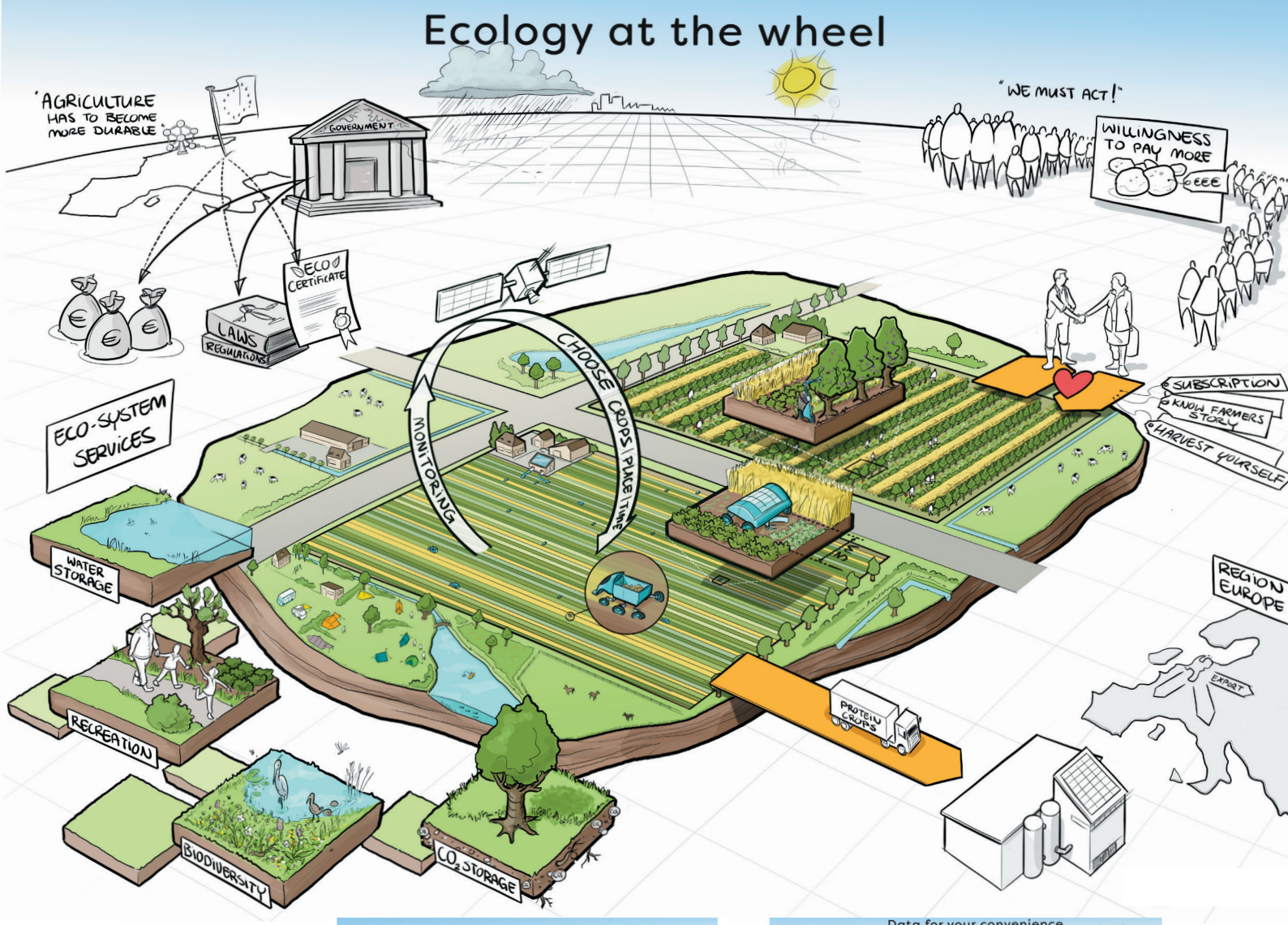

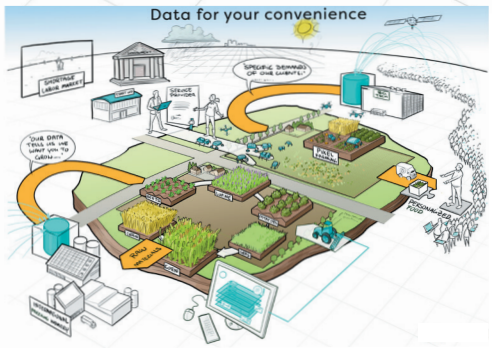

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Report WPR-OT-1017

WAGENINGEN
UNIVERSITY & RESEARCH

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1 Wageningen University & Research

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Contents

Summary

Current arable farming systems produce high yields of good quality, but also face a number of sustainability challenges that jeopardise the resilience of this system. Therefore, robust and resilient novel systems are explored to combat these challenges. Smart mixed cropping systems are one of such systems that is explored within the Public Private Partnership AGROS. Smart mixed cropping systems are systems that use biological and ecological processes as a starting point to create a climate resilient system by growing two or more crops simultaneously on the same field for at least part of their cycle. Complementary smart technology such as sensing systems can then be used to monitor biological processes and help understand biological processes and associated ecosystem functions on the field. This report describes three possible pathways for the development of smart mixed cropping systems. These pathways lead from the current agricultural system towards a future scenario. Using this scenario methodology, we explored what the future of smart mixed cropping systems could plausibly look like in 2040. The goal of creating such explorations is to broaden views and increase reflexivity for example in policy making and strategic decision making (e.g. Verbong and Geels, 2010).

We organised two interactive workshops: a scenario workshop and a strategy workshop. The scenario workshop resulted in three diverging future scenarios of smart mixed cropping systems, while the strategy workshop resulted in timelines of transition pathways towards these future scenarios. During the strategy workshop, the transition pathways were translated into action perspective for different stakeholder groups.

The first scenario was titled 'Data for your convenience: chain based transformation'. The main characteristics of this scenario are: big tech in the lead, widespread adoption of robotisation and automation, hedonistic consumer demands, diversified rotations, individual plant treatment in pixel cropping, and a highly technical system. The second scenario was titled 'Ecology at the wheel: Ecology based transformation'. The main characteristics of this scenario are: ecology in the lead, long-term policy visions for agriculture, regionalisation of agri-food systems, digitalisation in short value chains, mixed cropping as a broader approach of resilient and sustainable cropping systems, and an important role for protein crops. The third scenario was titled 'Crisis forces action: Climate based adaption. The main characteristics of this scenario are: climate crisis management, top-down centralisation, true pricing in the value chain, mixed cropping as a way to deal with weather extremes, combining annual with perennial crops, and fresh water as the new gold.

Starting from the future vision, we describe transition pathways that outline *how* we got from the current situation to the future vision. For each pathway, milestones for 2025, 2030, 2035 and 2040 are described that need to be reached in order to realise the described scenario. By identifying 'breakthrough' moments that create a crucial leap in development from the current system towards the future scenario, we made a first exploration of implications for practice. These breakthrough moments can be translated into action perspectives for different stakeholder groups such as researchers, farmer representatives, policy makers or engineers. An example of such an exploration was provided by exploring implications of the pathways for energy infrastructure.

Samenvatting NL

Huidige akkerbouwsystemen produceren hoge opbrengsten van goede kwaliteit, maar staan ook voor een aantal duurzaamheidsuitdagingen die de veerkracht van het systeem in gevaar brengen. Robuuste en veerkrachtige nieuwe systemen zijn nodig om deze uitdagingen aan te pakken. Slimme mengteeltsystemen zijn hiervan een voorbeeld. Binnen de publiek-private samenwerking AGROS onderzoeken we slimme mengteeltsystemen in de use-case akkerbouw. Met slimme mengteeltsystemen bedoelen we hier systemen die biologische en ecologische processen als uitgangspunt nemen voor een klimaatbestendig akkerbouwsysteem door het (gedeeltelijk) gelijktijdig telen van twee of meer gewassen op hetzelfde perceel. Aanvullende slimme technologieën zoals sensortechnologie kunnen vervolgens worden gebruikt om biologische processen te monitoren en te begrijpen, evenals de bijbehorende ecosysteemfuncties in het veld. In dit rapport worden drie mogelijke transitiepaden beschreven voor de ontwikkeling van slimme mengteeltsystemen. Deze transitiepaden leiden van het huidige landbouwsysteem naar een toekomstig scenario. Met behulp van een scenariomethodologie hebben we onderzocht hoe de toekomst van slimme mengteeltsystemen eruit zou kunnen zien in 2040. Het doel van deze verkenningen is het verbreden van het blikveld en stimuleren van reflectie, bijvoorbeeld in beleidsvorming en strategische besluitvorming (zie bijv. ook Verbong en Geels, 2010).
Er zijn twee interactieve workshops georganiseerd: een scenarioworkshop en een strategieworkshop. De scenarioworkshop resulteerde in drie uiteenlopende toekomstscenario's voor slimme mengteeltsystemen, de strategieworkshop resulteerde in tijdslijnen voor transitiepaden naar deze toekomstscenario's. Tijdens de strategieworkshop werden de transitiepaden bovendien vertaald naar actieperspectieven voor verschillende stakeholdergroepen.
Het eerste scenario kreeg de titel ‘Data for your convenience: chain based transformation’. De belangrijkste kenmerken van dit scenario zijn: grote technologiebedrijven aan de leiding, wijdverbreide toepassing van robotisering en automatisering, hedonistische consumentenеisen, gediversifieerde gewasrotaties, individuele plantbehandeling in pixelteelt, en een sterk getechnologiseerd systeem. Het tweede scenario kreeg de titel ‘Ecology at the wheel: ecology based transformation’. De belangrijkste kenmerken van dit scenario zijn: ecologie aan de leiding, langetermijnbeleidsvisies voor de landbouw, regionalisering van agrovoedselsystemen, digitalisering in korte waardeketens, mengteelt als een brede benadering van veerkrachtige en duurzame teeltsystemen, en een belangrijke rol voor eiwitgewassen. Het derde scenario kreeg de titel ‘Crisis forces action: Climate based adaption'. De belangrijkste kenmerken van dit scenario zijn: klimaatcrisismanagement, top-down centralisatie, true pricing in de waardeketen, mengteelt als een manier om met weersextremen om te gaan, het combineren van eenjarige met meerjarige gewassen, en zoet water als het nieuwe goud.
Vertrekkend vanuit de toekomstvisie beschrijven we vervolgens transitiepaden: hoe zijn we van de huidige situatie naar de toekomstvisie gekomen? Voor elk transitiepad worden mijlpalen voor 2025, 2030, 2035 en 2040 beschreven die moeten worden bereikt om het scenario te verwezenlijken. Door 'doorbraken’ te identificeren die een cruciale sprong in de ontwikkeling van het huidige systeem naar het toekomstige scenario teweegbrengen, hebben we een eerste verkenning gemaakt van de implicaties van de transitiepaden voor de praktijk. Deze doorbraakmomenten kunnen worden vertaald in actieperspectieven voor verschillende belanghebbenden, zoals onderzoekers, vertegenwoordigers van boeren, beleidsmakers of ingenieurs. Een voorbeeld van een dergelijke verkenning wordt gegeven door de implicaties van de verschillende transitiepaden voor de energie-infrastructuur te verkennen.

1 Introduction

Thinking about the future of arable farming is not only an exciting thought experiment, but also a useful way to prepare for the future and its challenges. After all, when imagining possible futures, stakeholders are forced to think about possible challenges to overcome and strategies to remain successful under changing circumstances.

This report describes transition pathways for smart mixed cropping systems in North-Western Europe. Transition pathways enable us to explore sustainable futures for arable agricultural systems. While current arable farming systems in North-Western Europe produce high yields of good quality, these same systems also cause sustainability issues and are simultaneously increasingly faced with sustainability challenges such as droughts or heavy rainfall. To combat these challenges, we therefore explore resilient and sustainable arable farming systems. Smart mixed cropping systems, focused on crop diversification, are an example of such resilient and sustainable systems. By elaborating transition pathways towards 2040, we explore what such smart mixed cropping systems could look like. How do we get from the current system towards a future scenario? And what are implications for stakeholders?

1.1 Smart mixed cropping systems

Within Public Private Partnership (PPP) AGROS we focus on a system change towards arable systems with more than one crop species on the same field (crop diversification through intercropping). Such mixed cropping systems have the potential to deliver sustainable intensification, based on more efficient land- and resource-use, while exhibiting significantly lower disease incidence and weed and pest infestation compared to systems with only one species on a field (Brooker et al., 2015; Yu et al., 2015). Within AGROS, we define mixed cropping systems as the practice of growing two or more crops or cultivars of the same species simultaneously on the same field for at least part of their cycle (e.g. Lizarazo et al., 2020). On the field, mixed cropping can therefore take on many forms from strip cropping to pixel cropping or more diverse rotations with varying cultivars of the same species. Starting from the ecological and biological benefits of mixed cropping systems, complementary smart technology such as sensing systems can then be used to monitor biological processes and help to understand these processes and associated ecosystem functions. This includes development of smaller and lighter machinery for these new arable farming systems without increasing labour requirements. Within smart mixed cropping systems, technology is developed around biological and ecological processes. Novel smart technologies are therefore crucial in supporting such a transition, leading to efficient and profitable management for farmers. The development of these new technologies is a long-term innovation process with many uncertainties. The challenge for technology developers and those who make this possible is to design robust development strategies that deliver success in different future situations.

1.2 Transition pathways

In short, transition pathways are narratives that describe how to get from a current situation towards a future situation. When developing transition pathways, first there must be a future vision, also called a future scenario. From there on, pathways can be constructed leading from the current arable farming system towards a future scenario. When discussing future scenarios, four different types of futures can be distinguished (Taylor, 1993)[1]:

- **probable** futures (what is likely to happen);
- **plausible** futures (what is reasonable to happen);
- **possible** futures (what might happen);

[1] See also Taylor's Cone of Plausibility, which was originally developed to develop scenarios and strategic planning for the US military, but has later been widely applied in business, industry, governments and academia.

- **preferred** futures (what we want to happen).

Overlap between these different types of futures is possible. For example, a future might be plausible and simultaneously preferred. The goal of working with future scenarios can subsequently also differ (e.g. Börjeson et al., 2006; Fauré et al., 2017):

- **predictive** scenarios describe what *will* happen;
- **explorative** scenarios describe what *can* happen;
- **normative** scenarios describe how we can reach a certain *desirable* (or: preferred) goal.

Within AGROS we use explorative scenarios to explore what the future of smart mixed cropping systems could plausibly look like in 2040, using transition pathways. In this study, Transition pathways are therefore not *predictions* of the future, but *explorations* of the future. The goal of making such explorations is to broaden views and increase reflexivity e.g. in policy making and strategic decision making (e.g. Verbong and Geels, 2010). By developing transition pathways together with stakeholders, hidden challenges or blind spots can be uncovered because stakeholders are 'forced' to think beyond current circumstances and barriers about future directions of change and their implications.

In developing the transition pathways, we followed three steps:

1. **System analysis** to describe the current state of affairs, trends and challenges of arable agriculture[2];
2. Describing **future scenarios** through narratives and visuals based on current trends that describe possible future smart mixed cropping systems;
3. Exploring plausible **pathways** from the current agricultural system towards the described future scenarios.

1.3 PPP AGROS

The Public Private Partnership (PPP) programme AGROS[3] is a collaboration between Wageningen University and Research and 26 private partners. AGROS stands for 'Evolution to sustainable AGRicultural Operation Systems'. AGROS aims to develop tools that can support production that is based on natural biological and ecological processes and thereby steer production towards sustainable use of inputs like energy, water, plant protection products and labour. Within the AGROS programme, three use cases are established: arable farming, greenhouse horticulture and livestock farming. This report on smart mixed cropping systems is part of the arable farming use case.

1.4 Reading guide

The results of steps 2 and 3 above are described in this report. In section 2 we elaborate on the scenario and strategy workshops that were organised in 2020 and 2021. Section 3 describes three pathways for smart mixed cropping systems, using narratives and illustrations. We conclude with implications and recommendations for practitioners.

[2] The system analysis we carried out within AGROS is covered in a separate report: https://edepot.wur.nl/574595

[3] More information about PPP AGROS can be found here: https://agros-smartfarming.nl/en/. PPP AGROS is part of the larger NWO programme Synergia (SYstem change for New Ecology-based and Resource efficient Growth with high tech In Agriculture).

2 Interactive workshops

The development of future scenarios and transition pathways within AGROS was done in a participatory process with relevant stakeholders, both stakeholders within the PPP and stakeholders external to the project. At the core of this process are two interactive workshops: 1) a scenario workshop; and 2) a strategy workshop. Below we describe the set-up of these two workshops. In Annex 3 you can find example scripts for both workshops. These scripts are based on the ones used during the workshops and can be tailored to fit specific topics and questions of others wanting to organise similar transition pathway workshops.

2.1 Scenario workshop

The goal of the first workshop was exploring what the future of arable farming could look like. Exploring diverging scenarios helps to clarify that there are *uncertainties*: we do not know what the future will look like. We also do not know under which circumstances smart mixed cropping systems would further develop. The focus of this first workshop was therefore to explore: what are plausible versions of the future?

Based on the system analysis of current trends and challenges in arable farming systems (Bulten et al., 2022), the project team developed scenario sketches; rough outlines of what the future of smart mixed cropping systems could look like. In Annex 1 you can find these scenario sketches. The main aim of the scenario workshop was to 'colour in' these scenario sketches and to make explicit what future smart mixed cropping systems could look like. After 'free association' i.e. focusing on the first images that came to mind for each scenario, participants worked on the scenarios by focusing on three topics and questions:

1. Wider context (regulations and climate): What are dominant discussions in society and politics in this scenario?
2. Agricultural practice (value chain and agriculture): What does the value chain around smart mixed cropping systems look like and what are the major challenges for arable farming?
3. Arable farm (technology and agronomy): What does a successful arable farm with smart mixed crops look like in this scenario?

The scenario workshop was held on the morning of 25 November 2021 at WUR Field Crops in Lelystad, just in between COVID restrictions that prohibited in-person meetings. The 15 participants represented several stakeholder groups: farmers, farmers' representatives, research, policy and technology experts.

Although guided by an analysis of current trends and topics of focus, scenario workshops remain a creative process. The final scenarios provide indicators of directions of future change, but the scenarios are not all-encompassing, nor are they predictive. They are, however, an exercise in exploring plausible futures and the implications of such change. Note that the pre-defined scenario sketches, based on the drivers of change in the system analysis were discussed during the workshop but this baseline for the final scenarios was not changed. The sketches provided direction and focus during the workshop, thereby enhancing the concreteness of the discussion. The final scenarios that were the outcome of the workshop were therefore build in the initial scenario sketches. The workshop can also be seen as an intervention in itself, since asking participants to think about the future without being hindered by current obstacles enables participants to come up with novel ideas and leaps towards sustainability.

2.2 Strategy workshop

The second workshop used the scenarios of the first workshop as a starting point to discuss the central question: In each scenario, how did smart mixing crops take off while desired outcomes remained intact? The goal of this second workshop was to formulate strategies for 3 stakeholder groups (arable farmers, technology

developers, governments) in which each group is successful in each of the 3 scenarios for smart mixed cropping systems. This resulted in an agenda for action for each stakeholder group, consisting of actions for stakeholders to enable successful implementation of agricultural practices around smart mixed cropping.

The workshop started with agreeing on desired outcomes for farmers, technology suppliers (related to mixed cropping) and how can governments facilitate this? These desired outcomes were based on results of the scenario workshop and the roadmap of Farm of the Future[4] and were related to: economic position and working conditions of farmers, societal appreciation of farming, sustainable way of food production, healthy business operations for technology companies and connection to policy ambitions around sustainability.

After agreeing to desirable conditions that should be upheld in each transition pathway, participants worked on the pathways using a timeline from the current situation to the future scenario of 2040. In this back casting exercise, participants also focussed on innovation challenges that were overcome along the way and connected developments to stakeholders (who was responsible for this development?).

After the back casting exercise, participants worked on a strategy and agenda for action by asking the question: what do these pathways mean for 1) the arable farming sector, 2) the technology sector and 3) governments and what are strategic actions to operate within the conditions of success in each scenario. At the end of this exercise, participants provided break through developments in each scenario and connected those developments to specific actions for the three stakeholder groups.

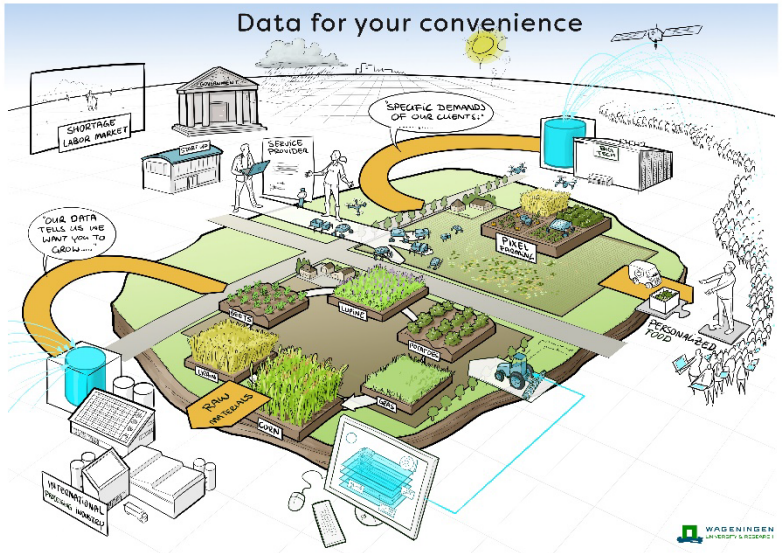
The strategy workshop was organised on the 21st of April 2022, at WUR Field Crops in Lelystad. The 15 participants partly overlapped with the participants of the first workshop and represented the same stakeholder groups: farmers, farmers' representatives, research, policy and technology experts.

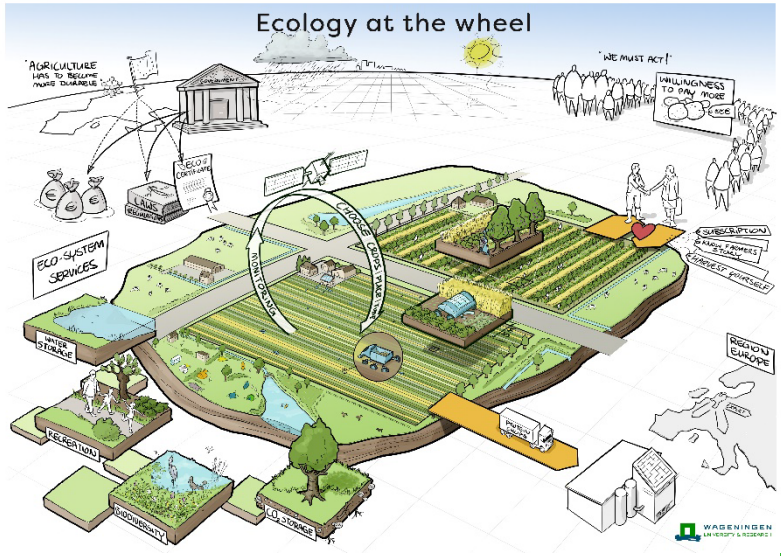
[4] https://farmofthefuture.nl/wp-content/uploads/2020/12/Innovatie-opgaven-Roadmap-Boerderij-van-de-Toekomst-2030-per-thema-definitief.pdf

3 Pathways for smart mixed cropping systems

Following the scenario workshops, three contrasting future scenarios for smart mixed cropping systems of 2040 were developed. Note that these pathways are explorations and should be interpreted as indicative pathways under different scenario conditions. In Table 1 below, we present an overview of the three scenarios, describing the main characteristics of each scenario in terms of **societal context**, **agricultural value chain** and **arable farm** level. Illustrations for each scenario are also included in Annex 2.

Table 1 *Overview of 3 contrasting future scenarios for smart mixed cropping systems.*

	In **data for your convenience**, **big tech** is in the lead: corporations manage **data streams**, utilising their knowledge of individual consumer choices and investing in agro **robotisation** and **automation**. Responding to **labour shortages** and **increasing extreme weather events**, governments take on **laissez-faire**, leave solutions to the market. There is a constant search for **labour extensive** solutions. Tech companies have become **service providers** for farmers, investing in and offering autonomous vehicles and data driven support. The agricultural value chain is dominated by **hedonistic consumer demands**, who are looking for cheap and **personalised food**. The agricultural chain for raw materials is primarily focused on the **world market.** International sourcing and chain integration leads to steering of farm management by industry and certification towards markets such as vegan, halal, organic, gluten-free. A typical arable farm in 2040 uses little human labour due to automation. **Diverse rotations** (e.g. 1:6) are used to deal with extreme weather events and as a tool to spread risks. **Individual plant treatment in pixel crop systems** is used to deliver personalised foods to consumers. This is a highly **technical** system that needs very little manpower.



In **ecology at the wheel**, there was a shift towards **regionalisation** of agri-food systems. More frequent **extreme weather events** have led to a **turnaround in society** with citizens prioritising sustainability and government taking on responsibility with **long-term visions** for the future of agriculture. **Ecology is leading**, the economy is structured around it. Through **digitalisation** in short value chains, chains are more **efficient** and food products are **traceable**. This creates **stronger connections** between regional producers and consumers. Within agro-food chains, there has been a shift from price competitiveness to **sustainability competitiveness**. This goes hand in hand with **new business models** for farmers including a broad range of ecosystem services. At the arable farm, **health** of the earth and of people are central. Mixed cropping is introduced as part of **broad approach of resilient, sustainable cropping systems**. Small, light **robots** are introduced as part of this approach. Farmers combine 3 metre **strip cropping** with **agroforestry** and **protein crops** play an important role.

Crisis forces action is characterised by **climate crisis management**. Governments operate within the **region of Europe**. **Economy is leading**, while governments perform **damage control** at the ecological level. Consumers need to be **'pushed'** to make sustainable choices, e.g. by introducing a meat tax. This **top-down centralisation** comes with increasing **polarisation** in society and ecology versus economy. **True pricing** is introduced as a possible solution. The agricultural value chain is characterised by a **regulated market**, while companies more explicitly influence political decision making. Decisions are made based on **science based evidence**. At the arable farm of 2040 mixed cropping is used to create a **resilient** system. The **toolbox of measures** for chemical pest control is getting empty and mixed cropping systems are used as the counterpart of chemical inputs. There has been a **shift of crops** from south to north; crops such as grapes are now cultivated more in NW Europe. Farmers use combinations of **annual and perennial crops**. Wide strips (20-40 m) ensure a quick transition to strip cropping using existing machinery. **Fresh water** is the new gold; farmers invest in **water storage**, as well as energy storage and production.

The three scenario description above provide three visions of what future mixed cropping systems could plausibly look like. However, these visions do not explain *how* we got from the current situation to the future vision. In the sections below, we describe possible pathways towards each future vision in steps of 5 years.

3.1 Data for your convenience: Chain based transformation

Between 2021 and 2025, important steps have been taken to work towards healthy soils and healthy crops, resulting in more resilient arable systems. Governments and the arable sector have agreed upon a clear vision for a direction of change for the sector. This includes agreement about investments. Moreover, the arable sector has taken further steps in decreasing nutrient losses. Big tech companies see the potential of investing in the food value chain, buying up start-ups and compensating costs of starting up.

By 2030, technology is ready for the monitoring of soil and plant performances. Because robotics and autonomous vehicles are able and allowed to go on the field independently, manual labour can be decreased and arable systems have become more efficient. Innovation mainly comes from industry, enabled by governmental policies that allow e.g. autonomous vehicles, international policy around data use and use of waste streams. Innovation and knowledge go hand in hand, and knowledge is developed by R&D departments of industry and (applied) research institutes. Additionally, cooperation between farmers and big tech is taking shape. For farmers, data ownership is an important issue but by 2030 agreements have been reached about ownership and use of data, clearing the playing field and offering transparency and clear regulations in the sector. Big tech has embraced the shift towards mixed cropping systems, enabling further development by investing in and developing matching technology. This makes a shift towards smart mixed cropping systems more attainable to farmers and ensures efficient harvesting and transport. To deal with the increasing occurrence of extreme weather events, diverse rotations (e.g. 1:6) are widely used as a tool to spread risks.

By 2035, data can be used to coordinate consumer demands with automation at the farm level and within the value chain. Infrastructure in short value chains is organised in a way where fresh produce can be delivered directly to consumers due to real time insights into what is growing where, what produce are available, etc. This gives consumers more choice and insights into impact in terms of e.g. CO2, or biodiversity. Farmers in turn start to work more demand driven, answering to consumer needs. Knowledge around cultivation and soil has become more accessible through a central knowledge repository made available by tech companies that developed appropriate datasets and use data availability as a competitive advantage. Simultaneously, cooperation and alignment between governments and between sectors have improved, leading to de-compartmentalisation.

Between 2035 and 2040, energy problems are solved through true cost pricing and accounting, supported by the cooperation between government and private sector. Logistics and general infrastructure on pixel farms and value chains are re-designed to serve consumers according to their demands. However, consumer demands are manipulated through consumer data and advertising. This also includes more one-on-one communication between consumers and producers. There is a broad acceptance among citizens that their personal data is used to inform processes around food.

Table 2 *Milestones transition pathway Data for your convenience.*

2025	2030	2035	2040
• Important steps towards a healthy soil and healthy crops • Clear vision about the direction of change, including in terms of investments • Sector has taken steps to further decrease nutrient losses	• Tech for monitoring of soil and plant features • Robotics and autonomous vehicles can be on the field independently • Cooperation between farmers and big tech • Agreements about use and ownership of data • Big tech embrace and enable shift to mixed cropping	• Data used to coordinate consumer demands with automation at farm level and value chain • Farmers work demand driven • Knowledge around cultivation and soil more accessible • Cooperation and alignment between governments and between sectors	• Energy problems solved through true cost pricing • Logistics and general infrastructure re-designed to serve consumers • Consumer demands influenced through consumer data • Broad acceptance among citizens about personal data use

3.2 Ecology at the wheel: Ecology based transformation

Between 2021 and 2025, regional and European cooperation has increased, at European level in a 'Fort Europa' cooperation and regionally e.g. through collective crop rotation plans. Together with arable interest groups, pioneering farmers form discussion groups around smart mixed cropping systems. Research shifts focus to climate resilient crops and indicators for healthy soils. In higher education, there is more attention for biological processes and healthy soils. Similarly, chain parties start experimenting with offering true pricing schemes.

As new pests and diseases have reached European agriculture by 2030, research has demonstrated that the right combinations of mixed crops ensure healthy and resilient systems. Together with indicators for healthy soils, and stricter CAP policies around greening measures, this gives banks more confidence to start experimenting with ecological loans and mortgages. Simultaneously, free trade outside of the EU is restricted. For farmers, this means that new business models such as eco-schemes that reward environmentally-minded practices become lucrative. At the consumer level, seasonal vegetables and regional produce become more important and there is a further diet shift from animal to plant proteins. This is confirmed by vegan products becoming mainstream, encouraged by the continued development of dairy products based on microbes as opposed to cows. Farmers try out subscriptions for seasonal produce. Citizens are more involved in food production through food inclusive spatial environments and by participating on arable farms. Citizen engagement is complimented by further development of robotics and sorting techniques at the farm level.

By 2035, the EU Farm-to-Fork strategy has been extended and received widespread support. At the same time, CAP regulations have tightened further and chemical crop protection has been banned. This has accelerated farmers' switch towards mixed cropping systems as a way to deal with pests and diseases and create resilient arable farms. Improved knowledge and expansion of approved plant breeding techniques combined with smart use of available crop protection measures and autonomous farming techniques help farmers to realise high production with minimal inputs. Due to consumers shifting to a 40-60 animal-plant protein ratio in NW Europe, farmers have started to cultivate a lot more protein crops. Food subscriptions catering to different consumer preferences now have a strong position in the market. Through these subscriptions and citizen engagement, farmer and consumer meet each other more often.

Between 2035 and 2040, all farmers are familiar with mixed cropping systems due to extensive knowledge and monitoring. Cooperation in the value chain has intensified with contracts around supply and delivery, transportation, quality, nutritional value and ecology. Farmers can create lucrative business models through true pricing systems that are coupled with monitoring systems.

Table 3 *Milestones transition pathway Ecology at the wheel.*

2025	2030	2035	2040
• Increased regional and European cooperation • Pioneering farmers form discussion groups around smart mixed cropping systems • Research for indicators of healthy soils • Experimentation with true pricing	• Proof of right crop combinations in mixed cropping systems • Stricter CAP policies around greening measures • Free trade outside Europe restricted • Seasonal vegetables, regional produce more important; diet shift from animal to plant proteins • Citizen engagement	• Farm-to-Fork strategy extended • Tightened CAP regulations; chemical crop protection banned • Expansion of approved plant breeding techniques • 40-60 animal-plant protein ratio in NW Europe • Strong position of food subscriptions	• All farmers familiar with mixed cropping systems • Intensified cooperation in value chain • Lucrative business models through true pricing coupled with monitoring systems

3.3 Crisis forces action: Climate based adaptation

Between 2021 and 2025, the arable sector and national governments work on a vision for climate robust arable systems. There is agreement that extreme weather events are coming that will lead to a crisis. To prepare for such a climate crisis, several topics are put on the agenda: the need for an underpinned picture of a robust arable farm; knowledge and skill development; knowledge about crop rotation in time and space; crop diversification; toolbox for crop protection that can deal with weather extremes; and increasing water retention capacity. At the same time, there is increased investment in plant breeding for example focussing on drought resistance and renewed attention for variety mixtures. This is complemented by investment in crop monitoring.

By 2030, farmers have a limited but expanding toolbox of crop protection measures that can better deal with weather extremes. Tech developments work in the direction of robots that can work 24/7. Knowledge about carbon sequestration and sustainable soil management is broadened and widely applied. Pioneering farmers are starting to switch to mixed cropping systems with wide strips that are compatible with existing machinery. Due to higher average temperatures, farmers in NW Europe start to cultivate new crops such as grapes and soy. However, water scarcity is simultaneously becoming an increasingly big problem, making governance around water distribution a hot topic. Questions about water distribution include the need for clarity about allocation, ownership and storage of water, or new collaborations for water storage to spread and manage risks. Water governance is based on farm data, with an important role for water sensors at the farm level. Farmers generate and store energy to respond to increasing energy demands, among others to power robotics on the farm.

By 2035, there is an *early warning - direct action* system in place. The early warning system is organised in a way that farmers and citizens know what to do in a moment of crisis. A 'flash approach' to quickly deal with new viruses and pests is operational. Even though these systems are starting to operate smoothly, there is increasing polarisation in society about which choices should be made when. Consumers need to be 'pushed' to make sustainable decisions, e.g. through a meat tax. At the same time, countries do not want to be too dependent on others in crises situations, resulting in a shift towards self-sufficiency that is facilitated by 24/7 robotic automation.

By 2040, it is common practice for countries to have a ministry of crisis to deal with the effects of climate change. Arable farms are an important player in water and energy storage, making farmers not only producers of food and raw materials but also of water and energy. Mixed cropping systems are scaled up.

Table 4 *Milestones transition pathway Crisis forces action.*

2025	2030	2035	2040
• Vision for climate robust arable systems • Agreement that extreme weather events will lead to a crisis • Agenda to deal with climate crisis	• Limited but expanding toolbox of crop protection measures • Tech developments in direction of 24/7 robotics • Quick switch to mixed cropping with wide strips • Introduction of new crops • Farmers focus on water and energy	• Implementation of early warning – direct action system • Increasing societal polarisation • Policy to push consumers towards sustainable choices • Switch to self-sufficiency	• Ministries of crisis common practice • Farmers as water and energy providers • Economy of scale for mixed cropping systems

4 Implications for practitioners

For each of the three transition pathways, workshop participants identified 'breakthrough' moments that create a crucial leap in development from the current situation towards the future scenario. Table 5 presents breakthrough developments for each transition pathway. These breakthroughs are first explorations of implications for practice that can be explored further by practitioners, both in terms of strategy and ethical reflections.

Table 5 *Breakthrough developments in transition pathways.*

Scenario	Breakthrough development
Data for your convenience	• Optimised data sharing, even between sectors • Good regulations around data ownership • Technology around harvest and transport focused on efficiency
Ecology at the wheel	• Comprehensive information provision about cultivation in mixed cropping system • Renewed value chain cooperation • True pricing • Monitoring of crop health and autonomous vehicles
Crisis forces action	• Shared vision around climate and robust cultivation systems • Water management based on sensors and farm data • Governance around water distribution issues arranged

These breakthrough moments were then translated into actions for 2 stakeholder groups: 1) farmers and their representatives; and 2) technology suppliers and agro supply/purchasing industry. For both these stakeholder groups, participants answered the question: If it was *only* up to this stakeholder to achieve these breakthrough developments, which actions would they need to take? Additionally, participants discussed the role of policy in supporting the development of smart mixed cropping systems.

Table 6 provides an overview of actions for farmers and their representatives to achieve the breakthroughs in each of the three scenarios. For farmers and their representatives, actions to achieve these breakthrough actions mainly relate to collaboration (both with other farmers and within the value chain), monitoring to unlock the potential of data for smart mixed cropping and investing in infrastructure, storytelling and value chain connections.

Table 6 *Actions for farmers and their representatives*

Scenario	Actions
Data for your convenience	1. Setting up a sectoral data cooperative, with ownership of data as part of the cooperative; 2. Sorting out infrastructure (in case of direct supply); gaining insight into what is where on the mixed cropping field and where possible keeping production on the field year round;
Ecology at the wheel	1. Investing in storytelling around mixed cropping as a Unique Selling Point: making visible Key Performance Indicators and making products attractive to consumers; 2. Invest in connections and alignment with consumers and value chain; exchange knowledge via (online) communities; 3. Monitoring and providing insights into services you provide (requires data!); look for concrete models.
Crisis forces action	1. Think along and be receptive to know about existing hurdles and subsequently actively participate in lobbying for a shared vision; 2. Optimise water usage on own farm and organise this locally through flexible redesign of land distribution and water retention via trees; 3. Collaborate with other farmers in a regional approach and create opportunities on the own farm to store water.

Robust actions for farmers that are relevant and effective regardless of how the future plays out are:

- **Monitoring and collection of data**, both for communication towards consumers as well as within the value chain in order to maintain (competitive) advantage and to strengthen market positioning;
- **Investing in resilient cropping systems**, mixed cropping can be part of that but also other measures such as resilient crop varieties;
- **Collaboration** between farmers is key in all three scenarios, though the way in which may differ depending on dominant directions of change. For example, collaboration around data sharing and ownership or collaboration around water governance.

Table 7 provides an overview of actions for technology suppliers and agro industry to achieve the breakthroughs in each of the three scenarios. For technology suppliers and other industry parties, actions relate to collaboration within the value chain, developing platforms and innovations that support the uptake of smart mixed farming practices and strategizing their position in relation to smart mixed cropping systems.

Table 7 *Actions for technology suppliers and agro supply/purchasing industry.*

Scenario	Actions
Data for your convenience	1. Setting up a platform aimed at visioning and making arrangement around standardisation, sharing of data within the value chain and data vault; 2. Maintain connections with emerging initiatives around just-in-time delivery and explore significance for logistics and business.
Ecology at the wheel	1. Develop FarmMaps-like platforms, including sensor data of crop, soil, weather and algorithms based on decision support; 2. Workable approach to determine a fair price (making hidden costs visible) and support current market innovations with technology.
Crisis forces action	1. Applying the scenarios of this report at the farm level: what is the significance? Then involve constituency in awareness and planning; 2. Work on innovations aimed at water storage, precision irrigation, exploit/utilise greywater.

Robust actions for technology and industry partners that are relevant and effective regardless of how the future plays out are:

- Investing in **collaborative platforms** to facilitate farmers and create clarity about standards and codes of conduct around data;

- **Applying** the scenarios and pathways of this report in more detail **at farm level** to further determine strategic planning options;
- Support farmers by developing **sustainable business models** for smart mixed cropping systems within the value chain, whether through true cost / fair pricing or development of other new business models.

Governments can play a vital role in supporting the development towards smart mixed cropping systems. Participants came up with 'robust actions' for governments that are always useful to support the achievements of breakthroughs towards smart mixed cropping systems, regardless of the scenario:

- Properly **regulate data ownership** related to smart agriculture. Both the 'soft way' via facilitating sectors that self-regulate (e.g. through codes of conduct) or if necessary through rules and regulations;
- **Manage natural resources** (water, energy, etc.) well, including addressing distributional issues;
- Supporting processes that ensure **fair pricing, proper regulation of compensation for ecosystem/social services** from smart mixed cropping systems, supporting the implementation of total cost accounting of such systems;
- Enable development of **new business models** around smart mixed cropping systems. Also provide room for experimentation with different types of mixed cropping and smart farming practices;
- Supporting the **knowledge and innovation system** (AKIS) and other processes that support the development of smart mixed cropping systems.

4.1 Implication for energy infrastructure

The scenarios and implications as discussed above are still rather general because they are applied to the agricultural system as a whole. The scenarios are useful for practitioners with more specific questions to see how a certain development or practice would play out in each scenario and determine a strategy based on this assessment. Executing this exercise also uncovers the complexity of strategic decision making in the real world. After all, by their nature not one of the three scenarios will become reality, rather a combination of elements of all three scenarios is likely to occur. One way to deal with these uncertainties is to formulate robust actions that hold up in each scenario and are therefore 'safe choices'. Moreover, exploring the three different scenarios informs current and future decision-making by creating awareness of the effects of certain developments. For example, if there is an innovation and policy trend towards promoting small machinery, it makes sense to anticipate on the outcomes of this trend by investing in on-farm energy storage. Exploring and anticipating the effects of developments in the scenarios therefore creates more agility and anticipation of future possibilities in strategic decision making.

Within PPP AGROS, we conducted this experiment for energy infrastructure in smart mixed cropping systems, one of the subprojects within AGROS. Together with researchers and engineers working on this part of the project, we organised working sessions around the question: what would each of the scenarios mean for energy infrastructure at farm level? In each scenario, general indications for energy infrastructure were already described, but of course these can be explored in much more detail. In this section, we describe the results of this exploration as an example of how the scenarios of this report can be further used by practitioners.

For each scenario energy demand was estimated in comparison to current energy demands. Then, three functions of energy at the farm level were determined: energy production, energy storage, energy use. These three functions of energy were discussed for each of the three scenarios, starting from what we already know from the scenario descriptions and transition pathways. Finally, 'robust actions' were defined: actions that align with all three pathways and are therefore relevant to implement regardless of what the future will look like. Table 8 provides an overview of the outcomes of this exercise.

Table 8 *Energy infrastructure in each scenario.*

Scenario	Data for your convenience	Ecology at the wheel	Crisis forces action
Elements related to energy already described in scenario descriptions	Robotisation and automation for personalised food; high energy demand from data centres; scaling up through smart, autonomous technology; still a role for large machinery, mainly for production of raw materials	Autonomous and electric vehicles, fitting to the landscape; mechanisation is small, light and fossil free; energy demand fitting of digitalisation in short value chains, mechanisation fitted to small strips	Farmers as food, water and energy producer; sensors for science based evidence; storage of water and energy; turnaround must be quick: no time to go fully electric; wide strips that fit current large machinery; mobile solar cells between strips
Energy demand	Energy demand drastically increases and comes at different times	Energy demand increases at farm level, but decreases in the system as a whole	Whether or not energy demand changes depends on how the crisis develops
Functions of energy in the scenarios	- Focus on **local energy production and optimisation** - Energy demand for both **small (electricity) and large (hydrogen) machinery** - **Energy storage** is needed for small machinery; robots also work at night - **Personalisation** of food increases energy demand - **Increased energy demand** because **data** demands a lot of energy	- Engaged consumer wants **zero emissions** - More recycling and more processing on the farm means a **higher energy demand at farm level**, but a lower energy demand elsewhere in the value chain - **Composting/ fermentation** of waste flows to produce energy for small electric vehicles - Farmers invest in **CO2 storage** on the farm - Reduced use of **pesticides** and **chemical fertilisers** also reduces energy use in the sector - Reduction of '**energy-guzzling**' crops such as flower bulbs	- In a crisis situation, energy price extremes are expected. This means managing **production and storage of energy on the farm** is attractive - Farmers focus on **providing services** that have become scarce, including energy but also water and energy storage - In a situation with no availability of natural gas, farmers **invest** in **batteries, H2 storage** and **self-sufficiency** - Question for reflection: will a business model around energy remain sustainable?
Robust actions	• **Optimisation of local energy production**: it is cheaper to produce your own energy (e.g. right now in the Netherlands H2 costs 56ct/kWh, own electricity from solar panels costs 6ct/kWh); • **Stabilisation** is possible if farmers collaborate with each other, with the requirement that e.g. each farm has comparable storage capacity; • **Producing, storing and trading energy** already provide new opportunities and business models for farmers. If trading is not possible or attractive, there is still the alternative of using energy at the farm level year-round (e.g. in a 'crisis forces action' scenario); • For each scenario there is a **business model related to trading** in energy in support of a mixed cropping system; • Producing and storing large amounts of energy always allows farmers to be **flexible**; they can either use it on their own farm or trade energy when it is cost-effective.		

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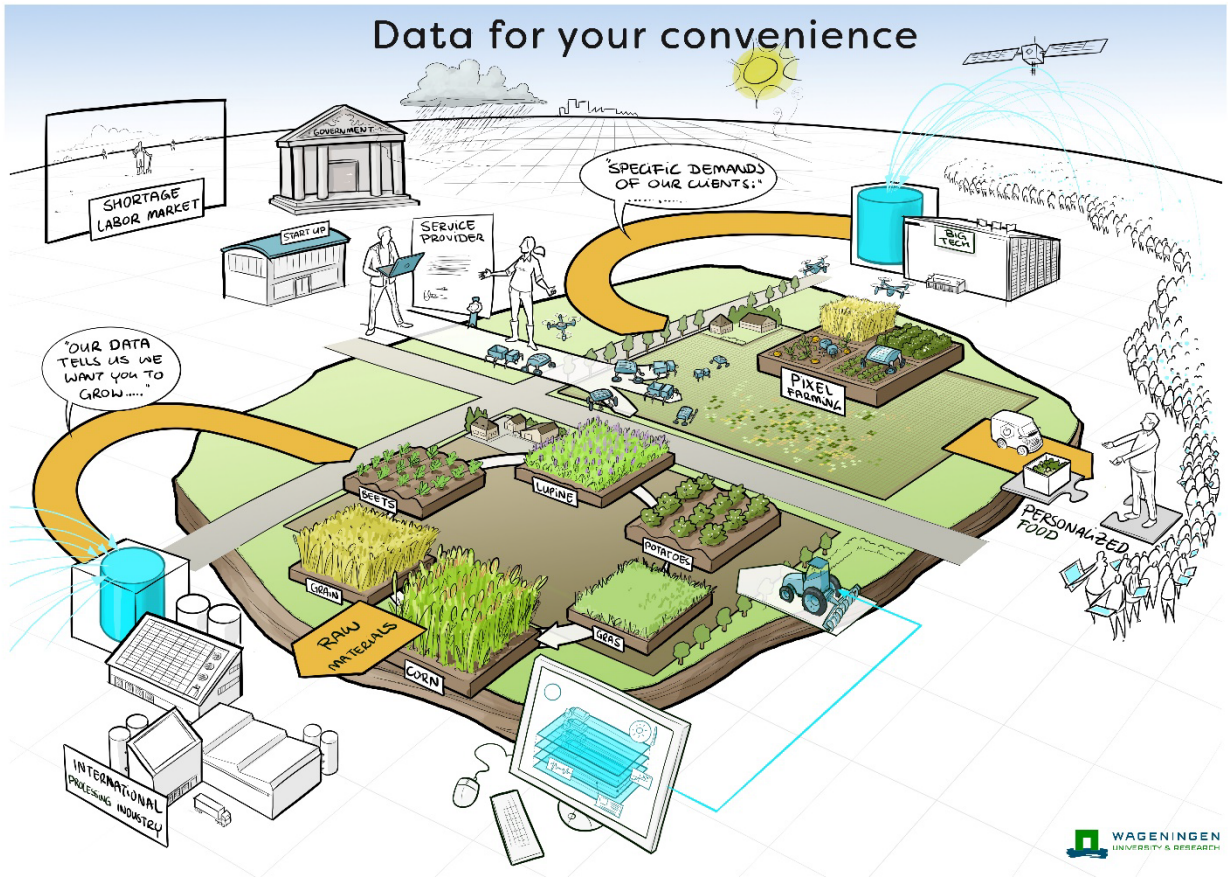
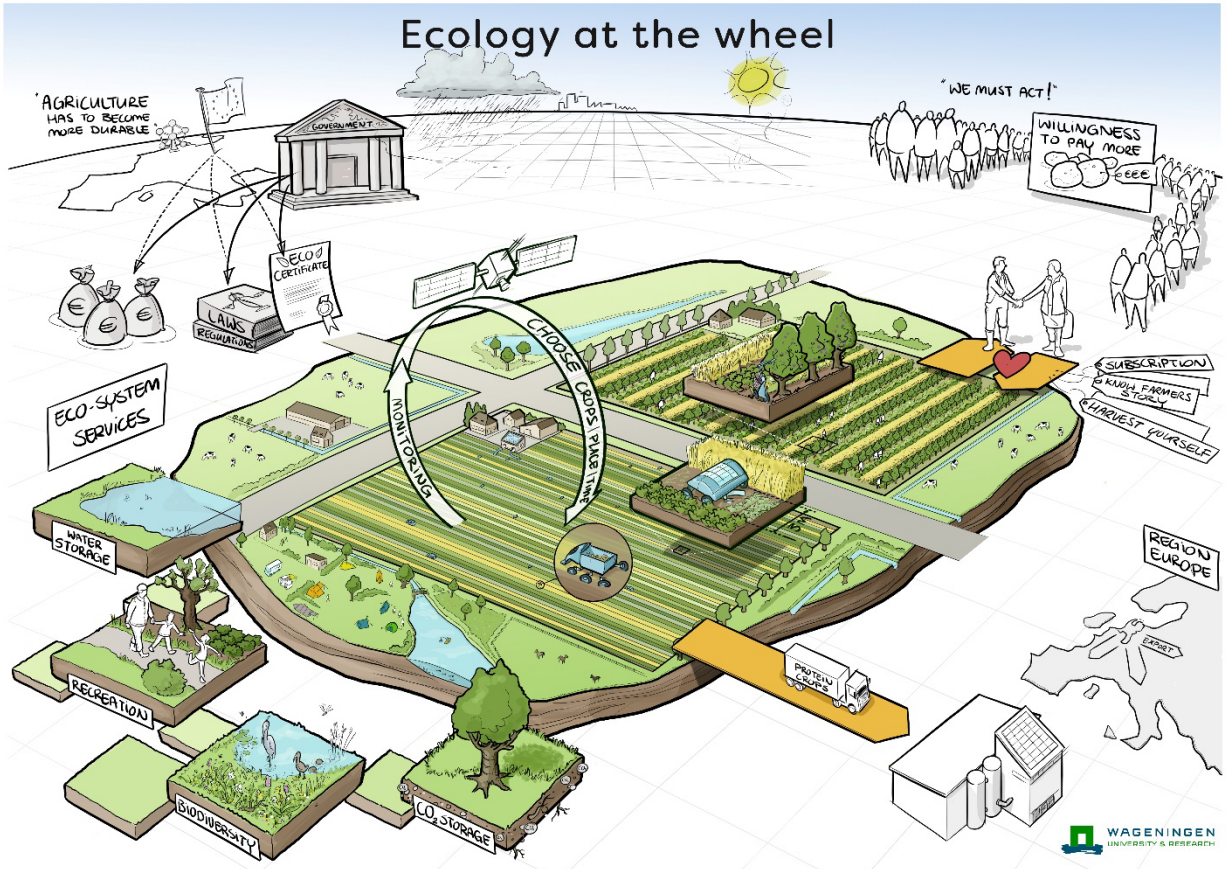
Annex 1 Scenario sketches

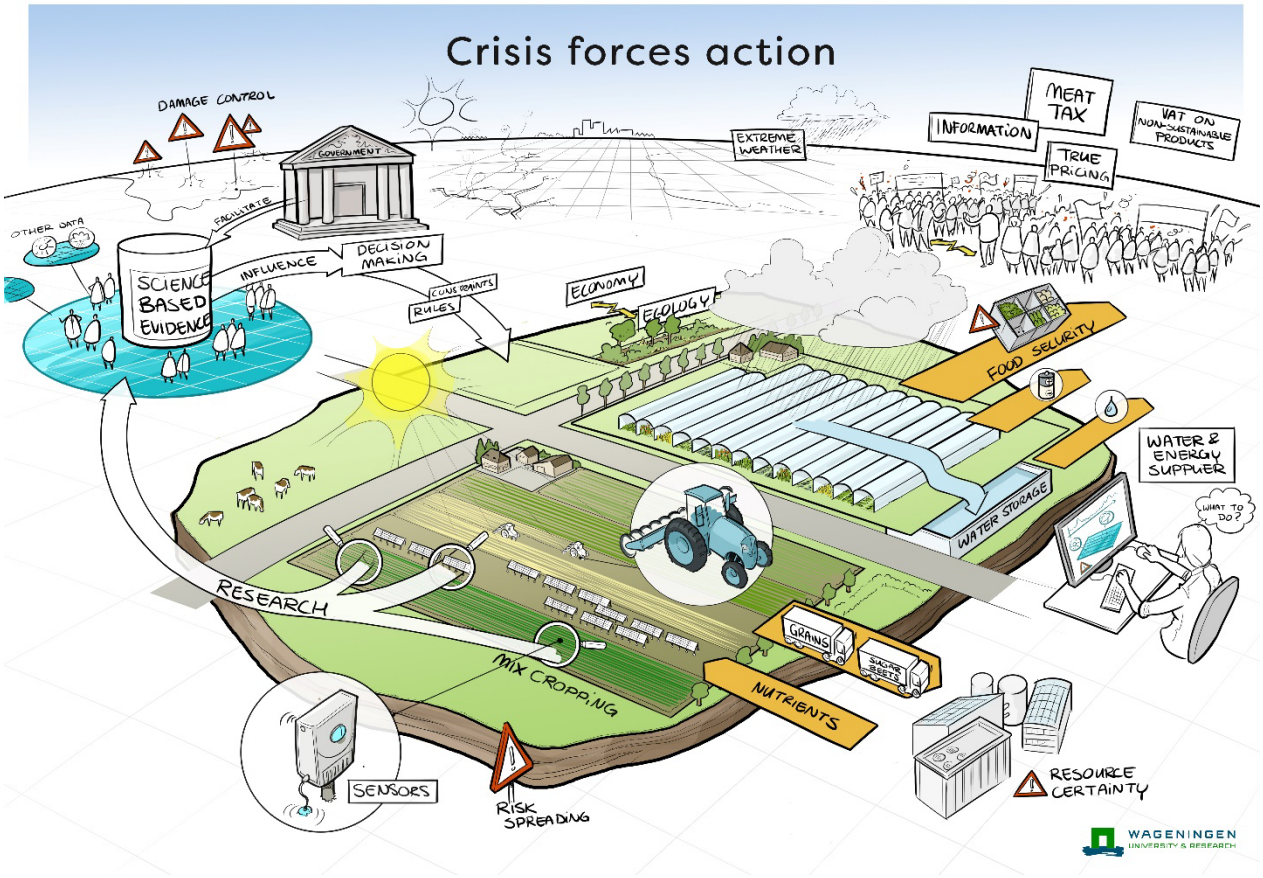
(external) factors that influence the development of smart mixed cropping systems*	Data for your convenience	Ecology at the wheel	Crisis forces action
Development direction market	Further globalisation	Regionalisation	'glocalisation': focus on 'region' Europe
EU and national policy	Laissez-faire/the market rules: sector looks for solutions with little government intervention	Facilitation government: create opportunities to innovate	Strongly guiding government, namely related to climate: crisis management
Changing consumer demands	Hedonistic consumer; 'kilo knaller' consumer	Responsible consumer	'Tamed' consumer
Availability of labour	Labour is scarce and expensive	Enough labour available	Shortage of steadily available labour
Soil quality	No urgency around soil quality	High urgency around reducing soil quality	Some urgency around reducing soil quality
Biodiversity and nature inclusiveness	Not seen as urgent – focus on intensive crop production	High urgency around reducing biodiversity and nature inclusivity	Some urgency around reducing biodiversity and nature inclusivity, but climate adaption gets priority

*We take the effects of climate change as a given in each scenario

Annex 2 Illustrations future scenarios smart mixed cropping systems






Crisis forces action
DAMAGE CONTROL
GOVERNMENT
FACILITATE
OTHER DATA
SCIENCE BASED EVIDENCE
INFLUENCE
DECISION MAKING
CONSTRAINTS
RULES
EXTREME WEATHER
INFORMATION
MEAT TAX
TRUE PRICING
VAT ON NON-SUSTAINABLE PRODUCTS
ECONOMY
ECOLOGY
FOOD SECURITY
WATER & ENERGY SUPPLIER
WATER STORAGE
WHAT TO DO?
RESEARCH
MIX CROPPING
GRAINS
SUGAR BEETS
NUTRIENTS
SENSORS
RISK SPREADING
RESOURCE CERTAINTY
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Annex 3 Example workshop scripts

Example script Scenario Workshop			
Goal: Interactive development of future scenarios that serve as a starting point for developing action perspective(s) for stakeholders. **Result expectation:** a set of diverging future scenarios for the future, preferably written as narratives and accompanied by visuals.			
Time	**Session**	**Methods/Comments**	**Material**
15'	Introduction	Explain **purpose** and **usefulness** of scenario workshop. E.g.: interactive exploration of future smart mixed cropping systems, to explore what the future of sustainable arable farm can look like and implications for stakeholders and agenda setting. Present a clear **problem definition**: why is it necessary and useful to explore alternative futures?	PowerPoint
15'	Presentation scenario sketches	Present scenario sketches that are prepared based on trends analysis. Scenario sketches show *uncertainty*: we do not know what the future will look like. Ask for reflection on the scenario sketches: do participants recognise these sketches as relevant and useful? Is anything crucial missing?	Overviews of scenario sketch(es)
10'	Introduction to scenario planning exercise	Introduce the scenario planning exercise and divide participants into groups (number of groups depending on number of scenarios) Think about group composition: e.g. make sure groups are a heterogeneous representation of stakeholder groups.	
45'-60'	Scenario planning	Participants add colour and detail to the scenario sketches; what does it look like to live in this version of the future? Ask participants to write down their first thoughts individually to ensure equal input by all participants. Think about questions/topics that need to be addressed in each scenario.	Template to structure discussion Sticky notes / pens / markers Guidelines with complementary questions and instructions for facilitators
15'		**Break**	
30'	Scenario presentations	Back in plenary, each group presents the main features of their scenario. After each pitch, there is room for clarifying questions, and concrete input/suggestions from the other group(s).	Flip-overs with summaries
30'	Reflection	Goal of this reflection: scoring the scenario's relative to each other. What are strengths/weaknesses in each scenario, e.g. in terms of meeting sustainability goals?	Template with strengths/ weaknesses and goals for each scenario
15'	Wrap-up	Review and reflection of the workshop. Present next steps.	

Example script Strategy Workshop

Goal: Based on the future scenarios, interactively developing robust strategies for relevant stakeholder groups through transition pathways.

Result expectation: Transition pathways from the current system towards the future scenarios, with corresponding action agendas for relevant stakeholder groups.

Time	Session	Methods/comments	Material
15′	Introduction	Introduction of the programme, summary and retrospective summary of previous workshop	
15′	Scenario presentation	Presentation of final scenarios (based on the previous workshop), including explanation of creation of the scenarios. Possibility of clarifying questions	(if available) scenario visuals and summary of each scenario Scenario narratives
10′	Determine desired outcomes	**Central question**: what are desired outcomes of success for relevant stakeholder groups? Goal of this session: determine desired outcomes that need to be upheld within the pathways (e.g. meeting certain sustainability goals, or being in line with existing policy measures) The organising team can make a first set-up with preconditions for success in the future reference year. During the workshop, reflect on these preconditions: is anything important missing?	Table with predefined desired outcomes for relevant stakeholder groups
50′	Back casting exercise	Divide participants into groups, each group works on 1 transition pathway. **Central question**: how did we arrive at the future scenario from the current situation, while desired outcomes are upheld? - Which innovation challenges were solved along the way? Timing, e.g.: - 5 min: free association: all participants take 5 minutes to write down their first ideas on sticky notes - 35 min: discuss the ideas on the sticky notes, complement them, translate developments to actions for stakeholders and place the notes on the time line. This includes a reflection: what needs to happen in which order? - 10 min: wrap up and reflect: what are the most important break-through developments that made the big difference on the way from today to the future scenario?	Time lines from present day to each future scenario Table with desired outcomes Sticky notes / pens / markers / flip overs

15’		**Break**	
15’	Report back results of back-casting exercise	Each group presents the outcomes of the back-casting exercise using the break-through developments/events	
45’	Strategy and action agenda	**Central question**: what do the transition pathways mean for each of the stakeholder groups and what are strategic actions to be successful in each scenario within the preconditions of success? Starting from the break-through developments, create an action agenda: what are no-regret actions, what are robust strategies and how can stakeholder groups remain resilient?	Template for action agendas Sticky notes / pens / markers / flip overs
10’	Wrap-up	Review and reflection of the workshop. Inform participants about any next steps and how workshop results will be processed and shared.	

To explore the potential of nature to improve the quality of life

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.