, local food is also becoming a new market of differentiation. European productions may find a competitive advantage not only in being able to produce at the lowest cost but also in producing high quality food associated with high ethical and societal concerns such as animal welfare. Organic livestock farming and closing agro-ecological crop-livestock systems must be assessed and their potential and levers for ecological intensification assessed.
In the context of increased price volatility, occurrence of extreme weather events due to climate warming and increased risk of outbreaks of epizootic diseases, the capacity of the systems to be maintained over time when changes occur becomes important. **Trade-offs between efficiency and resilience** may appear. The changes are not only external, they can also be internal to the system (modification of workforce power for example).
**Livestock production as an occupation** suffers from low attractiveness, either for farmers or farm workers. Farm numbers are rapidly decreasing and early abandonment of livestock farming activity (before retirement) are increasing. Low income, heavy workload with a servitude to animals, criticism from society about livestock farming, high levels of capitalisation that slows transmission of land between generations are suggested reasons of that lack of attractiveness.
It is now very difficult to imagine the best ways of (re)designing the production systems facing these challenges. Indicators of **adaptive capacity** do not exist in multi-criteria assessment of sustainability of livestock production systems. We need a better understanding of the trade-offs between efficiency and adaptive capacity to face global change at farm scale **in both intensive and extensive livestock systems**. It also requires understanding of the perspectives for local food development, conditions for development (human nutrition, origin, know-how included), to better understand the way the different and contrasted models of livestock and food systems co-exist, compete, or interact in producing safe and healthy food and maintaining a good standard of life for farmers. The development of innovative **livestock farming systems that fit the farmer's will and skills** will stimulate young farmer entrants, thus contributing to the development of less favoured regions and reducing the average age of farmers.
This topic is particularly suited for international cooperation as it allows to study a wide variety of livestock production systems (intensive, organic, agropastoral, pastoral extensive…), their respective contributions and responses to global challenges (quantity and quality of production, environmental impacts, social impacts….), and to understand how they co-exist, interact or compete on the same territories or production value chains?

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): EURODAIRY, LOWINPUTBREEDS, ISAGE, ANIMALCHANGE, EUROPEAN NETWORK FOR PIG GENOMICS, FECUND, GENE2FARM, GENOMIC-RESOURCES, IMAGE, NEXTGEN, QUANTOMICS, SELSWEEP, EUROPEAN NETWORK FOR PIG GENOMICS, ECONWELFARE, TREASURE, EUPIG, SHEEPNET…*

**The topics related to organic and low-input farming in this section are supported by TP Organics.**

- **Evaluation of economic competitiveness of livestock farming systems across Europe** to evaluate strengths and weaknesses of different sectors (pig, dairy notably), and evolution/reconfiguration processes of livestock farming systems under CAP and market drivers in different regions of Europe considering dominant regimes and also niche markets (PDO, GI, short chain, organic systems). A central question concerns the future demands of downstream operators and consumers (differentiated quality products, quality marks, discounts, products for exports) within the EU-internal market, and also the demand for European "premium" livestock products from non-European consumers.

- **Analysis of the adaptive capacities of livestock production systems**
  - **Evaluation of adaptive capacities of livestock systems and their potential trade-off with efficiency.** At farm level, the exploration of different concepts (resilience, vulnerability, flexibility) will help evaluate adaptive capacities in the short term (hazards on climate and prices), mid-term (change after shocks) and long term horizons (determination of key system properties to last in an uncertain environment) and to characterise adaptation levers. The development of adaptive capacity indicators and their integration in multi-criteria assessment tools will allow evaluation of potential trade-offs with efficiency, how acting on one aspect will impact the other (for instance a small gain in efficiency leading to a major decrease in resilience) and to quantify the relative role of the different components of the system in the efficiency-resilience relation to correctly allocate efforts. At territorial, local or national level, the question is to identify how different models of livestock and food systems co-exist, and to test the hypothesis that these interactions can give adaptive and innovative properties to farms, sectors, landscapes and local development.
  - **Analysis of various options to determine the most adapted agro-livestock combinations in a given environment**. In the framework of agroecology, diversity is a key aspect of resilience for production systems. Options to increase diversity at both herd level (genetics, various physiological status, complementary requirements/potential) and at feed production level must be evaluated. Creating more efficient ecological circular economy and better feed self-sufficiency for all-scale mixed farming should also be evaluated. The reconnection of livestock and crop production either within or between farms at regional level and the cooperation among farmers and various actors should be reinvented in order to better use biodiversity (implementing new crops rotation), close nutrient cycles and optimize the use of biomass for food production in various contexts.
  - **Improvement of the contribution of animal production and animal food products to the empowerment of rural areas** by the way of innovative socio-economic and logistics organization and adapted policies. The search for competitiveness through economies of scale and economies of agglomeration in privileged areas allow cheap products, but this evolution may lead to a loss of many kinds of agricultural activities is some rural areas. There is a need to maintain and develop animal production and related food chains in various contexts within the European Union, to identify and optimize organizations able to renew dynamics. A new kind of competitiveness (different from cheapest product strategy) could be found in an innovative relationship between farmers, other activities in the supply chain and other actors of territory. That will result in new ecological balances and in more value, because the products are more valued by consumers due to higher quality and to more transparent and reassuring conditions of production. The analysis of cases studies will be very relevant.

- **Using animal adaptive capacities to enhance the adaptive capacity of livestock farming systems**
  - **Identification of the mechanisms that drive animal efficiency and adaptive capacities** and how these elements will be expressed within the farm context. The development of new epigenetic indicators of adaptive capacities (in ruminants) is promising, as the epigenome moderates the genetic expression of a trait depending on the prevailing environmental conditions, which could confer an organism with the necessary plasticity to adapt to its environment through regulation of gene expression patterns (see also 1.2). International cooperation on this topic is particularly encouraged as tropical animal genetic resources present plasticity that allow them to adapt to harsh and variable environments.
  - **Alternative production systems with improved resilience** (organic farming, low inputs systems) need animals more suitable to such systems than animals bred for intensive systems. Breeding programmes for such systems should be developed on a European scale to ensure sufficient market for food products arising from these systems.

- **Designing livestock farming systems consistent with farmer's will and skills.** The search for increased competitiveness and resilience that can affect work organisation will require the development of labour efficiency indicators (characterisation and evaluation), and new frameworks to simulate the impact of changes in management on work organisation duration, efficiency and flexibility. Otherwise, it is necessary to analyse early abandonment and non-transmission situations for different livestock farming systems across Europe, to compare settlement policies, to develop a transversal approach of lock in and levers to settlement from the young farmer's (or student's) perspective.

## Expected impact

- Evaluation of the adaptive capacities of the various European livestock systems considering the diversity of systems (intensive vs extensive production versus organic/low-input products);
- Increased capacity of the diverse livestock (and mixed farming) systems to address global changes;
- Characterisation of the levers of adaptation including technical levers and collective actions;
- Adaptation of animal genetics to the various contexts;
- Perspective for local food development;
- Segmentation of food of animal origin to better fit the diverse consumers' demands;
- Characterisation of benefits and risk of the co-existence of livestock systems and a diversity of food systems (local/global).

## 2.4 Services provided by livestock production systems

## Challenges

Livestock systems provide **multiple benefits** such as protein-rich food for humans from inedible resources, contribution to food security and employment, provision of ecosystem services such as landscape heritage and biodiversity conservation. On the other hand, livestock systems also exert negative impacts such as environmental pollution, competition between food and feed, land degradation, emergence of zoonosis, animal welfare issues, and ethical issues related to changes in socio-cultural values.

We need to develop a comprehensive framework, including metrics, robust analytical tools and methods, to assess the **sustainability of EU livestock systems in various territorial contexts** while taking into account possible trade-offs and synergies among the supply of ecosystem services, social services, competitiveness and resilience of the livestock production systems. Backcasting scenarios can be used to predict future nutrient needs for humans, and how to fulfil these.

This will require a systems approach including inter- and transdisciplinary research and socioeconomic research.

## Suggested scopes of research/topics

*Very few past and on-going EU research projects are related to the suggested priorities (see Appendix 2): AGFORWARD, GRASSLANDSCAPE, PROVIDE, PEGASUS…*

**The topics related to organic and low-input farming in this section are supported by TP Organics.**

- **Developing metrics for measuring ecosystem and social services delivered by livestock systems**. While there are various indicators to measure and interpret benefits and costs provided by livestock systems at farm level, such metrics are lacking at the higher levels of territories, regions, and supply chains. There is a need to develop new sustainability metrics describing the ecosystem and social benefits provided by livestock systems at those levels to develop systematic analysis of trade-offs and synergies and to overcome a narrow vision of sustainability. It is also important to provide a framework for assessing cost-benefit portfolios of livestock systems at levels ranging from farm to territory and EU region encompassing the diversity of EU livestock systems (intensive, low input, organic, mountain regions, arid zones, etc.) (see also 3.4). In addition to scientifically robust metrics, development of "farmer-friendly" metrics that can be directly used by agricultural producers to diagnose the performance of their farming systems is required.

- **Understanding of trade-offs and synergies within and between benefits and costs.** The few studies addressing the three pillars of sustainability pay less attention to the social pillar (employment, rural vitality, cultural services…) and also ignore the underlying drivers promoting antagonistic or positive relationships, thus reducing our capacity to identify leverage points and solutions. These points underscore the need for a comprehensive assessment of the portfolio of the costs and benefits provided by livestock systems, to reveal the technical, economic, and ecological drivers of these portfolios and to compare scenarios according to their performance in terms of cost-benefit portfolios. A special attention must be paid to the synergies and trade-offs between efficiency of production of food and other ecosystem and social services in various contexts as for example:
    - **Analysis of integrated livestock-arable systems at farm/regional scale**: consequences on efficiency of land use, soil health, control of invasive plant species, use of pesticides and mineral fertilizers, maintenance of biodiversity, rural vitality, quality of foods, etc. This requires development of sustainability metrics tailored to mixed farming system.
    - **Analysis of benefits and services** (food, employment…) **provided by urban and peri-urban farming systems**;
    - **Analysis of the conditions for better connection between animal production value chains to territories** considering various issues such as competitiveness, employment and environment in a range of EU contrasted regions;
    - **Analysis of the potential role of horses for leisure, draught and landscape maintenance** (market garden production, etc.) **or sport** in various zones such as peri-urban zones, areas deserted by other livestock or crops to maintain landscape, biodiversity and agricultural activity.

- **Enhancing the establishment of a highly sustainable livestock sector by multi-actor approaches.** The development of exploratory scenarios must be based on the development of participatory approaches including various stakeholders (farmers, advisors, banks, industries, local authorities, NGOs…) to identify the role and importance of these various actors, to explore the influence of external factors that determine uptake of sustainable agricultural management techniques, to formulate innovation scenarios, to assess the acceptability of proposed evolutions and to support strategic research policy decisions at EU and national levels for the creation of favourable EU and national regulatory frameworks.

## Expected impact

- New sustainability metrics describing the ecosystem, economics and social benefits provided by livestock;
- Evaluation of hidden benefits of animal agriculture;
- Enhanced delivery of public goods by the livestock farming systems in Europe;
- Targeted policy instruments to promote the production of publics goods;
- Increased societal acceptance of animal agriculture thanks to the improvement of farming practices;
- Better understanding of farming practices by the society;
- Development of a more holistic view of animal production and show its benefits to the society;
- Transparent and comprehensive accounting for sustainability of the entire EU livestock sector;
- Better self-image of farmers;
- Improved livestock sector efficiency and profitability at four strategic levels: farm, territory, EU, and supply chain.

## 3. Healthy livestock for healthy diets and healthy people

In a context of continuous adaptation of farming systems towards sustainability, globalisation of societies, economies and societal expectations, animal health is of utmost importance for human health, animal welfare, resource efficiency, product quality (including sanitary, organoleptic, nutritional), efficiency of production and to safeguard the trade in animals and animal products. In Europe, losses from diseases represent 20% of primary production. Furthermore, 75% of emerging diseases jointly affect animals and humans, making them a major public health issue. Inappropriate uses of antimicrobials and other medicines have compromised their effectiveness (development of resistance to antibiotics, anthelmintics, biocides and synthetic acaricides/pesticides) and generated an increased emission of residues to the environment. The on-going emergence of antimicrobial-resistance is considered the single largest threat to both human and animal health. It affects consumers' confidence and leads to restrictive measures in public policies.

Health issues should be considered at a global dimension as new diseases and pests arise regularly and continue to do so. We support the 'One Health' approach to realise a healthy livestock sector allied to feed and food safety. We promote **integrated strategies** for disease prevention or control, and multi-disciplinary and multi-stakeholder research with a systems approach such as Integrated Pest Management and HACCP, to support adaptation of agricultural production systems to better fit human, animal and environmental health. Research and innovation could include **animal health and welfare, public health and the total food chain**. The challenges are to design, develop and deploy:

- novel technologies, innovative agricultural finance and risk management for disease surveillance, epidemiological approaches and remote monitoring of unwanted species in the environment;
- breeding programmes combining genotypes, new phenotypes and indicator traits for fertility, health and disease resistance recorded using novel techniques with optimal breeding methods such as genetic and genomic selection and new breeding techniques;
- innovative nutritional solutions to preserve gut health;
- innovative integrated farming systems aiming to manage animal health and welfare with less use of conventional medicines (systemic use of antibiotics, anthelmintics, biocides and synthetic pesticides) and more focus on disease prevention;
- new diagnostic tools, therapies and intervention strategies (e.g. vaccines, biosecurity measures, monitoring tools, use of therapies/treatments based on defined threshold);
- and to continue to reduce livestock losses due to diseases thus increasing efficiency.

The actions under this heading adhere to the EU animal health strategy "prevention is better than cure".

Besides innovations, we should not forget that for progress not only innovation is required but also optimal implementation of existing and innovative tools. There is already a sufficient amount of available tools, which use can be increased/optimized. These are low hanging fruits that may be harvested with more socio-economic research and adequate insights into the barriers for use.

For the 2018-2020 work programme of Horizon 2020, we recommend four main priorities to address the "Healthy livestock for healthy people" issues:

- Responsible use of antimicrobials;
- The microbiome from an integrated one-health perspective;
- Animal welfare supporting animal health and vice versa;
- Integrity of food of animal origin and the production system.

The "Healthy livestock for healthy people" research priority is particularly relevant for international cooperation, mainly with the Emerging Infectious Diseases (EID) hotspots, i.e. countries from sub-Saharan Africa and Asia (India, China, South-East Asia).

## 3.1 Responsible use of Antimicrobials

### Challenges

The steady increase in antimicrobial resistance (antibiotics) is a major threat in terms of public health and is a pressing economic issue. Very few antibiotics have been developed in recent decades or are expected in the near future. In livestock farming, there is a need to reduce the use of antibiotics, biocides and synthetic pesticides and optimise dosages and administration for therapy, control and prevention without compromising public and animal health and welfare to reduce the risk of resistance, especially for critical antibiotics (essential to treat certain human bacterial diseases).

Besides antibiotics, resistance to parasitic drugs (like anthelmintics and treatments against livestock pests and parasites) is also an important issue for animal health but also public health and health of ecosystems (e.g. Ivermectin). An organised **interdisciplinary research** is essential.

Managing animal health in an integrated manner requires development of preventive strategies and alternative therapies.

Concerning **preventive strategies, breeding** animals that are more resistant to diseases through acquisition and stimulation of immunity and implementing good husbandry practices will have a major impact, not only on the reduction of antimicrobial and anthelmintic usage, but also on farm profit and animal welfare. **New vaccine** development and optimal implementation/use of both existing and innovative vaccines are another important issue. In addition, the use of feed-based (**feed additives, functional feed materials, feed processing) and preventive biosecurity measures such as** disrupting host-pathogen cycles on farm and by altering the distribution of animals/herds in space and time can be an efficacious. **Alternative solutions** could be explored including phage therapy and use of bacteriostatic properties of certain natural feed ingredients (peptides, oligosaccharides, probiotics and plant extracts). **Integrated pest management** approaches are nowadays successfully used in arable farming and horticulture as viable prevention strategies. It is expected that also in animal husbandry this approach will also contribute effectively to pest control.

The **effectiveness of intervention measures** will depend on the behaviour of stakeholders (breeders, breeding organisations, slaughter houses, egg packers, policy makers, veterinarians, pharma and feed business operators). It is important to study the factors that influence their health management decisions to determine the best ways (policy instruments, insurance, incentive contracts…) to reduce antimicrobial utilisation in order to reduce the risk of AMR in human and veterinary antimicrobial therapy.

**Studying antimicrobial resistance** acquisition and transmission is a common concern for both human and veterinary medicine. Questions for research include: understanding the acquisition and transmission of resistance mechanisms, approaches to block and reverse transmission at different stages and at different levels of intervention (antibiotic treatment modalities, stakeholders vs food chain level…).

Preventing pests, parasites and disease is a priority, but it is not always possible to avoid exceeding threshold limits and it is therefore indispensable to have the possibility to treat animals. **New, efficient and targeted therapeutic tools** are necessary to limit the impact of diseases without risks for human health. The mechanisms inducing pathogenic effects and the importance of the animal's gut health are not well understood. By combining omic-technologies and more classical approaches, it is possible today to characterise and quantify key biological molecules responsible for dynamic changes that occur during an infection or during exposure to an organism in and on the host. This opens new perspectives to gain better understanding of host-pathogen interactions to infections that will enable the design of new preventive measures, diagnostics, treatments and vaccines.

The actions adhere to the JPI AMR ("Joint Programming Initiative on Antimicrobial Resistance") established in 2013.

This topic is particularly suited for international cooperation as Antimicrobial Resistance is typically emerging in third countries such as China, India and South-East Asia.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): ANTIBIOPHAGE, BLAAT, CLARA, COREPIG, KOLIMASTIR, MINAPIG, NMSACC-PCVD, PCVD, PHAGEVET-P, PORRSCON, SAFEORGANIC, DRUGTRACK, ACE-ART, FEED FOR PIG HEALTH, PRAHAD, ACTICAPS, REPLACE, THRIVE-RITE, up-coming project to be funded under SFS-46. [2017] Alternative production system to address anti-microbial usage, animal welfare.*

- **Study of the potential for reduction of the use of antimicrobials and anthelmintics for therapy, prophylaxis and prevention with the objective to reduce the spread and impact of AMR**

- **Improved One Health surveillance systems are key to collect currently missing data.** Holistic and multi-sectoral surveillance systems for AMR as advocated in the "One Health" approach should be designed and evaluated. This type of systems will provide critical information on AMR emergence and occurrence at the interface between human, animal and environment. "One Health" approach can allow for a better understanding of the relative importance of each compartment in the development, transmission and persistence of resistances. Multi-sectoral surveillance data can help to develop targeted interventions on antimicrobial usages or infection control, and evaluate the impacts of these interventions in human, animal or environmental health.
- **More efficient therapeutic approaches.** Innovative pharmacology approaches (better timing of administration taking account of physiological status or chronobiology) and earlier detection of diseases (early warning systems - (see 1.3) using animal or parasite based indicators and decision support systems. This will allow more targeted intervention, and have the potential to reduce the amount of drugs used when animal must be treated.
- **Improvement of animal's gut health and preventive biosecurity controls and development of preventive strategies.** A better understanding of biosecurity measures to reduce transmission rate and routes will contribute to pest and parasite control and the prevention of health problems. Research is necessary to develop management systems that promote biosecurity not only within and between farms, but also against wild animals (e.g. influenza). It will be necessary to evaluate relationships between the implementation of biosecurity measures, use of drugs or synthetic treatments and health status. Preventive strategies include monitoring method, innovative buildings with low infection pressure, improved feeding strategy (improved animal gut health), effect of nutrient supply and feed processing on the immune system and the use of feed additive/functional feed materials as immune modulators and bacteriostatic agents (e.g. immuno-stimulating molecules, insect or algae extracts, phytogenetic feed additives and probiotics), combined treatment strategies, biopesticides and natural enemies.
- **Increasing natural disease resistance or disease tolerance of the animals** by exploiting genetic diversity. Genetic approaches will depend on identifying easy-to-measure phenotypic markers of health that can be assessed in large numbers of animals. This requires identification of molecular markers to objectively quantify immune competence using groups of animals with divergent innate immune competence capacities. High throughput screenings using *in vitro* 3D biological systems (in vitro phenotyping) from relevant organs, combined with adoption of low-input, cost-effective genomic assays is a potential approach. This knowledge will allow identification of the underlying genetic and molecular basis of immune competence, inheritance of those components in different environments and their role in defence against infectious diseases. Research is also needed to strengthen the innate immune system through modulation of the local gut microbiota (see 3.2). We have to identify the host-parasite effect on the immunology of the host to identify methods to increase natural resistance or tolerance of the host (e.g. worms/ parasites). International cooperation in this area is encouraged as tropical breeds are excellent models to assess molecular bases of tolerance to different diseases. Indeed, several local breeds are well known for their resistance/tolerance abilities, especially against worms and protozoans.
- **Exploiting trained immunity in livestock.** Animals can exhibit a prolonged enhanced functional state of immunity after adequate training of the innate system. Trained immunity relies on innate immune cell types and will provide protection against secondary infection in a specific manner. The underlying mechanism may, at least in part, be explained by epigenetic reprogramming of macrophages, providing a scientific basis to a new form of disease prevention. New studies require identification of stimulants and markers of trained immunity in livestock. New knowledge will allow identification of (epi)genetic control mechanisms, and elucidate the molecular basis of trained immunity in livestock.
- **Development of new vaccines.** Specific attention should be given to the development of vaccines against immunosuppressing agents, including African Swine Fever. This may have broader implications for vaccine development against immunosuppressing infectious diseases in man, including HIV. It is also essential to develop vaccines against endemic pathogens that impact animal production and results in antibiotic use. These vaccines must be safe, provide immunity after a single injection when possible and should induce a long duration of protection that spans to the economic life of vaccinated animals. In some cases (i.e. PRRSV and other immunosuppressive diseases, like IBDV-Infectious Bursal Disease Virus, Gumboro, in poultry), effective vaccines are available on the market, but we lack **socio-economic research** to provide the good arguments to convince farmers to continue their use once the problem is solved by vaccination.

- **Development of alternatives for therapy, control and prevention**
  - **Utilisation of non-allopathic drugs.** Some molecules /compounds can act as alternatives to antibiotics. These may include some antiseptics, antimicrobial peptides (bacteriophages), immunomodulatory specific agonists or antagonists of molecules involved in pathogenic mechanisms that occur during infection and the use of alternative specialty feed ingredients such as plant extracts (essential oils, etc.). For this last aspect, a participatory approach is required for building and knowledge sharing. Most of these compounds are subject to a pre-market authorisation including toxicity assessment with regard to the animal as well as environment safety.
  - **Integrated approach to provide broader based-management strategies.** Little or no effort has yet been given to evaluating the opportunities for integrating these approaches to provide broader management strategies for disease and parasite management. Alternative strategies need to be modelled to evaluate effectiveness, and to devise optimal combinations that are effective and sustainable (e.g. breeding for resistance (or tolerance) should be combined with management, vaccination, detection, feeding, etc.). It will also be necessary to determine which major disease problems may be amenable to such approaches, to make recommendations on how such packages may be implemented and to evaluate the consequences for animal welfare.

- **Rethinking of innovative management of animal health and implementation thereof with stakeholders**
  - **Identification and implementation of good practices to limit the use of drugs.** The Identification of the reasons why farmers accept or reject health management recommendations (e.g. use vs. non-use of antibiotics/anthelmintics, use of vaccines) and analysis of practices, information and decision systems of farmers who manage animal health with (and without) reduced drug usage practices are prerequisites to develop more effective intervention measures. Raising awareness among farmers of the risks associated with the use of drugs is also a priority. The socio-technical transitions of livestock farming systems towards less antibiotics/anthelmintics usage is a priority (interactions between health, production, feed, reproduction and welfare -decision making - relationships with veterinaries).
  - **Improved understanding and prediction of human socio-psychology in animal health management** is necessary to better understand and predict the behaviour of stakeholders (breeders, professional breeding organizations or governments) in health management to estimate the effectiveness of intervention measures. The purpose is to assess resource allocation for health management (prevention, monitoring, therapeutic intervention, compensation of losses), as well as the determinants of behaviour, including risk. The evaluation of policy instruments and the coordination of various actors (regulatory, insurance, incentive contracts ...) must also be considered, especially in the case of strong externalities associated with decisions, inducing a need for integration of health management at a collective level (country or industry).

## Expected impact

- Reduction in antimicrobial resistance;
- Reduction of antibiotics and anthelmintics, pesticide and biocide use;
- Improved infection/contact and disease control systems and practical ways to combine actions;
- Animal genotypes more resilient to diseases;
- Development of preventive strategies and alternative therapies and use thereof;
- Reduced losses and improved resource-use, reduction of emission per unit of animal product;
- Facilitation of free trade of animals and their products throughout Europe and strengthen the European livestock sector’s position;
- More efficient and “country tailored” surveillance systems.

## 3.2 The microbiome from an integrated one-health perspective

### Challenges

With the policy emphasis on developing strategies for improved health and protection from disease (both in people and in livestock), microbiome research has become a priority topic. The numerous interactions between gut microbiota and the host and possible interactions between microbiota of animals, humans and soil with the risk of dissemination of genes responsible for antibiotic resistance underpins the importance of microbiome research.

Research has begun to reveal the great importance of interactions between the animal (or human) host and the **gut (and respiratory) microbiome** on the health of the host. Through their natural complexity and the various bioactive metabolites, the microbiota harbours a full range of functionalities that represent a tremendous potential for **health management**, therapeutic intervention and industrial applications of biological chemistry. The microbiota is under the influence of external parameters that we may wish to control (e.g. antibiotic use, animal genetics, diet with probiotics, weaning conditions, environmental conditions…). Better control of these parameters may help strengthen the immune system and influence its host's development, fitness and metabolism and reduce the use of drugs. Better understanding of processes mediating both antagonistic and beneficial symbiotic interactions is required. In addition, the dynamics of initiation, transmission, maintenance and dissolution of microbiome subpopulations and the interaction between host genetics, microbiota and environment on health indicators is needed to reveal practical options to better 'manage' the gut microbiota especially when "seeding" newborns. The microbiota may also affect animals' behaviour, which in turn may influence their health and welfare. Besides gut microbiota, **respiratory, reproductive tract, skin and mammary microbiota** can also play important roles that are largely unknown at the moment. Some of these microbiota can affect the sanitary quality of products. An underexplored area is the interaction between microbiota from faeces, soil and water, especially after manure application, and the fate of bacterial resistance.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): ECO-FCE, FEED-A-GENE, REDNEX, RUMENSTABILITY, RUMINOMICS, CAMCHAIN, PROHEALTH, ACE-ART, FEED FOR PIG HEALTH, PRAHAD, ACTICAPS, HEALTHYGUT, INTERPLAY, DIFAGH, POULTRYFLORGUT…*

- **Study of the early life development as well as stability over time of microbiota associated with an optimal health and production**
  - **Effects of feed characteristics** (e.g. nutrients, feed additives, prebiotic, probiotic, others), **host animal and environmental conditions** (dust/ammonia, etc.) in shaping the digestive tract microbiome, including temporal changes as the interplay between the control mechanisms of the host (eating patterns, salivary buffering, rumination, nutrient recycling, gut motility, etc.) evolve through time.
  - **Transmission of the microbiome between animals**, e.g. the gut, the microbiome of the teat (skin), or microbiome of the interdigital space of the claw and the interactions between the different microbiota within an animal (gut, genital, respiratory, skin).

- **Microbiome and microbial metabolomes, their implications on the immune system and host metabolism**
  - **Reveal the role of early life intestinal microbiota in immune programming and later life immunity** (responses, tolerance); identify nutritional and microbial factors underlying immune competence at mucosae; study the interaction between feed stuffs and microbiota in mucosal tissue and evaluate associations of immune competence and disease susceptibility;
  - **Identify the (minimal) set of microbial species (groups, families) necessary for efficient immune programming** of livestock animals living in specified environments and identify the effect of biological enrichment of the microbiota in the gut and on the skin of pigs, cows and chicken;
  - **Understand interactions between commensal and pathogenic bacteria and with viruses** to understand the barrier function (e.g. salmonella in poultry) and to design effective therapeutic and preventive strategies;
  - Investigate whether profiles of **environmental and/or animal associated microbial profiles can be used as early predictors for disease and or contamination;**
  - **Investigate the role of gut microbiota on animal learning capacity and feed digestibility.**

- **Interaction between multiple microbiomes (soils, feeds, animals, products and humans) along the food chain in a one-health perspective** need to be understood. Characterisation of the resistance reservoirs and routes of resistance exchanges with pathogens and other microbial communities is a necessary basis for developing new and more efficient strategies for improved health and reduced risk of transfer of genes responsible for antibiotic resistance. This includes understanding the interactions between microbiomes in soils, feeds, animals, products and humans.

- **Creation of European network(s) to enable integration of research efforts**, data management and subsequent synthesis is required.

## Expected impact

- Better health and production (One Health);
- Better control of feed use and modulation of immune competence in livestock species;
- Reduction in the growth of antibiotic resistance;
- Animal genotypes and animal systems that are more resilient to disease challenge;
- Reduced risks to human health; limits the transmission of pathogens and antibiotic resistance genes to the human population;
- Reduced losses and improved resource use.

## 3.3 Animal welfare supporting animal health and vice versa

### Challenges

Societal challenges concerning animal welfare are likely to remain an important topic. Some consumers in developed societies are increasingly questioning the ethical acceptability of some livestock production systems. Animal welfare is sometimes included as a benchmark for assessing standards. Major meat and food processing companies are taking a lead in animal welfare issues, particularly by developing guidelines for the supply chain for better welfare practices.

Animal welfare in the debate on sustainable production can be seen from three different perspectives:

- From an **animal husbandry** point of view: we must keep our animals in the best way possible to meet their welfare requirements while avoiding negative effects ( e.g. farmer income or environmental impact);
- From the **farmer's** point of view, the need to achieve economic sustainability is interacting (positively and negatively) with animal welfare, and better welfare of the animals may improve farmers and employees' satisfaction at work as well as self-image. Increased production costs related to higher welfare standards may be translated to retail prices;
- From a **societal angle**, incentives are needed for the sector to show corporate responsibility, improve transparency and embed clear, relevant and understandable communication to the society at large.

As welfare is a multidimensional concept, its assessment should be a multidisciplinary process. **Rigorous assessment of welfare** may combine both resource- and animal-based indicators which can be measured in various livestock production systems. Animal-based indicators have been developed (FP6 Welfare Quality) but have to be adopted by the farming industry and standardized by the public authorities.

Further research is needed to **confirm the reliability of the measures and their robustness**, to ensure valid welfare assessment, through a science-based approach. Adoption of these systems should be supported in combination with the EIP-Agri. There is a need to investigate how animal-based indicators are related to and can best be combined with resource-based indicators. The use of 'iceberg indicators' or 'sentinels' to scan large numbers of animals (e.g. at slaughter) may help to focus efforts on farms or production systems where it matters most. Suppressing stress and pain due to physical intervention (surgical castration…), housing, management, transport conditions and at slaughter has to be considered in view of ethical aspects, in addition to meat quality and safety of farmers' working conditions.

To further improve welfare, identification of new welfare traits should contribute to the development of innovative farming practices. As an alternative to selection based on behavioural phenotype expression, **individual genes or markers** for genes that are known to quantitatively influence traits important for welfare can be another route of progress. The ability to scientifically assess animal feelings and affective experiences should contribute to the development of innovative farming practices.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): SELECTIONFORWELFARE, HENNOVATION, SOLID, AWAP, IMBDATA, WELFARE QUALITY, PRO-PIG, MYCOBACTDIAGNOSIS, NADIV, PROPARA, DIFAGH, AWARE, BETTERBONES, EAWP, ECON-WELFARE, FAREWELLDOCK, HEALTHYHENS, LAYWELL, ORGANICDAIRYHEALTH, PIGCAS, PIGWATCH, RABHO, SOUNDWEL, AWIN, WELFARE INDICATORS, WIN-FISH, DIALREL…*

- **Measuring and evaluating animal welfare**
  - **Adoption of already developed animal-based indicators for animal welfare in practice** (Commission's Animal Welfare Strategy 2012-2015). The indicators have yet to be adopted by the farming industry and their robustness should be confirmed. Adoption of these systems in commercial farms should be supported in combination with the EIP-Agri.
  - **Identification and validation of novel indicators** based on automatic recording systems (video, etc.) and associated algorithms for treating the data for early detection of behavioural and welfare problems. Validation should involve measurement of a range of physiological and behavioural measures for all species (including horses).
  - **Study possibilities of using of iceberg indicators** or sentinels as early warning signals from automated data collection techniques during primary production or at slaughter.

- **Improving animal welfare**
    - **Improving husbandry conditions.** In confinement systems, this includes the development of housing systems with finely monitored ambient conditions and offering possibilities for the animal to explore their environment (growing pigs, poultry). ). It will also be necessary to objectively compare indoor and outdoor systems. The effect of diet and nutrition on the social behaviour of animals is an issue in various systems. This also includes the development of sensor-based systems for automated welfare assessment (see 1.3) and customised management that provides each animal (or group of animals) with its requirements at the right time.
    - **Breeding to improve animal welfare and consider animal welfare when breeding for other objectives**. This requires the development of improved tools to identify important welfare phenotypes, and to identify DNA markers that would facilitate incorporation of welfare traits into genomic selection breeding programmes. This will require integrative genomics/genetics and breeding approaches that reveal genes and molecular mechanisms that reduce stress and improve welfare. It is envisaged that welfare traits would be complimentary to other traits important for a sustainable livestock sector, in particular traits associated with **longevity across species** (dairy cows, sows and laying hens).
    - **Reducing stress and pain** has to be considered in view of ethical aspects: Developing alternative strategies based on environmental enrichment, genetic selection to raise animals without mutilation practices (surgical castration, debeaking, tail docking…) and reducing stress and pain during transport and at slaughter.
    - **Generate a good understanding of the animals' affective experiences, including their emotions** should contribute to the development of innovative farming practices with improved animal welfare based on the animals' sentience and their cognitive skills. Investigation of the relationship between management, husbandry practices, animal temperament and mental state of animals. The relevance of behavioural strategies to improve animal welfare has to be studied by taking into account the cognitive skills of the farm animals.

- **Monitoring of progress of animal welfare at policy level, implementation and practices in EU Member States** to confirm that corporate and farming efforts are having the desired effects at food chain, farm and animal levels, and also to improve transparency. This requires the design of new support policies (including the exploration of result-oriented remuneration) and the development of overarching advisory tools for farmers and politics combining welfare, productivity, environmental performance and possible win-win situations. The investigation into how to communicate the benefits to consumers and society (ICT technologies…) is part of the research (see 1.3.) Existing quality labels could be used as models. As such, this will support the EU Welfare Strategy.

- **Studying the links between welfare, efficiency, sustainability and health.** There is a need to assess how animal welfare improvement strategies are (or can be) combined with resource use efficiency, economic impact, animal health as well as sensory analysis of animal product and environmental issues. In particular, animal behaviour and health requires innovative thinking to include behavioural, physiological and health status considerations. It is important to understand the relationship between animal welfare and immune competence, and to predict and explain why an individual is more susceptible to an infectious disease or abnormal behaviour as a result of its particular position in a social network and at the group level. It predicts how fast a disease or an abnormal behaviour will be transmitted within the network.

## Expected impact

- Improved animal welfare in Europe and ethical acceptability of livestock production systems;
- More robust animals;
- Support to the livestock industry to open up doors, build corporate responsibility and become transparent in a way society understands;
- Rigorous assessment of animal welfare;
- New methods and tools to ensure animal welfare in animal breeding and in management practices;
- Innovative welfare practice guidelines;
- Better implementation of animal welfare monitoring throughout the production chain;
- Development of traceability throughout the agri-food chain.

## 3.4 Integrity of food of animal origin and the production system

## Challenges

Animal products are an important and essential resource of protein, minerals and vitamins in human consumption patterns. They are part of a healthy and balanced diet. But over-consumption of animal products is still questioned for its supposed adverse effects on human health (cardiovascular diseases, cancer…). Animal agriculture is also questionned for ethical reasons: animal welfare, high carbon footprint of diets rich in animal products and the competition between human and animals for food resources. Food processing companies are starting to develop husbandry guidelines for the supply chain.

Facing a challenge to please domestic market and to attain added value from the export of animal products (particularly for a growing middle class requiring high standard of livestock production in some developing countries), it is necessary to amplify quality approaches. Besides the need to maintain an impeccable hygienic quality, innovations must be developed in congruency with the various facets of social quality (i) modernity of animal products with product innovations, (ii) health, with products conveying to consumers a high nutritional value and other desirable functionalities (like for protective properties against allergies, inflammation and oxidation), (iii) authenticity with coherent production and processing methods avoiding the alteration of the native properties of the products (iv) pleasure, raising awareness and knowledge of the sector in terms of differentiation of organoleptic quality of animal products. More than ever, focus on animal **product integrity (safety, authenticity and quality)** is needed to secure Europe's role as a leading global provider for safe and healthy animal derived products and help European food systems earn consumers' trust.

**Improving the quality of animal products** requires a multi-dimensional and multidisciplinary approach. The health promoting properties of animal-derived food products from sustainable production systems (e.g. fatty acids profile, amount of essential trace elements, anti-inflammatory, anti-oxidation or anti-allergenic properties of milk…) are closely related to the diversity of feeds consumed by the animal, but also to the genetic background and health status.

There is still a lack of knowledge about the **interaction between the animal's genotype and** the feed components. Thus, attention should be directed towards high throughput phenotyping of animal products to determine the genetic, nutritional and physiological factors that underpin favourable phenotypes. Nutrigenomic studies are required to investigate the influence of diet components on gene expression profiles and metabolism, and to elucidate how these are associated with desirable phenotypes. Better understanding of the role of nutritional compounds at the molecular level is expected to impact nutritional value and health promoting properties of foods of animal origin, but can also improve animal efficiency and livestock health. **Genetics** can also provide long-term improvements in animal product quality.

The carbon footprint of foods is an important criterion of choice for some consumers. Besides the LCA of single products, **carbon footprint** evaluation should also consider collateral aspects of livestock production, such as its integration in a global agro-ecosystem, its utilisation of non-edible proteins, and other factors e.g. optimal land use, C storage and biodiversity. Furthermore, new ICT and digital technologies may help answer the evolving quality demands of a more aware consumer in terms of traceability from the farm to the retail. **An integrated approach along the whole food chain is important.**

## Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): SAFE FOODS, WELFARE QUALITY, TRACE, PHYTOMILK, TREASURE, BIOTRACE IP, FEEDING FATS SAFETY, PATHOGEN-COMBAT, RISKSCRA-SHEEP MILK, SCRAPIE-FREE, SAFEHOUSE, SUPASALVAC, ACTICAPS, REPLACE, THRIVE-RITE, POULTRYFLORGUT, AUTHENT-NET, BASELINE, FIELDFOOD, FUTURE-FOOD, GM-SCAN, HIPSTER, I3-FOOD, ICOPP, INTEGRA, MEATGRADING, MYCOSPEC, NAFISPACK, PIGSCAN, PROSAFEBEEF, PROTEIN2FOOD, Q-PORKCHAINS, QUALIMEAT, QUALITYLOWINPUTFOOD, STRENGTH2FOOD, SUSFANS, TRACEBACK, VITAL, PHYTOME…*

**The following topics are supported by the Food For Life ETP.**

- **Evaluation of the role and impacts of animal products in a sustainable food chain**
    - **The sustainability of various agri-food production systems** (on a global and local scales) **with and without animals needs to be evaluated**. The C-footprint evaluation of our diet requires quantification of many factors (land use, GHG emissions, use of pesticides, biodiversity, employment, etc.) and also determination of the relative proportion of animal and plant derived protein in the diet. Hence, it is necessary to consider

the integration of livestock systems in a global agro-eco system (recycling, C storage, etc.), the diversity of production systems which affect intensity of GHG emission and regional contexts (see also 2.4). The raising concern the soil's capacity of storing carbon just starts unveiling the central and historical role of grazing and herbivores on the construction of global soil fertility (e.g. American Prairies, African savannas…). This research will align with the joint work between FACCE and HDHL JPIs.

- **Deepening the knowledge about the effects of animal-based products and productions systems on human health**, incl. mental health, and developing strategies to improve their nutritional profile with genetics and animal nutrition (in particular emerging feeds): this include n-3 PUFA, n-6 PUFA, various bioactive peptides (milks, eggs) or glyco-proteins (milk), and folates. Research projects are required to delineate the factors affecting the fine composition of animal products (throughput phenotyping) and the links between the intrinsic characteristics of animal products and their functional properties (especially for milk and eggs). Analysis of nutritional properties of animal products will require development of metabolomics approaches on model animals. The effects of different diets on human health, requiring long time studies of cohorts, should also be prioritised.

- **Evaluation of the potential of food-derived products in new food and non-food applications.** Eggs and milk are a source of numerous active molecules that are of major interest for different industrial areas such as food industry, biotechnologies, cosmetics and human health. Exploration of the structure and functionalities of these proteins will allows development of more applications. This could include protective roles as antiviral agents, antioxidant capacity, immuno-modulating, anti-hypertension, anti-cancer, anti-inflammatory and protective roles against allergic diseases (complex-IgG allergen in milk against asthma for example) aside organoleptic properties. Beside their massive use as a human food, milk constituents also find numerous alternative applications in the non-food area such as in the manufacture of plastic materials, textile fibres, glues or in the production of ethanol or methane. With regards to the diversity of the biological activities and physicochemical properties present in egg and milk and maybe other food co-products, this research area provides promising potential for innovations.

- **Building up animal product quality (microbiological, nutritional, organoleptic) all along the value chain**
  - **Increasing the potential functional components in animal-derived products** that may reduce the risk of life style diseases and increase their sensory quality. Combined approaches (i.e. genetics, nutritional programming, feeding) have the potential to tailor adapted animal products (fatty acid composition, marbling of meat…). This requires a better understanding of the effect of feed on the regulation of gene expression and subsequent effects on animal products. In addition, studying the ways (how and when during the life of the animal or its parents) to establish specific favourable epigenetics modifications may improve production level and product quality. To achieve this goal, the modern wide scale techniques of molecular biology have to be applied. Numerous applications can be envisaged: shifting the milk fatty acid (or protein) profile, breeding pigs that convert dietary plant omega-3 fatty ALA acids into "fish type" omega-3 fatty acids (EHA, DHA) in skeletal muscle, without inducing a "fishy smell and taste".
  - **Increasing the control of animals' microbiota composition on-farm and transmission to the downstream sector** to promote safe products with high quality (taste, flavour, texture, stability etc.). This requires a better understanding of the paths of microbiota colonisation of products at all stages, and identification of transparent and mechanistic quality criteria for raw food products. The omic's technologies allow the origin of this microbiota to be traced (soil, feed, building, milking parlour, humans…). A better knowledge of the pathways of product colonisation would limit the risk of presence of undesirable microflora. For the dairy sector, this would allow the development of useful flora for milk processing (production of raw /low temperature processed milk products that preserve the original nutritional quality of milk). Food chains based on raw milk products answer the demand for authenticity and for the rural vitality in non-competitive areas for a mass market. Control of milk and cheese microbiota is of primary importance for food chains based on raw milk products for safety and organoleptic reasons. New and improved methodology for rapid determination of undesirable flora is also required (e.g. Campylobacter on carcasses).
  - **Precision livestock farming to create more value for the food chain.** Investigations are required to address consumer demand for traceability of animal products (origin, environmental impacts, welfare) from the farm to the downstream sector. This is now becoming feasible thanks to the new PLF/ICT technologies. There is also a need to take advantage of these technologies to evaluate and monitor in real time the quality (sanitary, nutritional) of animal products from the farm to downstream sector and to the consumer.

- **Healthier soils and healthier food products.** Most foods enriched in specific nutrients are based on the addition of nutrients directly to foods. While it can be argued that this helps to meet nutritional needs, many consumers view these products as unnatural and adulterated, which affect their market potential and attractiveness. There is a large reservoir of research on how nutrients flow along the food chain to naturally enrich the food as a result of farming practices. Soil management and farming practices that facilitate the flow of (micro) nutrients from the soil to the plant and the flow of synthetized plant components into livestock products (in meat, milk and eggs) would overcome this concern and meet a growing market demand for foods that are naturally good for consumers.

## Expected impact

- Improved nutritional value of animal products contributing to healthier diets in sustainable agri-food systems;
- Evaluation tools of the nutritional value of animal products;
- Innovative utilisation of proteins of animal origin both for human health and application in non-food area;
- Improved traceability of the products of animal origin.

# 4. Cross-cutting issues

## 4.1 Improving infrastructures for research and innovation

### Challenges

There are needs for improvement in research infrastructures, both physical and virtual, for efficiency of delivery and to ensure that European resources are up-to-date and fit for foreseeable purposes. Infrastructures should be seen to facilitate not only enabling research but also innovation, linking research experimental farms, commercial experimental farms, demonstration farms and innovative commercial farms and for harmonisation of ethical aspects for research on animals through Europe.

Livestock research facilities (incl. facilities at farm system level and high containment facilities with biosafety level (BSL) 3-4 contingencies) are notoriously expensive to equip and maintain. There is a need to **create synergies between different facilities across Europe**. Bearing in mind the range of different production systems and animal breeds, we also need to increase the research outputs from these units (e.g. by fostering transnational access and shared use). A network of demonstration and pilot units supported by modern ICTs would greatly speed up the implementation of new technologies and practices, particularly when they involve groups of farmers. Platforms in the European outermost countries and regions offer interesting research facilities, and international collaboration opportunities to study and contribute to global livestock challenges.

Whilst **high throughput phenotyping** has been developed for plants and laboratory rodents, it is still in its infancy for farm animals. "Deep" phenotyping (incl. 'omics technologies, cell cultures, etc.) generally refers to collection of a large number of measurements from a relatively small sample of animals, whereas "broad" phenotyping refers to collection of a relatively small number of easily managed measurements on a large sample of animals. This requires well annotated genomes, adoption of low input/single cell methodologies from model species, and of a suited DCC allowing data to be deposited and shared data across systems and species (FAANG-related). **Large-scale phenotyping in commercial herds** will pave the way for future implementation of scientific results. Due to genotype x environment interactions, it is important that these herds are spread out across regions and production systems. It is also of interest to Europe to study phenotyping methodologies adapted to tropical environments as they bring an added value to analyse genotype x environment interactions, cross-breeding effect and trade-offs analyses within local breeds. A network of commercial herds in Europe enable quantification of the benefits of new tools under commercial conditions.

**Evaluation of innovative production systems** also requires infrastructures of experimental or commercial farms. Investment in physical research infrastructures is needed both to link existing facilities and to develop new platforms for deriving relevant phenotypes, not only for descriptive phenotyping approaches but with a view to predictive phenotyping of farmed livestock. Investment also needs to be made to develop common data acquisition and storage protocols, incl. ontologies and well-defined meta-data in order to facilitate sharing between European partners or between projects, but also reuse of individual datasets to instruct meta-analyses and thus extend the use of each one.

The **genetic diversity** of European farm animals is a valuable resource that needs to be safeguarded through investment in biobanks of animal tissue. With the application of 'omics methodologies, cryo-conservation, single cell methodologies, such materials also provide new opportunities for understanding mammalian (incl. that of human medical significance) and avian biology. Biorepositories can evolve to store cryopreserved collections of novel biological systems, such as 3D (i.e. organoids etc.) to share in the European community.

### Suggested scopes of research/topics

*Past and on-going EU research projects related to the suggested priority were considered in the research gap analysis, in particular (see Appendix 2): ALLBIO, ERIN…*

- **Creation of EU research infrastructures** with large populations of farms used in combination with research herds to elaborate and manage reference populations for unique and novel phenotypes whereas more and more phenotypes are collected within breeding companies. Efficient integration of this 'big data' in (virtual) centres for data handling will allow data mining and re-use of data by a wide range of research groups for multidisciplinary analyses. Platforms for efficiency recording, immuno-phenotyping and testing robust and slow growing breeds (extensive poultry system) are among the priorities.

- **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).

- **Management of generic resources for efficient multi-omics research**: concerns the development of common systems for sharing deep phenotypes from different “omics” such as genomics, transcriptomics and metabolomics, the development of epigenetic maps and gene catalogues of microbiota (digestive, respiratory, skin) of farmed animals. Establishment of public resources of this kind could greatly enhance research in the area and support breeding programmes in utilising such technology.

- **Improving animal gene banks** management and the reproductive quality of gene bank samples for long term conservation purposes. Creating tissue banks for physiological studies as substitutes for animal experiments (application of the 3 “R” Replace, reduce, refine).

- Strong European support to the **FAANG international action** should be ensured.

- **Establishment of an EU-wide network** of (i) experimental farms to repeat in various contexts similar trials in animal husbandry to evaluate genotype-environment-interactions and environmental performances of livestock systems for different species and (ii) farm platform rolled out across Europe to encompass all livestock farming systems. More instruments are needed in order to develop research infrastructures in South East Europe (e.g. through synergies with national funding agencies). The NWFP could be used as a pilot/blueprint. In the establishment of this farm platform.

## Expected impact

- Optimisation of the utilisation of European infrastructures;
- Enhance the quality of research methodologies;
- Deep phenotyping on complex traits;
- High throughput phenotyping in commercial and experimental farms;
- More robust and efficient animals;
- More resilient and efficient production systems;
- Overall contribution to food security by supporting innovation in breeding and farming sector.
- Facilitation of knowledge dissemination and implementation.

## 4.2 Precision livestock farming

### Challenges

Precision livestock farming (PLF) technologies gives animal production new tools for the management of livestock by continuous automated real-time monitoring of production, reproduction, health and welfare of livestock. In addition, monitoring and management of environmental impact is possible through new tools for precision agriculture in terms of nutrient application (manure and mineral fertilisers). The advantages are several: the technology is objective, automated, continuous, it captures the responses of animals, and it provides interpretation of the huge amount of data, providing useful information for making advantageous decisions. The data, or more likely, the information produced by PLF technologies are useful for several purposes: monitoring and management of production, welfare monitoring and certification (which would ensure animal welfare values for consumers), management of the ambient environment (e.g. climate), assessment of variation in building design and function, preventive measures and changes in management to enhance health and provision of information on the animal to be used in genetic evaluation (phenotyping) among the most important.

To meet policy goals for more efficient use of resources combined with emphasis on better animal health and welfare, practical options should be sought for **combining genetic, genomic, metabolomic and phenotypic information** to gain a better understanding of biological processes and to improve selection decisions for livestock by exploiting technological gains in these areas. The goal is to provide a toolbox of deliverable products and/or processes to allow these potential advantages to be realised.

There are challenges to make PLF a reliable and validated source of information (from data collected from PLF devices). New techniques for **deeper phenotyping, including metabolic profiling, sensor technology, remote sensing, Precision Livestock Farming (PLF)** on the one hand, **and the genomic revolution ("omics tools and data")** on the other hand, are key elements for successful implementation in the breeding sector. However, these technological developments are so far evolving in two separate worlds. Breaking this fragmentation by bridging knowledge and relevant actors will renew predictive biology approaches, generate new knowledge and is crucial for simultaneously advancing smarter farming and competitive breeding. A main goal is to develop and share innovative pipelines dedicated to high-throughput delivery of big data generation and analysis. Computer databases and data management and analysis facilities are necessary tools for handling the huge amount of data relevant to livestock and for simplifying the localisation, extraction and analyses of relevant information. Such research databases will be shared through common projects and will include original data (genomic data, precision livestock farming data) and classical performance data (dairy production, body weights, health proxies, real health parameters, etc.). When research can demonstrate the added value of such data integration, this will be a powerful impetus to encourage data accessibility.

### Scopes of research/topics

- **Development of automated data sampling and analysis** from the production chain including appropriate indicator traits and sensor data is key for a further optimisation of efficiency, health and welfare at animal and herd level and nutrient management. The use of **precision livestock technologies** has a huge potential to provide the kind of precision in phenotyping that is needed to match the gain in precision of genotyping brought about by the genomic revolution. Sensors can provide new phenotypes for novel and complex traits difficult to measure (such as efficiency and robustness in large populations of animals) that can be used for both management and breeding purposes.

- **Development of ICT/Infrastructure to promote exchange of data between stakeholders** and to share innovative pipelines dedicated to high-throughput delivery of big data generation and analysis.

- **Data-driven research** on computer databases and data management and analysis facilities are needed for tools and methodology development to integrate all these databases (genomic data, PLF data, classical performances data, real health parameters etc.) and to connect with other public databases such (e.g. climate databases). This would allow integration and analysis of huge amounts of data from different sources (and different kinds of data), and allow full exploitation of the possibilities of cloud storage.

- **Development of predictive biology approaches in PLF** which requires (apart from technological innovations concerning sensors) the development of mathematical decision support modelling (e.g. data mining and artificial intelligence). Data from different systems/sensors need to be made available for farmers. This will enable development of decision support software for integrated farm management independent of hardware vendors and allow combining data from multiple single signal systems (multiple inputs/multiple outputs concepts). The goals are to create systems for the collection, collation and sharing of relevant data and the creation of protocols for the use of such data in software development for smarter farming system.

- **New business models** for sharing of data and open data sources should be developed to bring PLF to the next level and benefit from Big Data. Farmers are reluctant to give access to their farm management and sensor data and only a few farmers see that this big data can be used as a sign of Good Agricultural Practices and can become a licence to produce. For example, common use of equations and databases would lead to a market increase in the precision and efficiency of national feeding systems in Europe. There is also a need for access to good quality public data.

- **Research to improve the traceability within the supply chain**. Precision livestock technologies can be used to increase the possibilities regarding traceability of food, feed and animal welfare. It can be possible to identify when, where, how much and which feed was distributed to which animals.

## Expected impact

- Increased efficiency of livestock production systems;
- Improvement of animal health and welfare;
- Better work condition for farmers;
- Traceability of the product in a context of "connected plates";
- High throughput phenotyping in commercial and experimental farms;
- 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;
- Better understanding of the main reasons for the current lack of adoption.

## 4.3 Open innovation / Co-innovation

### Challenges

Three major changes occur to the advisory system: i) the development of private (industrial) advisory while professional advisory services have financial difficulties in some countries, ii) the demand for less prescriptive solutions but for accompanying methodologies, empowering farmers to make their own decision, iii) the necessary renewal of the back office of the advisory (the permanent updating of information and knowledge the advisors can rely on), livestock management being more and more complex and requiring an extended domain of skills).

Innovation is at stake for the future of livestock farming. Innovation is coming from research, private industries (notably through precision livestock and robotics) and from farmers themselves and the growing amount of information needs very clear and quick channelling to its end users which is currently often missing in many European countries. **New innovation regimes appear**: co/interactive/participatory design (notably through living labs and other open innovation frameworks) and implementation of radical changes (practices, values, management entities). The role of downstream operators in the dissemination of innovations is a core element to be studied. Finally, it is generally recognised that the barriers to implementing new technologies or new management methods are best overcome by **involving the end-user** (the farmer and industries in this case) in the research and development activities, and/or in defining the objectives in the first place.

### Suggested scopes of research/topics

- **Analyse and compare advisory systems** (ref. SCAR AKIS working group) back office and advisory methodologies, their connection to research. Explore the interactions and modalities of development of private advisory services (linked or not to industry).

- **Explore the diversification of information systems the farmers are using** (social networks, NTICs) and their influence on farmers' decision making.

- **Identify new professions that analyse and master the profusion of knowledge for livestock development (innovation brokers).**

- **Develop new methodologies for co-design of technological innovation** or of farming systems with end users, develop concerted actions with heterogeneous stakeholders at local scale and in chains (companion modelling).

- **Explore on farm innovation and develop a framework to analyse their interest and conditions for dissemination** analyse process of innovation on farm (radical change implementation) from farm to downstream operators or to local development (lock in approaches).

- **Knowledge exchange with farmers and industry towards innovation:** Groupings like EIP Agri multi-actor groups are acting (not yet in all EU countries) in a coordinated manner across Europe and provide an excellent opportunity to act as 'test beds' for new technologies, on-farm management methods and new business models, taking account of the full range of livestock production systems (including multifunctional approaches), different geographic settings and bio-diversity.

- **Management and business models** in how to run successful animal farms. Innovations in how to use human capital most efficiently together with the biological and technological resources and components in when the industry is challenged. Animal farms are complex and have complicated processes. With new monitoring systems and production models also new business models and organisations of operation are necessary.

### Expected impact

- Better understanding of the determinants and behaviour of various stakeholders (breeders, farmers, vets, governments, citizens and consumers…);
- New way of designing technical and organisational innovations; spotting farmers' innovations, evaluation and diffusion of those innovations;

- Increase societal acceptance of animal agriculture and new technologies by the society;
- Design and evaluation of innovative policy instruments and coordination between actors (regulatory, insurance, incentive contracts...).

# Appendix 1
# Fit with the Horizon2020 structure

| | ATF Second White Paper topic vs Horizon2020 Work Programme | Societal challenge 2 | Societal challenge 5 | Excellent science | LEIT-ICT |
|---|---|---|---|---|---|
| **1.1** | **Sustainable food production using human inedible agro-products as animal feed** | | | | |
| | - Improvement of biomass utilisation and development of alternative feed not competing with human food | * | * | | |
| | - Evaluation of the novel options/technologies for feed production, evaluation and optimised utilisation | * | | | |
| | - New feeding strategies to reduce feed versus food competition | * | * | | |
| **1.2** | **Efficient and robust animals adapted to new European feed sources** | | | | |
| | - Definition of the new sustainable breeding goals | * | | | * |
| | - Development of appropriate phenotypes and indicators for selection on efficiency and robustness | * | | * | * |
| | - Genome editing: a new issue | * | | * | * |
| **1.3** | **Precise management of animals** | | | | |
| | - Innovative sensors and intelligent models for monitoring efficiency, animal health and welfare and livestock performance | * | | | * |
| | - Innovation in precision livestock farming for pastoralism and more generally for nature-based systems | * | | | |
| | - Evaluation of the social consequences of implementation of precision livestock farming | * | | | |
| **1.4.** | **Efficient and safe management of manure and animal by-products** | | | | |
| | - Evaluation of the effect of manures and organic wastes from animal industry applications on soil fertility | * | * | | |
| | - Evaluation of local systems organisation to improve the efficiency of manure utilisation | * | | | |
| | - Evaluation of the risks linked to manure and organic wastes from animal industry utilisation | * | * | | |
| | - Innovative manure refinery technologies | | | | |
| **2.1** | **Consumers' perceptions and expectations about livestock production systems and consumption of animal products** | | | | |
| | - Understanding controversies related to livestock production systems and livestock products | * | | | |
| | - Improvement of the transparency of animal production chains and of the confidence of consumers | * | | | |
| **2.2** | **Emissions mitigation** | | | | |
| | - Method development for measurement of emissions | * | * | | |
| | - Avenues to further reduce emissions using win-win strategies | * | * | | * |
| | - Increasing soil organic matter | * | * | | |
| **2.3.** | **Competitiveness and adaptability of livestock farming systems facing global changes** | | | | |
| | - Evaluation of the economic competitiveness of livestock farming systems across Europe | * | | | |
| | - Analyse of adaptive capacities of livestock production systems | * | | | |
| | - Using animal adaptive capacities to enhance the adaptive capacity of livestock farming systems | * | | | |

| | | | | | |
|---|---|---|---|---|---|
| | - Designing livestock farming systems that are consistent with the farmer’s interests and skills | * | | | |
| **2.4** | **Services provided by livestock production systems** | | | | |
| | - Developing metrics for measuring ecosystem and social services delivered by livestock farming systems | * | | | |
| | - Understanding of trade-offs and vis-à-vis costs and costs and benefits | * | | | |
| | - Enhancing establishment of a highly sustainable livestock sector by multi-actor approaches. | * | | | |
| **3.1** | **Responsible use of antimicrobials** | | | | |
| | -Study of the potential for reduction of the use of antimicrobials and anthelmintics for therapy, control and prevention with the objective to reduce the spread and impact of AMR | * | | * | * |
| | - Development of alternatives for therapy, metaphylaxis and prevention | * | | * | * |
| | - Rethinking of innovative management of animal health and implementation thereof with stakeholders | * | | | |
| **3.2** | **The microbiome from an integrated one-health perspective** | | | | |
| | - Study of the early life development and stability over time of microbiota associated with an optimal health and production | | | * | * |
| | - Microbiome and microbial metabolome and their implications for the immune system and metabolism of the host | | | * | * |
| | - Interaction between multiple microbiomes along the food chain in a one-health perspective | * | * | * | * |
| | - Creation of European network(s) to enable integration of research effort | * | | * | * |
| **3.3** | **Animal welfare supporting animal health and vice versa** | | | | |
| | - Measuring and evaluating animal welfare | * | | | |
| | - Improving animal welfare | * | | * | * |
| | - Monitoring of animal welfare progress at policy level, implementation and practices in EU Member States | * | | | * |
| | - Studying the links between welfare, efficiency, sustainability and health | * | | | |
| **3.4** | **Integrity of food of animal origin and the production system** | | | | |
| | - Evaluation of the role and impacts of animal products in a sustainable food chain | * | * | | * |
| | - Evaluation of the potential of food-derived products in new food and non-food applications | * | | | |
| | - Building up animal product quality (microbiological, nutritional) all along the value chain | * | | | * |
| **4.1** | **Improving infrastructure for research and innovation** | * | | * | * |
| **4.2** | **Supporting the implementation of precision livestock farming, ICT and big data in animal sector** | * | | | * |
| **4.3** | **Co innovation / open innovation** | * | | | |

# Appendix 2
# Fit with past and on-going projects (EU funded)

**See PDF file**

atf

# Animal Task Force

Website: www.animaltaskforce.eu
✉ info@animaltaskforce.eu
☎ 00.33.1.40.04.53.85
@AnimalTaskFrc

**Address:**
Rue de Trèves 61
1040 Brussels, Belgium

**Animal Task Force Secretariat:**
149 rue de Bercy
75595 Paris, France