Plants for the future's perspective on sustainable agriculture

R&I Recommendation Report

Plants for the Future ETP, Working group on Sustainable Agriculture

Plants for the Future
European Technology Platform

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Executive summary

"Food systems have the potential to nurture human health and support environmental sustainability; however, they are currently threatening both." [1]

To address this global imperative, the EU Green Deal aims to transform Europe into a world leader in sustainability while ensuring economic competitiveness. In the agricultural sector, the Farm to Fork and Biodiversity Strategies provide ambitious goals to meet consumer needs for food, feed, and biobased raw materials, while respecting planetary boundaries and protecting soils, water, air, and biodiversity. The goals of the Green Deal can only be achieved if the necessary interventions operate in concert with highly complex socio-economic systems. This requires that basic economic principles regarding demand, return on investment and profitability are met and are applicable to all agricultural value chain actors throughout the transition period. The transformation of agricultural systems towards a sustainable One Health[2] society will inevitably lead to business uncertainty for some of these actors. However, it will also generate new business opportunities and space for innovation, new jobs and new farm and business models.

In agricultural systems, future supply and demand will need to support sustainable, healthy, and diverse diets. This will also require increased agricultural productivity based on production systems that minimise environmental impact and are resilient to the impacts of climate change. To deliver this, research and innovation (R&I) interventions that support short-, medium- and long-term goals will need to complement each other to achieve Farm to Fork and Biodiversity targets.

The Plant ETP is of the opinion that future sustainable agricultural systems will be determined by three main drivers:

(1) Innovative agricultural produce, meeting the demand for new, diverse, and sustainable food, feed, and biobased raw materials, and enabling the creation of new business models, industry structures and value chains.
(2) Resilient production (eco)systems, to optimise productivity under a changing climate while minimising environmental impact by leveraging knowledge on crop performance, cropping systems and the environment, delivered through management tools and solutions.
(3) A common agricultural data platform, Agri-Data, that supports innovative agricultural produce and resilient production (eco)systems through leveraging big data and artificial intelligence, and by matching supply with demand and enabling sustainable agricultural production through tailored advice.

The three interdependent drivers of change have been identified by expert knowledge as imperatives to deliver an effective and resilient transformation of EU agricultural systems.

This report focuses on the plant sector with a long-term vision and identifies areas of R&I that are considered essential to foster the co-development of innovative agricultural produce, resilient production (eco)systems and Agri-Data.

1. Willett et al. (2019) Food in the Anthropocene: the EAT– Lancet Commission on healthy diets from sustainable food systems.
2. The One Health concept views the health of soil, plants, animals, people, ecosystems and the planet as inextricably interrelated.

Glossary

Agrobiodiversity: Agrobiodiversity encompasses the diversity of animals, plants and micro-organisms that are associated directly or indirectly with agriculture. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, feed, and biobased raw materials. It also includes all species that support production (soil micro-organisms, predators, pollinators), and the agro-ecosystems (agricultural, pastoral, forest, and aquatic).[3]

Big data: Big data refers to collections of information so large (high volume), fast (high velocity) or complex (high variety), and incoming in such variable flows and quality that it becomes practically impossible to store, process and analyse using traditional methods. The field aims to develop new analytical tools that can deal with such intricacies.[4]

Bioavailability: This term refers to the proportion of a nutrient, drug or other substance introduced into the body which is digested or absorbed, and metabolised (i.e., which enters the circulation) and is thus able to yield an active effect.

Biobased platform molecules: Biobased platform molecules are biobased building blocks, such as carbohydrates, used to produce high-value chemicals and materials.

Biofortification: Biofortification is a practice where the nutritional quality of food crops is increased.[5]

Bioinformatics: Bioinformatics designates a discipline at the intersection of biology and computer science that investigates the acquisition, storage, analysis, and dissemination of biological data, most often DNA and amino acid sequences. It uses computer programs for applications such as determining gene and protein functions, ascertaining evolutionary relationships, and predicting three-dimensional protein shapes.[6]

Biopesticides: Biopesticides are derived from biological sources, such as microorganisms, plants, animals, and a few minerals. Biopesticides include microbial pesticides, plant-incorporated protectants, and biochemical pesticides.[7]

Bioplastic compounders: This term refers to those technology providers who prepare formulations with certain desired properties by mixing and/or blending biopolymers and bio-additives (i.e., polymers and additives that are either obtained from organic raw materials, biodegradable, or both) in a molten state.

Carbon certification: Carbon sequestration is any standard scheme on carbon management and emissions, designed and granted by an environmental standard protocol, which an organisation can seek, through ensuring its and its products' carbon footprint data complies with the standard's protocol, and having a Verification and Validation Body audit it to consequently award a mark of compliance.

Carbon farming: Carbon farming are agricultural practices, or land use, which aim to reduce greenhouse gas emissions and/or to capture carbon in vegetation and soils. Carbon farming can range from a single change in farming, such as introducing no-till cultivation or grazing management, to a whole-of-farm integrated plan.[8]

Carbon sequestration: Carbon sequestration refers to the removal and storage of carbon from the atmosphere in carbon sinks such as oceans, forests, or soils through physical or biological processes, e.g., through agroforestry.

Controlled traffic farming: Controlled traffic farming is an agronomic management tool which is used to reduce the damage to soils caused by heavy or repeated agricultural machinery passes on the land.

3. FAO (1999) Sustaining the Multiple Functions of Agricultural Biodiversity. Background Paper 1: Agricultural Biodiversity
4. SAS Institute (2021) Big Data – What it is and why it matters
5. Bouis und Saltzman (2017): Improving nutrition through biofortification: A review of evidence from Harvest Plus, 2003 through 2016
6. National Human Genome Research Institute: Bioinformatics
7. Thakur et al. (2020) Microbial biopesticides: Current status and advancement for sustainable agriculture and environment
8. Sharma et al. (2021) Carbon Farming: Prospects and Challenges

Data friction: Data friction refers to technical or social hurdles that impair the fluent exchange of data.

Data interoperability: Data interoperability is the ability to use data in various contexts, by various systems that create, exchange, and consume data. Data interoperability requires clear, shared expectations for the contents, context and meaning of data. Environmental stewardship: Environmental stewardship refers to the responsible use and protection of the natural environment, through conservation and regeneration practices that enhance ecosystem resilience, ecosystem services and human well-being.

Functional biodiversity: Functional biodiversity refers to the set of living organisms that provide benefits during crop production, e.g., lower incidence of disease. Green credits: Green credits are credit lines by financial institutions to support investments in renewable energy and energy efficiency.

Heritage crops: Heritage crops are old varieties that come from seed that has been handed down for generations in a particular region or area and that existed before commercial varieties.

Immutable network concepts: Immutable network concepts describe data that cannot be manipulated after being entered into a given systems.

Knowledge commons: Knowledge commons are made up of information, data, and content that is collectively managed by a community of stakeholders. Living labs: Living labs are a research concept referring to co-created, user-centred, open innovation ecosystems, conducted in real life conditions.

Machine learning: a branch of artificial intelligence and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy.

Microbiome: Microbiome refers to a microbial ecosystem (bacteria, archaea, viruses, fungi, and protozoa) that colonise an organism or a defined habitat with specific physical and chemical properties (human, animal, plant).

Mob-grazing: Mob grazing is short duration, high density grazing with a longer than usual grass recovery period.,

New genomic techniques: new genomic techniques are capable of changing the genetic material of organisms. In the EU context they have emerged or have been developed since 2001, after the GMO Directive was adopted, and include techniques such as gene editing and cisgenesis.[9]

One Health: The One Health concept views the health of soil, plants, animals, people, ecosystems and the planet as inextricably interrelated. It is a collaborative, multisectoral, and trans-disciplinary approach - working at local, regional, national, and global levels - to achieve optimal health and well-being outcomes recognising the interconnections between people, animals, plants and their shared environment.[10]

Orphan crops: Orphan crop refers to crops that play a rather subordinate role on the world market, in science and plant breeding, and therefore have a niche existence. However, they often play a vital role in local areas and are usually well adapted to low-input agricultural conditions.

Platform chemical: A platform chemical is a chemical that can serve as a substrate to produce various other higher value-added products.[11]

Pre-competitive breeding: Pre-competitive breeding refers to the development of a germplasm (a living genetic resource such as a seed or tissue) with a genetically broader base for utilisation by breeders, such as the introduction of exotic germplasm into a cultivar.[12]

9. EU Commission's study on new genomic techniques
10. One Health Commission – Definitions of One Health
11. Takkellapati (2018) An Overview of Biorefinery Derived Platform Chemicals from a Cellulose and Hemicellulose Biorefinery
12. Crop Genebank Knowledge Base

Predictive breeding: Predictive breeding is a technique that uses statistical models that inform breeding strategies by processing historical genetic data (mainly genotypes and phenotypes) to predict phenotypes, and thus crucially curb these strategies' time and money requirements by reducing the number of field testing needed.[13]

Proof-of-value systems: Proof-of-value systems are a step in the development of a product or service, usually the final one before commercialisation, in which the solution's value is identified based on potential customers' use cases, and in particular the solution's ability to address said use cases (i.e., solve the problems at hand or create a new benefit).

Sequence elements: Sequence elements are DNA sequence patterns that have biological significance, for example DNA binding sites for regulatory proteins responsible for gene expression.

Side streams: Side streams refers to all materials coming out of a production plant in addition to the main product (e.g., wood pulp in the case of a paper mill). Side streams can be turned into valuable raw materials or products themselves, while others end up as waste.

13. Hara and Ross-Ibarra (2015) Genetic, evolutionary and plant breeding insights from the domestication of maize

1. Introduction

1.1 Plant ETP's Working Group on Sustainable Agriculture (WG SA)

The European Technology Platform 'Plants for the Future' (Plant ETP) supports the transition of agricultural value chains to more sustainable and innovative systems that remain within planetary boundaries. To actively contribute to this transition, Plant ETP established a multi-stakeholder working group on Sustainable Agriculture in 2019, which consists of experts from academia, the seed and breeding industry, agricultural service providers, and the farming community. The aim of this working group is to consider, from a plant sector perspective, the challenges, and opportunities of agricultural value chains in a holistic way, while developing a vision for future systems spanning food, feed, and biobased raw materials. Strategic direction and recommendations of essential research and innovation (R&I) are presented here for the benefit of policymakers, research funding providers, practitioners, and innovators throughout agricultural value chains.

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1.2 Background and challenges

The EU Green Deal[14] is based on the understanding that human activities are putting planetary health, and consequently long-term social welfare, at risk. To mitigate the impacts of climate change, a transformation is necessary in all sectors of the economy. The EU Green Deal expresses a multitude of ambitious goals that will change the way we work, live, produce and consume food and other products. It puts climate neutrality, resource efficiency and economic competitiveness under one single umbrella. The primary challenge lies in achieving these goals in the complex socio-economic system of the EU, and, indirectly, the world. The extent of the required changes is substantial. This will on the one hand push industry sectors outside their comfort zone by creating business uncertainty, while on the other hand open new business opportunities.

The EU Green Deal aims to make Europe a world leader in sustainability. It kick-starts a change process that will require a 30-year period of learning and improving. Maintaining food supply and business continuity throughout the transition is crucial. The expected changes will nevertheless impose major challenges to the highly interlinked agricultural value chains. These value chains are often deeply internationalised and the complexities of international trade as well as import and export regulations are likely to increase. Ultimately this poses risks for the livelihoods of approximately 29 million workers across the supply chains in the EU[15].

Recent studies have revealed that the required changes rely on three equally important directions[16,17]:

- Future food supply and demand need to adapt to sustainable, healthy, and diverse diets.
- Overall productivity of agricultural production in the EU needs to gradually increase by 50% by 2050.
- Food production and processing must minimise environmental impact by reducing and optimising input use and increasing resilience to impacts of climate change.

Immediate changes can be accomplished by a range of different activities for each of the three drivers. However, significant progress in research and innovation (R&I) will be required to deliver truly sustainable agricultural systems.

It is important to note that the time to market for future innovations derived from *de novo* research can, in some cases, be as long at 20-30 years (Figure 1). It is therefore essential to consider how market needs will change over time, and that actions supporting short-, medium- and long-term goals will need to co-exist to achieve the Green Deal targets. Particularly the 2030 targets of the Farm to Fork[18] and Biodiversity[19] strategies will mostly be addressed in the short- and medium-term by innovation that is already under development. These actions can often not go beyond repositioning or repurposing what is already on the market, or in the research and development (R&D) pipeline. However, the 2050 targets are expected to be more stringent and will require de novo innovation. To prepare pathways for such innovation today, it is of paramount importance to understand how future farming in the EU, but also outside the EU, will likely evolve beyond 2030.

14. EU Commission: A European Green Deal
15. EU Parliament (2020) European Union Food system. EPRS Ideas Paper – Thinking about future EU policy
16. Poore and Nemecek (2018) Reducing food's environmental impacts through producers and consumers.
17. Clark et al. (2020) Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets.
18. EU commission (2020) A Farm to Fork Strategy for a fair, healthy, and environmentally friendly food system
19. EU commission (2020) EU Biodiversity strategy for 2030

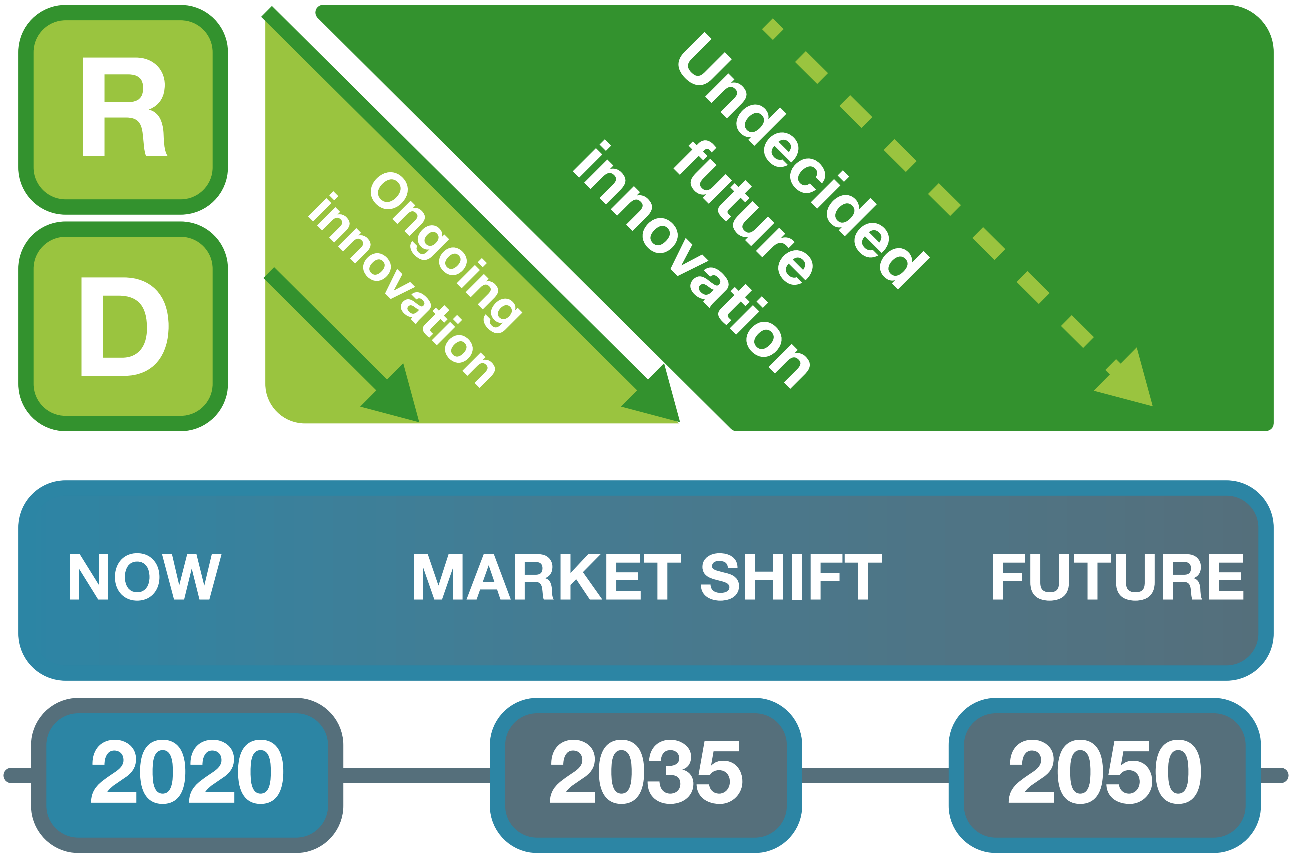


Figure 1. Innovation Flow. In the short- to medium-term, the market will be served by R&D that is already ongoing. Different biotechnology sectors address changes in demand by repositioning and emphasising what is in today's pipeline. De novo R&D will ideally address the demands of the future market. Adapted from[20]

Most importantly, change will very likely be driven by societal demand and emerging and applicable new business models. Without sufficient market pull, financial incentives, and supportive regulation in the short- to medium-term, the transition towards more sustainable agricultural systems risks pushing carbon-intensive production outside the EU, which would not reduce global GHG emissions. This would reduce the competitiveness of stakeholders across the EU agricultural value chains without reaching the objectives of increasing environmental and socio-economic sustainability.

20. Cornelissen et al. (2020) Biotechnology for Tomorrow's World: Scenarios to Guide Directions for Future Innovation

1.3 Essential drivers and interdependencies

Agricultural value chains are long-established and highly interdependent systems. To ensure the adoption and eventual success of new innovations, their impacts on the entire agricultural value chains need to be considered. In the same way, a holistic approach must be embraced, as no single solution can act as a silver bullet. In fact, a combination of several solutions, tailored to individual actors, is needed. These include the promotion of more sustainable and balanced diets, reduction in food losses and waste, increasing crop yields and improving production efficiency for food, feed, and biobased raw materials[21].

While much uncertainty around future food demands and needs exists, it is likely that the demand for high-quality and healthy food, both from plants and livestock, will increase in the EU. Additionally, it can be expected that cultural food preferences, local environmental conditions and transport costs will be influencing factors for shifting dietary patterns as well as changes in food production and processing.

Through ongoing digitalisation of agricultural systems, capacities for data collection and data analysis are increasing and are expected to accelerate the development of new business models, create new opportunities to test and scale products and enhance the development of new production methods. Agricultural data will help predict yields, demand, turn-over and margins across the value chains up to the end-consumer, as well as identify the best compromise between decisions on sustainable farming approaches and volume, quality, and profitability of farm output. It is expected that this interdependency of sustainable output and practices, and predictive data will evolve and eventually become the dominating working principle.

Summing up, the following three interdependent drivers should be developed in parallel and will enable agricultural systems to evolve towards more environmentally and socio-economically sustainable systems (Figure 2):

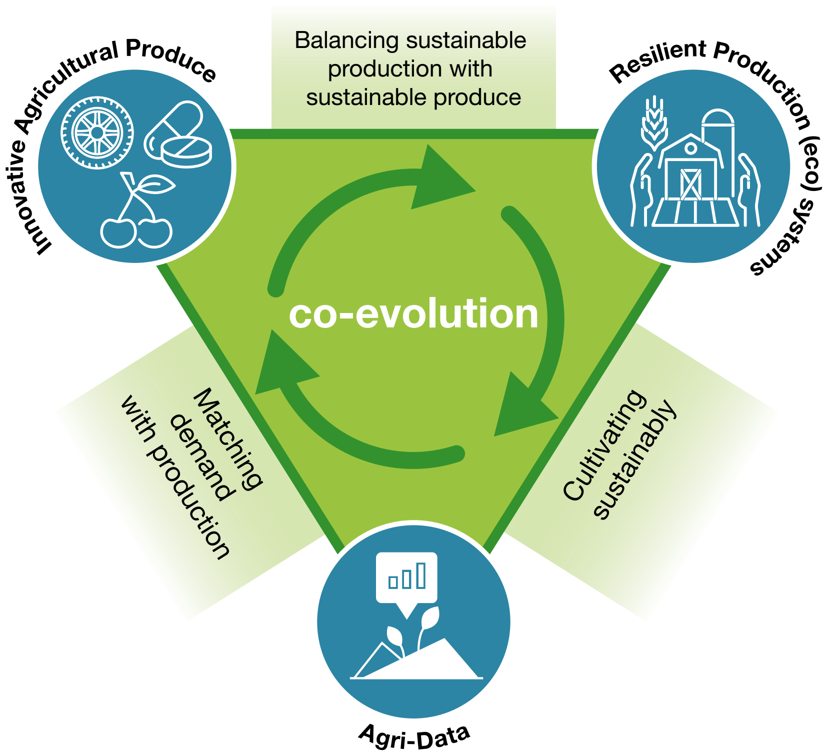


Figure 2. Co-evolution triangle for sustainable agricultural systems. Three interdependent drivers were identified as essential for a successful transition to sustainable agricultural systems: innovative agricultural produce for food, feed and biobased raw materials should be balanced with resilient production at the (eco) system level. This balance will be supported by agricultural data space by leveraging big data and AI to support decision making.

21. Clark et al. (2020) Global food system emissions could preclude achieving the 1.5° and 2°C climate change targets.

(1) Innovative agricultural produce will provide sustainable and healthy food, feed and biobased raw materials for the bioeconomy, meeting consumer needs and societal expectations.
(2) Resilient production (eco)systems will provide sufficient qualitative, nutritious food, feed, and biobased raw materials for society, while promoting One Health.
(3) Agricultural data will be harnessed to support agricultural systems by leveraging big data and artificial intelligence (AI) to balance innovative agricultural produce and resilient production (eco)systems, matching produce with demand and enabling sustainable agricultural production through tailored advice.

A stepwise transition to sustainable agricultural systems is most likely the only realistic way forward. However, due to the socio-economic complexity of agricultural systems, the transition will likely face barriers and resistance to change. Consumer choice drives demand and supply. However, consumer choice is ultimately a personal choice, whereas mitigating climate change requires global adoption of a novel consumption model, in a world that today faces major differences in welfare and welfare expectations. Ensuring that consumers understand the necessity for systemic changes in agricultural value chains is therefore important, as this understanding may drive the desired shift in mindset and knowledge. This obstacle, however, goes beyond what the actors in agricultural systems can address.

A further barrier to change comes from the economics of future sustainable agricultural systems. Scaling of a sustainable products will only work if they remain affordable for consumers and rewarding for the value chain actors, particularly farmers.

The focus of this recommendation report will be on R&I for the plant sector, that is required to deliver sustainable agricultural systems, balancing sustainable produce and production, and using agricultural data. All these topics are interdependent and should therefore be developed in parallel. The aim is to enable value chain actors to make informed choices about future demand streams for agricultural products, explore new business opportunities, and establish sustainable farming practices underpinned through advanced use of predictive data.

2. Innovative agricultural produce

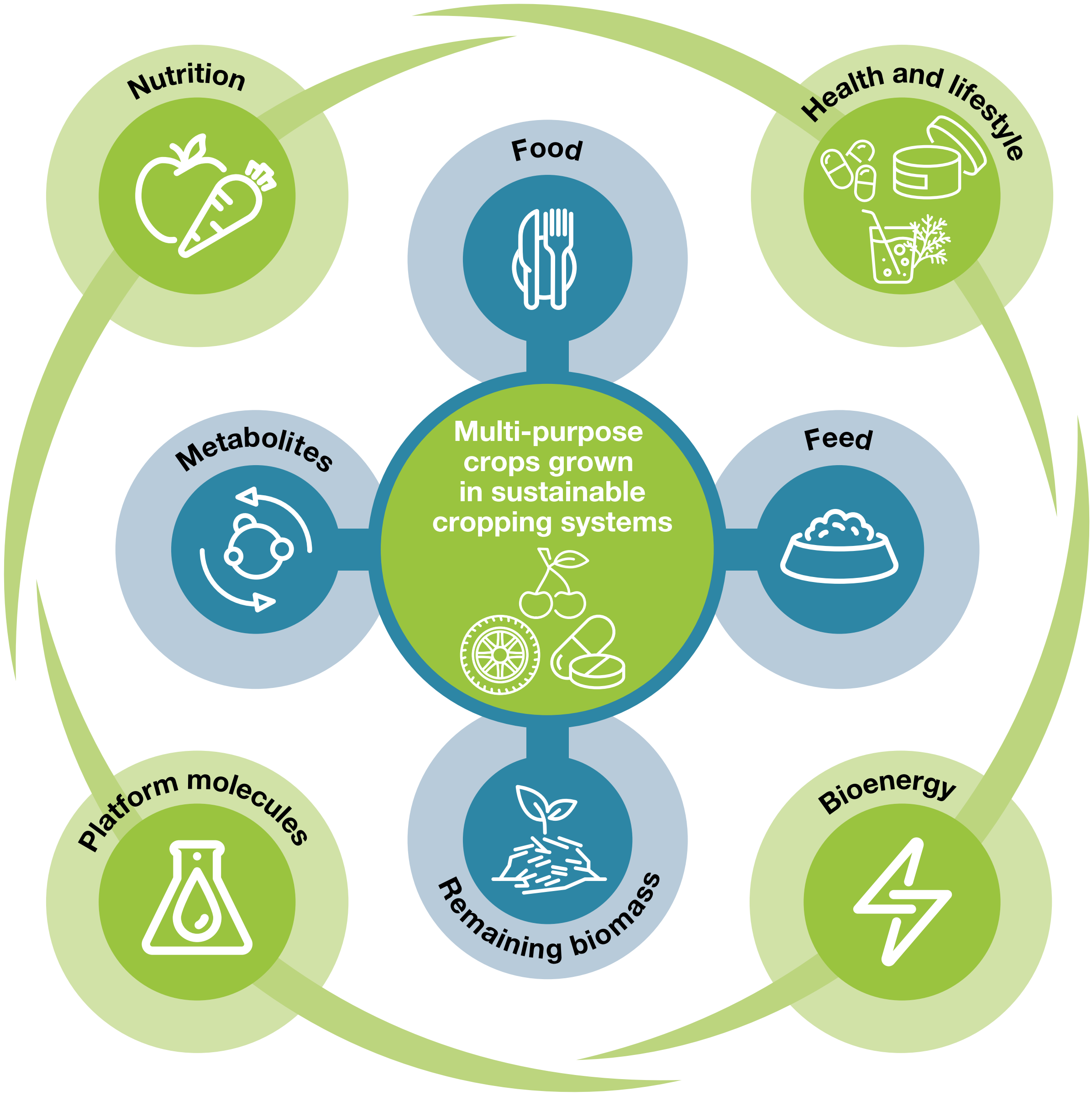


Figure 3. Innovative agricultural produce. New and/or optimised multi-purpose crops grown in sustainable cropping systems will provide the basis for serving a broad range of societal demands.

22. Organisation of the world's seven largest advanced economies
23. Holger and Sardon (2021) G-7 Calls for Making Climate-Change Reporting Compulsory
24. EU Parliament (2020) Towards a mandatory EU system of due diligence for supply chains

2.1 Current context

Pressure to reach sustainability targets (e.g., reducing GHG emissions) is growing across agricultural value chains. This is influenced by several policy drivers. The EU Green Deal, G7[22] commitments to make climate risk reports obligatory[23] and the ongoing development of EU Due Diligence for supply chains[24] are examples of such policy drivers. Additionally, the Farm to Fork strategy sets goals for sustainable agricultural systems by adopting the "One Health" approach[25].

Though ambitious and challenging, this transition also represents an economic opportunity. Growing demand for safe, nutritious, and diverse agricultural products that are more environmentally and socio-economically sustainable has already started to shape new, and existing agricultural markets.

The onset of this transition is exemplified by an increasing range of sustainability claims being featured on both food and non-food products. However, their impact and accuracy are subject to lively debate[26]. At the same time, the development of innovative agricultural produce is accelerating. The resulting products are expected to form the basis of an increasing circular bioeconomy. New value and supply chains, such as biorefineries producing protein feed, biochemicals, biofertilisers and bioenergy, are forecast to play an ever-increasing role (see example Box 1). Recent advances in plant biology, genomics and breeding could potentially unlock additional genetic variability and improve the efficiency and feasibility of developing new crop varieties. Unlocking and effectively sharing knowledge in different parts of agricultural value chains will be a key prerequisite.

Box 1

PLENITUDE aims to install a zero-waste integrated mycoprotein-based production system to create new biobased and high-quality protein foods. The five-year partnership project operates under the EU's Horizon 2020 R&I programme and unites a consortium of 10 partners covering the entire value chain from production to packaging and marketing.
The fermentation process in PLENITUDE will produce mycoprotein, a high-quality protein, containing all nine essential amino acids, comparable to the quality in meat and fish. The underpinning technology is an integrated system capable of producing and isolating ethanol and mycoprotein from sustainable sources such as primary grains (e.g., wheat).

Novel business models, co-created by key value chain actors and fostered by supportive policies, will be necessary to reward farmers and other actors for their participation in advancing agricultural sustainability and circularity. The Farm to Fork strategy explicitly proposes carbon sequestration through agriculture and forestry as an emerging green business model: "*Farming practices that remove CO_2 from the atmosphere contribute to the climate neutrality objective and should be rewarded, either via the common agricultural policy (CAP) or other public or private initiatives. A new EU carbon farming initiative under the Climate Pact will promote this new business model, which provides farmers with a new source of income and helps other sectors to decarbonise the food chain*."[27] To this end, in January 2021, the European Commission published a study outlining the operationalisation of such business models[28]. Additionally, several private corporations are already developing and implementing business models featuring financial compensation for sequestered carbon at the farm and forest level in the EU.

25. One Health is a collaborative, multisectoral, and trans-disciplinary approach - working at local, regional, national, and global levels – to achieve optimal health and well-being outcomes recognizing the interconnections between people, animals, plants and their shared environment
26. Brown et al. (2020) The future of environmental sustainability labelling on food products
27. EU commission (2020) A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system
28. EU commission (2021) Operationalising an EU carbon farming initiative

2.2 Desired future outcomes

Current and future trends will increasingly drive towards improved and more sustainable production systems of novel crops, bred for multi-functionality, at affordable costs. Therefore, breeders will seek to unlock the potential of a wide range of crops that may to date have been considered either novel, orphan or already mainstream. New crop varieties will have to benefit multiple purposes, thereby serving various markets (Figure 3). This includes the provision of nutritious food contributing to healthy and balanced diets, reducing obesity, non-communicable diseases, and malnutrition. In combination with such high-value food, crops will provide a high yield of platform molecules i.e., biobased building blocks, such as carbohydrates, to produce high-value chemicals and materials. The composition of crop-derived feed will favour efficient conversion into meat, milk, or other animal products, while reducing emissions of GHGs (such as methane in ruminants). Non-edible crop parts will increasingly serve as specific components for high-value non-food applications (e.g., latex for tyres). To grow these multi-purpose crops sustainably and efficiently, farmers will utilise an enhanced toolbox for production using new and/or improved farm management practices (see Chapter 3 on Resilient production (eco)systems).

In addition to the primary objectives of crop innovation, valorising side streams will optimise the use of all plant parts, thus increasing circularity and reducing the environmental impact of end products. New value chains, including actors from different sectors, will be required. Value chains for non-food biobased products might consist of actors such as processors, polymerisation plants, and bioplastic compounders. Consumers will be able to choose between a broad spectrum of sustainable biobased products derived from a wide range of crops.

In summary, innovative agricultural produce will deliver long-term positive outcomes for all stakeholders of agricultural value chains:

- Farm suppliers will provide an extended toolbox for resilient farm productivity and increased circularity, ensuring high-value nutrition as well as non-food qualities.
- Farmers will be embedded in agricultural systems that enable them to perfectly balance demand, farm management and farm application.
- Processors will utilise an adapted toolbox of equipment to open secondary value chains. They will integrate production for several markets from one crop; and they will safeguard and enrich nutritious compounds and/or their bioavailability.
- Retailers will benefit from optimised logistics and will be less dependent on imports.
- Consumers will fully understand and trust reporting on socio-economic as well as environmental impacts of agricultural products and their importance for food and nutritional security.

2.3 Main challenges for desired future outcomes

To reach the desired future outcomes, innovation along agricultural value chains is crucial. Innovation is generally recognised to be successful when it is desirable, feasible and viable. Significant innovation in agricultural produce necessitates the alignment of four complex and ambitious requirements:

I. Understanding the desirability of sustainable products.

Insight into effective consumer communication is key. This is fundamental to understand consumer perception and preference, gain consumer acceptance, as well as boost consumer demand for (new) products with a higher added sustainability value.

II. Novel business models and industry structures to ensure economic viability in value chains.

This includes the creation of markets for new biobased products in cooperation with processors and retailers, ensuring returns on investment for farmers, while remaining affordable for consumers.

III. Assess and improve feasibility of reaching sustainable value creation at the processor and farmer level.

This also means adopting innovative agricultural practices and technologies. These can be characterised as cropping systems that deliver farm outputs which meet commercial demand as well as providing food and nutritional security, while being socio-economically and environmentally sustainable.
At processing level this includes researching the use and production of environmentally friendly food while ensuring nutritional security. Additionally, the economic impacts of novel biobased raw materials, including new and more diverse value chains need to be regarded.

IV. Unlocking natural genetic variability and improving the feasibility of sustainable value creation at the crop level.

This means accelerating the breeding process through plant breeding innovation to meet commercial demands for the bioeconomy, while ensuring food and nutritional security and reducing production costs.

2.4 R&I recommendations for desired future outcomes

2.4.1 Understanding the desirability of sustainable products

There is an increasing societal demand for greater transparency in agricultural systems. Studies examining consumer commitment to support sustainable agriculture have demonstrated that providing information on sustainability has limited effects in changing consumer behaviour. The concept of sustainability remains abstract for many consumers and, unlike the taste or convenience of a product, is not a direct driver of consumer behaviour. R&I is needed to determine how to provide such information in a clear and accessible manner. Determining what type of information to make available, without compromising privacy and data ownership of the value chain actors is important (see Chapter 4 on Agri-Data).

To facilitate a shift to more sustainable diets, consumers need support when making their day-to-day food choices (see example Box 2). Some examples of possible interventions are labelling, benchmarking, or rankings, integrating sustainability risks, and subsidies. R&I combining social and life sciences will be needed to determine which, if any, of these will be most efficient in promoting demand for more sustainable agricultural products, while at the same time ensuring that socio-economic sustainability is unaffected, for all agricultural value chain actors. At the same time, R&I will be needed to ensure sustainable products remain affordable to consumers with lower disposable incomes, by identifying alternative financial mechanisms (such as subsidies or carbon certification schemes).

R&I is also necessary to determine best practices ensuring that future generations will continue to support the demand for sustainable agricultural produce. In this regard, education interventions, such as specific school programs or directly informing households, have shown promise[29]. However, these are often deployed as pilots, at small scale, and are often time restricted. A state-of-the-art initiative should be considered when investigating how to upscale such activities for higher impact.

Although scientific evidence regarding successful behavioural change mechanisms exists, further research is needed to understand what type of information and intervention, under which conditions and for what target groups works best. Data analytics can also play a major role in understanding these interactions and is generating various R&I leads for improved forecasting of green consumer trends[30]. Ultimately, as in the case of consumer labels, research insights must be carefully leveraged: it is imperative to disseminate information to the broad public with the goal of aligning consumer knowledge and promoting ‘new traditions’ of renewable resource use.

Box 2

Study shows: most EU consumers want to eat more sustainably but face barriers

In June 2020, the European Consumer Organisation (BEUC) published the study **“One bite at the time: Consumers and the transition to sustainable food”**, which investigated consumer trends regarding sustainable food in 11 EU countries. The study concludes that two thirds of consumers are already willing to change their eating habits for environmental reasons. However, to achieve this, access to sustainable food must become easier. The price, lack of information, the challenge of identifying sustainable food and limited availability are the main perceived barriers to sustainable eating. Even though consumers are mostly aware of the environmental impact of food habits in general, they still tend to underestimate the impact of their own food habits. The survey results also show that most consumers want national and EU governments to further promote sustainable food and, at the very least, adhere to the current level of ambition.

29. Sustainable Food Systems Network | FIT4FOOD2030: toward sustainable food systems
30. Chandra and Verma (2021) Big Data and Sustainable Consumption: A Review and Research Agenda

2.4.2 Novel business models and industry structures to ensure economic viability in value chains

Agricultural value chains often have deep roots in both traditional and modern society. As a result, the transition towards more sustainable agricultural produce will necessarily transform traditional value chains by introducing new value systems. In addition to replacing fossil-based with biobased raw materials for existing applications, consideration must be given to new processing and product opportunities created by the introduction of novel biobased raw materials and arising new value chains.

Launching new products incurs considerable investment risks, which are usually borne by private businesses. Nevertheless, the introduction of new products is crucial for the identification of new value chains and must be facilitated, whenever possible, at each step of development: testing, rollout, and upscaling. Therefore, R&I is required to rationalise the prioritisation for supporting pilot projects that deliver new products possessing strong sustainability profiles and market options that render them suitable for large scale production. At the same time, factors for upscaling successful pilots need to be identified and implemented throughout the EU.

The transition towards more sustainable agricultural produce depends on the establishment of supportive environments that facilitate innovation by small and medium enterprises (SMEs) and support business incubators. These will play a pivotal role in the drive beyond current horizons. Currently, regulatory hurdles and R&I cost-induced entry barriers hamper the success of such companies. Therefore, R&I is needed to identify the best ways to support start-ups, such as establishing a network connecting them with relevant resources and empowering them to leverage these resources (e.g., lab infrastructure, scientific and regulatory expertise) (see Box 3). The availability of such resources will also increase the probability of start-ups to mature, making them more attractive to investors. At an agri-food company level, R&I should also generate aggregated sustainability profiles that investor communities require (see Chapter 4 on Agri-Data). This will shift capital to more sustainable companies and catalyse sustainability gains along agricultural value chains.

R&I is needed to identify value chain opportunities and industry structures that best leverage new processing outcomes. Different combinations of interventions and business models are already being explored to support the growth of sustainable products. For example, joint ownership models of investors from the agri-food industry with farmers[31] can be one such approach. The objective of these joint ownership models is to generate revenues from public and private sources to improve sustainable

31. Grashuis (2018) Joint ownership by farmers and investors in the agri-food industry: an exploratory study of the limited cooperative association

production and landscapes, while supporting the livelihoods of farmers (i.e., in relation to the new CAP that better rewards environmental performance of EU farmers)[32].

Short value chains, such as those pertaining to consumer food products, exhibit broader social exposure and a relative systemic simplicity. As such, they may serve best as the initial domains of implementation of new policies, be it targeted towards new products or process pilots, facilitating start-up R&D, or designing regional value chains.

Overall, R&I is needed to evaluate the impacts of new policies on economic aspects of agricultural value chains. Inversely, R&I should explore how policies could support more sustainable products in the face of more competitive products, particularly imported products from regions with lower environmental standards, options to redistribute these revenues to farmers, and the right conditions under which to support sustainable primary production.

Box 3

Create an attractive innovation ecosystem to facilitate state-of-the-art innovation by SME's

Why?

Modern and sustainable farming requires continuous innovation. Previously, innovation predominantly focused on the development of synthetic plant protection products (PPPs) to secure higher yields. Due to increasing regulatory hurdles and the consolidation of some agricultural industries, innovation efforts on plant protection have lost their momentum and focus has shifted towards the digitalisation of agricultural practices and modern plant breeding efforts. Also, established PPPs have been taken off the market, limiting the options for farmers. One of the major challenges to enter the field of R&D of PPPs is to establish an infrastructure for product safety testing. The required investment and knowledge are often too extensive for new entrants to compete with the established agricultural industries. This is a huge obstacle for SMEs and start-ups to invest into innovation in synthetic PPPs. Therefore, there is a strong need to further advance and support the innovation ecosystem and to motivate and enable start-ups to step into this field of R&D.

What is required?

As start-ups and other entrants rely on strong partners for their R&D and innovations, the creation of research platforms, where partners provide the required infrastructure, would be a major step to close the gap of innovation for PPPs.

The outsourcing of R&D activities to contract research laboratories during recent years has provided these laboratories with sophisticated R&D infrastructure and knowledge, which makes them suitable research partners for start-ups. This would confer the advantage that start-ups would not need to invest into hardware and human resources. This activity could be funded by both private and governmental sectors and based on milestone achievements and/or risk sharing models between start-ups and partners. As an additional benefit for start-ups, contract research laboratories are already familiar with the attraction of investors, thereby simplifying the process of raising capital. Such a business model would complement the existing model for future agriculture systems, as it drives sustainable and environmentally friendly solutions, with outcomes being directed by the interests of investors.

32. EU Commission (2021) Political agreement on new Common Agricultural Policy: fairer, greener, more flexible

2.4.3 Assess and improve feasibility of reaching sustainable value creation at the processor and farmer level

As discussed previously, work on innovative agricultural produce is characterising an ever-increasing proportion of agricultural value chains. For this trajectory to be consolidated in a scalable and durable manner, numerous capabilities need to be built into the toolbox of key upstream actors; namely, processors and farmers. Outcomes as ambitious as enabling processors to harvest and process side streams and integrate production of single crops for several markets, as well as farmers balancing crop demand, farm management and input demand are equally significant. These will range from climate-resilient multi-purpose crops, adaptation to existing, new and alternative agricultural practices (such as re-imagined cropping systems and incentive systems to adopt these), to new technologies enhancing side stream processes.

Farmers today find themselves at the intersection of two challenges unfolding simultaneously: on the one hand, current farming techniques and input use are increasingly being regulated, and on the other hand market outlets as well as consumers have rising expectations with regards to the sustainability criteria of their food.

Two areas of innovation could play a pivotal role in helping farmers balance demand trends with farm management and emerging sustainability: climate-resilient, multi-purpose crops that can deliver food, feed and biobased raw materials will play a central role; and holistically designed cropping systems that will play an increasing role in future farm management (see Chapter 3 on Resilient production (eco)system).

Furthermore, competition between land use for food and non-food crops (NFC) must be considered. Regardless of whether biomass is used for high- or medium-value non-food products, the EU has strict regulations regarding land use for growing NFC[33]. Additional research is needed to evaluate the environmental and socio-economic impacts of non-food biobased materials (in comparison with fossil-based materials) throughout value chains. R&I should consider how to increase NFC production for biobased raw materials, without impacting food production by, for example, using marginal soils (see example Box 4).

R&I is necessary to understand and determine the value of biobased raw materials derived from (new) crop varieties and grown for a wide range of purposes.

Source: EU-project PANACEA
Network for the use of non-food crops
in the European biobased economy

Box 4

PANACEA is a network of actors from science, industry, and agricultural practices in 10 countries, which fosters exchange and promotes the entrance of non-food crops (NFC) into the EU bioeconomy. NFC are crops that do not enter the food chains and are used to produce a wide range of biobased products including polymers, lubricants, construction materials, pharmaceuticals, as well as bioenergy and fuels. Of special interest are lignocellulosic perennial NFC, which can not only be used to extract cellulose and carbohydrates, but also play a significant role in carbon sequestration. This Horizon 2020 funded project oversees more than 200 projects linked to sustainable growth and the use of NFC. It also provides training to farmers, agronomists, and agricultural students on practice-oriented knowledge of NFC- specific value chains.

33. Bruckner et al. (2019) Quantifying the global cropland footprint of the European Union’s non-food bioeconomy.

This, in turn, could lead to new value streams in areas, such as better valorisation of non-edible raw biomass to generate additional revenue for farmers. Processors are not new to transformation of materials and processes on this scale. The production of consumer goods (such as plastics using fossil-based raw materials) has developed over several decades to reach optimal efficiency and quality at the lowest possible cost. Although several biobased raw materials have the potential to replace fossil-based materials (see examples Box 5), these components are still at the formative stage of the optimisation process. Production costs are generally higher than those of their fossil-based counterparts and are often considered riskier in terms of infrastructure investment and future sales[34]. Consequently, increasing efficiency of extraction and purification is essential, as is considering toxicological profiles.

Therefore R&I is needed to develop and optimise mild separation techniques for valuable components in main and side streams, and to develop frameworks to identify the most suitable biobased raw materials for different purposes[35]. Although platform molecules that can provide a broad range of intermediary products are generally perceived as most suitable and cost-efficient, the share of products produced from biobased platform molecules (e.g., sugars) is currently only 0.3%[36]. In some instances, extractability and processability of these molecules can be improved by targeted plant breeding efforts. A feedback loop from the desired (molecular) structures and properties of plant ingredients in high-value end-applications back to new breeding technologies, i.e., a direct interaction between processing and breeding experts, should be established. In the Agri-Data section (see Chapter 4 on Agri-Data), a reliable platform that could support this feedback loop is suggested.

Securing economic well-being while promoting sustainability objectives means designing business models that can create markets for sustainability. These business models must, of course, be integrated into newly rethought cropping systems. One new business opportunity that is being widely discussed is carbon farming. This business model could unlock agriculture and forestry carbon sequestration potential. To meet the ambitions outlined in the new Circular Economy action plan[37], R&I should focus on enhancing carbon removal through various instruments, developing regulation and identifying incentives as well as financing options that can foster this approach. This would yield a two-fold benefit of contributing to climate change mitigation, whilst being an additional source of income for farmers.

34. EU Interreg (2020) What is the European market for biomass chemicals?
35. Bomtempo (2017) Developing new platform chemicals: what is required for a new bio-based molecule to become a platform chemical in the bioeconomy?
36. EU commission (2019) The future of bio-based chemicals in the EU Bioeconomy
37. EU Commission: Circular economy action plan

Box 5

DRIVE4EU: *Dandelion Rubber and Inulin Valorisation and Exploitation for Europe.*
In a consortium of 8 industrial partners and 5 research organisations from 7 EU countries and Kazakhstan, this EU project sought, from 2014 to 2018, to demonstrate the economic potential of a European production chain for natural rubber and green chemicals (inulin) derived from Russian dandelion. Currently, the EU is dependent on imports of natural rubber, which is harvested exclusively from the rubber tree (of which 90% is grown in Southeast Asia). Thus, a new (European) source for natural rubber is needed. During the project, new breeding varieties were cultivated and recorded, extraction methods patented and pilot products such as car- and bike tyres produced and tested.

INN PRESSME is an EU project, started in January 2021, which develops biobased materials and solutions for industry to replace fossil resources. The project is funded under Horizon 2020 and includes 27 partners from 9 countries. In addition to the development of new market-ready products from biobased materials by feedstock conversion – which, due to nano-enabling, will exceed performances of current fossil-based materials – INN PRESSME also supports the digital transition by providing companies with data and life cycle value chain modelling tools to maximise the use of feedstock materials in the circular economy.

2.4.4 Unlocking natural genetic variability and improving the feasibility of sustainable value creation at the crop level

Plant breeding is a key enabler for the transition towards a thriving bioeconomy. A crucial requirement to successful breeding is identifying the desired characteristics, such as productivity, resilience, quality, and palatability in crops. Additionally, concentration of certain substances as well as extractability of these, is increasingly important. Plant protein biomass processing has significant challenges in optimising product quality and taste because many plant proteins easily degrade at the high temperatures occurring during processing. Successful improvements therefore include modifications to the plant's chemical composition. Technical complexities of plant protein extraction notwithstanding, a crop-by-crop list of target characteristics will be a key driver in accurately addressing both needs for human nutrition and the bioeconomy.

Food production must not only provide a secure supply, but must also evolve with consumer habits and remain appealing. The priority among such consumer habits is perhaps the increase in consumption of plant products high in proteins[38]. Many crops high in protein present a less complete profile of essential amino acids compared to animal-based protein sources (see example Box 6)[39]. While much work has already been done to improve the nutritional profiles of plant proteins, this has agronomic challenges. Thus, R&I is necessary to develop new crop varieties that combine high nutritional value with strong resilience to pests, drought, acidic soils, and a host of other adverse climatic and biological factors (see Chapter 3 Resilient production (eco)systems).

Box 6

Several essential amino acids are scarce in cereal proteins. When relying on cereals as the primary source of proteins, this lack in certain essential amino acids can cause deficiencies in human metabolic systems39. Cereal proteins are low in lysine (1.5 - 4.5% vs. the World Health Organization recommendation of 5.5%), tryptophan (0.8 - 2.0% vs 1.0%) and threonine (2.7 - 3.9% vs 4.0%). In the past, plant geneticists and breeders have made great efforts to improve the quality of plant proteins. Mutations that increase lysine content in maize and barley, have already been identified. Unfortunately, positive mutations have also been associated with trade-offs, such as increased susceptibility to diseases and pests, and lower yields. However, R&D in this regard is ongoing as plant proteins are inexpensive to produce and already have high priority in the human diet.

Source:
Sun and Liu (2004): Transgenic Approaches to Improve the Nutritional Quality of Plant Proteins

R&I should also focus on the production and use of crops with climate change mitigating features, such as perennial legumes (e.g., clover and alfalfa) that reduce the need for nitrogen fertilisers, thereby fostering biodiversity, soil health, as well as reducing net GHG emissions (through CO_2 absorption) and even enhancing carbon sequestration (see example Box 7). Furthermore, new crop varieties with specific resistance to drought and frost, to increase their use availability in the northern parts of the EU, are important goals of current and future R&I.

38. Smart Protein (2021) Plant-based foods in Europe: How big is the market? The Smart Protein Plant-based Food Sector Report
39. van de Poll et al. (2005) AMINO ACIDS | Specific Functions

Box 7

TRUE (**TR**ansition paths to s**U**stainable legume-based systems in **E**urope) is a 22-partner consortium (from business and society) operated from 2017 to 2021 under Horizon 2020. The aims of TRUE were to identify new protein crops for food and feed, to promote legume-supported production systems and food chains, and to advance nitrogen use efficiency in non-legume crops.
Therefore, sophisticated mathematical approaches such as Life Cycle Analysis, and socio-economic and multi-attribute modelling were used to create unique decision support tools to identify optimal transition paths and to ensure that legume-supported systems are profitable from production to upstream supply chains, markets, and consumers.
During the project, different working groups developed novel food and non-food uses for legumes, investigated international market and trade aspects, tested nutrient quality and environmental impacts, determined the economic performance of legumes and analysed transition paths into food and business chains across Europe.

Additional R&I will be needed to improve – as a co-benefit to environmental sustainability – the food and nutritional security of staple crops (through biofortification) and underutilised crops (by improving their economic performance and further increasing their nutritional quality).

Gathering genetic information from a range of plant species and varieties is crucial for undertaking large-scale breeding initiatives. However, successfully analysing new genomic data relies on time- and resource-intensive collaborative efforts, usually undertaken by consortia. There is an imperative to scale up these efforts. High quality genomic data should ideally become available for each crop of interest, related species, and/or interacting organisms. Genes could then be mapped, and the functions of their corresponding proteins determined. This would allow scientists to utilise bioinformatic, AI and machine learning tools to identify target genes and propose necessary changes to improve crop characteristics.

To best utilise the genetic resources at our disposal, major funding is needed to support the development of publicly available genomes for multiple species and varieties[40]. Additionally, development and experimental validation of bioinformatic and machine learning tools for the analysis of genomes, as well as new AI-assisted approaches in systems biology and genomic selection to discover genes responsible for improved crop characteristics and performance, are necessary.

40. One example for such a research approach is the BOLD project conducted by the Crop Trust and funded with USD 58 million by the government of Norway. Access to more information on the project can be found here: The Crop Trust (2021): The BOLD Project: Harnessing Crop Diversity to Adapt to the Effects of the Climate Crisis.

3. Resilient production (eco)systems

Figure 4. Resilient production (eco)systems. Data informing integrated farm management practices will enable farmers to choose optimal methods for their conditions, that offer the best predicted outcome for environmental and socio-economic sustainability. Data would be collated at the farm system level and supported by a common agricultural data platform (see Chapter 4 Agri-Data).

3.1 Current context

The provision of sufficient nutritious food for a healthy society is a well-recognised global imperative, compounded by the overarching impact of a changing climate. However, a myriad of barriers to efficient and effective agricultural production prevail. These include an increasing yield gap for many staple crops in Europe, due to a stagnation of productivity growth[41], increased soil degradation, reduced soil fertility, and reduced biodiversity. Following a business-as-usual scenario, the impacts of agricultural production on the environment are projected to increase, while the socio-economic status of primary producers (e.g., low income, ageing population) is unlikely to improve[42].

Increased food production will therefore require enhanced use of resources and inputs, mainly nutrients, plant protection products (PPPs) and water. Furthermore, increasing populations will exert pressure to convert more wildland to cropland to deliver the required food, feed, and biobased raw materials for the bioeconomy. This will exacerbate existing issues surrounding GHG emissions, with the agricultural sector already identified as a significant contributor, not only to global emissions, but also to degradation and erosion of soils, threats to biodiversity, pollution, and competition for land and resources. Thus, a step-change in sustainable approaches to agricultural production should be adopted to deliver both socio-economic and environmental benefits, though trade-offs and conflicts throughout production systems are inherent and will provide significant challenges for agricultural production (eco)systems to remain within recognised planetary boundaries.

In recent years, there has been an increasing focus to deliver more sustainable solutions, including the use of minimum or zero tillage, adoption of controlled traffic farming and precision agriculture, the use of integrated pest management strategies, mob-grazing, the “4 per 1000” initiative[43] to enhance soil fertility through increasing soil carbon, and the increasing use of nature-based solutions[44] to support the production of food, feed, and biobased raw materials.

However, these practices are – on their own – often considered inefficient to deliver sufficient long-term (eco)systems resilience[45,46]. Future production systems will need to generate high quality, nutritious, and resilient produce, while at the same time be a focal point of environmental stewardship and socio-economic sustainability. Such systems should restore and maintain soil health, optimise land use, enrich biodiversity, and provide multiple societal benefits. A key focus will be the utilisation of genetic diversity from a broad range of sources and varieties developed through breeding programs. The challenge will be to progressively transform the use of all resources across different EU scales (farm, regional, national, international) with the goal to maximise circularity and to strive for self-reliant and resilient production (eco)systems adapted to local/regional conditions.

For this, new initiatives such as the EU mission on Soil Health and Food[47], and the European R&I partnership on agroecology living labs and research infrastructures[48], have potential to play a key role, if well managed and executed to balance environmental and socio-economic sustainability gains, while maintaining production levels. Existing initiatives, such as EIP-AGRI and its Agricultural Knowledge and Innovation Systems (AKIS)[49] should further be supported to scale impact. Finally, supportive measures, such as the Common Agricultural Policy (CAP), will be essential to enable and reward primary producers to transition to more environmentally sustainable production (eco)systems.

41. Giller et al. (2021) The future of farming: Who will produce our food?
42. EU commission (2017) Modernising and simplifying the CAP - Economic challenges facing EU agriculture
43. 4 per 1000 Initiative
44. FAO (2021) Nature-based solutions in agriculture: Sustainable management and conservation of land, water and biodiversity
45. Seddon et al. (2020) Understanding the value and limits of nature-based solutions to climate change and other global challenges
46. Bronson et al. (2020) National mitigation potential from natural climate solutions in the tropics.
47. EU Commission: Mission area: Soil health and food
48. EU Commission: European R&I partnership on agroecology living labs and research infrastructures
49. EU: EIP-AGRI Brochure Agricultural Knowledge and Innovation Systems

3.2 Desired future outcomes

Future resilient production (eco)systems will need to generate sufficient high quality, nutritious, and raw biobased materials for society. While agricultural systems transition towards greater environmental sustainability, it is essential that socio-economic sustainability increases in parallel. Primary producers, through their activities and practices, both depend on and are affected by the natural environment that intimately interact with their production (eco)systems.

Future farmers will produce high quality and high yielding crops for a range of purposes, while at the same time managing their production (eco)systems to promote One Health. Going forward, farmers will be recognised by society as stewards of the environment and receive adequate financial benefits for their contribution to environmental sustainability (e.g., green credits, carbon certification).

Main enablers to reach resilient production (eco)systems are

- An extensive toolbox of environmentally friendly and integrated resource and pest management solutions that will provide both yield stability and adequate financial returns for farmers.
- Information on a range of sustainable cropping systems and farm management practices and their respective outputs in different regions and locations, to identify the most suitable crops and practices based on the characteristics of each farm.
- A panel of resilient and multi-functional common, new, and diverse crops and varieties for food, feed, and raw biobased materials, meeting the demand for sustainable and innovative agricultural produce.
- Knowledge sharing and continuous learning options to upskill farmers, farm advisors and farm workers, and to support career development and uptake of new and innovative practices and technologies.

3.3 Main challenges to reach desired future outcomes

Farmers are expected to increase productivity, diversity, and quality, while meeting societal and political expectations to improve environmental sustainability. At the same time farmers must remain competitive and maintain socio-economic sustainability. This poses a major challenge to farmers across the EU. More precisely:

I. Developing and adopting resource and pest management tools supporting One Health.

Primary producers will need to produce nutritious and sufficient food, feed, and biobased raw materials with limited external inputs (e.g., fertilisers and PPPs), while facing a range of increasing external pressures (e.g., climate change, drought, heat stress, flooding, pest migrations), and the need to improve (eco) system health. New management tools and solutions will be necessary to deliver these ambitious goals.

II. Developing methodologies for monitoring and improving cropping systems and farm management practices for more sustainable production (eco)systems.

Outputs of cropping systems vary according to external factors, including climate, soil type, temperature, and day length, thereby also affecting the level of environmental sustainability of a given system. To support the transition to more sustainable cropping systems and management practices, standardised metrics on performance and sustainability are essential.

III. Breeding multi-functional, fit for purpose, crops for food, feed, and biobased raw materials, tailored for resilient production (eco)systems in different regions.

Plant breeding efforts will need to be accelerated. Focus needs to be put on a broad range of characteristics for a diverse set of underutilised, traditional and heritage crops. New plant breeding techniques, particularly new genomic techniques, have the potential to contribute to this process. Negative public perception and restrictive regulations hamper their use.

IV. Developing access and support for continuous learning and knowledge sharing for farmers.

Successful adoption of new, alternative and/or innovative practices and technologies necessitates demonstrations, education, and training. Farmers, farm advisors and farm workers need access to support systems and continuous learning, to make full use of the available tools that contribute to more sustainable agricultural systems while exploring new business opportunities.

3.4 R&I recommendations to reach desired future outcomes

3.4.1 Developing and adopting resource and pest management tools supporting One Health

Pest and resource (e.g., nutrients, water) management are fundamental aspects of agricultural practices to ensure food safety and security, as well as safeguarding the livelihoods of farmers. Water, in particular freshwater, is an important natural resource for agricultural production, which accounts for roughly 70% of freshwater withdrawals globally[50]. While there is sufficient freshwater supply for agricultural production on a global level, an increasing number of regions are facing growing water scarcity. This is a result of changing climate conditions and the increasing occurrence of extreme weather events, such as more frequent and extended periods of drought[51].

Concurrently, new, and emerging pests are threatening agricultural production, with a changing climate increasing their migration to new areas. The use of appropriate PPPs is therefore essential to manage emerging threats. However, past extensive and long-term use of PPPs, combined with the use of fertilisers and invasive land management techniques has already had significant negative impacts on the environment (e.g., biodiversity loss, reduced soil health and fertility, eutrophication of nearby waterways).

Maintaining or even increasing agricultural productivity and improving (eco)system resilience, while simultaneously reducing environmental impact and ensuring the livelihoods of farmers requires a holistic approach to improve resource and pest management systems. The integration of a diverse set of pest and resource management solutions is key to achieving sustainable agriculture. Enabling farmers to reduce their environmental impact in a socio-economically sustainable way, will require R&I aimed at developing innovative and environmentally friendly tools and solutions using a systems approach.

R&I should aim to develop integrated pest management strategies that exploit ecologically based solutions for pest control and improve the resilience of crops after pest infestation with behavioural and biological tools aimed at controlling a broad spectrum of pests (see example Box 8). Developing environmentally neutral, or ideally, environmentally positive PPPs, such as nature-based solutions and next-generation biocontrol will contribute to high quality, and sustainable agricultural production, without compromising the financial stability of primary producers.

Furthermore, R&I should aim to develop and improve smart machinery and equipment to deliver integrated nutrient, water, and pest management practices, including pre-symptomatic disease/deficiency detection, prevention measures and smart pest, nutrient, and water management tools. In addition, R&I is required to support the establishment of a pan-European pest monitoring system and develop an infestation alert service that would allow farmers and other landowners to prepare for and tackle pest infestations early on. This would significantly reduce the damage inflicted, while also offering the opportunity to learn about and share innovative techniques.

50. FAO (2017) Water for Sustainable Food and Agriculture - A report produced for the G20 Presidency of Germany
51. FAO (2015) Towards a water and food secure future – critical perspectives for policymakers

Box 8

IPMWORKS is an EU-wide farm network (covering 14 Member States) demonstrating and promoting cost-effective Integrated Pest Management (IPM) strategies. The objective is to reach a reduction of 50% of pesticide use of European agriculture by 2035. By the establishment of networks at EU, national or local levels, peer-to-peer knowledge exchange and activities to help farmers to design their own IPM strategies is facilitated. IPMWORKS produces demo events, training events, and practice guides.

IPM is based on a diversity of pest management measures such as prevention, non-chemical control, and best practices for optimising pesticide efficiency. These measures are combined at the farm level to enable reduced reliance on pesticides, and therefore minimise the effects on the environment and people.

To date, IPMWORKS has involved 3,700 farmers and reached a reduction in the frequency of pesticide treatments of 30%.

A better understanding of how to maintain and increase biodiversity and soil health requires additional R&I. Assessment and monitoring of biodiversity associated with agricultural production systems is crucial to ensure a successful transition to more sustainable production (eco)systems. A special focus must be placed on functional biodiversity that delivers ecosystems services related to agricultural production. In addition to assessments and monitoring, the need to identify and promote programs that improve and maintain biodiversity is essential. In parallel, R&I is also needed to better understand soil biology, chemistry, and physics to develop and implement innovative soil management practices aimed at maintaining and protecting soil structure for enhanced drainage, air filtration, root penetration and mitigating erosion. This includes increasing soil organic matter and carbon sequestration in the soil, as well as increasing soil fertility.

3.4.2 Developing methodologies for monitoring and improving cropping systems and farm management practices for more sustainable production (eco)systems

Cropping systems vary across the EU. The main reasons are diverse geographical and climate characteristics as well as different management systems. A successful transition towards more socio-economic and environmentally sustainable production (eco)systems will require extensive knowledge of the capacity of and impacts on traditional, current, new, and alternative farm management practices. The adoption of new crops and cropping systems across geographically diverse landscapes and regions with regards to water and nutrient availability, soil types, and pest burden is a challenge that must be met with a broad awareness of these systems.

R&I is needed to develop methodologies for efficient monitoring and cataloguing of farm outputs and corresponding environmental impacts (e.g., soil health, biodiversity, water quality) resulting from combinations of crops, cropping systems and practices across a broad spectrum of locations and environments. Further R&I will also be needed to determine how to best provide this data for tailored guidance to farmers and farm advisors to promote the sustainable improvement of resilient production (eco)systems. For example, identification of beneficial and innovative crop rotation or intercropping options could promote uptake of such practices, while reducing the need for external inputs (e.g., fertilisers and PPPs).

R&I into the impact of interactions with livestock, particularly in mixed cropping systems, as well as the potential of innovative and sustainable feed and feed additives is key to reducing the environmental impact of livestock. The objective is to define optimal crop/livestock systems tailored to different conditions or regions, to sustainably increase productivity per hectare while adapting to pest risks. The management of such data would ideally fall under a decentralised agricultural data platform such as Agri-Data (as discussed in Chapter 4 Agri-Data). Living labs and demonstration farms provide the opportunity to initiate data collection that has the potential to be used as a model to capture real time on-farm data.

Additional R&I is needed to identify the most relevant indicators of all three pillars of sustainability. Thus, farmers, and other agricultural value chain actors, could use these indicators to compare their sustainability metrics between farm units and/or previous years, and to determine whether improvement is being attained. This can, for example, prompt farmers to transition to different practices and/or crops that are better suited to their respective farming conditions. If desired, this information could also be used to communicate sustainability gains to downstream actors and consumers, thereby providing the opportunity to be rewarded for efforts made (e.g., premium market for more sustainable products). R&I will be needed to determine how to best promote and market such products, based on relative and internal sustainability scores (see Chapter 2 on Innovative agricultural produce) as well as ensuring that sustainable products remain affordable to all.

R&I must focus on how to establish a multi-year perspective for farm level economics, to provide more efficient and reliable economic benefits, as well as creating the financial space for investment in, for example, smart machinery and digital tools. Identification of the most efficient and supportive economic tools to enable the transition to more sustainable production systems will be crucial.

3.4.3 Breeding multi-functional, fit for purpose, crops for food, feed, and biobased raw materials, tailored for resilient production (eco) systems in different regions

Plant breeding is essential for maintaining and improving crop production. Over the past twenty years, plant breeding alone has accounted for roughly 66% of the annual yield increase in the EU[52]. The demand for increasingly sustainable agricultural systems requires plant breeding to further deliver on yield increase, while ensuring yield stability and resilience with lower external inputs (e.g., PPPs and fertilisers). A move from monocultures to mixed cropping systems is expected through adoption and increasing use of agrobiodiversity and agroforestry strategies.

R&I is essential to support breeding of underutilised, low yielding, wild, traditional, niche and heritage crops, with special focus on synergies among crops, crops and livestock, and other beneficial combinations. Focus should initially be on identifying, mapping, and cataloguing a range of characteristics (e.g., nutrient and water use efficiency, disease/pest resistance, heat tolerance, nutritional qualities, digestibility, microbiome interactions) (see example Box 9). Identifying the drivers of desired characteristics at the molecular level is equally important (see Chapter 2 on Innovative agricultural produce). To fully capitalise on this data, extensive pre-competitive breeding programs will need to be established, ideally involving public-private partnerships. R&I to both develop novel and innovative breeding technologies, and further optimise current breeding technologies for a wide range of crops and varieties, is an imperative.

Further R&I should focus on how to efficiently develop crops with multiple characteristics, to meet demand for high yielding, sustainable, resilient, and nutritious plant products for food and feed, while concurrently contributing non-edible biobased raw materials to the bioeconomy. These characteristics will need to be incorporated into genotypes that support local high-quality products, to avoid loss of biodiversity and forced use of mainstream genotypes in sub-optimal climatic and social areas. Such multi-purpose crops can better contribute to circularity, while increasing farmer revenue by providing new business opportunities and access to new markets (see Chapter 2 on Innovative agricultural produce).

Box 9

TOMRES is a novel and integrated approach to increase multiple and combined stress tolerance in plants using tomato as a model. TOMRES is a project co-funded by Horizon 2020, with the goal to enhance resilience to combined water and nutrient stress in tomato and to maximise water and nutrient use efficiency. New combinations of genotypes and management practices to reduce the environmental impact of agricultural activities were tested and designed in the field. In addition to the research on breeding possibilities for new traits (e.g., belowground), TOMRES tests and optimises sustainable crop management strategies such as legume intercropping, precision fertilisation and irrigation techniques, manipulation of symbiotic microorganisms, and the use of rootstocks better suited to water and nutrient uptake from the soil. The project pursues a multi-actor approach including farmers, advisors and farmer associations, private companies and public institutions that provide complementary knowledge as project partners.

52. Noleppa and Cartsburg (2021) The socio-economic and environmental values of plant breeding in the EU and selected EU member states

As future production systems are expected to shift towards mixed cropping systems, plant breeding should consider how to best benefit from co-breeding crops for optimised interactions delivered through intercropping, crop rotations and/or mixed crop/livestock production. Emphasis should be placed on how to best breed and integrate perennial crops, including trees, into cropping systems. Breeding for such complex traits and cropping systems will be extremely challenging without the use of precise and innovative breeding techniques. However, current EU regulations regarding plant products generated through innovative breeding techniques, including new genomic techniques, together with perceived negative public perception, discourage their use in commercial plant breeding programs. R&I combining social and life sciences, is therefore essential to improve public understanding and acceptance of safe and innovative plant breeding techniques. R&I will be needed to identify policies promoting and supporting the adoption of more sustainable crops and varieties.

Finally, R&I should determine how to increase uptake and acceptance of novel crops and varieties by agricultural value chain actors, particularly farmers. Focus should lie on identifying and overcoming the barriers limiting the uptake of novel crops and varieties, as well as how to best demonstrate benefits of adopting new crops and varieties. To promote uptake and knowledge sharing, performance data of novel crops and varieties under a range of cropping systems and locations should be systematically assessed and catalogued. Direct collaborations between breeders and producers would provide additional on-farm performance data complementing initial performance data from demonstration farms, living labs and/or field trials.

3.4.4 Developing access and support for continuous learning and knowledge sharing for farmers

Life-long learning is a key enabler to increase knowledge and expertise for those working in the agricultural and forestry sector. New R&I outcomes as well as information on new policies and regulations must be easily accessible to farmers and farm advisors to ensure that innovations are fully exploited. The continuous flow of new information and developments around agricultural systems presents a challenge for farmers to keep informed. To better support farmers, continuous training and learning opportunities should be made available and accessible (see example Box 10).

Box 10

NEFERTITI, carried out within the framework of Horizon 2020, is an EU-wide programme of 32 partners in 17 countries with the goal to establish a highly interconnected network of demonstration and pilot farms. These were designed to enhance knowledge sharing, mutual exchange of actors and efficient adoption of innovations in the agricultural sector through peer-to-peer demonstration of techniques on ten major agricultural challenges in Europe. Ten interactive thematic networks were created, bringing together 45 regional clusters of demo-farmers and innovation actors: advisors, NGOs, researchers, industry, and policymakers. Topics were selected based on demonstration feasibility, expected impact, effectiveness of demo activities and innovation potential. Together they covered a balanced range of topics in the three main agricultural sectors: livestock and arable production and horticulture. To date, more than 450 demo farmers and innovation actors have been involved in the regional and national centres.

R&I should determine how to best develop and promote continuous learning for maximum benefits to farmers and farm advisors, including how to incentivise participation in such activities. Tertiary education programs on agriculture-related disciplines, such as IPM, plant biology and crop production, will also be highly beneficial. Similarly, test sites and living labs can facilitate live demonstrations of, for example, new technologies, management practices and digital tools, thereby increasing farmer uptake.

R&I is required to determine how to best capture, collate and provide all this information (networks for knowledge sharing, training and courses for continuous learning, on-farm testing, and demonstrations). Such data would ideally be managed and provided through a common agricultural data platform (see Chapter 4 on Agri-Data). It will be essential to ensure that the benefits of innovation and new technologies are disseminated amongst European farmers. To facilitate this, collaborative international programs for agricultural studies and internships would allow future professionals to create new perspectives.

Furthermore, R&I is needed, particularly in social sciences, to develop effective programs of education and public awareness campaigns on, for example, farm management practices for resilient production (eco)systems, the role of plant breeding and plant breeding techniques, and more generally sustainability in agriculture.

4. Agri-Data

Figure 5. A common agricultural data platform. Smart big data approaches will progressively offer benefits to different actors of agricultural value chains and to consumers.

4.1 Current context

Today, EU agricultural systems are at the advent of many technological breakthroughs, such as remote sensing of plant health, aerial imaging of fields via drones, improved varieties via predictive breeding, and value chain optimisation via AI. Access to these cutting–edge technologies will be key for strengthening sustainable agricultural production as outlined in the EU Green Deal. Digitalisation will also be crucial for the competitiveness of EU agricultural systems and is expected to provide opportunities to support revenues for primary producers. With adequate support and access to innovative digitalisation technologies, agriculture and forestry can provide major contributions to the reduction of GHG emissions and carbon sequestration in soils and biomass.

Digital empowerment of agricultural value chains will be central to achieving these benefits. Agricultural data (also referred to as agri-data) – derived from various parts of the agricultural value chains – connects consumer needs and preferences on the one hand, and the activities of farmers, breeders, farm suppliers, and advisors on the other hand. Agricultural data thus allows for the data-driven optimisation of activities and resources, for instance by AI-based accurate forecasting, or AI-based advice to farmers. Agricultural data also allows for the emergence of new markets – for instance markets centred around innovative agricultural produce (see Chapter 2 on Innovative agricultural produce).

Data-driven agriculture unlocks new possibilities for R&I, by enabling the study of agriculture in the context of the natural environment as complex systems that is difficult to replicate in a laboratory environment. Agricultural data generated *in situ* (e.g., in field) can pave the way for a science of complexity. For example, such data can shed light on the interrelations between agricultural practices and biodiversity, and thereby providing a rich resource for further R&I directions.

In addition to the current recognised gaps in infrastructure (e.g., rural broadband), availability of suitable high-quality data is a major limitation to the advancement of data-driven applications in agriculture. AI approaches, for instance, require access to large datasets to make accurate predictions possible[53]. For society to derive benefits, it is necessary to break down current agricultural data silos. Initiatives such as the development of a Common European Agricultural Data Space[54] and the conversion of the Farm Accountancy Data Network to the Farm Sustainability Data Network[55] constitute strategic steps in the development of vibrant and accessible agri-data spaces aimed at increasing agricultural sustainability.

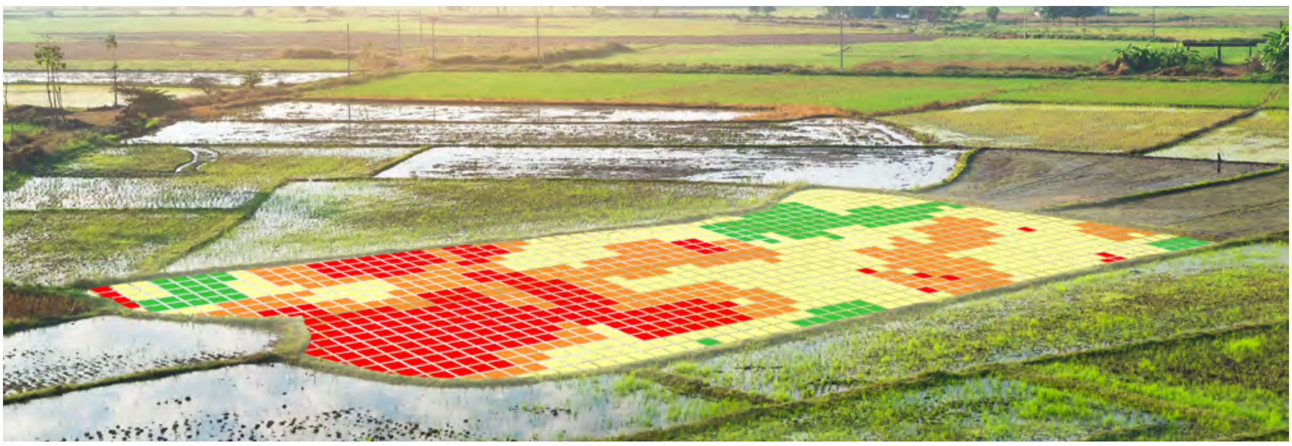
The development of such shared agri-data spaces and the related benefits require R&I at multiple levels. Initially, the needs and demands of each value chain actor need to be determined. Based on their data-requirements, principles for the development of shared agri-data spaces need to be identified. Such principles need to take stimuli and barriers for adoption at various scales into account. Furthermore, they need to be assessed for their potential to enable farmers in planning and ability to provide critical information from and to upstream and downstream value chain actors. In addition, there is a need to maximise the use of existing data (e.g., collect once, use many times) and data sources, while avoiding further administrative burden. Mechanisms and technologies need to be developed to ensure that shared agri-data spaces allow high data accessibility and inherently build trust. To enable the value chain to brand and create sustainability gains, further specific agricultural data requirements will need to be identified and prioritised.

53. Bayer and Edwards (2020) Machine learning in agriculture: from silos to marketplaces
54. EU Commission: Expert Workshop on a Common European Agricultural Data Space
55. EU Commission: Conversion to a Farm Sustainability Data Network (FSDN)

4.2 Desired future outcomes

The effective application of agricultural data can be an enabler for more sustainable and cost-efficient agricultural production systems. It will do so by optimising resource use (e.g., inputs for agricultural production) and reducing the production of waste (e.g., food waste, unused side streams), by using and producing the right amount, in the right place, at the right time.

Interoperable shared agri-data spaces will also drive novel business opportunities, for instance those based on sustainability. Existing business plans are expected to evolve to benefit from an increased availability of agricultural data. Data-enabled transparency will facilitate the access to new markets and sales of EU agricultural produce at scale. Consumer trust in agricultural value chains will be improved through high transparency at the data level. Blockchain technologies, for instance, could provide additional trustworthy information to consumers. Data-enabled transparency will also be instrumental in the further modernisation and simplification of administration, and in decreasing excessive administrative burden and their related costs.



4.3 Main challenges to reach desired future outcomes

I. Understanding data requirements along the value chains and facilitating agricultural data capture and collection.

Each actor along the agricultural value chain has different information requirements and makes use of various metrics and sources to gather the relevant data to meet their needs. This creates major barriers as information requirements vary for each group and makes capturing such information throughout the value chains difficult. Moreover, access to affordable technologies (e.g., sensors, drones, RFIDs[56]), infrastructure (broadband, 5G, satellite), as well as the development of digital skills (EU and national systems of digital upskilling and awareness) is currently imbalanced both geographically and between different actor groups of the value chains.

II. Principles for the development of shared agri-data spaces.

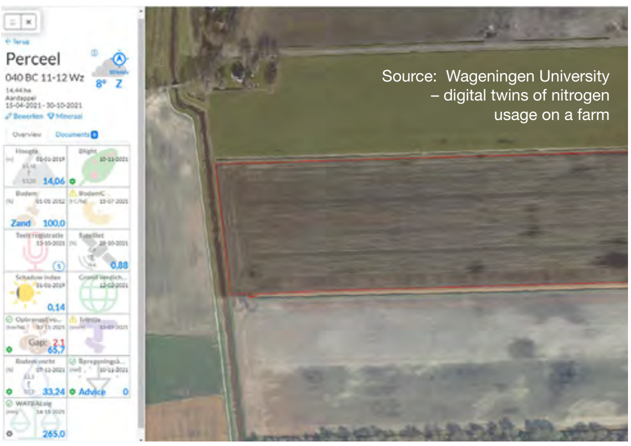
The agricultural data landscape is currently fragmented and sparse. Data is often inaccessible because large scale data-sharing mechanisms are not yet available. To establish solid data-sharing mechanisms, the question of data ownership and access rights must be resolved. The rights of all parties to protect sensitive information via restrictions on further use or processing must be ensured. For example, access to and use of data produced on-farm, or during farming operations, should be controlled by the farmer. Knowledge commons should be installed that allow for self-governance of the data by their owner(s) or those with the rights over their use. Solutions need to be developed to address problems of data interoperability, connectivity, and portability, so that integrated data analysis becomes possible. Mechanisms for data quality insurance must be installed.

III. Develop governance mechanisms and technologies for a common Agri-Data platform.

Running an independent common Agri-Data platform needs a concept and hosting party that is not inclined to use its position for personal gain. Thus, developing effective and efficient governance mechanisms and technologies for a common Agri-Data platform is essential. These mechanisms and technologies need to foster trust among the different data-sharing and data-consuming parties. A legal basis must be created, regulating use and penalising attempts to tamper or enter false information into global agricultural value chain databases.

IV. Requirements for value creation based on agricultural data.

Currently, data-driven efficiency is increasing, and data-driven novel business models are emerging. To allow their development, integrated data processing systems should be developed based on agricultural data streams. This allows for decision making support for farmers and other actors in agricultural value chains, based on agricultural data. Successful approaches should be disseminated, for instance via demonstration projects.



Source: Wageningen University – digital twins of nitrogen usage on a farm

56. Radio-Frequency Identification

4.4 R&I recommendations to meet desired future outcomes

4.4.1 Understanding data requirements along the value chains and facilitating agricultural data capture and collection

The successful transition towards more flexible, adaptive, and sustainable agricultural production systems and value chains will require extensive knowledge of the current and future consumption patterns and needs of end-consumers. Consumer-trends information will need to be translated into informed decisions on how to align the demands with the activities in the value chains. For instance, consumer consumption choices can be translated into trends for crop cultivation needs, which may include consumer expectations on e.g., healthy food and fair production. The information also needs to be converted into informed decisions on how to react to upcoming changes in a timely fashion, for instance an increased demand for plant-based protein.

To specify the information requirements for each value chain category, R&I should focus on the end-consumer stage of the relevant supply chains. Here, consumption choices and patterns should be analysed to predict upcoming consumer trends. Based on this information, trends of future crop cultivation needs can be defined and reviewed based on their likelihood of appearance. Gathering data on performance and sustainability from different cropping systems in combination with management practices in different locations will support optimal strategies to meet these needs (see Chapter 3 on Resilient production (eco)systems). In an optimal scenario, the related agricultural data will be hosted by shared agri-data spaces, to avoid data friction.

R&I is needed to identify what information is required to enable the various actors in agricultural value chains (e.g., farmers, food processors, traders) to align their needs and plans based on continuously updated information. This will enable agile decision making within the value chains, to meet changing consumer demands and consumption patterns. In this context, experiments with an independent data platform revealing raw material use, food consumption and export trends linked to farm outputs would be valuable. Such data platforms and related improvements in value chain management, as well as the revenue streams of single value chain actors (e.g., farmers), would enable R&I that seeks to better understand the impact on farmer income and a better alignment of crop production with consumer and/or value chain demand (see example Box 11).

Box 11

BigDataGrapes data marketplace is a platform or data-catalogue, where data on grape products, by-products and related food or cosmetics industries can be exchanged by relevant companies and organisations. Any public or private organisation can share the metadata for all the data assets that it creates or processes. With a self-service data access, the users of the data marketplace can find and try any open or private data assets based on their criteria. The data driven approach allows to support business decisions with real-time and cross-stream analysis of data from various actors. A data marketplace was developed where users buy or sell data streams from various sources.

The end consumer provides the benchmark for both the demand and the quality characteristics of viticultural products. Both the quantity and the quality depend on the ecosystem at a specific location, comprising soil and climate characteristics, locally used grapevine cultivars and their genetics, and the viticultural techniques used. Big data analytics provides a means to extract predictive relations out of the heterogeneous data generated, benefitting the various parties in the value chain as well as the consumers.

4.4.2 Principles for the development of shared agri-data spaces

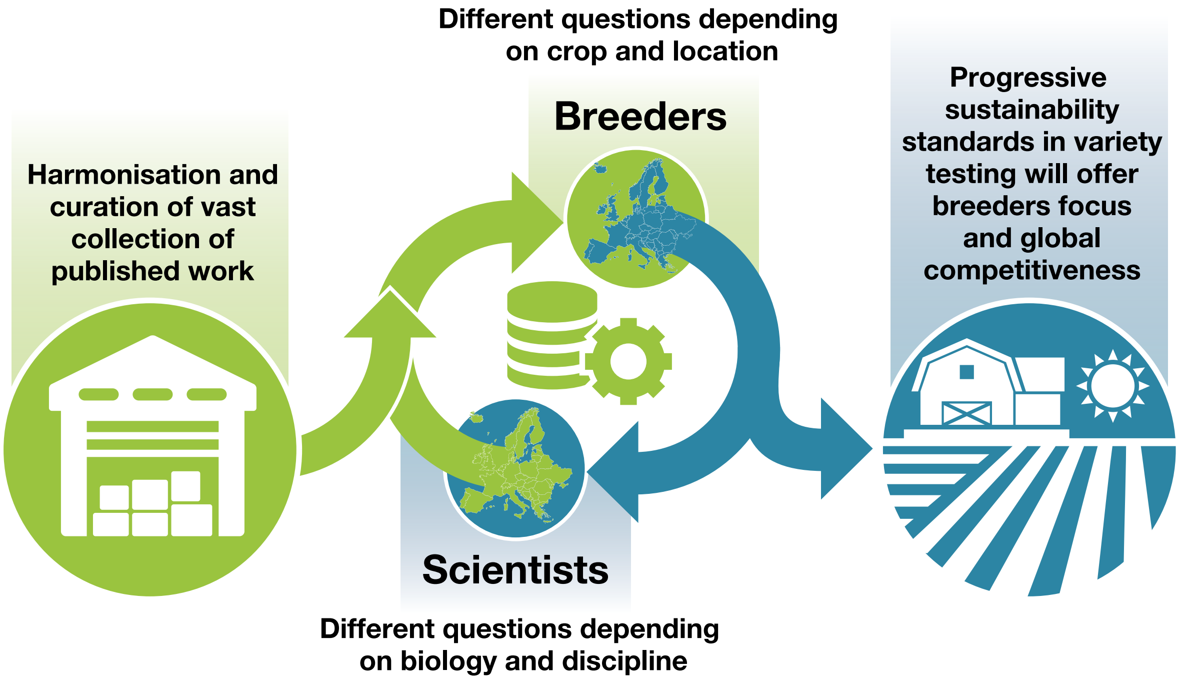
Development of effective shared agri-data spaces will require extensive information and further R&I on how to gather, analyse and act on consumer needs and demands. To enable a broad implementation of such shared spaces, utilisation options, performance barriers and accessibility requirements of agri-data spaces should be analysed from the perspective of each value chain actor. Business- and performance-related information (e.g., revenue, future market strategies) can provide high value in shared agri-data spaces, but access regimes and value capturing, need to be well regulated to avoid obstacles for value chain actors to join or participate. R&I should investigate the added value of the various categories of information, benchmark their usage against the potential loss of users the inclusion might cause, and identify strategies to organise data access and ownership.

Despite an active willingness to use shared agri-data spaces, indirect and non-tangible restrictions might hamper usage by certain groups of actors within agricultural value chains. R&I must therefore develop approaches to collect information on both capabilities and abilities of different value chain actors to engage using agri-data spaces, and based on this, develop strategies for addressing potential hurdles. Simultaneously, R&I should identify current and future value opportunities for value chain actors using farm planning agri-data spaces to further incentivise usage. The value opportunities provided by shared agri-data spaces should also be investigated for each value chain actor.

The integration of existing platforms, data-hubs as well as resources and experts into a comprehensive common EU Agri-Data platform would be a long-term goal. However, due to its scale, it is unlikely to be achievable in the short term. It may instead be desirable to, in the first instance, separate between farm planning and value chain business-to-business as well as business-to-consumer data platforms. R&I is therefore needed to determine how best to develop separate platforms with long term consolidation envisaged. This could be done by, for instance, charting which actors would benefit from shared data platforms (see example Box 12), or by investigating whether multiple platforms are an appropriate mechanism to bring certain actors together, without infringing on privacy requirements.

Collection of agricultural data will also require access to technologies (e.g., sensors, drones) and the means to implement these in a cost-effective way. R&I is needed to determine how to best support the implementation of such technologies for each value chain actor.

Box 12



The **virtual predictive breeding workflow** (see figure above) driven by biotechnology and big data governance aims at supporting continuous stakeholder interaction and thereby accelerate the path from discovery to innovation. Data and information from different disciplines such as plant, microbial, soil, agronomy, robotisation, machine learning, modelling, and weather/climate research shall be combined, integrating academia and different value chain actors. To install functioning **virtual predictive breeding workflows**, there are some critical success factors: for example, the alignment of key performance indicators of stakeholders, incentives to participate, an open innovation attitude, a common benchmark to measure progress, smartly located research field stations, dedicated data centres with a user-oriented data curation, storage and display approach, and an agreeable data governance concept. A series of successive innovations can be initiated by gradually raising the requirements for successfully passing the formal variety testing and registration procedure. In this example, consumer demand is translated into requirements for official variety testing trials that meet, for example, increasing sustainability levels.

Adapted from [Cornelissen et al. (2021) Biotechnology for Tomorrow's World: Scenarios to Guide Directions for Future Innovation]

4.4.3 Develop governance mechanisms and technologies for a common Agri-Data platform

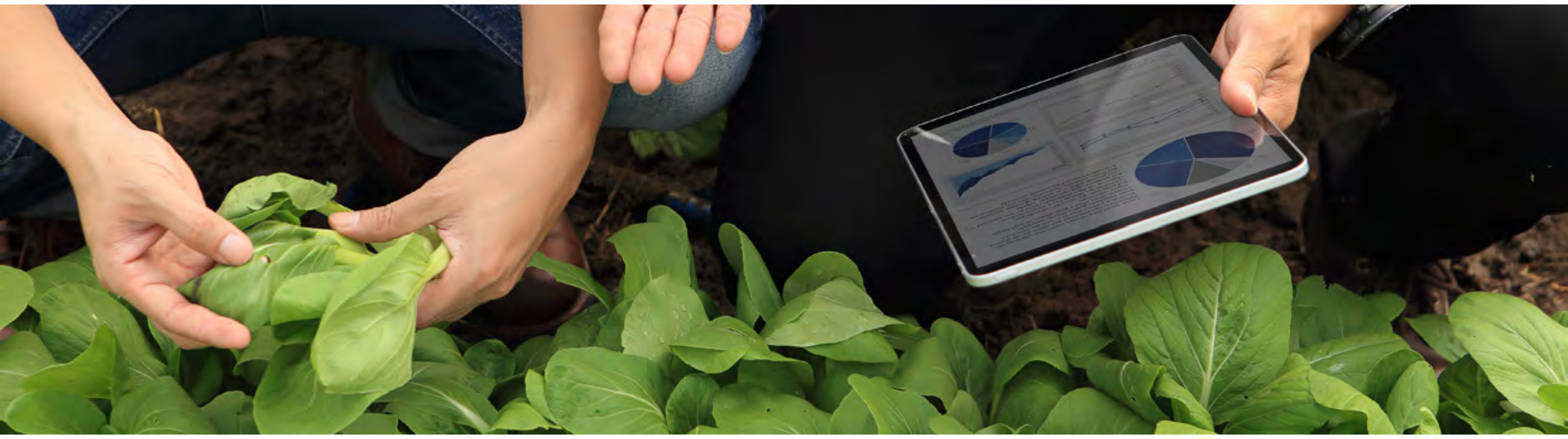
Delivering an independent Agri-Data platform needs a concept and hosting party that is not inclined to use its position for personal gain. Thus, developing effective and efficient governance mechanisms and technologies for a common Agri-Data platform is essential. R&I should develop governance mechanisms and technologies to establish and sustain a common Agri-Data platform. These mechanisms and technologies need to foster trust among the different data-sharing and data-consuming parties. They also need to foster trust in the data, for instance by applying FAIR data principles[57].

To enable traceability, a global, stable, accessible, secure and tamper-proof database for all supply chain users, to store and read relevant agricultural data parameters, is necessary. This can be achieved by developing and modelling digital platforms that can deal with distributed information repositories, foster collective self-governance, are financially self-supporting, and consider blockchain-like "immutable network concepts", so that data cannot be manipulated after being entered into the systems.

The implementation of distributed information repositories can be supported by already existing and widely used concepts of private as well as open-source data sharing practices. However, additional R&I will be needed to develop a self-governing system, by, for example, determining protocols and standards to be used. R&I should focus on technologies allowing the creation of such databases. Currently all these requirements can be achieved by utilising Blockchain technology[58].

Shared vocabularies provide another example of a technology that enables communication across stakeholders, for instance when associating global positioning with geolocation. Agricultural value chains often involve actors from countries outside the EU, therefore it is crucial to develop international standard vocabulary and units. To ensure sustained usage, a common Agri-Data platform should moreover be supported by specific incentive strategies and rules promoting data contribution and data curation. R&I should explore AI, flexible algorithmic structures, and smart graphical user interfaces to identify how to best support stated goals.

R&I should develop data stewardship and governance models to ensure privacy and ownership recognition and enable fair rewarding for participation, which could be based on the value created for the participants. A legal basis should be created to regulate usage and penalise attempts to tamper or enter false information into global agricultural value chain databases. R&I will be essential to test the developed structures, enable participants to test the platform(s) by offering demonstration opportunities to (early adopter) stakeholders, as well as monitoring user experience to increase uptake (see examples Box 13).



57. Wilkinson et al. (2016) The FAIR Guiding Principles for scientific data management and stewardship

58. Leong (2018) Blockchain Feasibility Study: Tracing the Supply Chain - How blockchain can enable traceability on the food industry

Box 13

ATLAS aims to develop an open interoperability network for agricultural applications and thereby to support the advancement of innovative data-driven agriculture. Resilient production (eco)systems require targeted application of PPPs and fertiliser, both of which could benefit from tailored advice from a common Agri-Data platform. The technologies developed in ATLAS are showcased in pilot projects, for example, precision agriculture, data driven irrigation and soil management. New business models can be built based on these pilots. This is done in interaction with innovative start-ups, SMEs, and farmers, and supported by seed funding. To ensure scalability of the approach, technologies are built according to a service-oriented architecture, which allows to scale from single farms up to large communities.

ATLAS is coordinated by the Fraunhofer Institute for Intelligent Analysis and Information Systems IAIS and supported by a team of experts from 30 institutions and companies in Europe. The project is funded by Horizon 2020.

Agri-GAIA developed a business-to-business platform for the exchange of data and algorithms in agriculture, whose aim is to connect developers of AI algorithms with users in the agricultural industry. It thereby provides an environment for innovations in AI that can derive value from sensor data and other types of agricultural data. Agri-Gaia builds on the GAIA-X data infrastructure developed in the EU. GAIA-X aims at the enablement of open, transparent, and secure digital ecosystems in which data and services can be shared in a trusted environment. Generic components like identity management and semantic description of services and data for instance can build on the GAIA-X architecture.

4.4.4 Requirements for value creation based on agricultural data

A common Agri-Data platform can support the quantification, and thereby the monetisation and branding of sustainability gains. This will require R&I on information and data collection with regards to sustainability impacts of fertiliser use, carbon sequestration, biodiversity, soil health, and water use as well as water quality. R&I should particularly focus on how farm practices relate to sustainability, such as precision agriculture, pest, water, and nutrient management (see Chapter 3 on Resilient production (eco)systems). Consequently, a common Agri-Data platform could in turn support sustainable farm management practices.

R&I will be needed to determine how a common Agri-Data platform could offer tailored advice to farmers regarding, for example, locally grown protein crops and beneficial intercropping systems, or methods for data-supported local pest management. Analytical and predictive algorithms generated by a common Agri-Data platform should also be developed to provide advice to farmers on possible sustainability gains and related revenues.

Proof-of-value systems should be built to demonstrate the value of a common Agri-Data platform in monetising sustainability gains. Such systems should clearly describe how the platform contributes to a comprehensive database with clear information on which steps can be taken to make production more sustainable and which strategies can be pursued for beneficial outcomes. This could include increasing transparency, to generate demand for sustainable products from the consumer side, or utilising certain sustainability incentives from governments (see Chapter 2 on Innovative agricultural produce).

R&I into big data and AI technologies that would enable such analyses from a common Agri-Data platform would be extremely valuable to, for example, generate guidelines on optimisation of agricultural value chains, and insights into new sustainably efficient production, business models, and products.

To make statements on the sustainability impact of agricultural products, a comprehensive analysis of the parameters that determine sustainability gains throughout agricultural value chains is required. R&I is therefore essential to determine the most appropriate standards for sustainability-related parameters, including a common vocabulary, metrics, measurements requirements, units, and definitions. R&I will also be needed to develop cost-effective devices to capture these parameters with appropriate accuracy (e.g., tracking and tracing, automation, robotisation). Related enablers (e.g., Internet of Things, see Box example 14; AI, broadband networks, blockchain) must also be assessed for their impact and their ease of implementation in specific agricultural value chains[59].

Box 14

The **Internet of Food and Farm 2020** aims at enabling more sustainable agricultural value chains, via targeted deployment of Internet-of-Things (IoT) technologies. Specific targets include the reduction of fertiliser use or the targeted application of PPPs. Use-cases are developed in the five sectors: arable, dairy, fruit, meat, and vegetables, and demonstrated in an operational farm environment. The project provides a brokerage platform where stakeholders of agricultural value chains can identify optimal technologies for IoT-based agricultural data generation. IoT is one of the technologies that can contribute to the traceability of food throughout agricultural value chains. Such traceability can for instance be used to ensure food safety, or to provide transparency associated with sustainability-related parameters.

59. Soma et al. (2019) Impacts of the digital economy on the food chain and the CAP

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