Brussels, 12 May 2023

COST 022/23

DECISION

Subject: Memorandum of Understanding for the implementation of the COST Action "European Network on Livestock Phenomics" (EU-LI-PHE) CA22112

The COST Member Countries will find attached the Memorandum of Understanding for the COST Action European Network on Livestock Phenomics approved by the Committee of Senior Officials through written procedure on 12 May 2023.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA22112
EUROPEAN NETWORK ON LIVESTOCK PHENOMICS (EU-LI-PHE)

The COST Members through the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action, referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any document amending or replacing them.

The main aim and objective of the Action is to foster the development, integration, organisation and practical implementation of technologies, tools, methods, approaches, models, expertise and resources useful to scan and interpret the animal phenome to paving the way for novel scientific knowledge and applications in the livestock production sectors. This will be achieved through the specific objectives detailed in the Technical Annex.

The present MoU enters into force on the date of the approval of the COST Action by the CSO.

OVERVIEW

Summary

As animal breeding relies on the availability of accurate and specific phenotype data to reach its goals, phenotyping is increasingly being recognised as a limiting factor in all applications of livestock genetics and genomics. The acquisition of relevant phenotypes is also fundamental to routine and daily management of livestock populations in order to optimise reproduction strategies, disease control and welfare of the animals. Consequently, this knowledge gap needs to be filled to facilitate long-term improvement and a sustainable landscape for livestock production. Phenomics is emerging as a major new technical discipline in biology. Phenomics is focused on one major aim: to systematically describe the phenome, referred to as the physical and molecular traits of an organism. This discipline can be defined as the ensemble of methodologies and technologies for the acquisition, analysis and exploitation of high-dimensional phenotypic data on an organism-wide scale. EU-LI-PHE will create a Europe-centred multidisciplinary, interconnected and inclusive community of experts that will enhance scientific collaboration, catalyse developments, and transfer livestock phenomics concepts and applications to improve the sustainability and competitiveness of the European livestock production sector. The Action will provide i) an overview of phenotyping technologies and infrastructures for applications in livestock phenomics, ii) approaches and methods for genome to phenome integration in livestock species, iii) computational resources and data analysis methods needed for this big data discipline, iv) a regulatory framework and a societal vision on livestock phenomics and v) a training environment for the benefit of the next generation of researchers in this field.

Areas of Expertise Relevant for the Action	**Keywords**
● Animal and dairy science: Agriculture related to animal husbandry, dairying, livestock raising, animal welfare ● Animal and dairy science: Databases, data mining, data curation, computational modelling ● Veterinary science: Databases, data mining, data curation, computational modelling ● Biological sciences: Biological systems analysis, modelling and simulation ● Electrical engineering, electronic engineering, Information engineering: Statistical data processing and applications using signal processing (eg. speech, image, video)	● Livestock ● Genomics ● Phenotype ● Breeding ● Big Data

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

- ● Advancing state-of-the-art high-throughput technologies and protocols required for deep phenotyping which can describe phenotypic information at multiple levels in farmed animals.
- ● Providing cross-disciplinary knowledge to develop new standards in phenotyping technologies, phenome data descriptors, phenotype ontologies, databases, data structures, storage and sharing, in line with open science policies.
- ● Evaluating available software and bioinformatic tools and defining methods for effective data mining, processing, summarisation, integration and visualization of genome/epigenome to phenome data in livestock.
- ● Exploring integrative dynamic responses and adaptations of animal phenomes to variable environmental factors.
- ● Exploring novel data integration and fusion approaches including omics and sensor data, images, videos and animal movement and sound data for generation and visualisation of complex system models of

livestock populations to facilitate prediction of interventions and outcomes.
● Investigating and proposing new applications for genomic selection and precision livestock farming (PLF).
● Exploring the regulatory landscape around livestock phenomics, including ownership of the data, open access data policies and intellectual property rights.
● Analysing stakeholder opinions and societal perceptions of innovations in this field for the reduction of negative impacts on the animals and on the environment (e.g., to increase resistance to infectious disease, improve animal welfare and reduce environmental impacts).

Capacity Building
● Providing well-trained Young Researchers and Innovators (YRI) and professionals in livestock phenomics and related disciplines that complement and complete the background and knowledge needed for the alignment of scientific progress and industry demands.
● Fostering the exploration and implementation of new training routes and methodologies, some of them based on e-learning environments, with the aim of widening career prospects of highly specialised researchers who can accumulate integrated skills on different disciplines around big data production and analysis, with an interdisciplinary vision.
● Stimulating new ideas and innovative methodologies in an open innovation framework to address new opportunities generated by livestock phenomics approaches with a comprehensive strategy of communication and dissemination and to benefit the whole scientific community, the relevant industrial sectors and all stakeholders, including policy and decision makers.
● Fostering the involvement and collaboration of teams from less research-intensive countries across Europe; promoting their inclusiveness, through the sharing of new knowledge around a network of opportunities focused on livestock phenomics generated by other COST Members and IPC with more developed research ecosystems.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. SOUNDNESS OF THE CHALLENGE

1.1.1. DESCRIPTION OF THE STATE OF THE ART

Myriad applications for genomic information in animal breeding and selection have emerged over the last decade. This is largely due to developments in high-throughput DNA sequencing and genotyping technologies. These new technologies have paved the way to consolidate improvement of livestock populations, with the final objective to design sustainable animal production systems. There is still the need to further develop species-specific genome tools and resources and to further expand their applications. The trajectories for these efforts have been already mapped by several international initiatives, funded projects, and consortia, including, for example, the Functional Annotation of Animal Genomes (FAANG) initiative. However, as animal breeding relies on the availability of accurate and specific phenotype data to reach its goals, phenotyping is increasingly being recognised as a limiting factor in all applications of livestock genetics and genomics (e.g., Rexroad et al., 2019; Pérez-Enciso and Steibel, 2021). The acquisition of relevant phenotypes is also fundamental to routine and daily management of livestock populations to optimise reproduction strategies, disease control and welfare of the animals and reduce the environmental impact of the animal productions (Halachmi et al., 2019). Consequently, this knowledge gap needs to be filled to facilitate long-term improvement and a sustainable landscape for livestock production that can help meet current challenges in line with the EU Farm to Fork strategy and the United Nations Sustainable Development Goals.

Phenomics is emerging as a major new technical discipline in biology. Phenomics is focused on one major aim: to systematically describe the phenome, referred to as the physical and molecular traits of an organism. This discipline can be defined as the ensemble of methodologies and technologies for the acquisition, analysis, and exploitation of high-dimensional phenotypic data on an organism-wide scale (Houle et al., 2010).

Phenotypic variation is produced through a complex web of interactions between genotype and environment, and accurate 'genotype–phenotype' map representations to study these interactions in detail cannot be reconstructed without rich phenotypic data (Houle et al., 2010). To understand the complexity of the relationship between genetic variation and phenotype differences for economically relevant traits, the underlying biological and physiological mechanisms should be explored by improving the description of the phenotypic information. Phenomic-level data are necessary to understand which genomic variants affect phenotypes, to understand epistasis and pleiotropy and to furnish the raw data that are needed to decipher the causes of complex biological phenomena (Houle et al., 2010). Complex traits that can be better understood with appropriate phenomics data include production and reproduction performances, disease resistance and disease progression, animal behaviour, robustness, and resilience. In addition, gene–environment interactions (G×E) can substantially modify animal responses and the expression of phenotypes. Collecting, combining, and using both high-density, multi-dimensional and continuous phenotypic data and environmental information are therefore among the major challenges to continuing progress that the livestock production sector is facing.

Animal phenotypes can be classified in different ways according to the level in which they are measured (e.g., cell, tissue, organ, or whole organism), the type of information that is recorded, the temporal acquisition of the information (e.g., a single event, a continuous event, or a combination of events) and the objective of the collected parameters. For example, targeted phenotypes can be dynamic (changing rapidly within short periods of time) or stable (minimal change across a predetermined time window). Depending on the level of analysis, phenotypes can also be classified i) as external or final phenotypes and ii) as internal or molecular phenotypes (endophenotypes). Examples of final phenotypes are performance, morphological, disease resistance and behavioural traits. Examples of molecular phenotypes are the level or the presence/absence of different types of biomolecules (and their modifications) in animal biofluids and tissues and so on. Final phenotypes are determined by the contribution and interplay of many molecular phenotypes (with multi-level relationships) and their interaction with environmental factors. As a consequence of the broad heterogeneity in phenotype classes, a wide array of scientific approaches and technologies can be used to capture and manage phenotypic information. For example, phenomics can benefit from the development and application of automatic sampling or non-invasive methods to obtain repeated sampling and images, records or continuous data collection (including photographs, videos, sounds, movement traces, and so on) from a part of an animal, the whole individual or a population at different stages, or on the final animal products to describe final external phenotypes with high resolution and in real-time. To capture internal phenotypes, phenomics can also use sequence-based and functional omics technologies to detect and quantify molecular phenotypes (e.g. DNA methylation, RNA transcripts, proteins, metabolites, microbiota, glycomics, etc.).

Considering the complexity of metazoan phenomes, it is extremely challenging to describe all relevant phenotypes in a livestock population. Despite recent developments in sensor technologies and analytics, there are some components of animal phenomes that cannot be acquired or that are too expensive or time-consuming to be measured. Therefore, phenomics will always involve prioritising what to measure and represents a balance between exploratory and explanatory goals (Houle et al., 2010).

The broad spectrum of phenotypes and the multiplicity of ways that they can be captured will inevitably produce very large quantities of heterogeneous and complex data outputs, placing phenomics firmly in the realm of data science and “big data”. We can therefore anticipate that, together with “astronomical” and “genomical” (Stephens et al., 2015), the term “phenomical” may be coined as a descriptor for very large phenotypic data sets. In this regard, phenomics is becoming increasingly important and attracting great scientific interest, particularly for investigations and applications in human biomedicine, animal models and agricultural species, including livestock (e.g. Watson et al., 2020; Kafkas et al., 2021; Tuggle et al., 2022). It may be predicted that phenomics will be either on a par with genomics or will be the most demanding biological discipline in terms of data acquisition, storage, distribution, and analysis.

In the agricultural sector, phenomics is rapidly expanding in plant sciences with a clear application in plant breeding (e.g., Yang et al., 2020). Currently, on a global basis, several plant growth and phenotyping facilities are either being established or are already in use. Alongside the development of these research infrastructures, several national and international networks have been established to support shared use of phenomics approaches and facilities in plants (e.g. Machwitz et al., 2021).

High-throughput phenotyping technologies are also growing in importance in livestock systems, due to their ability to generate real-time, non-invasive, and accurate animal-level information. Clear similarities but also differences are evident in phenomics approaches between plants and livestock. Despite the important role that phenomics can play in livestock, there are evident knowledge gaps compared to current progress in basic and applied plant science. This is because to-date, relatively few clear commercial applications have been recognized in animals, mainly due to i) the fragmentation of the livestock production sector and the heterogeneity of the production systems, ii) the large differences between species, iii) the technical complications associated with high-throughput phenotyping of non-static organisms, and iv) the need for further scientific advancements and knowledge to enhance the current state-of-the-art.

The major goal of phenomics in the livestock sector is to provide information critical to informed decision-making genetic improvement, as well as to improve on-farm management of animals through the lens of the precision livestock farming (PLF) concept (Cole et al., 2020; Schillings et al., 2021). For practical applications, novel phenotypes should be identified, standardized and their measurement be made economically feasible and automatable for electronic data collection (Baes and Schenkel, 2020). Development, application, and integration of high-throughput data assembly techniques derived from multiple research disciplines and targeting different biological levels are therefore urgently required. In addition, novel and repurposed analytics and computational approaches will be required to mine and interpret the vast data sets that will accumulate rapidly through application of phenomics to livestock production systems.

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Fine-scale high-throughput phenotyping of animals has been identified as a major obstacle to further progress beyond the current limits of the state-of-the-art (Rexroad et al., 2019). The development, integration, organisation and practical implementation of technologies and high-performance tools that can be used to scan the animal phenome (including both external and molecular phenotypes), together with the acquisition, interpretation and sharing of the resulting data, are major challenges to improving scientific knowledge of animal biology and livestock production systems. This knowledge will enhance genomic selection strategies and applications and help to implement PLF approaches. The animal phenome depends on the interaction between its genome and environmental conditions. Phenomics data should therefore be linked to high-resolution sequence and functional genome information to further expand implementation of genome-enabled breeding technologies. Livestock phenomics is a data analytics ("big data") discipline that is focused on livestock species (Koltes et al., 2019). It interacts with other big data fields in biology, particularly bioinformatics and computational genomics, proteomics, metabolomics, and metagenomics. Therefore, it is critically important that a wide-ranging and holistic approach is taken to develop, upgrade, enhance and adapt computational resources and infrastructures for applications in animal science.

The development and the application of phenomics in livestock clearly requires multi-disciplinary and multi-actor approaches to bring together different expertise, resources, and expectations. This will allow projection of a vision of the livestock production sector over the next 30 years. Livestock phenomics requires experts in many fields (e.g. animal breeding and genetics, animal science, animal feeding and nutrition, animal welfare, veterinary medicine, genomics, transcriptomics, metabolomics, proteomics, biomedicine, epidemiology, engineering, chemistry, physics, informatics, bioinformatics, database management, law, economics, and the social sciences) and animal science areas (e.g. researchers, breeding industries, associations, farmers and policy and decision makers). Therefore, there is a need to create a European-based network able to respond to the complex scientific, technical, and societal challenges that will need to be tackled in the context of livestock phenomics. The main aim of EU-LI-PHE is to create a Europe-centred multidisciplinary, interconnected, and inclusive community of experts from COST Members, COST Near Neighbour Countries (NNC) and International Partner Countries (IPC), involving researchers, industry representatives, policy makers and other relevant stakeholders. This multi-actor group will enhance scientific collaboration, catalyse developments, and transfer livestock phenomics concepts and applications to improve the sustainability and competitiveness of the European livestock production sector. Furthermore, EU-LI-PHE will generate and disseminate knowledge about emerging and innovative animal phenotyping technologies and approaches to dissecting, cataloguing, and understanding animal phenomes. It will also prepare the next generation of animal scientists for the advent of phenomics as a big data discipline. It will be interconnected with the other major 21st century biological disciplines and will communicate and inform decision makers and society at large about the foreseen and unforeseen novel innovations that will positively impact food security in Europe taking into account the reduction of the environmental impact of the livestock productions, as a consequence of the application of phenomics to livestock populations.

1.2. PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1. APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE OF THE ART

The development and application of livestock phenomics tools, methods and the data analytics approaches needed to best leverage high-resolution phenotypic information will require substantial investments in terms of time, human resources, and capital investments. The main challenges (**C**) in livestock phenomics for research and innovation that are largely unaddressed or, at least for some aspects, only partially addressed, have been grouped (**C1-4**) according to the proposed methodologies reported in the Implementation section:

C1) Phenotyping technologies: The limited knowledge on the potential of the currently available phenotyping technologies, their technological gaps and the lack of networked infrastructures and facilities that could provide high-dimensional phenotypic data on an animal-wide scale in different species, farming systems and analytical frameworks and conditions; the lack of standardization of the phenotyping technologies, methods and approaches and the absence of agreed protocols; the challenges derived by the lack of standards also in data acquisition and production and data transfer in and from different experimental and farming conditions and over the whole livestock production chains.

C2) Genome to phenome integration: The limited knowledge on the extent to which phenome and genome information can be interlinked and then used in livestock breeding/farming; the lack of methodologies/approaches to describe together and integrate these two levels of information; the limited knowledge on their relationships and interactions with environmental factors, including the management of paired data from these biological levels and the integration with environmental information.

C3) Computational resources and methodologies for data analyses: The big data that are generated by phenomics approaches and the needs to integrate internal and external phenotypes with other omics and environmental data create bottlenecks and burdens for data transfer, data storage, data management and data analysis; in addition, the methods to analyse, interpret and then use high-throughput genome-phenome information are still in their infancy; to overcome these limits, emerging opportunities can be derived in the future by the developments in computational capabilities.

C4) Economic impact, regulations, policies, and society: The overall direct and indirect current and future economic relevance of livestock phenomics needs to be properly evaluated to better address the regulation framework and all relevant policies. The challenge is to apply phenomics to contributing on the design of a sustainable livestock production sector, that is in line with societal expectations, focused on animal welfare and on the reduction of the environmental impact of the animal productions.

EU-LI-PHE will address the challenges related to the developments and applications of livestock phenomics for genomic selection and PLF. The approaches used will advance this and related fields by bringing together different scientific perspectives and expertise. EU-LI-PHE networking activities will promote the exchange of information between COST Members, NNC and IPC, the dissemination of results and the training of Young Researchers and Innovators (YRI). EU-LI-PHE will include international partnerships that will contribute to share and integrate expertise in different fields and areas of application for livestock phenomics. Representations from the livestock breeding industry and livestock production sectors will also be included in EU-LI-PHE. This will bridge research and innovation to practical applications filling the translational gaps.

1.2.2. OBJECTIVES

1.2.2.1. Research Coordination Objectives

To bring the coordinated activities of a multi-disciplinary Action that groups together experts in a variety of scientific, technological, and practical interactions, the following specific research coordination objectives (linked to the four main challenges: C1-4) will be achieved as follows.

1) Advancing state-of-the-art high-throughput technologies and protocols required for deep phenotyping which can describe phenotypic information at multiple levels in farmed animals (C1).

2) Providing cross-disciplinary knowledge to develop new standards in phenotyping technologies, phenome data descriptors, phenotype ontologies, databases, data structures, storage and sharing, in line with open science policies (C1 and C3).

3) Evaluating available software and bioinformatic tools and defining methods for effective data mining, processing, summarisation, integration and visualization of genome/epigenome to phenome data in livestock (C2 and C3).

4) Exploring integrative dynamic responses and adaptations of animal phenomes to variable environmental factors (C2).

5) Exploring novel data integration and fusion approaches including omics and sensor data, images, videos and animal movement and sound data for generation and visualisation of complex system models of livestock populations to facilitate prediction of interventions and outcomes (C3).

6) Investigating and proposing new applications for genomic selection and PLF (C3).

7) Exploring the regulatory landscape around livestock phenomics, including ownership of the data, open access data policies and intellectual property rights (C4).

8) Analysing stakeholder opinions and societal perceptions of innovations in this field for the reduction of negative impacts on the animals and on the environment (e.g., to increase resistance to infectious disease, improve animal welfare and reduce environmental impacts) (C4).

1.2.2.2. Capacity-building Objectives

To foster knowledge exchange and the developments expected under section 1.2.2.1, capacity-building objectives are as follows.

9) Providing well-trained Young Researchers and Innovators (YRI) and professionals in livestock phenomics and related disciplines that complement and complete the background and knowledge needed for the alignment of scientific progress and industry demands.

10) Fostering the exploration and implementation of new training routes and methodologies, some of them based on e-learning environments, with the aim of widening career prospects of highly specialised researchers who can accumulate integrated skills on different disciplines around big data production and analysis, with an interdisciplinary vision.

11) Stimulating new ideas and innovative methodologies in an open innovation framework to address new opportunities generated by livestock phenomics approaches with a comprehensive strategy of communication and dissemination to attract parallel and synergistic research fields and to benefit the whole scientific community, the relevant industrial sectors and all stakeholders, including policy and decision makers.

12) Fostering the involvement and collaboration of teams from less research-intensive countries across Europe; promoting their inclusiveness, through the sharing of new knowledge around a network of opportunities focused on livestock phenomics generated by other COST Members and IPC with more developed research ecosystems.

2. NETWORKING EXCELLENCE

2.1. ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

EU-LI-PHE will provide an open environment that will promote the development of new concepts and knowledge to overcome the phenotyping bottleneck in all the main livestock species to improve sustainability of the animal production sector overall. The inclusive and expanding networking philosophy of EU-LI-PHE will create fruitful opportunities for the sharing of interdisciplinary efforts between the scientific realm and the breeding and animal farming industries. The main framework around which the Action is organised – livestock phenomics – is very innovative and of great interest at present, not only for the animal production sector but also for the other technology-rich contexts where big data in life sciences are used. Considering that other international initiatives (AG2PI in the United States, focused on agricultural species; International Plant Phenotyping Network: IPPN – focused on plants) have been established it is the right time for a European initiative on livestock phenomics and EU-LI-PHE will fill this gap.

There is a very broad and rich body of knowledge and experience in several international research programmes (FP5-FP7, H2020, Horizon Europe, PRIMA, ERA-NET, Erasmus+, EIT, BARD, etc.) and network schemes (European and International Platforms, COST, etc.). However, the topic has been only partially explored in other EU projects (BovReg, Gene-SWitCH, GenTORE, GEroNIMO, IMAGE, TREASURE, iSAGE, SmartAgriHubs, Smarter, Feed-a-Gene, PILLOW, eu-PLF, GplusE, ECO-FCE, MARKTHEPIG, PIGWEB, Re-Livestock, etc.) and COST Actions (FAANG-Europe, RGB-Net, IPEMA, TEATIME, LIFT, etc.). None of these is specifically focused on the integral and specific approaches that are focused on livestock phenomics as described in this Action. EU-LI-PHE will enhance synergies between research activities in ongoing national and European projects throughout several COST Members and, additionally, will enable development of future joint projects among the participants. The collaboration, exchange of knowledge, and practical experiences of members will lead to scientific excellence in fundamental and applied research in livestock phenomics and, consequently, will result in competitive projects that contribute to the Horizon Europe Strategies. EU-LI-PHE will find synergies among existing national and European initiatives, such as ongoing projects, also considering regulations, intellectual property rights and societal vision on livestock phenomics. Coordinators of these running and past projects will be contacted and invited to EU-LI-PHE meetings and involved in relevant Working Group (WG) activities. EU-LI-PHE will also closely match a similar US initiative (AG2PI, Agricultural Genome to Phenome Initiative). AG2PI is a collaborative and multidisciplinary science engagement that combines advanced computing, automated high throughput phenotyping, genotyping and modelling to expand knowledge in phenomics related to the agricultural and breeding sector of the US. Within EU-LI-PHE, joint US and EU initiatives will be proposed. Besides AG2PI, EU-LI-PHE will also collaborate with the International Mouse Phenotyping Consortium (IMPC) and the IPPN and linked European and National initiatives on plant phenomics for exchange of ideas and sharing of common strategies. Coordinators/directors of these initiatives will be invited to EU-LI-PHE meetings and joint activities will be proposed and organised within the themes of the relevant WG.

A COST Action is the right funding mechanism to provide the momentum to foster the construction of a European-based network on livestock phenomics that can coalesce around the other relevant international and national initiatives. A COST Action centred on this emerging scientific field will largely benefit the actual and future EU-LI-PHE actors and stakeholders, since the flexibility and dynamic nature of the COST scheme will enable and promote the creation of a multi-disciplinary group of experts that can be adjusted according to WG activities and needs. Moreover, the COST Action has advantages over other EU funding mechanism/programmes: i) it can easily create a multi-disciplinary network that is needed to tackle livestock phenomics from several perspectives; ii) it can create training opportunities for YRI as well as for more advanced scientists and professionals that will provide the needed background to understand and exploit the emerging discipline of livestock phenomics; iii) it can create opportunities for knowledge transfer at different levels to benefit the development of new entrepreneurship skills and business models around livestock phenomics; iv) it can create opportunities to establish links with key operators/scientists/stakeholders/other related initiatives (AG2PI, IMPC, IPPN, other EU and national projects, etc.). Through these mechanisms, the obstacles and challenges limiting full development and exploitation of livestock phenomics will be smoothed and overcome.

Clearly, the required level of communication will need a framework like a COST Action. Additionally, COST Actions promote targeted mobility and interdisciplinary training environments around the main topic of livestock phenomics. The networking, strengthened by the organisation of Working Groups, workshops and international conferences, Short-Term Scientific Missions (STSM), interaction with and visits to innovative companies, training and development for professionals as well as postgraduate students in all COST Members, and NNC, will initiate new scientific collaborations and knowledge exchange between participants. At present, these are limited to some national/international collaborations but in small consortia of 2-3 partners that are not enough to generate sustainable improvement and development in this field. Networking will add value to existing national research budgets.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS, EXPERTISE AND GEOGRAPHICAL BALANCE WITHIN THE COST MEMBERS AND BEYOND

Networking is critical to achieve the objectives defined in this Action, especially in this case because livestock phenomics is essential for innovations in animal production systems. In particular, the exchange of knowledge, latest scientific results, and technological developments among the Action, involving both academia and industry of many countries will be key. This will be the engine for the Action that will also identify further research needs, enabling the development of appropriate grant applications to national and EU-funded research programmes. This will create a critical mass of research, exploitation, and dissemination capabilities, already interconnected with several international networks and initiatives [e.g., CIGR International Commission of Agricultural and Biosystems Engineering; European Federation of Animal Science (EAAP); European Association for Precision Livestock Farming (EA-PLF); International Society for Animal Genetics (ISAG); SmartAgriHubs Regional Clusters, Digital Innovation Hubs and Flagship Innovation Experiments; etc.], which will be further engaged to expand the mass of expertise of EU-LI-PHE. In addition, EU-LI-PHE will be actively involved in these networks' related events [Annual EAAP Conferences; ISAG Conference; World Congress on Genetics Applied to Livestock Production (WCGALP); European Conference on Precision Livestock Farming; U.S. Precision Livestock Farming Conference (USPLF); Animal Ag Tech Innovation Summits; European Farmers Congress; EuroTier, the world's leading annual trade fair for animal farming and livestock management; etc.] that will network many other experts, stakeholders and farmers. The Action will focus on collaboration, dissemination of current and new knowledge, mobility of researchers (especially YRI) and training. E-learning environments will also be used to enhance transfer of knowledge and reach a broad audience.

The backbone of the Action will cover expertise on all key aspects, from theory to experiment and the practical aspects of livestock phenomics. The participants will have backgrounds that encompass a broad range of complementary disciplines (e.g., animal breeding, genetics and genomics, all other omics sciences, animal welfare, animal husbandry, PLF, veterinary sciences, bioinformatics, data analytics, statistics, computing sciences, informatics, engineering, sensor technologies, Internet of Things, Information and Communication Technologies, agricultural economy and policy, law, intellectual property rights, science communication, etc.) that will make it possible to fully achieve the activities designed by the 5 Working Groups. Extension of the network within all COST Members, NNC. IPC and International Organisations will be of high priority as will the establishment of cross-European infrastructures devoted to livestock phenomics similar to that within initiatives that are already in place for plants (e.g., IPPN).

EU-LI-PHE will involve participants from different COST Countries, International Organisations and IPC to combine their research and development interests to generate and disseminate knowledge on livestock phenomics that would not be covered in a similar time frame by other funding mechanisms. This will allow the exchange of knowledge inside and beyond Europe with participation from the beginning by many Inclusiveness Target Countries (ITC) and aiming to enable the dissemination of scientific knowledge to less research-intensive areas.

ITC will play a key role in EU-LI-PHE as they will bring expertise not only in animal/vet sciences but also will provide the core of knowledge in several branches of computing sciences that will contribute substantially to the multidisciplinary approach of the network and to the development of livestock phenomics in the direction of big data discipline.

Furthermore, EU-LI-PHE will be based on a close collaboration between academia and the livestock industry that will be fully represented in the Action, which is focussed on addressing the real demands of the latter. Another pillar of the network will be the education and training by research of early career professionals and scientists promoting their mobility and exchange under the 4 main thematic areas identified by the corresponding 4 research-focused Working Groups.

The inclusion in the Action of IPC will bring their expertise, facilities, and relationships with the AG2PI initiative to coordinate research actions and share knowledge and technological solutions for the implementation of livestock phenomics. Dedicated meetings will be organised with the AG2PI board and members, and common e-training initiatives will be developed. The question of standardization of phenotyping protocols, systems, outputs, data production and analysis, and the definition of ontologies and data sharing policies will be considered for COST Members and IPC with the final aim to define standard operational procedures in livestock phenotyping and facilitate interoperability at international levels for livestock phenomics data and procedures. The importance of this harmonisation should not be understated, as a lack of harmonisation can fundamentally block both understanding and progress at an international level. These issues will be specifically addressed together with the AG2PI initiative. The Action focuses on a series of networking activities, scientific training and dissemination of new knowledge that will aid YRI from many countries, including NNC that have less-intensive research programmes.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

EU-LI-PHE has been designed with a multi-actor approach, from the identification of the main challenges and the definition of the objectives to the implementation of the task activities. The outcome of this Action will be derived from the coordinated activities of different categories of end-users and stakeholders including universities and research institutes, animal breeding industries, farmers and farmer associations, biomedicine experts, service providers, engineering enterprises, software houses, innovation stakeholders, policy makers, regulatory authorities and, finally, the society as a whole. EU-LI-PHE will provide an enhanced framework for cooperation among researchers, industrial partners, and relevant stakeholders, promoting the transfer of knowledge through the tasks proposed in the Action (workshops, conferences, meetings, dissemination activities, case studies, etc.). The Action will aim at the continual interaction with end-users.

One of the first outcomes of this Action will be to create a full list of both national and international stakeholders and organisations, including EU bodies, into domains of interest for livestock phenomics (e.g. ELIXIR, NCBI, FAO, Interbull, ICAR, COPA-COGECA, WOAH-OIE, EFSA, ISO, and European Technology Platforms and related initiatives, like Animal Task Force) and combine this with a list of relevant small- and medium-sized technological enterprises focusing on high-throughput phenotyping, production of sensors or provision of computational services and infrastructures. This list will be used to expand the EU-LI-PHE network. The community that will participate in this Action is expected to collaborate with several private companies. The list of all important stakeholders and technology companies will be made available and a mid-term stakeholder meeting will be organised. The outcome of the meeting will be a list of objectives and challenges related to the application of livestock phenomics concepts that will be also included in the final white paper and research and policy recommendations. Stakeholders will be also invited to participate to all meetings, workshops, and Training Schools. In addition, to capture the attention and involvement of the stakeholders, EU-LI-PHE will provide relevant information through the public website, social media networks, specific "Users Meeting Sessions" during the workshops, STSM, and reports and papers detailing important achievements and prospective results on the impacts and benefits of livestock phenomics. Finally, demonstrations/case studies developed together with interested companies will be proposed and carried out.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

EU-LI-PHE will connect many research groups across COST Members and IPC, particularly strengthening links for sharing expertise and infrastructures. EU-LI-PHE will also connect specialists in many research and applied fields to provide solutions to overcome the 4 main challenges related to i) phenotyping technologies, ii) genome to phenome integration, iii) computational resources and data analyses, and iv) economic impact, regulations, policies, and society. These aspects will make it possible to fully exploit the direct and indirect potentials of livestock phenomics in the technological, biological, computational, and economic/societal contexts.

At the end of the Action, it is expected that there will be a much wider network that has expertise and can cover one or more of these areas leading to scientific, technological, and socioeconomic progress, which will change the current state-of-the-art and fill the phenotyping gap with exploitable innovations. It is expected that short-term impacts will include an operative network of existing technologies, facilities and approaches available in livestock phenomics. The integration and developments of high-throughput phenotyping technologies will provide the biggest technological step forward in the long term and will change how animals are phenotyped and how the data generated are used and managed in the cascade that will impact all other areas including phenome to genome interactions, integration of environmental data and expansion of computational infrastructures that are expected to grow exponentially and improve substantially. EU-LI-PHE will have the needed critical mass and potential to support innovations in this sector and to establish a long-lasting network that will continue over the Action time.

At the end of the Action the successful execution of the work programme will ensure a set of new phenotyping approaches and methods, many novel phenotypes, large datasets, database design and implementation, and computational methodologies that will drive commercial applications and improve competitiveness of the European livestock production landscape. The first direct impacts will be in animal breeding and selection: phenomics will advance the sector in a similar way that genomic selection is currently doing. The application in this context will increase production efficiency in the main livestock species, giving the possibility to use novel and more precise phenotypes to enhance animal health and welfare and reduce the environmental impacts of the animal productions. In parallel, other direct impacts on the livestock sector will be also derived by the applications of PLF that can have on the farmers' income, and again on animal welfare and on the reduction of the environmental impact of the animal productions. In addition, the regulatory framework that will define questions on the data properties, intellectual property rights on innovations and access and benefit-sharing (ABS) will have positive impacts on the sustainable application of livestock phenomics. EU-LI-PHE will also impact relevant issues of concern at the societal level (animal welfare, reduction of environmental pollution and risk reduction for animal diseases and zoonoses that are important in a One Health context). An overall potential income for the EU livestock sector derived by these developments could be tentatively and prudently estimated of ~0.1% per year, for 10 years starting at the end of the Action. Projecting these values on EU statistics (an output of the livestock industry in the EU in 2020 of ~160 billion €) the impact could be ~160 million € per year. The impacts in other sectors are difficult to be estimated but they could be of similar value per year, at least.

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

At the MC1 meeting all mandatory responsibilities will be distributed and voted for by the Management Committee (MC) considering both ITC and career development of YRI and to ensure the scientific critical mass required for knowledge creation in the Working Groups (WG). This includes as a minimum selection of an Action Chair (AC), Vice-Chair (VC), Grant Holder (GH), Working Group leaders (WGL) and WG composition. A Science Communication Coordinator (SCC) is expected to have special responsibility to ensure two-way communication, knowledge transfer and engagement with the stakeholders and the Action. Other responsibilities such as managing the website, social media accounts, training schools, gender issues, early career scientist training, STSM, and producing thematic journal count, demonstration activities and the dedicated book will be coordinated by a Core Group (CG: constituted of the AC, VC, WGL and SCC), which can be expanded across the Action lifetime based on the scale of the tasks. At least 50% of the CG positions should be filled by YRI, with the inclusion of ITC members. During the Action there will be 4 Training Schools, several WG meetings and Workshops focusing on different WG activities. Inter-WG activities will be promoted to foster interdisciplinary cross-fertilization and development of new knowledge. These activities will be coordinated to ensure participation from ITC and YRI, considering the gender balance. The Action will also organise a large midterm stakeholder meeting. The scientific results obtained through these cooperative initiatives and exchanges will be published in high impact journals and/or patented. Support services from Enterprise Europe Network (EEN) will be exploited to expand the potential business opportunities related to the Action activities. To further support career development, EU-LI-PHE will implement a system to disseminate job positions, job searches (in academies, industries, and other entities), fellowships, traineeships, and other opportunities that will emerge within the network around the topic of the Action and related fields. This service will last at least 4 years after the end of the Action (curated by the AC, VC and SCC) through the EU-LI-PHE website, LinkedIn page, and mailing list. Demonstration activities will be organised to ensure novel transfers of knowledge and attract/involve scientists from different fields and stakeholders.

3.2.2. PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

Dissemination of the Action will be developed to target scientific users, stakeholders, the wider public, and private companies. This requires a multi-faceted approach so that each end-user will be provided maximum relevant information. The following methods will therefore be used in the Action:

1) A website, that describes the Action, and that is kept up-to-date with formal documents, open datasets, news, events, videos, activity summaries, communication materials (posters, brochures, etc.), newsletters and publications produced by the WG activities. The website will contain specific targeted sections for stakeholders, farmers and the wider public, including multi-languages sections. **2) Use of traditional and social media**, with dedicated accounts (Twitter, LinkedIn and YouTube) for the Action based on a defined social media strategy. **3) Annual meetings with invited experts and stakeholders** that will go beyond the large stakeholder meeting, also involving policy and decision makers. **4) Development of a special issue/section in a relevant open-access peer-reviewed journal** that will allow for submission throughout the Action lifetime. **5) Demonstration activities on the application and usefulness of phenotyping technologies and methods** specifically designed for different types of audience, including specialised audience, practitioners, farmers, breeding and farming industries and the general public. These demonstrations will be organised on-site (in presence), with real-time disseminations through the Action social medias and with recorded videos. Video pills and posters will be then produced based on these demonstrations. **6) A book on Livestock Phenomics** that will include basic and advanced chapters to benefit both experts and non-specialists. **7) Mapping of national and international stakeholders** and their relevance and activities in relation to livestock phenomics and provision of feedback to partners involved in relevant R&D and the policies and regulations that need to be developed.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

The activities of this Action will be carried out within 5 Working Groups (WG), each divided into tasks that organise specific activities and produce major deliverables. Participants will join the WG according to their specific field of expertise and research interests, although it is expected that there will be opportunities for cross-WG and cross-disciplinary interactions and collaborations. Cross-WG activities and collaborations will be promoted. This is a strength of the large network included in the Action. A brief description of each of the WG is provided below. Working methods, data collection processes and use/production of relevant open databases will be based on specific road maps defined within each WG and designed to better achieve the expected deliverables. Data needed in the different tasks will be derived from research projects and activities funded to the participating institutions involved in the Action.

WG1. Phenotyping technologies.

Main aims: i) Provide an overview of current phenotyping technologies and infrastructures that can be used for applications in livestock phenomics; ii) define a roadmap of the research needs to capture high-dimensional phenotypic information on an animal-wide scale.

Task 1.1. Phenotyping technology mapping. This task will list and assess existing technologies and platforms for high-throughput and large-scale animal phenotyping at multiple levels (including external and molecular phenotypes). Several aspects of the phenotyping approaches, technologies and strategies will be considered: the technological features and scientific background required; the possibility of application to different species and the modifications needed for cross-species applications; capturing single-level or multiple-level phenotyping information, including the use of sensors, videos, images and animal sounds and movement; applications using animals in research centres or in experimental cohorts, breeding nuclei and commercial populations in different production systems (e.g. on pasture, on extensive/intensive production systems, etc.); the possibility to design in-vitro phenotyping approaches, to avoid animal distress and respect animal welfare; and leveraging information for specific use or multiple applications (e.g. for research purposes, genomic selection, PLF, etc.). Case studies in livestock species will be proposed/developed through collaborative efforts.

Tasks 1.2. Standardization of phenotyping systems and information. This task will review: i) the protocols and procedures used and applied and ii) the types of information captured and recorded by phenotyping technologies and approaches under different conditions and for applications defined in Task 1.1. Based on this information, the need to standardize protocols and methodologies, data production and datasets will be evaluated. Phenotype ontologies and new standards will be proposed.

Task 1.3. R&D infrastructures. This task will map and link R&D phenotyping infrastructures and facilities from research organisations, including private R&D structures where possible, which have as objectives the development, testing, and application of high-throughput phenotyping approaches in livestock for different uses. This activity will include R&D initiatives and structures not only in European but also in non-European countries (e.g., USA, Canada, China, Brazil, etc.).

Task 1.4. Identification of technology gaps and research needs. This task will define gaps and research needs considering the different aspects defined in Tasks 1.1 to 1.3 and will examine how to set common research priorities and enhance the joint development of mutually beneficial collaborations. This will provide background information to discuss and design common research agendas and priorities.

Task 1.5. WG1 training school, WG1 meetings and STSM. This task will identify the main topics and the framework around which a training school focused on high-throughput phenotyping in livestock can be organised. WG meetings using web-based platforms (e.g., Zoom, Teams) will be organised to discuss, collect, manage, and finalize the activities of Tasks 1.1-1.4. STSM will be promoted with particular attention paid to enhancing interdisciplinarity and opportunities for new partnerships.

Major deliverables: D1.1. A list of phenotyping technologies that can be used in livestock phenomics (a document/report, a continuously updated web portal with links to technologies, and other initiatives); D1.2. Proposals to establish standardization rules, ontologies and/or systems in livestock phenomics (a document/report); D1.3. A map of R&D infrastructures in different countries (a document/report and a continuously updated web portal with links to infrastructures and facilities); D1.4. A white paper focused on research gaps and priorities (produced in conjunction with WG2 and WG3, with the involvement of stakeholders/networks: Section 2.2.2); Milestones: Completion of annual activities and production of annual reports with progress monitored for the work programme designed in WG1, with potential adjustments to the level of ambition of the deliverables.

WG2. Genome to phenome integration.

Main aims: i) Provide an overview of the links between genome/epigenome variation and phenotypic variation at multiple levels in the main livestock species; ii) identify synergies with related initiatives on functional analyses of livestock genomes (e.g., the FAANG initiative); iii) identify knowledge gaps and research needs and provide a road map with a clear trajectory to new applications.

Task 2.1. Genome biology and phenome differences. This task will work to link genome/epigenome variation and phenome differences in livestock species. It will connect and promote related activities that will provide new information on gene expression, gene function, and epigenetic mechanisms governing gene regulation. This task will evaluate genomic/epigenomic tools/methods useful for establishing association with phenotypic differences at the molecular level. The usefulness of animal genetic resources will also be explored. G×E interactions and the effects at the phenome level will be evaluated. Collaborative efforts that can provide proof-of-concepts will be proposed.

Task 2.2. Expand genome information with phenome data. This task will work to establish genome annotation systems that can incorporate phenome information, integrating and visualising gene expression, gene function, epigenetic mechanisms and phenomics relationships, as well as capturing the fact that they are dynamic, interrelated and genetically variable, as opposed to static univariate annotation. A general framework will be designed, and methodologies will be proposed. Case studies in livestock species will be proposed/developed through collaborative efforts.

Task 2.3. Applications of genome to phenome information. This task will review all current and future applications of integrated genome to phenome information that can be employed to advance animal breeding and selection strategies. The potential usefulness of genome to phenome data integration for design and evaluation of genome editing systems will also be assessed. Moreover, a scientific perspective will be taken to fully understand the advantages of livestock population management, regarding animal disease reduction, environmental indicators, and animal welfare.

Task 2.4. Identification of knowledge gaps and research needs. This task will summarise knowledge gaps and identify research priorities considering the different aspects defined in Tasks 2.1 to 2.3. This task will also promote mutually beneficial collaborations between parties, institutions, and research fields to improve genome and phenome integration in livestock species. These activities will provide background information to discuss and design common research agendas and priorities.

Task 2.5. WG2 training school, WG2 meetings and STSM. This task will identify the main topics and the framework around which a training school focused on genome to phenome integration in livestock can be organised. Working Group meetings using web-based communication platforms (e.g., Zoom, Teams) will be organised to discuss, collect, manage, and finalize the activities of Tasks 2.1 to 2.4. STSM, integrated with approaches of E-learning or E-tutoring across groups.

Major deliverables: D2.1. A map of initiatives/projects focused on genome to phenome integration in livestock (a document/report and a continuously updated web portal with links to initiatives/projects and case studies); D2.2. A document/report with (a) proposal(s) to establish genome annotation systems with phenome data and information; D2.3. A review on the current and potential applications and approaches generated by integrating genome and phenome information; D2.4. A white paper focused on research gaps and priorities (produced with WG1, WG3 and stakeholders); Milestones: Completion of annual activities and production of annual reports with progress monitored for the work programme designed in WG2.

WG3. Computational resources and methodologies for data analyses.

Main aims: i) Provide an overview of the computational models, methods and tools available and current and future needs for development of applications in the context of livestock phenomics; ii) identify the needed synergies and developments in terms of cyberinfrastructures and computational capabilities.

Task 3.1. Development and application of new computational models and methods. This task will explore application of new methodologies, systems, algorithms and computational strategies to: i) improve data extraction and interpretation from high-throughput phenotyping systems and consider approaches based on different technologies and approaches; ii) analyse and integrate environmental data with phenome and genome data; iii) improve genomic selection using, for example, predictive modelling methods such as machine learning, network reconstruction methodologies based on systems biology concepts, and the opportunities for better integrating G×E interactions; iv) improve the interpretation, integration and visualisation of genome/epigenome and phenome variation; v) explore new methodologies that integrate phenotypes for early warning for animal health and welfare.

Task 3.2. Definition of data structure, computational standards, formats, and metadata. This task will review the opportunities for adopting and proposing standards for phenomics databases, data structures, data transfer and computational methods to link the activities of Tasks 1.2 and 2.2. This task will also explore the needs to establish platforms and methods to mine and analyse environmental data for Task 3.1. Standardization of metadata will be proposed to further expand opportunities for reusing high-throughput phenotyping data for multiple purposes.

Task 3.3. Computational infrastructures and computing capabilities. Phenomics is a big data discipline that interacts with other big data fields in biology, particularly bioinformatics and computational genomics, epigenomics, proteomics, metabolomics, etc. This task will identify existing computational infrastructures and computing capabilities dedicated to livestock phenomics and related disciplines and their potential links. Needs in terms of data storage and computational performance will be projected over different time windows and considering different scenarios for future developments in the context of livestock phenomics. The potential performance boosts will be explored for relevant algorithms and computational tasks using GPU-based systems and, in the longer term, quantum computing.

Task 3.4. Identification of research needs and bottlenecks. This task will summarise research priorities and resources needed considering the different aspects defined in Tasks 3.1 to 3.3. This task will also promote mutually beneficial collaborations between institutions and engage computational infrastructures developed or under development for other purposes to improve access to computational resources for livestock phenomics applications. These activities will provide background information to discuss and design common research agendas and priorities and to overcome bottlenecks in this area and ensure rapid progress in livestock phenomics.

Task 3.5. WG3 training school, WG3 meetings and STSM. This task will identify the main topics and the framework around which a training school focused on computational models and methods and livestock phenomics databases can be organised. Working Group meetings using web-based communication platforms (e.g., Zoom, Teams) will be organised to discuss, manage, and finalize the activities of Tasks 3.1 to 3.4. Short-Term Scientific Missions will be promoted with particular attention paid to extending interdisciplinary collaborations and transfer of computational skills, integrated with approaches of E-learning or E-tutoring across groups.

Major deliverables: D3.1. A review publication/report of computational models and methods needed to explore and exploit livestock phenomics information (including a continuously updated web portal with links to initiatives, projects, software, and tools); D3.2. A document/report including (a) proposal(s) to establish standardized databases and computational procedures; D3.3. A database of the existing cyberinfrastructures and computational capabilities available and those needed over the next decades for applications in livestock phenomics; D3.4. A white paper focused on research gaps and priorities (produced with WG1, WG2 and stakeholders); Milestones: Completion of annual activities and production of annual reports with progress monitored for the work programme designed in WG3.

WG4. Economic impact, regulations, policies, and society.

Main aims: i) Provide an overview on the potential technological and economic impact of livestock phenomics; ii) Summarise the regulatory frameworks around this discipline and evaluate access to information and data generated; iii) Analyse societal perceptions of livestock phenomics. Exchange and collaborations with the other WGs will be essential for the development of the activities in WG4.

Task 4.1. Impact analysis. This task will map and assess the current and potential near-future impact of livestock phenomics in terms of its utility and the novel opportunities it will provide for scientific discovery, knowledge development and commercial application in animal breeding and PLF. Current applications will be mapped and prospects for additional development and interdisciplinary collaborations will be analysed and evaluated through a cross-comparison of the activities in WG1-2-3.

Task 4.2. Ownership of the data, regulations, and policies. This task will review and evaluate the regulatory landscape around ownership of data generated via livestock phenomics. In particular, it will focus on the interaction with open data concepts, intellectual property rights and access and benefit-sharing (ABS) policies that inform how genetic resources may be accessed for livestock phenomics and genomics research, and how the benefits that result from their use should be shared. EU regulatory frameworks and policies will be reviewed in conjunction with regulatory environments in other countries.

Task 4.3. Society: societal perceptions and consumer opinions. This task will develop, collect, and analyse surveys among various stakeholder groups and consumers in European and non-European countries. The purpose of this task will be to evaluate knowledge of livestock phenomics and the perceived benefits and risks associated with application of these technologies and related innovations.

Task 4.4. WG4 training school, WG4 meetings and STSM. This task will identify the main topics and the framework around which a training school can be organised focused on exploitation, regulation, public policy, and societal implications. Working Group meetings using web-based communication platforms (e.g., Zoom, Teams) will be organised to discuss, manage, and finalize the activities of Tasks 4.1 to 4.3. Short-Term Scientific Missions will be promoted with particular attention paid to extending interdisciplinary collaborations, integrated with approaches of E-learning or E-tutoring across groups.

Major deliverables: D4.1. A report on the expected impacts and applications of livestock phenomics (2-3 review papers, a continuously updated web portal with links to initiatives, projects, and economic analyses); D4.2. A review of the regulatory framework including the major issues of concern in the context of livestock phenomics (1-2 document(s)/review(s)); D4.3. Surveys/reports obtained using the analysed and evaluated data and opinions; Milestones: Completion of annual activities and production of annual reports with progress monitored for the work programme designed in WG4.

WG5. Stakeholder engagement, communication, and dissemination.

Main aim: i) To ensure a continuous engagement of the stakeholders; ii) To ensure overall communication; iii) To ensure publication of reviews, reports, surveys and establishment of a website and social medias.

Task 5.1. Stakeholder engagement and job announcement/search service. This task will ensure a continuous engagement of the stakeholders, with exchange of feedbacks and establishment of new relationships/cooperations. To attract and strengthen the involvement of stakeholders, including farmers, demonstrations on the application of phenomics technologies/approaches will be organised. To attract and strengthen the involvement of YRI, a service of job announcement/search will be implemented with the aim to support their career development.

Task 5.2. Communication and dissemination. This task will identify the major national and international stakeholders to establish direct discussions with and also address specific communications. It will also address general communications to the farmers and to the public, with translations in several languages to facilitate their involvement/uptake. It will include the distribution of an annual newsletter, the use of social media accounts (Twitter, LinkedIn, YouTube), the Action website, the organisation of a mid-term stakeholder conference and a final white paper and research recommendations from the Action to both scientists and relevant stakeholders. Dissemination of results derived by the networking activities will be ensured through publication of peer-reviewed research papers, reviews, scientific and technical reports, a book on livestock phenomics, YouTube videos on the applications of livestock phenomics.

Major deliverables: D5.1. A special themed issue/section of an appropriate scientific journal for submission of Action manuscripts and reviews (e.g., *Frontiers in Genetics | Livestock Genomics, Computers and Electronics in Agriculture*);. D5.2. A periodic newsletter with information from the Action; D5.3. A report from the stakeholder conference in relation to existing technology and user needs; D5.4. A white paper focused on research gaps and priorities (derived from the results of WG1, 2, and 3). D5.5: An Action website; D5.6. Peer-reviewed manuscripts; D5.7. A book on livestock phenomics. Milestones: Annual reports concerning contact with stakeholders, technology companies and end-users. A job announcement/search initiative. Demonstration of livestock phenomics technologies. A mid-term stakeholder conference. An annual newsletter. A list of chapters of the book on livestock phenomics.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

WG	Deliverable number	Deliverable name	Delivery date - semester=sem
1	D1.1	A document/report with a list of phenotyping technologies/approaches that can be used in livestock phenomics	2nd sem, year 1
1	D1.2	A document/report with (a) proposal(s) to establish standardization rules and/or systems in livestock phenomics	2nd sem, year 2

1	D1.3	A document/report with a list/map of R&D infrastructures in different countries	2nd sem, year 1
2	D2.1	A document/report including information of initiatives and projects focused on genome to phenome integration in livestock species	Every year, updated regularly
2	D2.2	A document/report with (a) proposal(s) to establish genome annotation systems with phenome data and information	2nd sem, year 2
2	D.2.3	A review on the current and potential applications by integrating genome and phenome information	1st sem, year 3
3	D3.1	A review publication/report of computational models and methods needed to explore/exploit livestock phenomics	1st sem, year 2
3	D3.2	A document/report including (a) proposal(s) to establish standardized databases and computational procedures	1st sem, year 3
3	D3.3	A document/report with information of the existing cyberinfrastructures and computational capabilities available and those needed over the next decades	2nd sem, year 3
4	D4.1	A report on the expected impacts and applications of livestock phenomics	1st sem, year 4
4	D4.2	A review of the regulatory framework including the major issues of concerns in livestock phenomics	1st sem, year 4
4	D4.3	Surveys and reports obtained using the analysed and evaluated data and opinions	2nd sem, year 3
1, 2, 3, 5	D1.4, D2.4, D3.4, D5.4	A white paper focused on research gaps and priorities	2nd sem, year 4
5 (1, 2, 3, 4)	D5.1, D5.6	A special themed issue/section of a scientific journal for submission of Action manuscripts and reviews	2nd sem, year 3 (and every year)
5	D5.2	A periodic newsletter	Every year
5	D5.3	A report from the stakeholder conference	2nd sem, year 2
5	D5.5	An Action website containing scientific and dissemination reports, teaching and training documents, the annual newsletters, announcements	Every year, updated regularly
5	D5.7	A book on livestock phenomics	2nd sem, year 4

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

Considering the complexity and integrated activities of the Action, the management of risks will be an essential component. Therefore, it will be an ongoing activity and there will be regular reappraisal by the CG of the risk analysis, especially at the beginning of each new activity/task. The role of the MC and CG will ensure coherence in a) the development of the Action and its activities; b) timely deliverables; and c) maximisation of impact. The MC, at the request of the AC and the CG, will be responsible for assessing the progress of the Action yearly. If necessary, they will take corrective and incentivising measures to ensure the success of the Action within the expected timeline. A first list of potential risks with possible mitigation measures or contingency plans is listed below:

Risks (High, Medium, Low)	**Contingency measures**
COVID-19 and Ukraine war effects on the actions (H/M)	Most of the WG meetings can be scheduled using web-based communication platforms (i.e., Zoom, Teams). Several other activities can be scheduled using remote systems if necessary. More virtual mobility will be used instead of STSM.
Low involvement and low outcomes (L)	Proactive measures will be taken to increase the interest in the Action, including additional workshops, WG meetings, newsletters and seeking additional participants. Additional MC meetings will be organised to deal with these issues.
Limited access to complete information (M)	Limited access to information on phenotyping technologies, applications of livestock phenomics and computational infrastructures will be overcome by involving private breeding companies and other partners that could be more active and willing to cooperate. Links to international initiatives will be established.

Problems of communication from experts of different fields or countries (M)	Promotion of interdisciplinary relationships and interactions will be carried out. STSM will be designed for the acquisition and transfer of new scientific and technical knowledge. Multiple WG meetings will be organised using video conferencing (e.g., Zoom, Teams). Bilateral initiatives to establish links between groups working in complementary fields will be organised.
Any conflict arising among the Action partners (L)	Management of conflicts will be through the actions of the CG and the MC to find consensual solutions. Bilateral collaborative agreements can be prepared and signed to avoid misunderstanding on the use of background and foreground.

4.1.4. GANTT DIAGRAM

Activity	**Year 1**		**Year 2**		**Year 3**		**Year 4**	
	Sem. 1	Sem. 2	Sem. 1	Sem. 2	Sem. 1	Sem. 2	Sem. 1	Sem. 2
MC1 meeting								
Website creation/maintenance (WG5, D5.5)								
MC annual meetings								
Core Group meetings								
Separated or joint WG meetings								
STSM – All WG (Tasks 1.5, 2.5, 3.5, 4.4)								
WG1 – Task 1.1.								
WG1 – Task 1.2.								
WG1 – Task 1.3.								
WG2 – Task 2.1.								
WG2 – Task 2.2.								
WG2 – Task 2.3.								
WG3 – Task 3.1								
WG3 – Task 3.2								
WG3 – Task 3.3								
WG4 – Task 4.1.								
WG4 – Task 4.2.								
WG4 – Task 4.3.								
WG1, 2, 3 – Tasks 1.4, 2.4, 3.4								
Mid-term workshop								
Final report								

REFERENCES

Baes, B., Schenkel, F. 2020. The Future of Phenomics. Anim. Front. 10, 4-5.

Cole, J.B., et al. 2020. The future of phenomics in dairy cattle breeding. Anim. Front. 10, 37-44.

Halachmi, I., et al. 2019. Smart animal agriculture: application of real-time sensors to improve animal wellbeing and production. Annu. Rev. Anim. Biosci. 7, 403–425.

Houle, D., et al. 2010. Phenomics: the next challenge. Nat. Rev. Genet. 11, 855-866.

Kafkas, Ş., et al. 2021. Linking common human diseases to their phenotypes; development of a resource for human phenomics. J. Biomed. Semant. 12, 17.

Koltes, J.E., et al. 2019. A vision for development and utilization of high-throughput phenotyping and big data analytics in livestock. Front. Genet. 10, 1197.

Machwitz, M., et al.2021. Bridging the gap between remote sensing and plant phenotyping - Challenges and opportunities for the next generation of sustainable agriculture. Front. Plant Sci. 12, 749374.

Pérez-Enciso, M., Steibel, J.P. 2021. Phenomes: the current frontier in animal breeding. Genet. Sel. Evol. 53, 22.

Rexroad, C., et al. 2019. Genome to phenome: improving animal health, production, and well-being—a new USDA blueprint for animal genome research 2018-2027. Front. Genet. 10, 327.

Schillings, J., et al. 2021. Exploring the potential of Precision Livestock Farming technologies to help address farm animal welfare. Front. Anim. Sci. 10.3389/fanim.2021.639678.

Stephens Z.D., et al. 2015. Big Data: Astronomical or Genomical? PLoS Biol. 13, e1002195.

Tuggle, C.K., et al. 2022. The Agricultural Genome to Phenome Initiative (AG2PI): creating a shared vision across crop and livestock research communities. Genome Biol. 23, 3.

Watson, C.J., et al. 2020. Phenomics-based quantification of CRISPR-induced mosaicism in zebrafish. Cell Systems 10, 275-286.

Yang, W., et al. 2020. Crop phenomics and high-throughput phenotyping: past decades, current challenges, and future perspectives. Mol. Plant 13, 187-214.