



COMMON STRATEGIC RESEARCH AND INNOVATION AGENDA

❖ Finding a new balance ❖

Cofund ERA-NET “Sustainable Animal Production Systems” (SusAn)



EUROPEAN UNION

The ERA-NET SusAn is co-funded by European Union's **Horizon 2020 Research and Innovation Programme** under Grant Agreement n°696231

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Production Systems” (SusAn)

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Manuscript of the agenda completed in February 2022

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The SusAn consortium

Figure 1 shows the countries of the Cofund ERA-NET SusAn consortium (blue colour).



Figure 1: Countries of the SusAn consortium

The 39 partners in the Cofund ERA-NET SusAn consortium are:

1. Federal Office for Agriculture and Food (BLE), **Germany**
2. Spanish National Research Council (INIA), **Spain**
3. Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW), **Austria**
4. Flanders Innovation and Entrepreneurship (VLAIO), **Belgium**
5. Institute for Agricultural and Fisheries Research (EV-ILVO), **Belgium**
6. Public Service of Wallonia (SPW), **Belgium**
7. Hermesfonds, **Belgium**
8. The Ministry of Environment and Food (DAFA), **Denmark**
9. Aarhus University, **Denmark**
10. Ministry of Rural Affairs (MEM), **Estonia**

11. Ministry of Agriculture and Forestry (MMM), **Finland**
12. Agence Nationale de la Recherche (ANR), **France**
13. French National Institute for Agricultural Research (INRA), **France**
14. Federal Ministry of Food and Agriculture (BMEL), **Germany**
15. Forschungszentrum Jülich GmbH (JUELICH), **Germany**
16. Hellenic Agricultural Organization, Veterinary Research Institute (DIMITRA), **Greece**
17. Teagasc – Agriculture and Food Development Authority , **Ireland**
18. Department of Agriculture, Food the Marine (DAFM), **Ireland**
19. Ministry of Agricultural, Food and Forestry Policies (MIPAAF), **Italy**
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26. Research Council of Norway (RCN), **Norway**
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28. Foundation for Science and Technology (FCT), **Portugal**
29. Ministry of Agriculture and Rural Development (MPRV SR), **Slovakia**
30. Slovak Academy of Science (SAS), **Slovakia**
31. Ministry of Agriculture and the Environment (MKGP), **Slovenia**
32. Basque Food Safety Foundation (ELIKA), **Spain**
33. Centre for the Development of Industrial Technology (CDTI), **Spain**
34. State Research Agency (AEI), **Spain**
35. The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (Formas), **Sweden**
36. Ministry of Food, Agriculture and Livestock, General Directorate of Agricultural Research and Policies (MFAL – GDAR), **Turkey**
37. The Scientific and Technological Research Council of Turkey (TUBITAK), **Turkey**
38. United Kingdom Research and innovation (BBSRC), **United Kingdom**
39. The Secretary of State for Environment, Food and Rural Affairs (DEFRA), **United Kingdom**

List of abbreviations

4G/5G	4 th /5 th Generation
AKIS	Agricultural Knowledge and Innovations System
AMR	Antimicrobial Resistance
ATF	Animal Task Force
BMEL	Federal Ministry of Food and Agriculture
CAP	Common Agricultural Policy
CH ₄	Methane
CO ₂	Carbon dioxide
COP21	21 st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC)
CSRIA	Collaborative Strategic Research and Innovation Agenda, the official title of the SusAn research and innovation agenda
Cu	Copper
CWG SAP	Collaborative Working Group Sustainable Animal Production
DLG	German Agricultural Society
EASAC	European Academies' Science Advisory Council
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
EEA	European Environment Agency
EFSA	European Food Safety Authority
EIP	European Innovation Partnership
EMA	European Medicines Agency
ERA-NET	European Research Area Network
EU	European Union
EUROSTAT	Statistical Office of the European Union
F2F	Farm to Fork Strategy
FACCE-JPI	Joint Programming Initiative on Agriculture, Food Security and Climate Change
FAIR data	Findable, accessible, interoperable, and re-usable data
FAO	Food and Agriculture Organization of the United Nations
FAWC	Farm Animal Welfare Committee
FNS	Food and Nutrition Security
FP6	6 th Framework Programme
FP7	7 th Framework Programme
GATT	General Agreement on Tariffs and Trade
GHGs	Greenhouse Gases
GLEAM	Global Livestock Environmental Assessment Model

H2020	Horizon 2020
ICT	Information and Communications Technology
IFPRI	International Food Policy Research Institute
INTERREG	EU cross-border co-operation programme
IPCC	Intergovernmental Panel on Climate Change
IPPC	International Plant Protection Convention
JPI	Joint Programming Initiative
LCA	Life Cycle Analysis
LEI	Agricultural Economics Research Institute
LGBTQ+	Lesbian, gay, bisexual, transgender, and queer (or questioning), plus other sexual and gender identities
LIFE	EU funding instrument for the environment and climate action
LL approach	Living-lab approach
LPS	Livestock Production Systems
MAA	Multi-actor-approach
MMA	Mastitis metritis agalactia
N	Nitrogen
N ₂ O	Nitrous Oxide
NH ₃	Ammonia
NRC	National Research Council
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
R&I	Research and Innovation
SCAR	Standing Committee on Agricultural Research
SDGs	UN Sustainable Development Goals
SPUC	Scotland's Rural College
TP Organics	European Technology Platform for organic food & farming
UN	United Nations
WTO	World Trade Organization
WWII	World War II
ZALF	Leibniz Centre for Agricultural Landscape Research
Zn	Zinc

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Foreword

The livestock production sector forms an important part of Europe's agricultural economy and plays an essential role in the provision of Europe's citizens with high quality animal products.

The animal sector covers a very complex background of different species farmed in extensive, organic, semi-intensive or intensive production systems using multiple resources to produce a wide range of animal products, by-products and other services. Since livestock production is mainly run by family farms, the socio-economic aspects and the societal importance for the different regions in Europe should also be well taken into account. Moreover, farm animals have shaped Europe's cultural landscape for centuries.

However, the challenges for future livestock production are very demanding in terms of climate change, greenhouse gas emissions, resource scarcities, animal welfare, diseases caused by zoonoses, and other aspects. Furthermore, consumer behaviour and acceptance as well as international trade flows have an impact on the livestock sector.

In order to address these challenges and to reduce trade-offs, it was recognised by the Cofund ERA-NET SusAn that system thinking and the involvement of relevant actors along the value added chain are essential to develop the animal sector in Europe towards a more sustainable and balanced direction.

SusAn is characterized by a paradigm shift from a traditional one-dimensional to a multi-dimensional research approach supporting the three pillars of sustainability – economy, environment and society – with equal importance. Systems and multi actor approaches consequently permeate all SusAn activities and calls as well as the Common Strategic Research and Innovation Agenda (CSRIA).

The SusAn CSRIA reflects on the mentioned challenges and the urgent needs of transition of the livestock sector in Europe as requested by the Green Deal and its related EU strategies "Farm to Fork" and "Biodiversity". In addition, in 2023 the new CAP reform comes into force and will have a particular impact on the animal sector. In this context, research and innovation plays a key role for the transition process.

It is very gratifying, that the SusAn CSRIA is being published at the right time to provide research advice for the European Commission, the Member States and the Standing Committee on Agricultural Research (SCAR). The SCAR Collaborative Working Group (CWG SAP) will take up the SusAn results and recommendations.

As the coordinator of the ERA-NET SusAn, I take the opportunity to express my sincere thanks to the European Commission for providing the funding, to the authors of the SusAn CSRIA for their high degree of commitment and dedication, and to all SusAn partners for their trusted collaboration during the last 6 years.

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Coordinator of the Cofund ERA-NET SusAn

Preface

This CSRIA has the aim to contribute to the transformation of livestock farming as a part of the European agri-food system. It outlines the research and innovation needed to support the formation of opinions and solutions based on scientific reason.

The term “transformation” here means change that is fundamental, i. e. more radical than that brought about by “evolution”. For the livestock sector, this means that, despite the progress made during the past decades, continued progress in the agricultural sciences alone will most likely not be sufficient. Political and socio-economic considerations have significant contributions to make to more sustainable production and consumption.

There is widespread support and approval for fundamental change in livestock production in both, the expert community and society.

The European Farm to Fork Strategy speaks of the need for a “transition to a sustainable food system” (EC, 2020a). In the same year the members of the Standing Committee on Agricultural Research (SCAR), incorporating EU member states and associated countries, stated in their Berlin Declaration that “(...) *a drastic transformation of the way we produce and consume food and exploit natural resources is necessary* (...)” (SCAR, 2020). Both documents reflect the UN’s 2030 Agenda for Sustainable Development, titled “Transforming our world”, where sustainability goals were agreed at international level (UN, 2015).

Livestock production as part of a complex food system is a highly political issue and the scientific community does not have any political mandate. However, the agricultural sciences are necessary to inform and to support political decision making.

Given the time frame set by the 2030 Agenda for Sustainable Development, the Farm-to-Fork (F2F) Strategy and the Paris Agreement, this CSRIA tries to sketch the steps to be taken to deliver research results and innovation with the desired impact. In that context, the SusAn consortium follows the motto “Public money for public goods”.

Transformation research = “to study and scientifically support societal change with the goal to contribute to effective, equitable and durable solutions to (...) problems. (...) concerned with the exploration and navigation of fundamental structural change processes towards sustainability. (...). Transformation research is emerging as conceptual glue between (...) a variety of research strands” (Wittmayer et al., 2018). Transformation research has a longer history in sectors such as the heavy industry and the energy sector (steel, coal).

This document has been drafted by a network of experts and associations in Europe. Guided by the principles of inclusiveness, openness and participation, core partners of SusAn and selected experts have been invited to express their views on the contents of the CSRIA.

The SusAn research and innovation agenda shall contribute to the aims of the Farm to Fork Strategy.

Executive Summary

1. Aim of this agenda

SusAn's Common Strategic Research and Innovation (R&I) Agenda has the aim to contribute to the transformation of livestock production within the European agri-food system. The term "transformation" here means change that is fundamental, i.e. more radical than that brought about by "business as usual". For the livestock sector, this means that, despite the zootechnical progress made during the past decades, continued progress in agricultural sciences alone will most likely not be sufficient. In addition, political and socio-economic considerations can be expected to provide significant contributions to more sustainable production and consumption.

Livestock production is a highly political issue and the scientific community does not have any political mandate. However, the field of agricultural sciences can be used to inform and to support political decision making.

The agenda described in this summary uses the UN Sustainable Development Goals (SDGs) and the COP21 Paris Agreement as a common reference for all partners of the ERA-NET SusAn. Food and agriculture play a pivotal role in the UN SDGs and livestock production is linked to several of them.

The SusAn strategic research and innovation agenda shall contribute to the aims of the Farm to Fork Strategy of the European Commission.

2. Status of European livestock production

SusAn's view on the present status of European livestock production is as follows:

- » Achieving global food and nutrition security has become a more complex and multifaceted challenge than in the first decades after World War II. The complexity of the European agri-food system means that livestock production is seen as a sub-system in a larger context.
- » A significant part of present European livestock production systems compete for land and resources that can alternatively be used for e.g. growing plant based food or for nature conservation. Strategies for sustainable livestock farming must take existing trade-offs into account, for instance, food versus feed.
- » Current overconsumption and food waste in Europe considerably contribute to excessive resource use, public health costs and environmental costs. These costs could alternatively be used to support sustainable practices, and as long as they are unaccounted for, they distort prices and interfere with market mechanisms. Sustainable production can only be achieved in a framework of sustainable consumption.
- » Excessive intensification beyond nature's capacity leads to an unbalanced concentration and specialisation of livestock production, and to overconsumption of animal-source food. This has detrimental effects on farms, the environment and society. There is no universal solution that fits all livestock production systems in Europe. Diversity of production and adaptation to local conditions should be increased rather than decreased, also to benefit resilience.
- » Societal expectations about agriculture and food systems are high in Europe. The consumption of animal based food is high per capita and currently has a decreasing trend while consumption is increasing in other parts of the world (e.g. China, South East Asia).

From this point of view, the European livestock sector may start development processes that could later also take place in other regions of the world.

- » A shared vision of European livestock production is lacking, including its role for global health, and food and nutrition security. Furthermore, there is a need for concrete targets and corresponding evaluation methods (indicators, metrics).
- » Strategies for future global food and nutrition security should not only look at increasing crop and livestock production in Europe. They should also take other aspects into account, for instance consumer behaviour, food loss and waste, inequalities in global food distribution, and the food sovereignty of developing economies.
- » The European agri-food system as a whole, including livestock production, is currently not sustainable. Therefore, a fundamental change of the system is required. The next ten years are decisive for this necessary development.

3. Challenges for European livestock production

The challenges presented in this agenda were selected on the basis of the UN Sustainable Development Goals. Priority was given to the relevance for European livestock production systems. However, any effects outside Europe must be considered as well. This includes, for instance, GHG emissions, deforestation in countries exporting animal feed to Europe, as well as the effect of European exports on local markets of developing economies.

Detailed descriptions of the challenges are given in the full version of this agenda.

Major challenges for European livestock production systems are:

- » To achieve food and nutrition security
- » To restrict emissions and nutrient losses
- » To keep resource use within planetary boundaries
- » To preserve and enhance biodiversity
- » To support rural livelihoods
- » To provide high standards of animal health and welfare

Key messages regarding challenges

- » *All challenges must be met simultaneously and in accordance with set targets. Therefore, the above named challenges are not ranked.*
- » *The challenges are interdependent and need to be tackled within a systems based approach in order to account for potential synergies and trade-offs.*

4. Strategic approach

The strategic approach to R&I on livestock production systems is at the heart of this agenda. Because a system is more than the sum of its components, in this chapter the thinking and acting in systems is dealt with as an entity. Moreover, the effect of changing system components needs to be assessed at system level. Most importantly, the changing of system components requires a vision towards which the system should be developed, and it requires measurable targets.

The strategic approach comprises five areas that can be used together as a strategy for R&I on livestock production systems (see Figure S1):

- » Area 1: Develop a shared vision of European livestock production
- » Area 2: Design livestock production systems
- » Area 3: Support implementation of sustainable systems
- » Area 4: Evaluate system performance
- » Area 5: Facilitate collective action

The areas can be regarded as steps that need to be followed in chronological order, as well as areas that are dependent on mutual feedback. The circular design also enables choices to be reconsidered for this strategy and allows it to be adapted over time.

All five areas are essential to a successful systems based approach to R&I in the field of livestock production. However, they may have different impacts on any change.

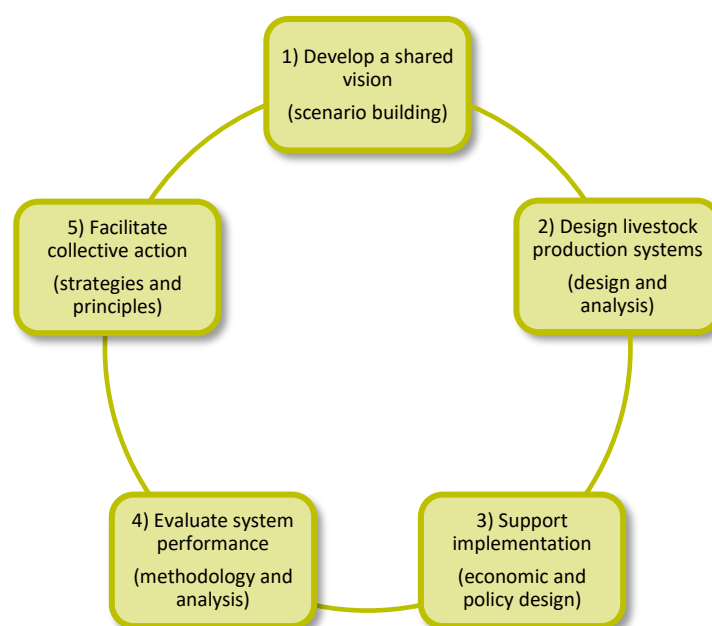


Figure S1: Strategic approach to research and innovation in livestock production systems

A prerequisite to successfully change a system is a vision of another, alternative system. According to Donella Meadows, the power to transcend paradigms and to change the goal of a system are the most effective leverage points to intervene in a system. However, the least effective leverage points often are “Constants, parameters, numbers”, even though much attention has been paid to those. In this agenda, they would correspond to the single components of livestock production systems, for instance, zootechnical parameters related to nutrition, housing or genetics. This does not mean that the components are generally of little importance. Undoubtedly, they are critical parts of running and optimizing livestock production systems. However, changing single components rarely changes system behavior.

4.1. Area 1: Develop a shared vision

A shared vision of a future agri-food system, and the role of European livestock within it, is a prerequisite for the efficient (re-)design of livestock production systems (Area 2), development

of a socio-economic framework to support them (Area 3) and for the evaluation of the system's performance (Area 4).

One or more future scenarios may be developed. A discussion of scenarios also facilitates the opportunity to explicitly state and examine assumptions, expectations and ethics. The visions and development paths will have to balance demands (e.g. food and nutrition security) and limitations (e.g. GHG mitigation). They must also leave sufficient room for farmers', scientists' and others' initiatives and creativity, with regard to the development of locally adapted solutions.

4.2. Area 2: Design livestock production systems (agricultural/technical)

The design of livestock production systems involves combinations of its basic components like animal health, animal nutrition, genetics, housing and manure management ("single components", see below), in order to tackle the challenges for European livestock production: Food security, emissions, resource use, biodiversity, livelihoods, and animal health and welfare.

Following the conclusions delivered in the 5th SCAR Foresight Exercise report (2020), within this agricultural/technical area, this agenda will be focused on two features characterizing the design of the system, namely circularity and diversity (including biodiversity).

4.3. Area 3: Support implementation (political/socio-economic)

Without societal facilitation, sustainable livestock production cannot be viable in practice. In order to enable Europe's agri-food system to become sustainable, the existing political and socio-economic framework needs to be developed further, in line with the European Green Deal. The principal rules of an (eco-) social market economy, public support (subsidies) and specific regulations must be coherent with regard to this goal. The economic and financial system is a major driver for how businesses, including farm operations, work.

4.4. Area 4: Evaluate system performance

If a system is more than the sum of its components, the evaluation of a system must take an approach that is able to catch the system's essential properties beyond just its components.

In the suggested agenda the following properties are to be considered:

- » Productivity and profitability, including ecosystem services
- » Efficiency of production, including reduction of emissions and waste
- » Stability of yields and resilience of the production system
- » Equitability and moral integrity, also regarding livestock and nature

4.5. Area 5: Facilitate collective action

The complex nature of livestock production systems implies that a diversity of knowledge and values are involved. It seems obvious that policy and research approaches will benefit from the consideration of the input of different stakeholders. This will assure the societal relevance of their output and their transfer to practice. However, stakeholder participation may not guarantee success. Opening a decision process to many participants means it will be a long and often complicated process and there is the risk of reducing the focus. Nevertheless, there seems to be agreement that a fundamental change of the European agri-food system will require concerted action of all stakeholders, in different fields and at different levels.

Key messages regarding the strategic approach

- » *The most effective leverage point to transform a system is the power to transcend paradigms and change the goal of a system.*
- » *Changing single system components (see below) has a relatively low potential to transform a system. However, they are critical parts of running and optimizing livestock production systems.*
- » *Highest priority should be given to the development of a shared vision of future European livestock production systems.*
- » *Priority should also be given to establish methods to evaluate the performance of livestock production systems with regard to their sustainability.*

5. Complementary research needs: single components

The components of livestock production systems are divided here into two parts:

1. political and socio-economic system components, and
2. agricultural and technical system components.

They are further divided as listed below. All components are seen as tools or means, *i.e.* “adjusting screws” to optimize system performance, and, consequently, to meet the challenges of European livestock production. The research topics for each component are described in detail in the full version of this agenda.

5.1. Political and socio-economic system components

- » Governance and public policy
- » Market and prices
- » Consumption patterns and food waste
- » Working conditions

5.2. Agricultural and technical system components

- » Animal nutrition
- » Breeding / genetics
- » Animal housing
- » Manure management incl. biogas
- » Animal health and welfare management
- » ICT, robotics and Big Data

Figure 2 of this agenda (p. 16) shows the relation between SDGs, challenges, strategic approach and system components.

Key messages regarding single system components

- » *To achieve major changes, a systems approach is required and more than one system component needs to be changed.*
- » *Political/socio-economic components are at least as important for a transformation of the livestock sector as agricultural/technical components.*

A. Introduction

A.1 Structure of this agenda

This agenda uses the UN SDGs and the COP21 Paris Agreement as a common reference for all partners of the ERA-NET SusAn. Food and agriculture are playing a pivotal role in the UN SDGs and also livestock farming is linked to several of them.

Chapter A is setting the scene, introducing livestock production in Europe and the scope of this research agenda.

Chapter B and H (Annex 2) describe the challenges, which were selected on the basis of the SDGs.

Chapter C is the core part of this agenda, presenting a strategic approach to Research & Innovation to meet the challenges described in chapters B and H (Annex 2).

Chapter D describes the components of livestock production systems and research questions related to them.

Chapter E refers to the role of agricultural knowledge and information systems (AKIS).

Chapter F gives general conclusions. It can also be regarded as a postface.

Figure 2 shows the relation between different parts of this agenda: The **challenges** (pink) are closely linked with the **SDGs**. The (livestock production) **system components** (grey) are regarded as means, i. e. “adjusting screws”. They optimize the performance of the systems that are developed, designed and evaluated within the **strategic approach** (green). And the strategic approach is the key to meet the challenges, and, consequently, contribute to achieve the SDGs.

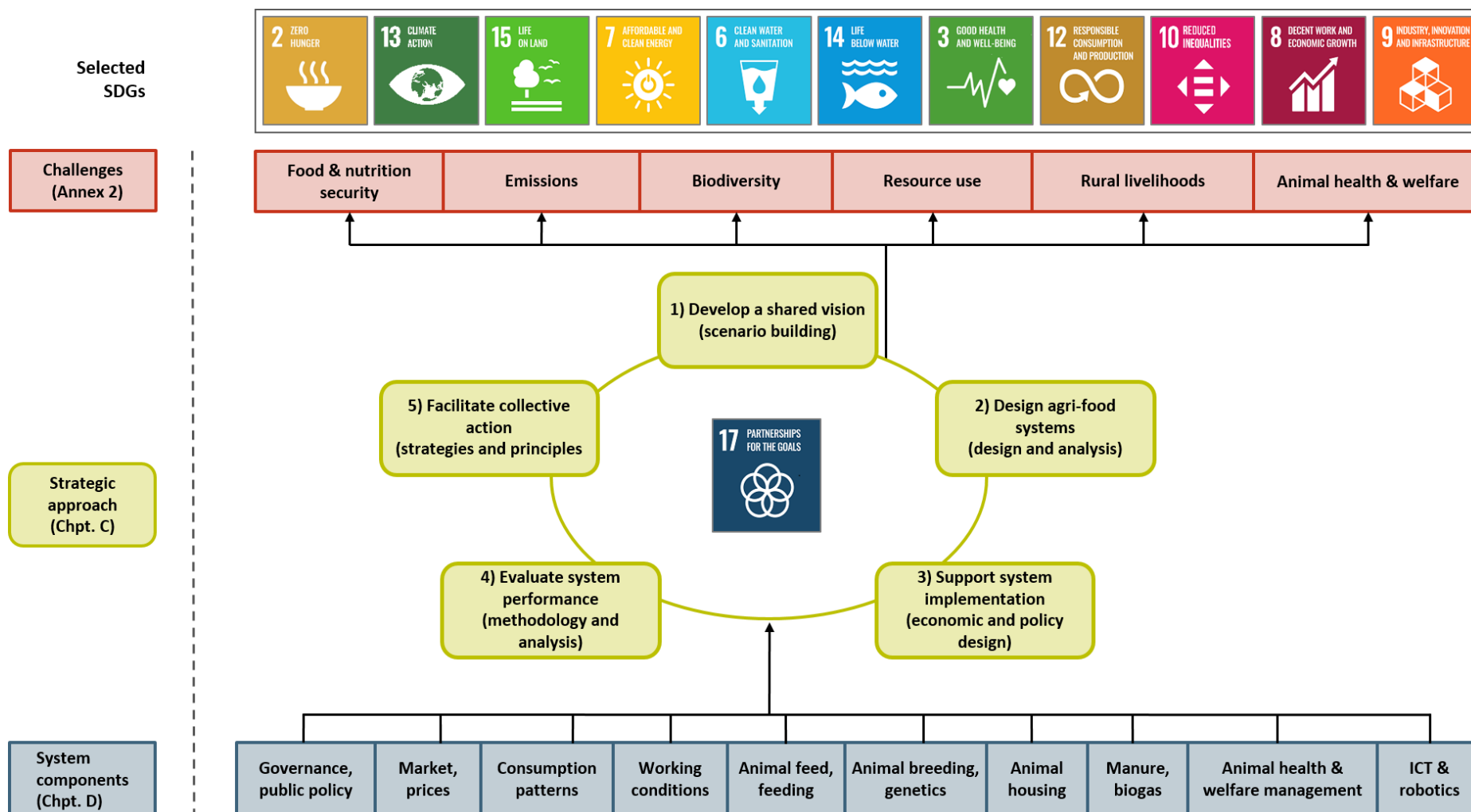


Figure 2: Relation between the chapters on system components, strategic approach to R&I, challenges and related SDGs

A.2 Livestock production in Europe

Livestock has a significant place in Europe's culture. Local breeds are a part of regional identities. Food of animal origin is valued for its taste and richness as well as for its high nutritional value. Meat, dairy products and eggs are a source of protein of high biological value, minerals and vitamins, and, consumed in appropriate amounts, can contribute to a balanced diet. Grazing animals contribute to a diverse landscape with high biodiversity that is valued by society. The ability of ruminants to convert cellulosic materials, which are indigestible for humans, into highly digestible products and high-quality proteins makes it possible to efficiently utilise land that would otherwise be less suitable for food production.

After WWII, the highest priority for European agriculture was to increase food production, make food affordable for consumers, and to provide competitive incomes for farmers (Lang & Barling, 2012). The development of the sector was characterised by three interlinked processes: intensification of input and output, regional concentration, and specialisation of activities (Bowler, 1986).

Both, crop and livestock production grew quickly. The combined production of beef, pig and poultry meat in the EU-27 countries increased 2.5 fold, from 17 to 43 million tonnes from 1961 to 2011. This increase took place mainly in pig and poultry production (Stoddard & Kilner, 2013). It was a success regarding the goal to provide Europe with food. By the end of the 20th century, however, societal concerns regarding animal welfare and health, and environmental impact were widely established and backed by scientific evidence.

The livestock sector makes a large contribution to the European food system. The turnover of the entire bioeconomy for the EU-28 was around EUR 2.45 trillion in 2017. The primary sectors of agriculture and forestry and the food and feed industry make up around 70 % of the bioeconomy market. With a share of 45 %, farmed animal husbandry contributes significantly to the European economy and plays an important role in European and global food safety and food security. Around 10 million people worked in agriculture in the EU-28 in 2015 and this accounted for 4.4 % of total employment. In 2016, there were 5.7 million farms with livestock in the European Union, compared to 10.5 million farms in all. This meant that more than half (54.8 %) of EU farms were raising livestock. Livestock farms can be found all over Europe.

A.3 The ERA-NET SusAn

The SCAR Collaborative Working Group on Sustainable Animal Production (CWG-SAP) recommended and prepared the establishment of the EU-cofounded European Research Area on Sustainable Animal Production Systems (Cofund ERA-NET SusAn). In 2014, members of the CWG-SAP agreed that the future development of the European livestock production sector would need to build on the three pillars of sustainability (economy, environment and society). Sustainable development means meeting the needs of the present generation without compromising the ability of future generations to meet their needs. Since then, the three pillars concept evolved into the SDGs.

Based on this common understanding, four approaches characterised SusAn's view on research and innovation:

Systems approach: The official name of the ERA-NET SusAn is "Sustainable Animal Production Systems". This name reflects the specific approach of the initiative. While "Sustainability" is the fundamental concept of SusAn, "Systems Thinking" is its essential approach.

Multi-actor approach: A multi-actor approach shall encourage input and draw effort from across multiple actors along the value chain, including consumers at the fundamental, strategic and applied levels. Its aim is to ensure involvement of all relevant stakeholders along the whole value added chain.

Cross-scale approach: The scale is defined here as 'level of organization', e. g. animal, herd, farm, region and can thus also be a geographical scale. Ideally, research would target effects at different scales and discuss their relevance whenever appropriate. The cross-scale approach shall not separate levels but, on the contrary, shall create awareness of the link across levels.

Multidisciplinary approach: SusAn's approach combines the system approach, the consideration of the three sustainability pillars and the assessment at different levels or scales. Therefore, a multidisciplinary approach, which brings together researchers to collaborate across research disciplines is needed.

Further details about the activities of the ERA-NET SusAn can be found in chpt. G (Annex 1). It describes a mapping of SusAn-related European and international initiatives (chpt. **G.2**), an analysis of recent EU funded research on livestock production systems (chpt. **G.3**), and a literature review on livestock production systems (chpt. **G.4**).

A.4 Common points of reference and scope of the CSRIA

Common points of reference

Agriculture in the EU is diverse, reflecting the different geological, climatic, historical and cultural conditions that characterise the regions and under which farmers work.

This agenda uses

- » The UN Agenda 2030's Sustainable Development Goals (SDGs)
- » The COP 21 Paris Agreement, confirmed at COP 26 in 2021

as common points of reference to elaborate and meet challenges in economical, ecological and societal areas. Both are comprehensive challenges that research projects on sustainable livestock production should help to meet.

Scope of the CSRIA

System boundaries are a key characteristic of any system and could be a strong determinant of the scope. However, the scope of SusAn includes many different systems. A single system or scale will therefore not define the scope of this research and innovation agenda.

Research aiming to make livestock production more sustainable at animal level or herd level by changing, for instance, feed ration or breeding goals, focus on "pre-farm gate" activity, i. e. ways to produce primary products (e. g. finished livestock, milk and eggs). This kind of research can further consider on-farm management and husbandry interventions.

This CSRIA will also consider research that has its starting point outside the on-farm livestock production system, i. e. post farm gate.

This allows for research areas such as:

- » The role of livestock in circular agri-food systems.
- » The potential contribution of livestock farming to farm-based public good provision.
- » The extent to which European livestock production can be classed as currently sustainable (Buckwell & Nadeau, 2018).
- » Leverage points and ways to transform the livestock production sector to enhance measurable contributions to the SDGs.
- » Interrelation between improved livestock production, changes in human consumption patterns and benefits for the environment.

Themes included in the scope are, for example:

- » Different production systems (e. g. organic, extensive, semi-intensive, intensive) producing a diverse range of animal products and other services.
- » Different animal species, including the main farm animal types (i. e. beef and dairy cattle, sheep, goats, pigs, poultry, honeybees) and species that play a significant role in certain regions or production niches (e. g. rabbits, reindeer, buffalo). The focus of this CSRIA is on animals kept for the production of food.
- » Feed production as an essential component of sustainable livestock production systems, for example with regard to closing nutrient cycles or accounting for GHG emissions.
- » Research on the region specific role of livestock in circular agro-food systems.

B. Status of European livestock production: Challenges

The challenges presented here were selected on the basis of the SDGs. Priority was given to relevance for European livestock production systems. However, any effects outside Europe must be considered as well. This includes, for instance, GHG emissions, deforestation in countries exporting animal feed to Europe, as well as the effect of European exports on local markets of developing economies.

Major challenges for European livestock production systems are:

- a) Achieve food and nutrition security
- b) Restrict emissions and nutrient losses to agreed, sustainable limits
- c) Keep resource use within planetary boundaries
- d) Preserve and enhance biodiversity
- e) Support rural livelihoods
- f) Provide high standards of animal health & welfare

B.1 Challenges in European livestock production

This chapter summarises the present status of European livestock production. It is based on a more detailed description of challenges, which is given in chpt. H (Annex 2).

1. The European food system as a whole, including livestock production, is currently not sustainable. A fundamental change of the food system, including livestock production, is required (SCAR, 2020).
2. Achieving global food and nutrition security has become a more complex, multifaceted challenge than in the years after WWII (Lang, 2009). Important challenges are, for instance, mitigation of greenhouse gas emissions, preserving and enhancing biodiversity, and maintaining human health.
3. The need of a fundamental change and the complexity of food systems requires livestock systems be seen as systems that are integrated in a wider food system. Even though this is widely recognised, research on livestock systems of this kind is still rare and needs to be developed.
4. Strategies for sustainable livestock farming must take existing trade-offs into account, for instance, between food vs feed and environmental protection and resource efficiency vs animal welfare.
5. A major part of present European livestock production systems are competing with land and resources that can alternatively be used for growing plant based food, biofuels, or for nature conservation and/or greenhouse gas mitigation.
6. Global diets are a key link between human health and “planetary health” (Tilman & Clark, 2014). Sustainable production can only be achieved in a framework of sustainable consumption.
7. Consumption, losses, waste and exports of European animal products are directly related to the number of farm animals raised in Europe. Current overconsumption and food waste in Europe considerably contribute to excessive resource use, public health costs and environmental costs. These costs could alternatively be used to support sustainable practices, and as long as they are unaccounted for, they distort prices and interfere with market mechanisms.

8. Livestock production in line with natural principles has a range of beneficial effects, like biodiversity, soil quality, soil fertility and safe, diverse and nutritious diets, securing incomes, contribution to cultural landscapes and rural development and others. However, excessive intensification beyond nature's capacity leads to unbalanced concentration and specialisation of livestock production and overconsumption of animal-source food. This has detrimental effects like narrow crop rotations with increased pesticide demand, feed imports, increased disease pressure, and heavy metals, antimicrobials and pathogens in soil and water, nutrient pollution of air, ground and surface water, compromised animal welfare and animal longevity, human health risks due to unbalanced diets, air pollution, zoonoses, antimicrobial resistance (AMR) and climate change.
9. There is no universal solution that fits all the different livestock production systems in Europe. Diversity of production systems and adaptation to local conditions should be increased rather than decreased.
10. The EC aims to increase the share of organic agriculture in Europe. Future R&I should take into account the knowledge built in this field so far, for instance, at European level by the ERA-NET CORE Organic and by TP Organics. This knowledge may be relevant for 'conventional' livestock production as well.
11. Societal expectations regarding the agri-food system are high in Europe. Consumption of animal based food is high per capita and tends to decrease while consumption increases in other parts of the world (China, South East Asia). European farming systems remain different from those of other regions of the world such as Chinese or American mega-farms or the small family farms in low income countries. From this point of view, European livestock may to a certain extent play a precursor role, starting developments that could later also take place in other regions of the world. This is a big responsibility for research and knowledge transfer.
12. Strategies regarding future global food and nutrition security should not only look at increasing food production. They should also take into account the potentials of a) plant based diets vs. meat based diets regarding resource use and GHG emissions; b) reducing food loss and waste; c) tackling the reasons for present unequal global distribution of food; and d) supporting developing economies to achieve food sovereignty.
13. A shared vision of European livestock production is lacking, including its role for global health, food and nutrition security, and including a political and socio-economic framework that would support that vision. Further, there is a need for concrete targets and corresponding evaluation methods/indicators/metrics.
14. The next ten years are decisive for the future of the European food system. There is a need for a strategic plan for Europe that links a vision with a time plan ("Roadmap").

B.2 Conclusions regarding current challenges

Two conclusions are drawn from the current challenges:

1. It is acknowledged that today's challenges are more complex than they were in the past. The challenges for European livestock production after WWII were to increase production in order to provide enough calories at affordable consumer prices and to raise the standard of living of farmers. In today's world the following issues must be addressed as well:
 - » Resource use and emissions have to be taken more into account.
 - » Consumption patterns have to be revised, also to maintain human health.

- » Biodiversity has to be preserved and enhanced.
 - » High animal health & welfare standards have to be met.
 - » The global consequences of European livestock production have to be considered
2. The challenges are regarded as multiple and often interdependent. Therefore, they need to be tackled simultaneously: global warming, biodiversity and food and nutrition security, for instance, are not ranked. Instead, all challenges must be met in accordance with the targets set for a future vision of sustainable livestock production. Care must be taken to not meet one target at the expense of another target. It is likely that individual targets cannot be minimized or maximized when they are part of a multi-objective optimisation process.

C. Research priorities: A strategic approach

C.1 General

The present chapter provides a strategic approach to livestock production systems. As a system is more than the sum of its components, this chapter adds another level to single system components (chapter D), i. e. that of thinking and acting in systems as an entity. The effect of changing system components also needs to be assessed at system level.

Most importantly, changing system components requires a vision towards which the system shall be developed or transformed, and measurable targets. Livestock production shall contribute to various aims within a multifunctional agriculture [see chpt. H. (Annex 2)]. It is not an isolated system, but an integral part of wider agro-food systems. This strategic approach is in line with the 5th SCAR Foresight exercise report (SCAR, 2020) and the principles of agroecology described by Wezel et al. (2020). Further, the third white paper of the Animal Task Force “A strategic research and innovation agenda for a sustainable livestock sector in Europe” is acknowledged (ATF, 2021).

The present chapter contains five subchapters that can be used together as a strategy for R&I in livestock production systems (see Figure 3):

1. Develop a shared vision (chpt. C.2)
2. Design agri-food production systems (chpt. C.3)
3. Support implementation (chpt. C.4)
4. Evaluate system performance (chpt. C.5)
5. Facilitate collective action (chpt. C.6)

The areas can be regarded as steps that need to be followed in chronological order as well as areas that are depending on mutual feedback. The circular design also enables this strategy to reconsider choices and to adapt over time. This also reflects the view that farming systems continuously are in a process of change (Schiere et al., 2012).

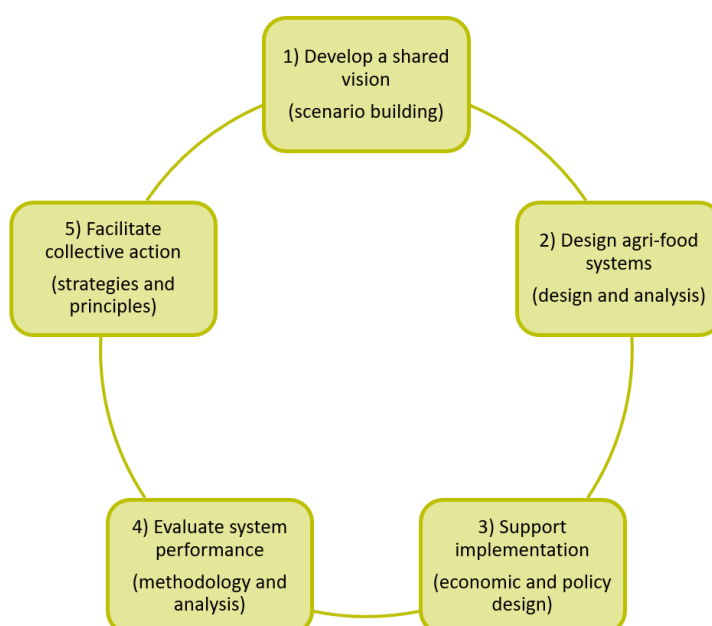


Figure 3: Strategic approach to research and innovation in livestock production systems

All five areas are essential to a successful systems approach to research and innovation in the field of livestock production systems. However, they may have different impacts for change in systems or system outcome:

A prerequisite to successfully change a system is a vision of another system. According to Meadows (1999), the power to transcend paradigms and to change the goal of a system are the most effective leverage points to intervene in a system. On the other hand, the least effective leverage points often are “Constants, parameters, numbers”, even though most attention goes to those. Figure 4 shows the effectiveness of places to intervene in a livestock production system with the aim to change system behavior (leverage points).

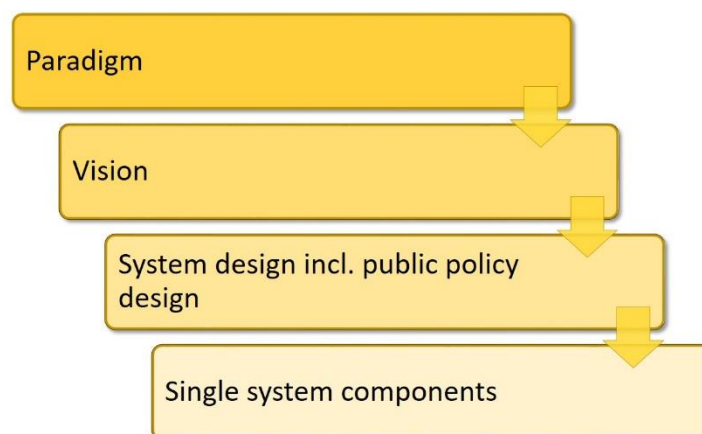


Figure 4: *Leverage potential of some areas for a transformation of livestock production systems (ranked)*

In this agenda, Meadow’s “Constants, parameters, numbers” would correspond to the system components of chapter D, for instance, zootechnical parameters related to nutrition, housing or genetics. This does not mean that components are generally of less importance. Undoubtedly, they are critical parts of running and optimizing livestock production systems. But changing single components rarely changes system behavior (Meadows, 2008). The leverage potential of any system component depends on the impact it has on other parts of the system. For instance, significantly changing the origin and type of protein feed may have a relatively strong impact by affecting GHG emissions, biodiversity, feed costs, animal performance, breeding goals, product quality, product prices, crop rotations, soil quality etc. However, without a vision of future livestock farming that considers a range of challenges (chpt. H. Annex 2) it is more difficult to deal with the costs and benefits of such a change in practice.

C.2 Develop a shared vision

A shared vision of a future food system (and the role of European livestock within it) is a prerequisite to efficiently redesign livestock production systems (chpt. C.3), develop a socio-economic framework to support them (chpt. C.4) and to evaluate the system’s performance (chpt. C.5).

One or more future scenarios may be developed. Discussing scenarios also holds the opportunity to explicitly state and examine assumptions, expectations and ethics. The vision shall provide a framework for European livestock production. This framework or development path

has to balance demands (e. g. FNS) and limitations (e. g. GHG mitigation) while leaving sufficient room for farmers', scientists' and others' initiatives and creativity to develop locally adapted solutions.

Drivers of change, whether of societal, economic or technical nature, need to be understood in order to identify different development paths. But a vision of the future requires innovations that not only extrapolate or adapt already existing solutions in the sense of incremental innovations, but proactively shape the future environment by creating new niches (Schomberg, 2013). Hence, innovation in this sense is about shaping the environment and a whole ecosystem according to emergent new qualities, values, technologies, social changes, etc. This can only be achieved by a process of emergent and future-oriented innovation (Peschl & Fundneider, 2017). Such an approach is based on the following concepts: (i) radically questioning existing approaches, models, solutions, and premises; (ii) exploration of completely new knowledge/theory spaces that are loosely related to the field to be innovated; and (iii) "Learning from the future as it emerges" (Scharmer, 2018). The centre of this approach is to identify emerging future potentials that are "not yet here" and to bring them into the present in order to incubate them into viable solutions.

Even though food security shall be given the highest priority globally (von Braun, 2021), the environmental effects of the present European food system also require consideration of how much and what kind of food of animal origin shall be produced, in Europe or elsewhere, and how it shall be produced. In addition, European food exports need to be included in the calculation. Other targets, like a politically-decided share of organic production, or land area set aside for nature conservation, should be taken into account as well.

In order to be able to evaluate the performance of production systems, it is important to set measurable targets, even though not all that is important for the system to succeed may be quantifiable.

This research area may include:

- » Explore the potential impact of changes in different areas to improve sustainability, e. g. in agricultural practice, in the food industry, or in consumption patterns.
- » Identify the amount of animal products needed for consumption and export.
- » Specify how and where the amount of animal products can be produced (e. g. monogastrics or ruminants; organic, etc.).
- » Find strategies that allow for a diversity of locally-adapted food systems within a market economy framework, while simultaneously having quantified long-term goals for sustainable livestock production.
- » Identify who would be economic winners and losers of a transformation of the European agricultural sector (or parts of it) in accordance with the SDGs.
- » Integrate existing research on leverage points and analyse their transformational role related to sustainability issues.
- » Identify concrete leverage points and critical control points for sustainable transformation, and the interactions between shallow and deep leverage points (Abson et al., 2017).
- » Improve modelling tools for future impact assessment in agro-food systems.

C.3 Design agri-food systems (agricultural / technical)

The design of livestock production systems involves combinations of its basic components like animal health, animal nutrition, genetics, housing and manure management (chpt. D.2), to tackle the challenges described in chpt. H (Annex 2): Food security, emissions, resource use, biodiversity, livelihoods and animal health & welfare. Livestock production must tackle several challenges, from local to global level, and it needs to use synergies and avoid trade-offs between them.

Following the conclusions of the 5th SCAR Foresight Exercise report (SCAR, 2020), this agenda puts focus on two features characterising the design of the system, namely circularity and diversity (including biodiversity), within this agricultural / technical area.

Circularity has the aim to use materials and substances prudently by either preventing losses (waste) or reusing or recycling them (De Boer & van Ittersum, 2018). Today, a significant part of biomass and nutrient flows is related to livestock suggesting that they can play a key role in circular food systems (Koppelmäki et al., 2021).

Diversity includes diversity within species (e. g. breeds) as well as different types of animals (e. g. cattle, pigs, poultry) or branches of farming (e. g. livestock, crops). It also includes diversity in nature, for example at landscape level. Diversity can be seen as both, a goal in itself (biodiversity) and a means to achieve ecological and economic resilience.

While circularity can be regarded as a strategy to use materials and substances efficiently at system level, diversity can contribute to both, provision and utilization of different materials, substances and services. Both properties may interact.

This research area may include:

- » Identify synergies and trade-offs between challenges, and strategies to optimise them.
- » Design circularity, including cascade utilisation of materials and resources.
- » Develop modelling, implementation of results in novel models.
- » Define the terms “waste” and “by-products”. (De Boer & De Olde, 2020); estimate the number of livestock that could be kept on rations exclusively based on grass, waste and by-products; take stock of relevant waste and by-products, regionally and nationally.
- » Determine the optimal scale at which circles should be closed (regional, national, international) (De Boer & De Olde, 2020).
- » Optimise diversity, both, within and between production systems, and including supply chains and markets (SCAR, 2020).
- » Investigate how diversity can become a structuring principle of food systems (SCAR, 2020).
- » Research to boost resilience and long-term stability (SCAR, 2020).

C.4 Support implementation (political / socio-economic)

Without societal facilitation, sustainable livestock production cannot be viable in practice. In order to enable Europe's food system to become sustainable, the existing political and socio-economic framework needs to be developed further, in line with the European Green Deal. The principal rules of an (eco-) social market economy, public support (subsidies) and specific regulations must be coherent with regard to this goal. The economic and financial system is a

major driver for how businesses, including farm operations, work (“As much market as possible, as much state as necessary”). Looking into the principles of this system may reveal possibilities with a leverage effect for the livestock sector that could not be achieved in other ways. Policy measures are needed when market mechanisms do not sufficiently balance profitability, equitability, the use and protection of natural resources, and health hazards, the burden of which is, at present, externalised to society.

This research area may include:

(also see chapters D.1.1 “Governance and public policy” and D.1.2 “Market and prices”)

- » Understand how actions at different governance scales need to be taken for an effective transformational change of the livestock sector, e. g. for circular and diversified production, regional/localised markets and global markets.
- » Investigate the potential and direction of subsidies.
- » Understand the role of financing models for (agricultural) business.
- » Assess rules and regulations according to their coherence.
- » Understand the synergies and trade-offs between different policy goals, e. g. synergies between sustainability and consumption patterns, or balancing the demands for biomass of the bioeconomy and the livestock sector.
- » Understand the structure of political decision making, e. g. at EU level.
- » Compare the costs of transformation with the costs of “business as usual”.
- » Develop cost calculation and pricing for sustainable food systems; costs at societal level vs. costs at farm level.
- » Develop new niches of economically viable livestock production systems; marketing strategies for sustainable food.
- » Develop mechanisms to balance the power between market players.
- » Investigate the role of ownership for sustainable practice.
- » Develop sustainability criteria in international trade.
- » Understand the effect of capital investment practices (e. g. incorporated companies, pension funds, venture capital) regarding the livestock sector.

C.5 Evaluate system performance

If a system is more than the sum of its components, the evaluation of a system must take an approach that is able to catch the system’s essential properties beyond its components. Life cycle assessment (LCA) and ecological or carbon footprints are methods for a systematic analysis of environmental or other impacts of products or services. However, they are mostly following a linear way of thinking (“take, make, dispose”; “cradle to grave”) which makes it difficult to account for, for instance, circularity or diversity. Alternatively, indicators or groups of indicators may be used to evaluate systems. Still, it appears to be challenging to scientifically assess multidimensional systems like agricultural production.

It is important to notice that a system’s performance outcome may depend on the scale at which it was evaluated (also see chpt. C.5). For example, a high feed efficiency at animal level may reduce emissions at animal and farm level, but this benefit may be compromised by the inputs and emissions associated with where and how this feed is grown and processed.

It is therefore necessary to show that advances at one level (e. g. feed efficiency at animal level) are also beneficial at a higher level (system efficiency) (van Zanten et al., 2020). And also here, there is a need to identify and investigate synergies and trade offs between different challenges.

This agenda suggests to consider the following properties of livestock production or food system performance:

1. Productivity and profitability, including ecosystem services
2. Efficiency of production, including reduction of emissions and waste
3. Stability of yields and resilience of the production system
4. Equitability and moral integrity, also regarding livestock and nature

This research area may include:

- » Design methodologies to evaluate system performance, e. g. metrics for environmental and animal welfare performance, ecosystem services, the degree of circularity in a system; a systemic approach to assess GHG emissions from agriculture.
- » Find ways to couple qualitative and quantitative information.
- » Determine how much and which form of European livestock production can currently be regarded as sustainable (Buckwell & Nadeu, 2018).
- » Define the term “industrial livestock production” and assess its sustainability.
- » Identification of unsustainable practices that should be promptly terminated.
- » Investigate how collective actions of a number of farms affect sustainability on a landscape scale (NRC, 2010).
- » Evaluate adaptive capacities of livestock systems; assessment of the sensitivity of farms to e. g. global warming.
- » Investigate the role of market economy in sustainable food systems.
- » Investigate distribution of benefits across farms and MS or between farmers and society.
- » Determine the targeting accuracy of policy measures regarding specified objectives.
- » Estimate the potential cost of not using a new approach or technology, or being slow in adopting it (EASAC, 2020).
- » Assess the compatibility of EU agricultural policy with GATT/WTO.
- » Enable farmers/stakeholders to evaluate system performance on farm and develop locally adapted best practice.
- » Establish long-term studies (i. e. living-labs) to identify benefits and bottlenecks. Development of long-term monitoring programs and standardized protocols.
- » Design schemes to systematically assess the impact of individual R&I projects.

C.6 Facilitate collective action

The complex nature of livestock farming systems implies that a diversity of knowledge and values are involved. It seems obvious that policy and research approaches will benefit from considering the input of different stakeholders in order to assure the societal relevance of their output and their transfer to practice. However, stakeholder participation may not guarantee success. Opening a decision process to many is a long and often complicated process and holds the risk of reducing the focus. On the other hand, there seems to be agreement that a

fundamental change of the European agri-food system will require concerted action of all stakeholders, in different fields and at different levels.

This research area may include:

- » Identify and manage competing values and visions among stakeholders (SCAR, 2020).
- » Identify how and by whom fundamental change / transformation / disruption should best be initiated- and who blocks it and why.
- » Better understand and prioritise the factors that make stakeholder participation lead to stronger and more durable decisions, e. g. quality of representation and type of involvement; acceptance of the procedures; decision-taking ability across sectors.
- » Investigate whether decisions emerging from participatory processes are perceived to be more holistic and representative of diverse values and needs.
- » Develop methods to improve interdisciplinary communication and quantify social learning (Reed et al., 2013; Martinez et al., 2019).
- » Identify ways to encourage social innovations, and on-the-farm experimentation, in new farming methods that can improve both biodiversity and productivity (SCAR, 2020).

C.7 Conclusions regarding the strategic approach

From a scientific perspective, priority should be given to (ranking list):

1. Develop a shared vision of future European livestock production systems, based on scientific opinion and balanced stakeholder participation. In this context, it is important to set measurable targets. One or more future scenarios may be developed providing concepts for European livestock production. This concept has to balance demands (e. g. food and nutrition security as well as healthy diets) and limitations (e. g. GHG mitigation) while leaving sufficient room for farmers', scientists' and others' initiative and creativity to develop locally adapted solutions.
2. Establish science-based methods (metrics) to evaluate the performance of livestock production systems with regard to their sustainability. This may include the development of new indicators and simultaneous analysis of multiple indicators (multicriteria assessment). In particular, a systemic approach to assess GHG emissions from agriculture is needed.
3. Redesign livestock production systems (agriculturally / technically), particularly regarding circularity and diversity, and put in place a coherent political and socio-economic framework that supports the implementation of sustainable livestock farming.

D. Complementary research needs: Single components

The components of livestock production systems are divided into two parts, 1) political and socio-economic system components, and 2) agricultural and technical system components. All components in these parts are regarded as tools or means, i. e. “adjusting screws” to optimize system performance, and, consequently, to meet the challenges (H. Annex 2).

D.1 Political and socio-economic system components

D.1.1 Governance and public policy

To foster transformative change for a sustainable European livestock sector, both, supporting governance systems and supporting policy measures need to be put in place. It is important that governance and public policy always take a systems-view and ensure policy coherence, particularly for circular livestock systems which will interact with other systems in the primary sector and beyond. For instance, governance and policy research will have to solve conflicts between bioeconomy policies and the livestock sector given competing biomass uses. The European livestock sector interacts with systems far beyond Europe’s borders e. g. through the import of feed and export of meat. How policies such as the Farm to Fork Strategy may be utilised for more circular and regional production needs to be elaborated. Sustainability objectives such as animal welfare and social inclusion need to be balanced. The European livestock sector is high on the citizens’ agenda. It is the role of governance to ensure that sustainability agendas are plural and do not exclude important stakeholders and societal actors to foster trust. Community and citizen-led initiatives, as well as co-creative approaches to governance, can be one way to achieve transformative change in the livestock sector, particularly at local and regional levels. However, little is known on how these approaches may be utilised.

This research area may include (also see chpt. C.4 “Support implementation”):

- » Assessment of existing rules and regulations according to their coherence and the degree of their enforcement.
- » Exploring and understanding how approaches beyond market-based approaches can help push behavioural change, e. g. ‘true cost’ pricing or democratic, community-based points-systems.
- » Mapping and understanding the policy impacts of circular livestock production e. g. impact of feeding by-products to livestock.
- » Understanding of how the livestock sector can work with other sectors in the bioeconomy (e. g. energy) and how to work with local and regional communities.

Expected outcome:

Insight on which governance systems and policy measures can best support transformative change in the European livestock sector, and at which scales (local, regional, European) policies are most effective. A first mapping of the possible impacts circular livestock production may have on other sustainability goals and how to optimize them. A clear overview of the key policy synergies and trade-offs, across policy domains or scales with strategies for policy coherence identified. With these insights, policy tools can be improved or developed allowing all stakeholders to review and renew policies supporting a sustainable livestock sector.

D.1.2 Market and prices

Sustainability may be enhanced by using a “full costing”, covering the whole supply chain from producer to consumer. Systems thinking has to be connected to pricing schemes at critical points in food systems. Developing a better understanding of issues or levers of action concerning EU competition and trade in the food sector is of importance. This includes an analysis and review of pricing and trading systems on an international scale. Planetary boundaries bring the international community closer together. In this regard communication and ecologic-negotiation become fundamental to accompany the transitory phase.

The development of prices needs to be better understood from the perspective of a socio-ecologic market structure. Furthermore, market institutions may need frameworks for socio-ecologic true cost pricing.

Pricing and communication may also affect consumption and lifestyle differently in different social groups, and there is a need to understand the impact socio-structural changes have on various consumer segments, e. g. in terms of differences in affordability and accessibility, including cultural accessibility, and food-related knowledge in general.

This research area may include (also see chpt. C.4 “Support implementation”)

- » Understanding how both intrinsic and extrinsic qualities can be incorporated in pricing and market systems, including consequences and scenarios at the primary sector (at farm level), for the secondary sector (beyond the farm gate) and consumption at various social levels.
- » Understanding how “full-costing” would affect innovation and investment.
- » Understanding negotiation and communication between market actors supporting sustainability, development of synergistic pathways for e. g. less resource intensive consumption.
- » Understanding how to elaborate socio-ecologic market structures, including a balance of power among market players.
- » Develop frameworks and strategies for creating and marketing sustainable products.
- » Devise new business models to get people to use and support circular food practices (SCAR, 2020).
- » Investigate, how the current market system and agrifood industrial structure affect diversity in food supply (SCAR, 2020).
- » Identify incentives for companies to become more “mission led” (SCAR, 2020).
- » The effects of a transformation on farm income and farm resilience – “robust, adaptable, transformable” (Meuwissen et al., 2019) – need to be better understood on farm level and from a European perspective, comparing different production systems and farming conditions.

Expected outcome:

Insight on the extent to which pricing and market structures may impede sustainable production and consumption. Identification of opportunities, levers and interventions to support development of coherent pricing on sustainability. This insight will provide tools for all stakeholders to review and renew policies supporting sustainable food production and consumption.

D.1.3 Consumption patterns and food waste

Sustainable lifestyles are not widespread at present, and the existing barriers are not yet fully understood. There needs to be an in-depth analysis of the status-quo as well as the obstacles, followed by an analysis of the most effective interventions needed. Sustainable lifestyles fulfil multiple needs and values with regard to human, environmental and animal health.

Communication and education need to be targeted to societal groups in pluriverse ways and actions. Multicultural and transgenerational approaches ask for elaborated concepts to establish a comprehensive understanding of sustainable human consumption.

This research area may include:

- » Understanding the value of sustainable consumption for human, animal and environmental health.
- » Understanding of barriers for sustainable human consumption in different areas and target groups.
- » Understanding how and which interventions (education, communication, public/environmental health policies, access to sustainable food) may contribute to sustainable lifestyles.
- » Study how to regain consumer trust and inform the public debate with scientifically-sound knowledge on animal product quality and production conditions.

Expected outcome:

Insight on the extent to which human consumption patterns may support sustainable production as well as market structures. Identification of leverage points to support development of coherent frameworks for sustainable consumption.

D.1.4 Working conditions

According to the EU Farm to Fork Strategy, the EU will strive to promote international standards and encourage the production of agro-food products complying with high safety and sustainability standards. To avoid social dumping from imports into the EU, it will be important to also include the implementation of International Labour Organization (ILO) conventions and standards on safe working conditions within the Farm to Fork concept of high safety and sustainability standards.

Food safety, animal welfare, climate change and environmental standards will continue to increase, as will a growing trend in voluntary food quality and ecological labels, placing farmers under pressure to modify their working practices and comply with a growing number of rules, regulations and schemes. All this puts pressure on the farmers. The increasing financial pressure in farming is among the many stressors to which they are subject and which affect their mental health and stress levels.

This research area may include:

- » Strategies to support farmers in complying with a growing number of rules, regulations and schemes, and in modifying their working practices if their working environment changes.
- » Assess social indicators of farmers work (e.g. work life balance, happiness with the job, security of income, public reputation of farmers).

- » Risk assessment, strategies and technologies to reduce the occupational risks for farmers and, for instance, slaughter house employees.
- » Strategies to guarantee that meat companies meet their legal liability for pay, for working time, and for accidents and injuries of slaughterhouse employees.

Expected outcome:

Improve working conditions of farmers, employees and atypical workers. Avoid social dumping from imports into the EU.

D.2 Agricultural and technical system components

D.2.1 Animal nutrition

If future feed must not compete with food production, considerable shares of feed rations will have to consist of, among others, by-products and food waste from circular systems. New feed rations will need to be composed and optimised.

Feed costs are a major contributor to the variable costs in livestock production. Animal nutrition further has significant effects on productivity, animal health & welfare, emissions and the nutrient composition of manure. The origins of feedstuff have environmental impacts, for example, soybeans from South America or regional legumes.

Ruminants can convert cellulosis into high quality human edible food. Feed additives may reduce emissions at animal level.

This research area may include:

- » Identification of biomass from the circular bioeconomy, e. g. from the food processing industry or restaurants, incl. taking national stock of the amount and quality of biomass of this kind.
- » Evaluate the ability of livestock to efficiently utilize a diverse range of biomass that is inedible to humans.
- » Systematic assessment of by-products regarding potential competitions of use (feed, energy, green fertiliser) and local synergies (farm and industry cooperation).
- » Develop procedures and technologies to prevent hygienic / health issues related to the use of biomass from circular systems.
- » Develop procedures and technologies incl. enzymes to improve the digestibility and value of side stream products for animals.
- » Develop novel feedstuff, based, for instance on earthworms, insects, algae or yeast.
- » Optimise integration of livestock and crop production regarding feed production (e. g. N-fixation, use of cover crops and crop residues).
- » Development of the logistics necessary to utilize regional feed sources, e. g. for cooperations.
- » Optimise management and use of permanent grassland, ley and agroforestry regarding nutritional value, biodiversity and carbon sequestration.
- » Investigate the effect of new feed rations on productivity, product quality, animal health & welfare.

Expected outcome

Provision of feedstuff in a system that makes best use of resources, minimizes environmental impact, is hygienically safe, and contributes to biodiversity and carbon sequestration where possible.

D.2.2 Breeding / genetics

There is a need for continuous improvements and innovations for more sustainable livestock production systems that ensure productivity, resource efficiency, environmental protection and high standards of animal health & welfare. Improved breeding and genetic techniques offer promising opportunities for increasing the transformation efficiency of biomass by livestock, reducing negative consequences for the environment, and minimising the competition of biomass use for food, feed and fuel. Continued investigations of livestock microbiome compositions and the mechanisms behind microbiome-host interactions should be undertaken to investigate the reduction of greenhouse gases from ruminant production, for example through generating biomarkers. These are useful in understanding and informing microbiome alterations and the development of feed additives that may aid in the inhibition of methane-production. Investigations into biomarkers associated with emissions should also be used in selecting for animals with lower emissions. Genetic evaluations of the feed and nutrient use efficiency of livestock, to permanently select for animals, which can attain slaughter weight with no welfare compromise, lower emissions and increased economic response are of priority. Data from such studies should be included into breeding goals and include work on reducing nitrogen and phosphorus excretion in addition to methane to achieve a broader range of environmental benefits. The opportunities associated with emission reductions when breeding for integrated dairy and beef production systems versus specialist systems should be examined further. For quicker gains in less productive systems, the possibility of imported genetics should be considered. Future breeding needs to consider the effect of the changes that production systems undergo due to climate change and societal demands for improved animal welfare from livestock breeding. In addition to the analysis of genotype-environment interactions, a continuous adaptation of livestock to the new production environments and conditions is required. Increasingly, the focus is on traits of resilience, resistance and robustness. Autochthonous breeds including endangered animal genetic resources have a high potential to contribute to locally-adapted farming systems, for the maintenance and conservation of cultural landscape areas and improvement of functional traits including longevity and vitality. Further attention is also warranted on the potential role of genetically modified or engineered feed crops as natural methane inhibitors or through improving metabolizable energy content or protein quality of the material.

This research area may include:

- » Suitable breeds for livestock production integrated in a circular economy.
- » Appropriate breeding goals and how to integrate data from smart/precision farming tools, improved breeding methods and new bio-techniques to improve sustainability.
- » The role of genetic modification for sustainable livestock farming (e. g. in breeds, animal nutrition).
- » Focus on individual variability between animals.
- » Investigations of microbiomes to sustainable livestock farming.
- » Breeding for resilience and longevity, e. g. in dairy cows, to contribute to sustainable livestock farming.

- » Genotypes adapted to each region's own ecological conditions; resistance to diseases and parasites.
- » Genetics contribution to “unwanted” male (high producing) dairy calves or males of laying hen breeds.

Expected outcome

More sustainable livestock production systems through the use of enhanced breeding goals and innovative tools aiding in emission reductions and increased productivity.

D.2.3 Animal housing

The development of different housing systems has been driven by technical innovations, regulations, societal demands, and environmental impact. Animal health & welfare, behavioural needs, local conditions, workers’ safety and wellbeing are just some of the criteria that need to be met. New developments in housing systems for livestock may create conflicts with environmental sustainability, health issues or even tensions regarding the aesthetic of buildings in the landscape. Holistic approaches should explore these interactions, both, short and long term.

This research area may include:

- » Animal welfare: e. g. space allowance, outdoors access, heat stress, social groups, light and air, environmental enrichment, ability to perform natural behaviour.
- » Floor types, bedding systems, mobile houses, manure storage.
- » Reusable and recyclable construction materials.
- » Multifunctional buildings, e. g. combination of different type of animals, horticulture, cow gardens, generation of energy, energy efficiency.
- » Health aspects, e. g. hygiene measures, wild animals, air quality, bio-aerosols, spreading of AMR.
- » Low emission housing; energy supply for ventilation, heating, cooling etc. from renewable sources.
- » Multidisciplinary and long- and short-term approaches to evaluate innovative housing systems, considering environmental, societal and economic issues.

Expected outcome:

Improved livestock production, increased diversity of type of farms, better adapted to regional and local needs (animal species, farm size, climate and cultural differences etc). Housing innovations will increase efficiency in circularity. Improved animal housing may increase its acceptance by society.

D.2.4 Manure management incl. biogas

It is essential to return manure nutrients to arable and grassland farming and make optimum use of manure nutrients for crop growth and soil quality. However, regional surplus of livestock manure and its environmental impact has contributed to a decline of agriculture’s reputation. If used adequately, however, manure is a valuable resource for the management of soil fertility, improving not only crop yields but indirectly also plant health and resilience of crop and soil against extreme weather events.

On the other hand, livestock manure contributes considerably to global emissions of ammonia (NH₃), methane (CH₄) and nitrous oxide (N₂O).

This research area may include:

- » Optimise nutrient supply from livestock manure to crops, e. g. targeted manure inputs for enhanced N uptake, in combination with green manure and cover crops (Pullens et al., 2021).
- » Describe long- and short-term legacy effects that livestock manure has as part of a holistic soil fertility management, including effects on soil organic matter.
- » Minimise emissions from manure during storage and application.
- » Apply systems analysis to biogas production: evaluate the energetic, economic and environmental performance of biogas production together with resource efficiency, while expanding the system to both, the use of the digestate (replacement of mineral fertiliser) and the use of the produced gas (Lindkvist et al., 2019).

Expected outcome:

Decreasing GHG and N emissions and optimising the cycling of nutrients. Biogas production is a source of renewable energy with the potential to substitute fossil fuels. It has the potential to reduce gaseous emissions from manure and, when using livestock manure, most nutrients are retained and can still be used as fertiliser.

D.2.5 Animal health & welfare management

Animal health & welfare issues are at the core of the current societal debate on livestock farming. Housing and managing farm animals in a way that requires excessive use of antimicrobials in order to maintain desired productivity has become a threat to human health, while the negligence of animal welfare has led to significant ethical concerns in a growing part of the population. Therefore, there is a need for scientific knowledge on the potential trade-offs and synergies between animal health & welfare, productivity, and economics in order to establish best practices for a sustainable, resilient animal farming sector.

Research topics include:

- » Developing reliable, valid animal health & welfare indicators that can be implemented throughout the process of farming, from breeding to the slaughterhouse. Ideally, indicator sets will be established that (at least partly) rely on automatic measurements. This will allow for individual tracking of animal health & welfare from farm to fork, and provide reliable, easily accessible information to consumers and stakeholders in the industry. This will require the aggregation of multiple welfare and health indicators into a limited number of indices, and multi-level benchmarking.
- » Development of databases for, e. g. physiological and behavioral data aimed at identifying indicators for animal welfare. Creating farming environments that meet the animals' needs for abiotic and biotic factors, including enriched housing conditions; access to high quality feed and water; microclimate for thermal comfort; 'positive' human-animal interaction; promotion of a strong mother-offspring relationship; and group structures that minimize aggression while maximizing the stress-buffering effects of social support. Special attention should be paid to deepening the knowledge of the cognitive and emotional capacities of the animals.

- » The interaction of animal health & welfare with immune system physiology (neuroimmunomodulation), with a special focus on resilience to stress and disease. The role of the microbiome, especially in the gut, needs to be investigated, as well as potential epigenetic mechanisms regulating animal health & welfare. New approaches for preventative medicine, instead of disease therapy, need to be established in order to come to an increased level of health, and therefore a reduced, more efficient use of therapeutic drugs. This includes management practices for identifying individual risk factors in different housing systems to enable system-specific, regional solutions.
- » Best practices to reduce resource use and increase efficiency while maintaining high levels of animal welfare and health. This includes land use for growing animal feed as well as water use and water contamination. Efficient but sustainable animal nutrition that meets the animals' needs must be at the core of future farming.
- » Breeding programs that focus on animal health & welfare, resilience to stress and disease and robustness in diverse farming environments. The former focus on productivity alone must be replaced, or at least be accompanied by aspects that will safeguard socially acceptable, economically feasible animal farming in the future.
- » Initiatives to better inform the general public are needed to raise the awareness for current issues, possible solutions, and the cost at which they come. Consumers should be able to make informed decisions when purchasing animal-derived products and value the efforts the industry takes to provide high-quality, safe, sustainable, and ethically acceptable products while being able to make a living.

Expected outcome

The outcome of the research topics outlined above shall lead to sustainable, ethically acceptable, economically feasible livestock production systems that make minimal impact on the environment and climate while supplying the population with safe, high-quality products. Based on the One Health idea, farm animal health, and especially a shift from therapeutic interventions to disease prevention, can make a significant contribution to human health.

D.2.6 ICT, robotics and Big Data

New technologies in ICT, robotics and Big Data have already been introduced in the livestock production sector several years ago. Mainly dairy sector technologies (milking robots) and animal welfare technologies have successfully been adopted in the daily farm management. New technologies in ICT, robotics and Big Data may have the potential to become some of the most promising system components to make livestock production more sustainable.

This research area may include:

- » Further integration of animal monitoring systems for animal health & welfare and environmental issues. Linkage with decision support systems to take actions. Use of Artificial Intelligence (AI) technology and self-learning algorithms (smart dashboarding) to optimize the decision support systems.
- » Integration of robots into farm management systems in order to support autonomous operation of farms and allow better integration into the data streams along the entire value chain (primary production to consumers), better production on demand and new forms of marketing, retail and consumer contact.
- » Use of ICT technologies and Big Data to optimize feed intake, reduce emissions, assess animal stress and health, and avoid food losses; use of these data for information along

the value chain incl. farm and supply chain management, traceability, transparency (authenticity, cold chain, food safety, tracking and tracing, animal welfare, environmental footprints, etc).

- » Data-economy, importance of data to be findable, accessible, interoperable, and re-usable (FAIR data), protection and transparency: strong guidelines and openly available data from publically funded research, clear instructions (regulations) on data ownership and data sharing. Most data and information sources are fragmented, dispersed, difficult, and time consuming to use.
- » Understanding what is necessary to implement and adopt ICT, robotics and Big Data technologies better into the daily farm management. While there appears to be a widespread agreement on the significance of digital agriculture for more sustainable practices, currently there remain many challenges demonstrating the added value (especially for small stakeholders) and encouraging adoption.
- » Gathering insights on the performance in areas with lower coverage, or upgrading options. ICT is mainly designed for use in a well-developed communication infrastructure with 4G/5G coverage.

Expected outcome

By integration of a systems approach and broader adoption, the use of technology and ICT will have more impact on the challenges that the sector is facing and on the sustainability of the sector in all terms.

D.3 Conclusions regarding system components

Because components of livestock production systems are, by definition, interconnected, it is obvious that more than one component needs to be involved to address the challenges comprehensively. Further, the political and socio-economic system components are here regarded to be at least as important as the agricultural and technical system components are for a transformation towards more sustainable livestock production systems.

E. Knowledge transfer (AKIS) and systems approach

The Commission proposal for the future common agricultural policy (CAP) regulation 2021-2027, comprises a cross-cutting objective (Article 5), which seeks the modernization of the agricultural sector through the promotion of knowledge, innovation and digitalisation in agriculture and rural areas, in particular by means of CAP Strategic Plans developed by Member States (MS).

With regard to “Agricultural Knowledge and Innovations System (AKIS)”, this includes:

- » A description of ‘the organisational set-up of the AKIS designed as the combined organisation and knowledge flows between persons, organisations and institutions who use and produce knowledge for agriculture and interrelated fields’, as well as
- » A description of ‘how the advisory services, research and CAP networks will work together in the framework of the AKIS, and how advice and innovation support services are provided.’

AKIS comprises the entire value-added chain from primary production to consumption including players such as processing, retail, storage, markets, trade and humans/society in general. It is human interaction that generates information and knowledge flow at all system levels and forms – from a single field/barn to regional production cooperatives (i. e. mixed farming) to national and global markets with thousands of players involved. To facilitate the transition to a system-based, circular livestock production with the involvement of multiple players, a multi-actor-approach (MAA) in research & innovation is required. Prominent examples exist such as the EIP-AGRI network with its operational groups, the INTERREG-system, pilot and lighthouse projects, or more recently the living-lab (LL) approach.

Living labs (LL) are planned to be used in several new large-scale initiatives in Horizon Europe. Common components of LLs are:

- » Active involvement of the users so that they are empowered to thoroughly impact the innovation process.
- » Testing and experimentation in real-life communities and settings.
- » Participation of a multiplicity of stakeholders (i. e. the involvement of technology providers, service providers, relevant institutional actors, professional or residential end users).
- » Use of a multiplicity of methods and tools originating from a range of disciplines and domains.
- » Co-creation, co-design and co-development using iteration of ideation or design/implementation/evaluation cycles with different sets of stakeholders.

In conclusion, the strategic approach described in this agenda (chapter C) is matched by the aforementioned AKIS elements. In many member states the AKIS consists of multi-layer sub-systems forming an intertwined whole. Therefore, an integrated and interdisciplinary approach is needed to facilitate any major transformation towards a system-based livestock production, including performance and innovation. Digitalization is seen as an important crosscutting element, and should serve as a common tool. Livestock research activities under Horizon Europe and EIP AGRI should be linked more closely in the future.

F. General conclusions

Livestock is an important part of European agriculture and its cultural landscape and it will continue to be so in the foreseeable future. However, due to issues like biodiversity, animal welfare and global warming, there is wide agreement among European governments that a new balance has to be found between the environmental, economic and societal aspects of the agri-food system, including livestock.

This huge task cannot be accomplished without significant input from research. Research and innovation is a key issue to support the transition pathways towards a more sustainable and balanced livestock production in Europe. Applied research will have to take a systems approach, involving multiple disciplines, stakeholders, AKIS, and different scales, from animal level to European level and beyond. Finding solutions in a complex world requires research to facilitate an optimisation process with multiple objectives (e. g. food security, biodiversity etc.), thereby being able to quantify synergies and trade-offs between the challenges. In addition, new methods are needed to evaluate the performance of livestock production at system level. The multi-actor approach enables the involvement of all relevant actors along the added value chain (farmers, advisors, processors, companies, retailers, consumers).

Even though many on-farm solutions need to be adapted to local conditions, networks like the ERA-NET SusAn have shown the importance of being able to gather different actors, to initiate cross-border research and to give advice to Member States and the European Commission.

Last but not least, implementing sustainable livestock production requires a political and socio-economic framework that supports sustainable practices. Regional, national and European policy makers have to offer a “secure economic environment” for all actors who are involved in the transformation of the livestock sector.

G. Annex 1. Existing European research and networks

G.1 CWG-SAP and SusAn

Collaborative Working Group on Sustainable Animal production (CWG-SAP)

The CWG-SAP was established under the SCAR (Standing Committee for Agricultural Research) of the European Commission and first met in January 2014. It recommended and prepared the establishment of the EU-cofunded European Research Area on Sustainable Animal Production Systems (ERA-NET SusAn) in 2016.

The focus of the ERA-NET SusAn and the CWG-SAP are clearly distinguished. The CWG-SAP scope is broader than SusAn's, with a long-term vision to help shape policy and support science. SusAn's focus is on research and innovation results and strategies.

The ERA-NET SusAn officially started on 1 March 2016. When the ERA-NET SusAn was prepared, thinking was still influenced by the “three pillars” concept of sustainability of the UN 1992 Rio Conference on Environment and Development. In late 2015, when SusAn already was well on its way, the UN Agenda 2030 and the Paris Agreement, COP 21, were finalised. Here, economic, environmental and societal dimensions were intertwined and cut across the entire framework. The SDGs and the COP21 Agreement address both, developing and developed countries.

Simultaneously, in late 2015, the EC launched FOOD 2030, a research and innovation (R&I) policy response to the international developments described above. FOOD 2030 presents a single thematic R&I narrative by looking at “*food systems*”, exploring what is needed to “*transform and future-proof*” them. Keywords are nutrition, climate, circularity and innovation.

SusAn's original systems approach was put into a wider context, making European livestock production a subsystem of a larger food system with not only regional and European dimensions, but global dimensions as well, not least in terms of economy, food security and global warming.

SusAn has embraced this approach from its beginnings and has been advocating a paradigm shift in animal science, towards systems thinking, interdisciplinarity and a cross-scale approach, which includes, but also goes beyond the single animal, or a herd or flock. SusAn has been promoting concepts like circularity and agro-ecology.

In May 2020, the Farm to Fork Strategy, a central part of the European Green Deal, was published. The overarching aim of the Green Deal is to make Europe climate neutral by 2050, while at the same time checking the use of resources, protecting and restoring biodiversity and increasing the awareness of healthy diets. The Farm to Fork Strategy contains quantified targets regarding the extension of organic agriculture, reduced use of pesticides, fertilisers and antimicrobials, reduced nutrient losses and food waste, as well as the aim to label sustainable food. The strategy further dedicates EUR 10 billion for related research and innovation.

The development of sustainable livestock production systems can make significant contributions to these targets.

In December 2020, the SCAR published its 5th Foresight Exercise report titled “Resilience and transformation (Natural resources and food systems: Transitions towards a ‘safe and just’ operating space)”. The SDGs are used as common reference to answer the question how to better manage natural resources and food systems. The authors identify and elaborate on three major areas for change: 1. Healthy, sustainable diets for all, 2. Towards a ‘circular’ food supply and 3. Towards greater diversity.

The SusAn CSRIA follows the analysis of the SCAR Foresight Exercise and builds on its conclusions. For example, research and innovation on circularity and diversity as features of live-stock production systems are proposed in chapter C.3.

SusAn launched a call with cofund from the EC in early 2016 and subsequently two other, non-cofunded joint calls, in 2018 and 2020, together with the ERA-NETs FACCE ERA-GAS, ICT-AGRI2 / ICT-AGRI-FOOD and SusCrop: www.era-susan.eu

2016 Call

Topics: *Research Area 1*: Improve the productivity, resilience and competitiveness of European Animal Production; *Research Area 2*: Improve and manage resource use to reduce waste and enhance the environmental sustainability of European Animal Production; *Research Area 3*: Improve on-farm practices to enhance consumer acceptability and address societal challenges associated with animal welfare, product quality and safety, biodiversity and provision of ecosystem services.

2018 Joint Call

Topic: On novel technologies, solutions and systems to reduce greenhouse gas emissions in animal production systems.

2020 Joint Call

Topic: Circularity in mixed crops and livestock farming systems with emphasis on climate change mitigation and adaptation

G.2 Related European and international initiatives

Present and past European and international initiatives concerned with research on sustainable livestock production between 2008 and 2021 were mapped, resulting into 96 documents: fact sheets, strategic research agendas and foresight studies.

The most prominent gaps mentioned in the documents were the lack of a systemic or holistic approach towards food systems, including the participation of stakeholders. Moreover, gaps regarding the research in animal health & welfare were mentioned, such as lack of research regarding diagnostic tools and vaccines. Also, lack of research regarding the transformation of food systems to circular systems, integrating, for instance, agroecology and regional protein feed, was identified, and the need for precision livestock farming, with the aim to minimize emissions and to restore ecosystem services (e. g. soil health, biodiversity).

The distribution of the keywords and the gaps mentioned in the documents support the view that livestock production should be seen as part of a wider system (food system) and that there is a need for an interdisciplinary approach. A detailed report on mapping and gapping can be found in SusAn's Report on research in the field of sustainable animal production (Deliverable 6.4).

Thematic links with future partnerships

For the future, thematic links are foreseen with the following European Partnerships:

4. Food Systems (European partnership on safe and sustainable food systems for people, planet & climate)

5. Agroecology (Accelerating farming systems transition: agro-ecology living labs and research infrastructures)
6. Animal health (European Partnership for Animal Health)
7. Agriculture of data (Environmental observations for a sustainable EU agriculture)

G.3 Analysis of recent EU funded research in livestock production systems

EU funded research projects with content related to SusAn were mapped. Aim of the study was to find any hints on how many of the projects revealed any system approach. The analysis was based on the projects' abstracts. The abstracts were manually subjected to a systematic qualitative analysis, using the software MAXQDA. The projects were selected from websites and databases of EU Framework Programmes for Research and other research initiatives after 2002 (FP6, FP7, H2020, LIFE, ERA-NETs, JPIs and EIPs). More than 3,600 research projects were screened and 962 projects were finally included in the analysis.

Only a minority of project abstracts specified the animal husbandry system under investigation. Different husbandry systems, possibly addressing some kind of system comparison, were specified even less often.

Beside the specification of the husbandry system(s) under investigation, another coding category for the qualitative analysis was the level or scale of a production system that the research project was conducted at. Here, the majority of projects focused on animal/herd/farm level, which was the lowest level-category. Levels above that scale were found to a much lesser extent, and, again, consideration of two or more levels in a project was rarely mentioned in the abstracts. This suggests that also only a minority of projects took a cross-scale approach.

It was not possible to identify further hints of applied system approaches, except for a significant number of projects dealing with ruminants and extensive grazing in relation to nature conservation and biodiversity. However, these were primarily LIFE projects, and the described association was not prominent within the other funding frameworks FP6, FP7, Horizon 2020 and ERA-NETs, JPIs or EIPs.

For a detailed report see SusAn's Report on research in the field of sustainable animal production (Deliverable 6.4).

G.4 Literature review – Research on animal production systems

From the middle of the 20th century, agricultural production has increased significantly based on high-yielding crops and livestock breeds due to improved breeding, use of inorganic fertilizers and pesticides, improved and increased mechanization, larger specialized farms and for livestock, indoor production with improved feeding and use of antimicrobials and vaccines. This intensification of agriculture has posed environmental challenges, contributed to loss of biodiversity and to greenhouse gas emissions.

Livestock production in Europe is diverse and depends on conditions and traditions. Various livestock production systems e. g. conventional, organic, extensive and silvopastoral have different characteristics to be considered in evaluating the overall sustainability of the systems. Principles for a sustainable agricultural production supporting food security are outlined for agroecological production including organic farming and for sustainable intensification.

In line with the European protein plan, proteins extracted from legumes and green biomass can replace imported soy protein for animal feed while providing ecosystem services for increased sustainability. A shift from a linear to a circular approach in agricultural production based on ecological principles with integration of crop and livestock production will similarly support sustainability. Life cycle analyzes (LCAs) that assess the environmental impact of livestock production must include resource use and emissions, but also ecosystem services as well as economic and social aspects for a fair evaluation.

Research in livestock production and its results shall contribute to food security and safety, mitigation of greenhouse gas emissions, protection and restoration of biodiversity, efficiency in use of natural resources and improved animal health & welfare. Solutions to these complex problems must be based on research with a systems approach.

For the full literature review see SusAn's Report on research in the field of sustainable animal production (Deliverable 6.4).

G.5 Conclusions regarding existing research and networks

There is agreement among European and international initiatives concerning livestock production that a systemic approach towards food systems and research to support the transformation of food systems is largely missing and needed. These initiatives also find that livestock should be seen as part of a wider food system, including all stages of the value chain, from primary production to waste management.

A systems approach to livestock production has been the core of the SusAn approach from its beginnings, including its 2016 cofunded call. The ERA-NET SusAn started to fill an important gap in the European Research Area.

H. Annex 2. Challenges in European livestock production

Referring to chapter B, the challenges presented in this annex were selected based on the SDGs. Priority was given according to their relevance for European livestock production systems.

H.1 Food and nutrition security

H.1.1 Prevalence of undernutrition and obesity

- » Today, one in nine people in the world suffer from hunger and every third person is overweight or obese.
- » In the European Union, the major problem is the increasing number of obese, which has doubled between 1980 and 2008 and is foreseen to further increase in the coming years, also globally.
- » The adoption of healthy diets can significantly contribute to reducing health costs and climate-change costs.
- » The implementation of effective obesity-prevention policies has been slow and inconsistent.

H.1.2 Nutrition recommendations and the value of food of animal origin

- » A healthy diet includes a wide variety of foods, mainly plant-based food products (fruits, vegetables and whole grains), fish, moderate amounts of dairy products and eggs and limited amounts of meat.
- » EU average meat consumption is around 69 kg per capita and year, which is more than twice the amount recommended (upper limit) by e. g. UK Scientific Advisory Committee on Nutrition & World Cancer Research Fund.
- » High meat intake has been positively associated with obesity prevalence (Wang & Beydoun, 2009; You & Henneberg, 2016).
- » Poor diets are thought to be responsible for 49 % of the burden of cardiovascular disease, which remains the leading cause of death in the EU (Wilkins et al., 2017).

H.1.3 Food security, trade and food sovereignty

- » Globally, access to food is not even, which also is an issue of equality and power (IFPRI, 2015).
- » Meat and milk production of some European countries significantly contributes to the global market (OECD-FAO, 2016). While international trade may benefit consumer prices, it may also put local producers under financial pressure, both, in Europe and elsewhere. For low-income economies, a restriction of local production could increase the risk of future food-shortages (BMEL, 2015; Reichert & Thomsen, 2019).
- » Regarding humanitarian food assistance to low-income economies, the EU prioritises “restoring self-reliance by building resilience and protecting the livelihoods at risk of food shortages” (EC, 2013).

H.1.4 Relation between consumption patterns and food security

- » Global meat consumption doubled during the past 20 years. Population growth and increasing wealth in middle-income countries are the main contributors to this development (OECD-FAO, 2021).
- » Sustainable and healthy diets are regarded as key for achieving food security and environmental sustainability (Bajželj et al., 2014).
- » It is estimated that food loss and waste represent one third of global food production (Gromko & Abdurasalova, 2018).

H.1.5 Agricultural potential and food security for 10 billion people

- » There is common agreement that global food production will have to increase until 2050, including increased production of food of animal origin in some areas. At the same time, it is essential to substantially decrease food waste and food losses. Europe's current domestic food production potential has been estimated to be theoretically sufficient to feed its population (Zahrnt, 2011).
- » Neither Europe's population nor its food consumption is expected to grow significantly between now and the year 2050.

H.1.6 Ecological resilience, incl. adaptation to climate change

- » Due to climate change, livestock will have to cope with increased average temperatures and more frequent extreme weather events, e. g. droughts and heat stress.
- » The diversity of livestock production systems, combined with a diversity of species, provides ecological and economic resilience, i. e. the system's ability to absorb disturbance, to the entire agriculture and food sector.
- » Opportunities to adapt and improve production of farmed animals lie within, for instance, housing and management tools (digitalization, sensor-, robot- and biomarker-supported care) and animal breeding (genomic selection, genome editing, epigenetics).
- » Resilience of the individual animal is linked to endogenous allocation of resources and the degree of freedom available to cope with challenges. In this context, the question arises of the extent to which it is possible to increase the productivity of livestock, while preserving resilience, welfare and health.

H.2 Emissions and livestock farming

H.2.1 Greenhouse gases

- » In 2019, the European Parliament declared a global "climate and environmental emergency" and the new Commission set as its headline ambition to become a climate-neutral continent by 2050 (EU, 2021), targeting to reduce net GHG emissions by at least 55 % by 2030 compared to 1990.
- » It is estimated that food systems are responsible for a third of global anthropogenic GHG emissions, amounting to 18 Gt CO₂-eq per year globally (Crippa et al., 2021), while recent estimates by the FAO attribute just over 8 Gt CO₂-eq per year to global livestock supply chains (FAO, 2017).

- » Across the livestock supply chain, emissions from feed production and processing (45 %) and enteric fermentation from ruminants (39 %) dominate, with much smaller contributions from manure storage and processing (10 %) and the processing and transportation of animal products (remaining 6 %) (Gerber et al., 2013).
- » Methane (CH₄) is the most significant GHG within the livestock sector, accounting for about 50 % of total global emissions, followed by nitrous oxide (N₂O) and carbon dioxide (CO₂) which represent almost equal shares (24 % and 26 %, respectively) (FAO, 2017).
- » On a global basis, fossil fuel supply chains account for 35 % of human-driven methane emissions, 40 % are coming from agriculture and the remaining 25 % from waste and other sectors (Chandrasekhar, 2021).
- » In the EU, livestock-related GHG emissions declined from 1990 to 2015, including a 22 % decrease in methane enteric fermentation emissions, caused mainly by a reduction in livestock numbers (Eurostat, 2017).
- » The EU livestock sector is highly dependent on imports of animal feed, particularly soybean products, which means that, in a sense, GHG emissions are exported by Europe (Brunori et al., 2020). Both cattle and soya have been linked to significant global tree cover loss, often concentrated in the tropics, having major negative consequences (eg. carbon sequestration, biodiversity loss) (World Resources Institute, 2021).
- » Within the livestock sector, there is potential to mitigate GHG emissions through more efficient use of resources, low carbon energy production and soil C sequestration (grassland, agroforestry techniques) (EC, 2020b). However, decreasing livestock-related non-CO₂ emissions remains challenging.
- » Pathways to improve livestock sustainability, including GHG emission reductions, largely fall into three areas: (i) improving efficiency, which can contribute to reduced GHG emissions per unit product; this includes, among other topics, feeding strategies, genetics, incorporation of precision techniques and ICTs applied to livestock; (ii) substituting high impact inputs with lower impact alternatives, such as N-fixing legumes and sustainable use of pastures, and (iii) a more fundamental redesign of agricultural systems involving shifts from linear approaches to circular approaches (EC, 2020b), including boosting the safe management of manures.
- » It was estimated that farmers could achieve GHG reductions of 30 %, for example, if they adopted the technologies and practices currently employed by the top 10 % of farmers with the lowest GHG emission intensity (Gerber et al., 2013).
- » Individual food choices that result in sustainable and healthy dietary patterns are considered to be potentially more effective than technical agricultural GHG mitigation options (Lindgren et al., 2018; Nemecek et al., 2016; IPCC, 2019).

H.2.2 Nitrogen

- » Livestock manure is a valuable N-fertiliser that can replace mineral N-fertilisers to sustainably improve plant growth and soil quality when used according to soil conditions and plant needs.
- » Nitrogen surpluses are correlated with high regional stocking densities and can threaten local and regional water supplies.
- » One of the greatest potential for reducing N emissions per unit of animal product is the reduction of the crude protein content of the diet and introducing phase feeding strategies for pigs and poultry similar to those described for P (DLG, 2019, 2020).

- » Around 94 % of ammonia emissions in Europe originated from agriculture in 2015, mainly from activities such as livestock housing, manure storage, manure spreading and the use of inorganic nitrogen fertilisers (EEA, 2020).
- » Ammonia is an important precursor for secondary fine particles in the air (see also chapter H.2.6), and in addition, ammonia contributes to the nitrogen deposition which causes the acidification and eutrophication of soils and contributes to water pollution and eutrophication.
- » To reduce ammonia emissions from livestock production, several policies have set boundaries (ceilings of emissions, regulations) and national and international (IPPC) monitoring programs. Despite these efforts, ammonia emissions have only decreased by 5 % from 2005 to 2016 within the EU-28 (Giannakis et al., 2019).

H.2.3 Phosphorous

- » Despite increased efficiency during recent years, livestock production remains an important user of P and also a source of P losses (via excess P fertilization through manure, erosion, run-off or leaching) to surface waters from rural areas which causes eutrophication and ecological deterioration. (van Krimpen et al., 2019; EEA, 2005).
- » It is expected that climate change will accelerate the loss of nutrients from soils.
- » In contrast to nitrates, there is no European Directive or other European regulation concerning P application in agriculture and P losses from agricultural land.

H.2.4 Copper and Zinc

- » Copper (Cu) and zinc (Zn) are essential trace elements for plants, animals and humans. However, these heavy metals reappear in the faeces and can accumulate in the soil, reaching levels toxic to some animals and soil organisms and giving rise to long-term environmental concern (Gooneratne et al., 1994; Hill & Shannon, 2019; Monteiro et al., 2010).
- » Both in swine (nursery pigs) and poultry production (broilers), pharmacological Cu additions to the diet improve their performance. In pig production, feed efficiency and growth in nursery, growing and finishing pigs is improved (Barber et al., 1957; Arias & Koutsos, 2006), possibly by the bactericidal and/or bacteriostatic effects of copper on the gastrointestinal tract microbiota (Jensen, 2016). Also Zn is commonly fed for pharmacological reasons, to stabilise performance and wellbeing of monogastric livestock (Brugger & Windisch, 2017).
- » In order to reduce the environmental affect of these two heavy metals from livestock production European authorities reduced the allowed upper limits for Cu and Zn in complete feed. (EFSA, 2016).

H.2.5 Antimicrobials and pathogens in urine and feces

- » Between 20 % and 90 % of antibiotics administered to livestock pass into urine and faeces, either unaltered or as a metabolite with potential antimicrobial activity (Filippitzi et al., 2019; Chee-Sanford et al., 2009; Spielmeyer, 2018).
- » Antibiotic residues may potentially impact soil and water microecology and the environmental microbiome. Recent research has shown that even small antibiotic residues in soils can spark the development of additional antibiotic-resistant bacteria.

- » Manure may not only contain antibiotic residues but also parasitic diseases, non-food borne zoonoses and pathogens. In livestock manure, there are several bacterial pathogens shed capable of causing disease in humans, including *Escherichia coli* O157:H7, *Salmonella* and *Campylobacter*, all of which are affected by antibiotic resistance (EFSA & ECDC, 2018).
- » This led to growing concern about the entrance of antibiotic residues into soil, ground water (leaching) and surface water (run-off), as well as plant uptake (Huygens et al., 2021; Kivits et al., 2018; Van den Meersche, 2019). Pathogens, antibiotic-resistant bacteria and antibiotic residues may reach livestock or humans when raw manure is spread on arable lands, which may eventually lead to untreatable diseases for both animals and humans.
- » Safe management of manure is vital to prevent spillover of infectious or parasitic agents and resistant microbial strains and genes into the environment and ultimately into the human domain.

H.2.6 Bioaerosols

- » Bioaerosols are airborne compounds or microfragments from plant or animal matter, or from microorganisms. They also comprise whole microorganisms that are either dead or alive. They can have an impact on the welfare, and performance of animals and on the health of humans and animals.
- » Some constituents of bioaerosols (aeroallergens) can represent external stressors (Art & Lekeux, 2005) and be responsible for pulmonary disorders such as asthma (Bond et al., 2017) or bacterial or fungal lung diseases (Duquesne et al., 2017; Greppi et al., 2017).
- » The environment thus plays a key role in the development of respiratory diseases (see also chapter H.2.2: NH₃ as precursor of particulate matter formation).

H.3 Resource use and livestock farming

H.3.1 Energy and nutrient use

- » Animals accelerate nutrient cycling within the ecosystem due to a rapid return of plant nutrients to the soil.
- » As a rule of thumb, in a food chain, only around 10 % of the biomass and energy is passed on to the next trophic level (plants, herbivores, carnivores). From this perspective it is often significantly more efficient for humans to eat plant based diets, if the plants are digestible for humans.
- » Consideration of a feedstuff's (low) nutritional value for humans (e. g. grass), or the fact that the land used for feed production can only be used as grassland and not for arable crops, can change the assessment of efficiency (van Zanten et al., 2020). Efficiency may also be evaluated differently, when the origin of the feed (soya imports) or the animal's life-time productivity is taken into account, or if the (human edible) output is compared in terms of, for instance, protein and its biological quality (e. g. casein), instead of energy and biomass alone.

H.3.2 Soil and land use

- » 72 % of agricultural land in the EU, i. e. grazing land and feed production, is dedicated to feeding animals, about half of which is arable land (Buckwell & Nadeu, 2018).
- » Two third of the cereal crops grown in the EU are fed to livestock.
- » In 2011 the EU imported 70 % of its requirement for high-protein crop commodity. This accounted for about 14 % of the world-wide production of soya beans, and used about 15 M ha of arable land outside the EU (European Parliament, 2013).
- » Mixed crop-livestock farming systems have a high potential to build and maintain soil organic carbon stocks. This can especially be seen in organic mixed farms that include fodder legumes and grass-legume mixtures in their crop rotations (Urbatzka & Beck, 2015).
- » Organic soils (moor, fen) have widely been drained for agricultural use and are often used for grazing. If only 3 % of selected EU agricultural land was rewetted, GHG emissions from agriculture could be reduced by more than 20 %.

H.3.3 Water use

- » Water consumption for food production more than doubled between 1961 and 2000 (Wada et al., 2011) and it is estimated that this trend will continue.
- » The livestock sector has been considered one of the main causes of overuse of water reserves.
- » Feed production represents the segment with the most water use and the largest margins for improvement regarding water efficiency.

H.3.4 Antimicrobials use

- » Europe's Farm To Fork Strategy sets the goal of reducing AM sales used for farmed animals and aquaculture by 50 % by 2030.
- » Extensive action to reduce AM use has been taken since 2006. In European countries, the overall sale of veterinary antibiotics dropped by more than 34 % between 2011 and 2018 (EMA, 2020) without significant impact on productivity.
- » The overall global situation regarding AMR is still worrisome. Studies estimate that global AM use will increase by 69 % from 2010 to 2030, due to increased demand for animal-source food protein in middle-income countries (van Boeckel et al., 2015).
- » Excessive use of AMs threatens the efficacy of antimicrobials for successful future treatment of humans and animals as well as the integrity of the natural microbiome in the environment and the associated microbial ecosystem services.

H.4 Biodiversity and livestock farming

- » Biodiversity within the food system is under a strong challenge. In 2019, nearly 26 % of local livestock breeds were reported to be at risk of extinction (FAO, 2019).
- » Loss of genetic variation in livestock is potentially contributing to reduced fertility, fitness and resilience (FAO, 2019).
- » Mixed crop-livestock farming can widen crop rotations by including grass-clover ley and other fodder crops. This enhances crop diversity and can improve soil fertility, plant health and resilience (ATF, 2021; EC, 2020b; FAO, 2020; Lemaire et al., 2014).

- » Low-intensity livestock grazing is often associated with a high plant and insect species diversity (Marriott et al., 2009; Di Giulio et al., 2001).
- » Among the leading causes of the global mass biodiversity loss are: (1) Habitat change: e. g. deforestation for pasture and soya production, intensification of agricultural production, (2) Climate Change (3) Pollution of air, water, and land with manure (ammonia, nutrients, heavy metals, pathogens, drugs), and (4) Use of only a few high producing commercial breeds globally (Opio et al., 2011; FAO, 2019).

H.5 Rural livelihoods and livestock farming

H.5.1 Farm income and economic resilience

- » The development of livestock farms in industrialised countries is characterised by intensification of inputs and outputs, regional concentration and specialisation of activities and in Europe, this trend is continuing (Bowler, 1986).
- » The vast majority of those actions required to transform livestock production are associated with additional costs and a reduction of profits on farm-level, at least according to present standards. However, there are also examples of how reduction of GHG emissions can save money for farms: <https://www.teagasc.ie/media/website/publications/2018/An-Analysis-of-Abatement-Potential-of-Greenhouse-Gas-Emissions-in-Irish-Agriculture-2021-2030.pdf>
- » Animal diseases, like Avian Flu and African Swine Fever, show the potential of pandemics to severely disrupt markets and pose a specific threat also to more animal-friendly systems with outdoor areas.
- » Climate change, more extreme weather events and climate mitigation measures (especially rewetting of peatlands and associated reduction in ruminant/dairy livestock productivity) can result in lower yields and higher costs but also higher product prices in case of regional or global supply decreases.
- » Changes in international trade and the rising importance of self-sufficiency of the European continent – for example with regards to growing importance of China in international sourcing and production – can change price relations between products and alter cost of production levels.
- » Improvements of grazing systems seem to be potential exceptions where multiple wins in terms of productivity gains, environmental benefits, animal welfare improvements and increases of farm profits can be realised (FAO, 2019).

H.5.2 Working conditions

- » In the future, food safety, animal welfare and environmental standards will continue to increase, as will a growing trend in voluntary food quality and ecological labels, placing farmers under pressure to modify their working practices and comply with a growing number of rules, regulations and schemes.
- » Animal handling is responsible for one out of ten occupational related deaths in agriculture, primarily due to being attacked or crushed by animals (Doupbrate et al., 2013) or zoonosis such as MRSA and others (Lindahl et al, 2013; Donham & Thelin, 2016).
- » Social aspects, like work-life balance, security of income, or public reputation may significantly contribute to the quality of farmers' working conditions.

- » The slaughterhouse presents a work context with stringent and monotonous production routines, health hazards, and physical strain (van Holland et al., 2015). Temporary workers and contracts with external recruitment agencies have become widespread, increasing the vulnerability of workers by preventing trade unions from taking action (Hansen, 2018).
- » Meat processing was previously largely carried out by skilled butchers. Work at slaughterhouses has changed into an operation where each worker carries out small, standardised operations (Hansen, 2018).

H.5.3 Gender issues

- » Agriculture in the 20th century's industrialised countries was dominated by family farms and a "farmer and farmers wife" model, where the woman's work was less visible (Rosenberg 2015, Bas-Defossez & Pagnon, 2021). It is argued that this model is not a "natural" phenomenon but a social construct of the last century (Leslie et al., 2019).
- » The economic share of womens' work in the "farmer and farmers wife" model is not fully documented and, for instance, only partly reflected in income statements.
- » The share of women managing farms is on average around 30 % of farms across the EU-28, ranging from around 5 % in the Netherlands to around 50 % in Lithuania (Franić & Kovačiček, 2019). In the EU, farms run by women are on average 40 % smaller than men's and their income is on average 16 % lower (Michalopoulos, 2019).
- » There is an increasing amount of literature establishing a link between gender, sexuality and sustainability, especially regarding sustainable farming practices: Women and LGBTQ+ farmers play an important role in alternative and environmentally-friendly approaches (Leslie et al., 2019).

H.5.4 Demographics

- » In 2016, 32 % of farm managers in the EU were 65 years of age or more. Only 11 % were under the age of 40 years (Eurostat, 2018). The majority of EU young farmers are in countries with lower than average income levels, like Poland and Romania (EC, 2021a).
- » It is foreseen that many farmers may have no successors and that this may fuel the concentration in land use, i. e. fewer and larger farms (EC, 2021b).
- » Among the reasons why young people do not choose farming as a profession are a) poor income opportunities, b) long working hours and hard work c) attractive city life and d) the reputation of agriculture due to public concerns about, e. g., animal welfare and environmental effects (SURE Farm, 2020).

H.6 Animal health & welfare

H.6.1 Production related diseases

- » Production related diseases are health issues induced or exacerbated by managerial factors. Production diseases can include metabolic and nutritional diseases but are usually multifactorial (e. g. feed, housing, genetics, hygiene) and often also include infectious and genetic components, potentially necessitating antimicrobial intervention or even more drastic measures of infectious/zoonotic disease control. (Gilbert et al., 2021).

- » Common production diseases in slaughter pigs are, for instance, ear necrosis, respiratory signs, lameness and diarrhoea (Petersen et al., 2008), and in postpartum sows, it is MMA (mastitis metritis agalactia) (Karst et al., 2021). In dairy cows, the main reasons for culling are mastitis, fertility problems and lameness (Merck, 2020). The health of high yielding dairy cows can be compromised by digestion problems related to a high share of concentrates in the feed ration.
- » Production diseases reduce the efficiency of livestock production systems, biologically and economically, and thus create a much larger environmental footprint of livestock agriculture by the inherent waste of resources. German dairy cows have an average productive life of three lactations before they are culled. Biologically, however, they would reach their peak milk yield around their fifth parity or later (Hoischen-Taubner et al., 2021). The costs for replacement heifers at herd level therefore are accordingly high.
- » Tackling production diseases starts with acknowledging that a considerable number of animals are incapable of coping with the existing management and production environment. One way to approach the situation is to simultaneously take into account different levels (e. g. animal, herd) and different perspectives (e. g. biological, socio-economic) instead of focussing mainly on average herd or flock production (Hoischen-Taubner et al., 2021).

H.6.2 Zoonoses

- » The rapid increase in livestock populations in developing countries together with a trend towards larger-scale livestock production enterprises and greater intensification have increased the likelihood of disease.
- » International demand for livestock products and increased human movement and migration is leading to increased movement of livestock products and pathogens.
- » Global warming and land use change are major drivers by creating new conditions for pathogens, vectors and hosts.
- » Modern agricultural practices, such as the worldwide shift towards raising pork and chickens in confined animal feeding operations may be amplifying public health threats.
- » To address zoonoses, the One Health approach is recommended.

H.6.3 Animal welfare

- » Issues like long-distance transports of animals, killing male chicks of laying hen breeds or castrating piglets without anesthesia have been attracting public attention for years. Other issues, like lameness in broiler chickens, pigs and dairy cows also appear to be prevailing stubbornly.
- » Not only is animal welfare a complex topic in the field of animal science, it also involves an ethical perspective. Further societal and political pressure to alleviate the plight of welfare-poor livestock comes from animal welfare advocacy groups in EU MS and the EP itself.
- » Widely used as measures for welfare have been the so called five freedoms (FAWC, 1979), which include freedom from hunger and thirst, discomfort, pain, injury or disease, fear or distress, and the freedom to express normal behavior. In addition, it is commonly accepted that good welfare also includes the presence of positive experiences such as pleasure (Boissy et al., 2007).

- » Just like production related diseases, today's animal welfare issues are associated with the intensification of livestock production. Factors putting welfare under pressure are measures to reduce production costs, for instance, costs for labour and buildings (e. g. surface area in the stable), measures to increase productivity (e. g. genetic selection, minimised feed conversion ratio), and poor management of housing conditions (Gilbert et al., 2021; Dawkins et al., 2004).
- » However, improved animal welfare may also be financially profitable through (i) reduced mortality; (ii) improved health; (iii) improved product quality; (iv) improved disease resistance and reduced medication; (v) lower risk of zoonoses and foodborne diseases; (vi) farmer's job satisfaction and contributions to Corporate Social Responsibility; and (vii) the ability to command higher prices from consumers (Dawkins, 2017).

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