START
CENTRE FOR SUSTAINABLE AGRIFOOD SYSTEMS

A START INPUT PAPER FOR THE EUROPEAN COMMISSION

AN INTEGRATIVE, INCLUSIVE AND INTERDISCIPLINARY APPROACH FOR A JUST TRANSITION TOWARDS A BIOBASED GREEN EUROPE

THIS INPUT PAPER PROVIDES INSPIRATIONAL AND TANGIBLE PATHS FOR THE EUROPEAN COMMISSION WITH A VIEW FOR THE NEXT STRATEGIC PLAN FOR HORIZON EUROPE AS WELL AS THE 10TH FRAMEWORK PROGRAMME

AALBORG UNIVERSITY
IT UNIVERSITY OF COPENHAGEN
UNIVERSITY OF COPENHAGEN
AARHUS UNIVERSITY
DTU
SDU University of Southern Denmark
RUC Roskilde University

ABOUT START

The Center for Sustainable Agrifood Systems - START - has been established as a unique platform for collaboration between all Danish universities for strategic research, with the overarching purpose to deliver future research solutions to unlock the green transition of Agrifood Systems. The fact that all eight universities in Denmark participate in START gives optimal opportunities for defining common goals and collaborations in which we share capacity and facilities. This united action of the Danish Universities aims to create more scientific impact on the green transition of the agrifood-system by targeting on strategic research in an integrative, inclusive, and interdisciplinary approach.

TRIPLE I-APPROACH - THE HEART OF START

A successful green transition of agriculture and food systems is paramount to addressing the various worldwide green challenge to secure nutritious food and other biomass for the biobased society through resource sufficiency within the planetary boundaries. This transformation can solely be achieved by disruptive changes in our society and economy with evidence-based co-creative world-class science. The unique assets of the START community favour a setting for co-creating in which researchers can generate realistic future solutions, together. Such a setting requires:

- an Integrative approach to technical innovation and societal transformation for the various interlinked green challenges related to climate, environment, biodiversity, food, health, society, biobased economy, etc.
- an Inclusive approach, with all stakeholders and actors in science, society and businesses by means of novel methodologies such as living labs and citizen sciences.
- an Interdisciplinary approach by further enhancing the cooperation of scientific researchers from a wide diversity of disciplines from natural, technical and digital sciences to social sciences, humanities and arts.

With strong focus on an integrated and inclusive approach based on interdisciplinarity, START aims to gear and provide optimal conditions for extended academic collaborations across disciplines that support researchers to work together to develop and unfold tools and strategies for future solutions. START works with an integrative approach and narrative that covers 7 principal elements of the green transition towards a sustainable biobased society:

- Integrative Land Use: climate smart, biodiverse and resilient.
- Circular Resource Sufficiency.
- Connecting Sea and Land.
- Novel Food and Feed for optimized use of proteins.
- Safe and Diverse Food for healthy people.
- Food Systems in the digital age.
- Shared Integrated Research Facilities and Living Labs

This START mission has been elaborated in several interacting topical research hubs for orchestrating joint interdisciplinary research in these priority areas. In Summary, STARTS stands for:

- Identify and develop pathways for systemic transition of the agrifood system towards the SDG objectives in terms of climate, environment, biodiversity, food, health, energy, land use, inclusive society and resource sufficiency.
- Be an attractive lead partner in international research consortia to contribute to high-impact transition programmes and public-private partnerships.
- Showcase and exploit Danish innovative leadership cultured by tradition and a drive for sustainability.

DESIGN & LAYOUT: NIKOLAI LANDER, AU DESIGN

PREAMBLE

The green transition

The European Union adopted the UN Sustainable Development Goals, in terms of a policy-base for European Green Deal ambitions and related strategies. The EU aims to be a global leader in transforming the economy for a sustainable future through a just transition that leaves no one behind. A transition to a circular economy in a digital world, preserving Europe's natural capital and achieving a zero pollution in Europe. With a transformation of the rural areas with a modernized agriculture and food system, 'from farm to fork'. The 'Green Science' is on the move to provide evidence based and 'out of the box' support to the systemic 'Green Transition' that is required to realise the Green Ambition. With a 'Green Science', including both natural sciences, social sciences and humanities, technical and digital sciences. The 'Green Transition' in the 21st century differs from the Green Revolution in the 20th century because our current transition is both more pressing and encompassing. A 'Just Transition' with a transformation of agriculture and rural areas, while preserving Europe's natural and social capital by a resource sufficient circular biobased economy with zero pollution in a society that values health and well-being while at the same restores biodiversity and environmental resources.
This is what drives START - the Center for Sustainable Agrifood Systems. Taking responsibility as a 'green academic society', creating urgently needed societal impacts together.

JUST TRANSITION

The green transition towards a sustainable biobased society implies a disruptive, systemic trans¬formation of our society and economy. It is a transformative evolution, a metamorphosis. A just transition leaving no one behind requires a new gen¬eration of transformative innovations that are social, behavioural and institutional, as well as technological. Innovations which by default must start from an integral perspective on green resource sufficiency within the planetary boundaries, cultural needs and wellbeing of citizens in a biobased circular economy with net zero emissions. Due to the diversity of natural capital, a place-based and inclusive approach is needed to unlock the opportunities both for a rural (blue and green) economy and for people to thrive in a health promoting biobased society which succeeds securing the habitats of our Earth.
The evolution in innovation models over the last decades can among others be characterized by the following developments of principles and concepts:

- Level 1: Linear technological research and innovation from TRL 1 to 9 (disruptive technologies), i.e., EU Framework Programme / FP7 (2005– 2012).
- Level 2: Societal research and innovation (challenges for improvement), i.e. EU FP 8 / Horizon 2020 (2013-2020).
- Level 3: Mission driven research and innovation (meeting the 2030 targets for SDG in a changing world), i.e., EU FP 9 / Horizon Europe (2021-2027).
- Level 4: Transformative and integrative systemic research and innovation where the EU drives global green transition for genuine global sustainability and in order to secure EU resilience, competitiveness and strategic autonomy. Consequently, this will rely on systemic, integrative, and inclusive transitional models and approaches to deliver on 'our World in 2050'), i.e., expected in EU FP10.

DENMARK AS NATIONAL LIVING LAB TO EXPLORE PATHWAYS FOR A JUST TRANSITION TOWARDS A BIOBASED EUROPE

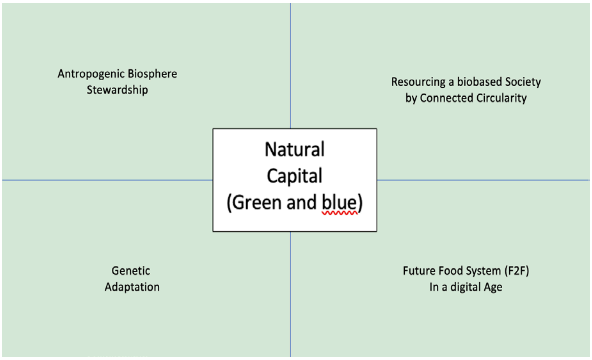
Denmark is an exploratory country. The agrifood system is cultured by tradition, innovative by character, and has a strong drive for sustainability at its heart. Denmark aims to become an integrated European living lab in a broad sense– with showcases for Europe that envisions the green transition of European agrifood systems. START aims to develop these showcases and exploit Danish leadership in innovation.

In the meeting with European Commission representatives in May 2022, START was challenged to present novel ideas and propositions for future research, relevant for the ambitions of the European Green Deal. In this paper we provide points and pathways that showcase the narrative of START and research perspectives that can facilitate meeting the targets and goals of the European Green Deal. All is based on research conducted in Denmark with relevance to the European context and for scaling up to have a wider impact.

Danish research has a history of citizen inclusion processes and short distance between local people and governance structures; accessibility and transparency; high trust society that makes experimentation more possible.

In this paper, we present four integrated cases related to a cautiously sustainable use of natural capital at land and sea:

•



THE FIRST CASE - (Climate smart integrative land use management for closing carbon cycles in the anthropogenic biosphere), deals with the climate smart land use transformation, as the next level approach to achieve a net zero climate neutrality in biobased society. The contribution of land use related greenhouse gas (GHG) emissions is substantial and hence this gets special attention. Denmark is known for its ambitious and progressive Climate Action Plan. The Climate Act, approved in June 2020, sets legally binding targets of a 70 % reduction in GHG emissions by 2030 (compared with 1990) and climate neutrality by 2050 at the latest. Next to the standard mitigation measures for specific GHG and stimulation of carbon sequestration, more systemic approaches are needed to capture carbon in natural biospheric cycles to prevent imbalanced losses into the atmosphere in order to achieve climate neutrality. This has also been recognized by the World Resource Institute in their 2021 report: A Pathway to Carbon Neutral Agriculture in Denmark.

DENMARK AS NATIONAL LIVING LAB TO EXPLORE PATHWAYS FOR A JUST TRANSITION TOWARDS A BIOBASED EUROPE

THE SECOND CASE - (Resourcing the biobased society by residual resource valorization with interconnected circularity) deals with the challenges of resource use sufficiency and circularity in a primarily biobased society by valorization of residual biomass in a circular biobased economy. As traditional agricultural biomass production exceeds the planetary boundaries, an increased need for organic resources in a biobased society requires a systemically diverged use of the available biomass stocks. Denmark is a frontrunner in valorization of food waste, manure, sewage sludge and other agricultural, industrial and domestic biomass residuals. But also in innovative approaches to avoid food waste, and upcycle side-streams to value-added so called ‘upcycled food’.

THE THIRD CASE - (Healthy, attractive and sustainable food system, fitting in the digital age) deals with the challenges to arrange the ‘future food system 2050‘ from farm to fork in a more diverse, healthy and sustainable way in the digital age. Denmark has a reputation in fine and precise microtechnology based on the emerging power of digitalization. The societal adoption and inclusion is a challenge alongside the fast technical developments. Moreover, Denmark also has a reputation in innovative food perception with a novel food identity: from organic food to a broadly adopted ‘Nordic Cuisine’.

THE FOURTH CASE - (Genetic adaptation for future agrifood systems under planetary boundaries) deals with the requirement for new resilient and adaptive breeds of plants (from crops to seaweed and trees) and animals (from livestock to fish and insects), to enable the transitions in land use, resource sufficiency and a diverse, healthy and sustainable food system as driven by the other three cases. Denmark has a long tradition in customized breeding.

We hope that the four Danish cases will inspire the European Commission for Strategic Plan for Horizon Europe’s last years as well as FP10, as we are looking for more intensive international cooperation in transformative research in Europe.

Case 1: Climate smart integrative land use management for closing carbon cycles in the anthropogenic biosphere

Land use and land management are critical to delivering a wide range of ecosystem services, including resilient production of food, biomaterials, and bioenergy, as well as a liveable planet. Current land use and management at global and European scales have contributed to deterioration of natural resources and biodiversity, pollution of the environment, and emissions of greenhouse gases. This calls for urgent changes in land use and management with an integrative perspective on delivering a broad portfolio of goods and services through multifunctional anthropogenic landscapes. This aligns with the European Green Deal with specific actions outlined in the Farm to Fork strategy and the European Biodiversity strategy.

LAND USE

Land use transformations need to be underpinned by improved understanding of underlying conditions such as climate, soils, hydrology and landscape, as well as social conditions facilitated through market relationships, tenure systems, public policy design and implementation and technological developments. Therefore, an integrated social-ecological perspective on land and land-use management is needed, supporting visionary research that addresses how new technologies and social innovation s can be optimized to contribute to carbon neutrality, maintenance of natural resources and resilience to external pressures. This must be complemented by improved understanding of how governance systems can reliably overcome barriers to change. Such barriers operate at multiple scales, including national, regional and local with the involvement of governments, supply chains and financial systems. To reach policy targets, governance systems need to improve how polarization between shared and individualized motivations are addressed through regulation and planning.

Land use refers to how land is organized and allocated for various critical ecosystem services. There are considerable challenges related to closing nutrient and carbon cycles and enhancing biodiversity while also increasing quality production for various human usages. This includes management of interstitial habitats and biotope corridors embedded in production landscapes, which harbor permanent vegetation, modulate nutrient and water transport, and support biodiversity and ecological resilience. Key research themes include: (1) Innovating rewetting measures to protect existing large carbon stocks in peatlands and organic soils, (2) Implementing landscape water structures that protect infrastructure and agricultural production while providing habitats and landscape nutrient filtering solutions, (3) Quantifying carbon fluxes within different land uses and how they contribute to human needs and ecosystem carbon stocks, (4) Testing novel circular land use systems together with stakeholders and (5) Developing new ways of integrating space for high quality habitats within anthropogenic production landscapes.

LAND MANAGEMENT

Sustainable land management at the individual field and farm scale is key to delivering diversified, resilient and productive cropping and forestry systems with low environmental and climatic impacts. New circular production systems and technologies should be developed and implemented, as well as measures to test and incentivize these.

Case 1: Climate smart integrative land use management for closing carbon cycles in the anthropogenic biosphere

Land management directly changes the terrestrial environment and the quality, type and magnitude of ecosystem services with emergent outcomes at landscape scale. This makes it necessary with an integrated, multi-scale research approach, including: (1) Developing and testing diversified, resilient and productive and resilient annual and perennial cropping and forestry systems with low environmental and climate impacts and greater resilience, (2) Developing new measures to enhance soil carbon inputs and their persistence in top- and subsoils while also enhancing soil health, (3) Developing technologies to predict and reduce nitrous oxide emissions from soils, (4) Developing the technological foundation for plant breeding to support higher quality crop yields, greater soil carbon retention, higher nutrient use efficiencies and lower dependencies on pesticides, (5) Providing decision support and capacity building for decision makers linking technologically driven development with local objectives at landscape scales, (6) Improving tools for effective on-the-ground implementation, including approaches for including citizens and civil society actors.

LAND GOVERNANCE

Land governance includes rules, institutions, actors, and processes that govern the use, development, and conservation of land resources. Effective and sustainable land governance is essential to ensuring that land resources are used in sustainable and equitable ways, and for promoting economic development, social stability, and environmental protection. Public policy informed by research are integral to achieving socially and ecologically sustainable, transparent, responsible and inclusive governance arrangements in future land use systems. Key research themes include: (1) Addressing spatial organization of land use supporting multiple functions; (2) Updating and improving tenure institutions and associated land administration systems to facilitate efficient transitions on privately held land based on public policy interests; (3) Strengthening spatially targeted approaches to land use regulation, to accommodate integrated environmental and economic land use; (4) Ensuring policy integration across sectors and issues, and between top-down and bottom-up decision making.

DENMARK AS A GREEN LIVING LAB

In Denmark, barriers to implementing climate smart approaches relate to the fact that most policies are designed, planned and implemented in silos, and it can be argued that the spatial planning system in many European countries and in Denmark consist of multiple policies and actors governing individual sectors within the same landscapes. Each sector has its own governance structures limiting the development of integrated and green solutions. Danish institutions have a history of effectively bridging basic research, technical innovations and governance to ensure implementation of changes in agriculture with citizen inclusion. Danish institutions currently experimenting with aligning and bridging legislation, agencies and objectives across multiple sectors at national and local levels, supported by research spanning the technical, natural and social sciences and the humanities. Denmark has placed itself as a frontrunner in identifying and implementing integrated and innovative solutions for sustainable land use and management. Considered as a living lab, Denmark represents a small yet diverse, well documented, data-dense experimental setting for researching solutions to the biodiversity, food and climate nexus.

Case 1: Climate smart integrative land use management for closing carbon cycles in the anthropogenic biosphere

EXPECTED IMPACTS
An integrative vision on land use and management that considers novel spatial land uses, agricultural and forestry technologies, and realigned governance process may achieve multifunctional landscapes that produce the quality goods for human society while retaining nutrients, capturing carbon and enhancing nature and biodiversity. Such a research program should also consider how the changes are documented and incentivized. This may be achieved through ambitious, transdisciplinary experimentation in real landscapes affected by high levels of land use allocation pressure, e.g., in Denmark.

Case 2: Resourcing the biobased society by residual resource valorization with interconnected circularity

Circular bioeconomy will be a cornerstone for future developments of a fossil free society, where all carbon must come from renewable and reusable sources. Moreover, from an agricultural, food producing, environmental and climate point of view, circular bioeconomy is not only restricted to carbon, but comprises also recycling of nitrogen and minerals as phosphorus, potassium and all the micro-minerals. Currently, nitrogen base fertilisers are highly dependent on fossil energy, and nitrogen emissions have a strong impact on environment and climate. These minerals (P&N) are on the other hand a limited resource. Food and biomass production, in a broad sense, interacts with most of the topics within circular bioeconomy. Therefore, the goal is to co-optimize food production and biological carbon production for non-food use to achieve real circularity and sustainable production systems while avoiding competition and conflicting interests for carbon uses. Biorefining and cascading use of biomass and its carbon content will be part of such co-optimization. Citizen-consumers are part of the nutrient cycle in the food-water nexus, and will play both a passive and active role in future circularity. The main goal is to increase the demand for carbon sources for non-food (e.g., energy, materials) purposes, but/while at the same time deliver high-quality feed or food protein, other nutrients and bioactive compounds with health promoting or other biological effects.

Key approaches should be interdisciplinarity, including natural, technical, and social sciences, strong stakeholder engagement (industry, SMEs, regulators, consumer organisations etc), and a dynamic systems perspective. The latter could consider, e.g., food and non-food interactions, integration of biomass and non-biomass pathways for satisfying society's carbon demands, and broader transition pathways for sectors/industries, value chains, or regions. This would help ensure that new products, processes, and technologies not only contribute to environmental sustainability but are also economically and socially feasible and lend themselves to upscaling. As the examples below illustrate, not just scale but also diversity of approaches are central factors in developing an effective and inclusive circular bioeconomy. This calls for approaches to research and innovation policy that open-up the opportunity space, allowing for the participation of a plurality of ideas, technologies, and actors, rather than investing only in a few pathways that may turn out to be unsustainable or ineffective.

INCREASING RESOURCE USE EFFICIENCY OF AGRICULTURAL PRODUCTION SYSTEMS
Agroecosystems are often intensive in terms of input and management, and therefore provide high yields of the desired products. However, European agriculture can still increase the utilisation of solar radiation to increase carbon capture – in some cases a doubling is possible. This is possible by increasing the period of the year with green photosynthetic active plants. Danish research has documented the many added values of producing green crops (grasses, clovers, cover crops, beet roots): increasing yields and soil carbon, while nutrient losses and pesticide use decrease. The green crops can be refined into protein concentrates, packaging material, bioactive compounds, lipids, textiles, bioenergy etc. in green biorefineries, from where the minerals are recycled as fertilizer. The biorefineries can be situated in, e.g., nitrate sensitive areas, where there is a great need to improve nutrient use efficiency to fulfil the goals established by the Water Framework Directive.

Case 2: Resourcing the biobased society by residual resource valorization with interconnected circularity

However, there is still much process optimisation, breeding of new crops optimised for biorefining, extraction methods and business models to be developed to advance the state of the art in this area.
Increasing circularity of biomass resources through cascading processing and upcycling
Upcycling of side-streams from waste or low-value products to higher value products, e.g., food and food ingredients can provide large companies and sme's with strong economic incentives to increase circular resource use. Prominent examples from Denmark are e.g., KMC (which has developed from manufacturing starch from potatoes to highly specialized food ingredients), and Arla Foods Ingredients (producing high-value compounds from whey). On a smaller scale, Circular Food Technology uses spent grain (traditionally fed to cattle) sourced from local breweries to produce high-end foods such as flour, crackers, and granola under the Danish 'Agrain' brand.

The current exploitation of the aquatic biomass by the seafood industry is still hampered by inefficiency as up to 70 % of the biomass is wasted (e.g., dumped into the sea) or used for low-value products not intended for human consumption. Danish research has demonstrated the possibility to upcycle a large proportion of the side-streams and convert them to high-value ingredients for the food, dietary supplement, and cosmetics industry. Examples include cascade processing of seaweed, mussels, starfish, and side-streams from shrimp (head and shell) and fish such as cod. It has been demonstrated that both solid and liquid side-streams can be upcycled. Several of the developed solutions are currently being implemented at industrial scale.

There is a need for continued and new efforts in cascade utilization of side-streams from the food production system for separation of food ingredients, microbial enzyme production and for alternative feed and food production, e.g., by using microorganisms, insects, or micro-algae. Ideally, this should be carried out in an integrated production of food, feed, specialty compounds and bioenergy in a circular, sustainable and climate friendly way, where excess minerals are re-circulated back to the soil.
Symbiotic sector integration and inter sectorial cascading.

Low carbon technology for electricity production and electrification of heat, transport and a large part of industry is a main strategy for low carbon emissions, but many sectors are still in demand for carbon such as food, feed, organic compounds in materials and chemicals including plastics, textiles, building materials, fuels for aviation, deep-sea shipping, and part of road transport. Recent Danish research has shown that ensuring a sufficient carbon supply for all carbon-demanding sectors motivates a high degree of symbiotic system integration and cascading of carbon resources across all sectors. To achieve net zero emissions, both Direct Air Capture, DAC and Carbon Capture and Storage, CCS from point source emissions are required.

Case 2: Resourcing the biobased society by residual resource valorization with interconnected circularity

Under such framework conditions, sector integration and co-optimization across all sectors becomes techno-economically attractive: 1) Integration of agricultural production with the energy and materials system comprising innovative crops and cropping schemes in agriculture for joint supply to food, feed, fuels, and materials. 2) Integration of biomass conversion pathways with hydrogen and PtX pathways to optimize the use of biogenic carbon and avoid carbon losses through reactions with hydrogen. Examples include technologies for converting the CO2-part of biogas to methane or methanol by hydrogenation. 3) System design and combinations of technologies for integration of processes. Examples include combination of biogas with pyrolysis/gasification or hydrothermal liquefaction of residual biomass in the digestate after biogas conversion.

Multiple conversion pathways exist, and there is a large demand for clarifying pros and cons in the effort to strive for optimizing carbon use. Moreover, indications from previous research suggest that PtX pathways will potentially become cost-competitive in satisfying some carbon demanding compounds, while bioconversion pathways are attractive for other demands.

Case 3: Healthy, attractive and sustainable food system, fitting in the digital age

VISION / CHALLENGES
A healthy, attractive sustainable, and scalable food system is crucial for the Green Transition and is required as a necessary precondition a Digital Transition of the food system, all enabled by a multidisciplinary Future Food System Science bringing together technical science, food science, consumer science, and social science. Sustainable agri-food systems involve a system perspective on farming operations, resource use towards zero environmental footprint, food processes and supply chains, consumer demands, and value flows (combining data from all the agri-industry-gastro-value-chain, AIVC), and must rely on extensive digital devices and infrastructure technologies and their resulting data and information chains.

In this vision of the future food system, there is a significant interconnectivity between all actors and multiple sectors through the flow of information and materials creating new opportunities for enhancing: Healthy Diets, Food Safety, Traceability, Certification, Recycling, Recovery, Remanufacture, Reuse & Redesign food systems, Needs, Engagement and Preferences. By supporting consumer choices with credible, certified information from the value chain, consumer demand for healthy and sustainable food will trigger changes all along the value chain. Although better information leads to better informed consumers but does not necessarily lead to behaviour change. Performance will be assessed at a system level, rather than at an individual level or technology level, by measuring the net value added using various metrics (e.g., resource effectiveness, climate impact, waste and energy reduction, food safety, animal welfare, social impact, nutrition, economic benefits).

A key digital innovation is to enable interlinking consumers and producers in innovative ways, development of innovative apps, differentiated products, reaching an advanced level of food/product customization feeding back to production and processing diversity in needs, requirements, and preferences. In this way, besides working with the farm-to-fork concept (value integration, operations efficiency, traceability, etc.), engagement and demand driven food production (from fork-to-farm) will be pursued at the same time. Decision making by various stakeholders in the food system, not least by consumers and professional procurers of food, will become more efficient, as information flows can become transparent providing only information relevant for a specific decision.

Unlocking the potential of digitalization, microtechnologies and data technologies involves academic research challenges like purpose-driven design and data/information requirement specification, big data analytics, development of digital twins, data interoperability as the basis for integrated decision-making, data standards and semantics and user interfaces and user adoption. It requires that we go from using digitalization for solely operational performance efficiency to hyper-automation involving dynamic and intelligent design/re-design of technical processes and business processes.

Case 3: Healthy, attractive and sustainable food system, fitting in the digital age

The envisioned Future Food Science will include an extensive interdisciplinary approach involving competences like data science, computer science, data analytics, modelling, system engineering (AI, ML), process analytical technology (PAT), communication technologies, living labs, actor-network analysis, social science/economics/business/organization, food processing, consumer behaviour, socio-technical analysis, production and operations management, as well as extensive domain knowledge in food and health. However, obstacles such as lack of efficient data access, data sharing, lack of quality assurance and standards, interoperability issues (both technical and semantically), purpose driven data representation, and lack of sustainable infrastructures hamper these developments, and lack of implementation/adoption.
Moreover, cross-cutting gaps in terms of impact accounting not capable of reflecting variations and effects of existing/new technologies need to be identified.

Objectives of this case include:

- Digitalization, microtechnology, robotics, drones, and data science providing quantitative metrics and indicators for interlinking producers, customers, etc.
- Mapping of key indicators for sustainable and healthy food (diversity needs, preferences, etc.) as the blueprint for developing an aligned digital system enabling data sharing in the farm-to-fork as well as the fork-to-farm system.
- AI/ML supporting disruptive and comprehensive redesign (technical food processes, business processes, etc.) as opposed to current focus on efficiency of processes (cementing current food value chains).
- Data-user interfaces that allow user-tailored individualization of data streams and that facilitate adoption and continued use.
- Mapping of relational and organizational food system connections that allow for individual and societal transparency, scalability and useability.

As digital technologies, infrastructures, and data are some of the key prerequisites for a sustainable agri-food system transformation, the challenge of digitalization is not incremental, but represents a fundamental and disruptive socio-technical transformation of the entire food production system, its technologies, and its practices, in other words a “change of minds”. This separates digitalization from previous and other technology innovations in the agri-food domain.

Case 3: Healthy, attractive and sustainable food system, fitting in the digital age

A systemic approach to sustainable agri-food digital transformation will integrate across:

- User-level digitalization: Changing and introducing new practices including new digital objects, values, practices, nutritional health data, tasks and skills.
- Farm-level digitalization: designing and managing new production systems and processes, resource and operations practices, stakeholder networks, and innovative and sustainable digital business models.
- Agri-food chain digitalization: Data-enabled design and management/optimization of supply chains logistics and retail chains, bringing production, retail, food procurers, consumers and citizen groups together in new forms of relationships.
- Policy-level digitalization: New and transformed agri-food system modelling, automated monitoring, and data analytics to enable enhanced insights for policy making and regulatory decisions that provide better governance, incentives, and accountability structures.

THIS CASE WILL:
Develop and facilitate a multi-disciplinary, academic strategic research partnering, targeting an agile approach for digital innovation in the food system and create solutions for a productive, healthy, sustainable and resilient food system enabled and pre-conditioned by digitalization. At the same time, the showcase will address the application of the innovations by guiding the demonstration and setup of, for example, Living Labs. This will entail Europe's first academic research hub bringing together leading scientists using inter- and transdisciplinary research to address challenges on the data-driven food system of tomorrow on an international scale.

Case 4: Genetic adaptation for future agrifood systems under planetary boundaries

Human activities impose severe pressures on our planet. As a result, we have crossed several planetary boundaries such as climate change, land-system change, biodiversity and disturbed biogeochemical flows. This has led to several global-scale environmental crises, which call for urgent actions. As a response, the European Green Deal reflects our long-term ambition towards a green, biobased EU, which requires a transformative, systemic transition in our society and agricultural production systems. Agriculture relies first on biological organisms, livestock and crops, whose basic properties are defined by their genetic makeup and variability.
A core element in the green transition lies in genetic adaptation of current and new agricultural spe¬cies for future sustainable agrifood systems. The complexity of the problems we face call for more synergy between multiple actors, technologies and disciplines. Also, for new species and novel tech¬nologies to effectively contribute, consumers need to accept and adopt the resulting products. Genetics tools and knowledge have three interconnected roles to play: (i) characterize genetic and phenotypic diversity of novel and existing agricultural species, breeds and cultivars; (ii) best improve their genet¬ics, though advanced breeding, New Genomic Techniques' (NGTs) like gene editing and cisgenesis; and (iii) describe and account for the relationship between genetics and socio-ecological contexts.

CHARACTERIZATION OF GENETIC DIVERSITY
Modern agriculture has globally reduced agricultural biodiversity (fewer breeds, cultivars and species). However, the diversity of genes, variety and species is a crucial resource to ensure resilient agrifood systems. Therefore, we must use the tools of modern genetics to characterize the inter- and intra-specific genetic diversity that likely contains untapped potential to adapt for our future agrifood systems. These include describing and maintaining the genetics from various sources: the historical diversity in gene banks and conservatories, and the elite gene pool maintained in ongoing breeding programs. Likewise, as we must transition from linear to circular agrifood systems, we need to describe the species and varieties, which fit new niches, in circular bioeconomy, market segments, and climate or disease pressures. It is likely, that our current elite genetic pools is not adapted to these niches, many of these new roles may require evaluating under-represented varieties or domesticating new species. Beyond mere characterization of genetic resources in crops, livestock, and new species, genetics will also describe the key biological components, which contribute to environmental contexts: microbiomes of soils and guts, genetics of companion crops (e.g., in intercropping and mixed cropping) and pathogens.

NEW BREEDING GOALS
Throughout the 20th century, breeders have improved the productivity of crops and livestock, but have focused on production under conventional systems (plant monoculture, controlled livestock environments).

Case 4: Genetic adaptation for future agrifood systems under planetary boundaries

Under the ongoing green transition, we must define and quantify valuable traits: side stream upcycling (e.g., composting, carbon sequestration, nitrogen recovery), consumer preference (e.g., taste, nutritional value), and resilience (e.g., biotic and abiotic stress resistance, nutrient use efficiency). Building on the characterization agridiversity genetic variation for these novel traits must be identified for broader resources in plant and animal breeding. Moreover, understanding the relationship between genomes and environments will allow breeders to define breeding goals and choose optimal gene variants under new production systems and changing environments. As new constraints arise (e.g., pest pressure, climate change, new policy regulations), breeding goals must be dynamically updated. Then, geneticists must implement efficient techniques for fast genetic gains, which include genomic speed breeding for genome-wide changes, and molecular breeding techniques for targeted genetic edits.

GENOMIC SPEED BREEDING

Complex traits like yield, production efficiency, quality, and resilience depend on many genes which interact among themselves and with the environment, in an intricate manner. Therefore, improvement of these traits has relied on selection of best parents without mechanistic understanding of genetic effects. Traditionally, such selection has been slow (at most one cycle of selection and mating per year). To accelerate this process of selection, speed breeding dramatically shortens life cycles under controlled conditions (e.g., up to three cycles per year in plants).

To realize this potential, we must combine this technology with genomics-assisted breeding techniques like genomic prediction, which detects traits of interest using only DNA information. Speed breeding combined with genomic prediction (genomic speed breeding) can modify plant and animal genomes much more efficiently than traditional breeding, which relies on measurements under field conditions. For an effective deployment of genomic speed breeding, geneticists must develop accurate genomic prediction models, which maintain their accuracy over many successive generations by integrating information on genes and genetic networks affecting the phenotypic traits.

MOLECULAR BREEDING TECHNIQUES

New Genomic Techniques (NGT), such as CRISPR and cisgenesisis suited for simpler traits impacted by relatively few genes with high effect. This is particularly relevant to lower pesticide requirements (e.g., disease resistance) and increase productivity under stressful environments (e.g., tolerance to drought, heat, or heavy metals), but can also modify cell wall constituents in feed crops, so greenhouse gas emissions during livestock production is decreased. Desired variants can be introduced in genomes by molecular techniques for precise DNA changes: CRISPR-based editing for modifying specific genes or DNA sites or naturally occurring disease resistance genes can be combined in elite variants to produce high and durable disease resistance.

Case 4: Genetic adaptation for future agrifood systems under planetary boundaries

Though currently limited by European regulations, NGTs holds great promise for improving crop species, because it induces or combines new genetic variants which may not be available. Moreover, this technology holds key advantages over mutagenesis by chemicals or radiations: it relies on few constraints to target exact sites for mutation; it results in few off-target edits; and it is widely applicable across plant varieties. Furthermore, CRISPR represents the most effective technology for translating research knowledge already existing from model species into real crops, thus potentially capitalizing on the huge investment done in basic research over the last several decades.

EXPECTED IMPACTS

Characterizing genetic diversity will allow us to build resilience against new agricultural constraints: extreme weather events, regulatory or financial restrictions on agricultural inputs, new agroecological practices (e.g., polyculture and circular bioeconomy). Likewise, genetic improvement is an efficient and necessary way to adapt agriculture to be more sustainable and geographically appropriate. Furthermore, we must optimize our genetic offer for different consumer preferences (cultural, ethical and dietary appropriateness) while meeting the needs of various stakeholders: from farmers and industries, to consumers and policy makers. START is designed to integrate research across multiple disciplines focusing on stakeholders in the entire value chain and thus coordinating and focusing research to pursue genetic fitness for relevant and inclusive agrifood systems in a changing socio-ecological contexts.

COLOFON - List of cowriters

Cases	Cowriting Teams	Position and expertise
Climate smart integrative land use management for closing carbon cycles in the anthropogenic biosphere	Andreas Aagard Christensen, RUC	Technology, Society and Environmental Planning
	Beate Strandberg, AU	Biodiversity and multifunctional land use
	Claus Beier, KU	Biogeochemical cycling and climate change impacts in terrestrial ecosystem
	Dorte Bodin Dresbøll, KU	Resilient crops and cropping systems
	Frederik van der Bom, KU	Management of soils and cropping systems. Climate change management
	Henrik Hauggaard, RUC	Food Studies, Food Systems & Food Policies
	Jørgen E. Olesen, AU	Agriculture (cropping systems), Climate change management
	Morten Graversgaard, AU	Technology, Society and Environmental Planning
Resourcing the biobased society by residual resource valorization with interconnected circularity	Charlotte Jacobsen, DTU	Biorefinery of marine resources and residuals
	Henrik Wenzel, SDU	Environmental Engineering (circular bio-economy), Resource Management,
	Mette Lübeck, AAU	Biorefinery concepts (enzymatic), Protein extraction, Fungal gene technology
	Simon Bolwig, RUC	Technology, Society and Environmental Planning
	Søren Krogh Jensen, AU	Green biomass, circularity and animal nutrition
	Uffe Jørgensen, AU	Agriculture, green biomass, energy and circularity
Healthy, attractive and sustainable food system, fitting in the digital age	Anna Haldrup, KU	Crop genetics, biotechnology and plants
	Claus Aage Grøn, AU	Decision support evaluation/optimization production, logistics, supply chains
	Klaus G. Grunert, AU	Food and agribusiness marketing; Consumer behavior; Product development
	Nanna Viereck, KU	Food analytics and Biotechnology
	Niels Heine Kristensen, RUC	Sustainable Food Systems, Food Studies & Policies, Food Living Labs
	Ulrik Pagh Schultz, SDU	Robotics and drones for efficient and sustainable automation, Digitalization
Genetic adaptation for future agrifood systems under planetary boundaries	Henrik Brinch-Pedersen, AU	Biotechnology/molecular biology (cereal plants and seed)
	Kåre Lehmann Nielsen, AAU	New Genetic Technologies and Genomics Assisted Breeding (potatoes)
	Mogens Sandø Lund, AU	Development and validation of QTL , Implementation MCMC based genetics

Editors: Martin Scholten, special advisor to START, Robert Pedersen, special consultant for START and Mogens Rysholt Poulsen, Chairman of START (2023)

FOR MORE INFORMATION

START.UNI.DK

START
CENTRE FOR SUSTAINABLE
AGRIFOOD SYSTEMS

PARTNERS:

DTU

SDU
University of
Southern Denmark

AALBORG
UNIVERSITY

IT UNIVERSITY OF COPENHAGEN

CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

UNIVERSITY OF
COPENHAGEN

RUC Roskilde University

AARHUS
UNIVERSITY