Advancing societal food system knowledge and innovation

D 1.4 Summary Report on

New topics and developments

from the Horizon Scanning & collection phase

Kerstin Cuhls [Kerstin.Cuhls@isi.fraunhofer.de]

Ariane Voglhuber-Slavinsky [Ariane.Voglhuber-Slavinsky@isi.fraunhofer.de]

Miquel Banchs-Piqué [Miquel.Banchs-Pique@isi.fraunhofer.de]

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Contributors	Full consortium

Reviewers

Partner	Name	Contact information
Kerstin Pasch	DIL, Quakenbrück	K.Pasch@dil-ev.de
Anne Loeber	VU University, Amsterdam	a.m.c.loeber@vu.nl
John Ingram	University of Oxford	john.ingram@eci.ox.ac.uk

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Glossary

Abbreviation	Full form
AKIS	Agricultural Knowledge and Innovation System
CAP	Common Agricultural Policy
CDI	Change-Driven Initiative
EC	European Commission
ERA	European Research Area
EU	European Union
K&I	Knowledge and Innovation
IoT	Internet of Things
NGO	Non-Governmental Organisation
NWJMs	New Water Justice Movements
RFID	Radio Frequency Identification technology
SCAR	Standing Committee on Agricultural Research of the European Union consisting of representatives of the Member States
SDG	Sustainable Development Goal
SMEs	Small- and Medium-size Enterprises
WP	Work Package (of a project)

Executive Summary

FOSTER is a European Horizon Europe project called ‘Fostering food system transformation by integrating heterogeneous perspectives in knowledge and innovation within the ERA’. The FOSTER project was set up to ‘build a foundation from which a Knowledge and Innovation (K&I) governance structure for Europe's food system can emerge’ (FOSTER, 2023). In FOSTER, we work on how to change, improve and broaden the scientific knowledge base and the associated knowledge and innovation system (in and for the food system). Futures knowledge is gained by scanning the horizon, assessing the findings by our practical partners and by co-creating interdisciplinary knowledge.

We can thus conclude that the food system in the EU is facing many challenges within new geopolitical contexts but also changes within the system and its environment that have to be taken into account when thriving for transformation (OECD 2023a). We should not forget that many opportunities for change are visible – and this is why we added a section on bioeconomy in our framework. But as we do not know how the future unfolds, there are different scenarios possible (see Deliverable 1.5 on context scenarios) serving as working materials in FOSTER.

This report contains a preliminary, updated summary of ‘futures knowledge’ and information, meaning new topics in the food system, old and new drivers for the food system and new framework topics for food systems, which were found during a broad scanning and a participatory assessment process in the project. The conceptual background of the project FOSTER is described elsewhere (Loeber et al. 2025, Paper 0, Deliverable 6.6). In this Deliverable 1.4, you can find the conceptual frame and the methodology of the Horizon Scanning (again and updated from Deliverable 1.2) as well as a summary of developments and some single topics, which will be relevant in the future and are requiring new knowledge or will provide new knowledge for and within the food system.

The changes in food systems in general and updated challenges are summarised at the beginning. Drivers for changing the EU food system and topics that are expected to undergo changes within the food system are shortly outlined. They go far beyond climate and demographic change and question our food security in the EU, too. The results from the Horizon Scanning are signals and developments, problematic issues and new topics. All findings are displayed on the digital FOSTER Knowledge Platform (via website https://fosterfoodsystem.eu/) as new future food systems knowledge – with uncertainty and always under change. We stress once again that the whole consortium is the knowledge platform that all participated in filling the digital platform.

The identification process of signals and developments within the food system and those driving the food system had several steps and the findings are used for further discussions by some CDIs. The scanning results are the basis for the identification of a potential new theme for a Change-Driven Initiative (CDI) in addition to the already existing ones within the FOSTER project. This new CDI is supposed to remain when the FOSTER project as such has already ended.

Chapter 1

Introduction

Chapter 1 - Introduction

1. FOSTER Narrative and Background

FOSTER is a European Horizon Europe project called 'Fostering food system transformation by integrating heterogeneous perspectives in knowledge and innovation within the ERA'. The FOSTER project was set up to 'build a foundation from which a Knowledge and Innovation (K&I) governance structure for Europe's food system can emerge' (FOSTER 2023). In FOSTER, we work on how to change, improve and broaden the scientific knowledge base and the associated knowledge and innovation system (in and for the food system). The food system in the EU is facing many challenges within new geopolitical contexts, climate change, political re-directions but also changes within the system and its environment that have to be taken into account when thriving for transformation.

More explanation on the approach of FOSTER and the conceptual background can be read in the White Paper of FOSTER[1]. This deliverable is not about the changes of policies but the different changes within and around the food system. Other ongoing projects analyse very different aspects of the food system[2]. Networks are trying to organise activities, e.g. the Food 2030 network, but only a few of them take the long-term view. Horizon Scanning is looking at the present and the future for giving an outlook. We also use it for the longer term view up to 2040 and thinking beyond the classical horizon but also tried to think forward and backwards on the timeline to motivate our CDIs to draw their own conclusions for their work. As our CDIs are very different in nature and could decide what to use and what to ignore, not all findings were used by them. The reason is a practical one: time constraints and for them, the long-term is far away and not part of their daily business. Thus, it needs to convince them that this kind of futures information or knowledge is also relevant to them and to their own futures, even though parts of the information gathered are still speculative. We provided the major selected findings to the public and gave the possibility to ask questions on the website[3].

An important feature of futures knowledge is that we do not exactly know how the future might unfold and if the disciplines doing research on food systems now are still the same and relevant ones in 15 years time. There is no right or wrong in our current views but observations of change can be made – also in research and technology. One of the observations is that the present system of AKIS seems to be well organized, the actors know each other, and information flows are open. With a closer look, we observe that AKIS is representing agriculture but does not represent the needs and realities of the entire food system. It should be noted, however, that awareness of this issue has been growing at all levels (politics, society, business, education and

[1] The FOSTER White Paper or Paper 0 will be published as Deliverable 6.6, soon.
[2] https://fosterfoodsystem.eu/other-eu-projects/.
[3] https://fosterfoodsystem.eu/results-from-the-horizon-scanning-activities/.

research) for several years now.. The primary focus in AKIS in 2025 is still on agriculture, ascribing a central role to farmers and associated advisory services. AKIS is operating 'within its existing boundaries and the conventional structure involving agricultural advisors, agricultural research, agricultural infrastructure and, where appropriate, customers of agricultural production' (Spendrup et al. 2019, see in Paper 0 from Loeber et al. 2025 forthcoming). The differentiation of research areas and working in disciplinary silos as well as funding according to the differentiation are a reality (Boer et al. 2021; Kok et al. 2019; Kok et al. 2021; Loeber et al.).

The consequence are blind spots (parts of the system we do not see) and black boxes within the full food system – the role of certain players in the game, for example retail, remains unclear. And many drivers that may affect the food system and in the consequence agriculture are not in the forefront of research or observation, for example the question if cultivated meat replaces livestock farming in a bigger scale or if land use is not the bottleneck of farming, anymore, when precision fermentation, industrial production of food inhouse, in cities or with 3D printing can be realised on a large scale. These are assumptions and we do not know how they will unfold during the next years but we have to think about them and their consequences for policy-making, companies or our CDIs.

How will traditional food production change? How will our food culture change? And how will our landscapes look like in 15, 25 or 35 years time? Is it really healthy for people, animals, plants and planet what the food system provides as an output? What is a healthy diet at all?[4] Can we produce more circular and build up a bioeconomy that is using more from what is produced primarily? If we say yes, we are not only talking about the agricultural knowledge system, anymore, but about industrial food production, production of goods from the remainders and side-streams, about new technologies, transport systems and business models to make a bioeconomy profitable. We are not talking about full circular economies as this is rather a model for orientation than a realisable option (Giampietro et al. 2020). This is why we enhanced the food system framework for FOSTER, its thinking and what we searched for in the Horizon Scanning approach.

This Deliverable 1.4 is the summary of the many single findings – from the semi-automated scanning, the discussions in the consortium including academics, practitioners and CDIs, from the discussions around a conceptual framework that was needed to start the searches, and the problems with it grasping the real findings of potential future changes. In FOSTER, we assume that adequately **changing how knowledge is produced** (by scientists, people engaged across the food sector, etc.) **and used** (by policy makers, scientists, farmers and other food system actors, etc.) **will serve as a lever** towards a more sustainable, resilient and just system, **change how our food is produced, processed, distributed, consumed and its waste is discarded or re-used**. But this is a possibility – it also has to be realised by real activities.

[4] This is a question, the 6th SCAR Foresight is examining in 2025 for the European Commission.

For this reason, the following report provides an input of future topics across the agri-food system with a **focus on the perspective of six change-driven initiatives (CDIs)**. The CDIs are collaborators and partners of the FOSTER project and contributed to knowledge production in the food system from a very practical perspective. They described if the findings (trends, signals, developments, observations) were useful knowledge for them and if we should keep the information in the list. The findings are new for some, for others they are well known. Interestingly, most of our findings in the Horizon Scanning were assessed as important and useful by the CDIs (short survey with qualitative assessment). This deliverable is the **summary** and we share many of the findings from the Horizon Scanning on the digital FOSTER Platform (https://fosterfoodsystem.eu/future-food-systems-knowledge/). During the project until 2026, the digital platform will be regularly updated.

We thank all members of the consortium and especially the CDIs for their contributions and vivid discussions as this is and was a participative and co-creative process – a platform. What was called 'post-normal science' (Funtowicz et al. 1993; Giampietro et al. 2020) is thus (hopefully) more and more the new normal or 'normal science', 'normal research', normal knowledge generation but still needs permanent efforts to realize interdisciplinarity, work between heterogenous actor groups, being acknowledged by scientific communities as well as the public and develop new modes of work for looking ahead and thinking in systems.

Chapter 2

Methodological Approach and Framework

Chapter 2 – Methodological Approach and Framework

2. Methodological Approach and Framework

2.1 The Framework Concept

Foresight is integral part of the project FOSTER. Foresight is defined as the 'systematic debate of complex futures' (Cuhls 2003, 2019) opening up contexts like open and exploratory possible futures, realistic/ probable futures, and desirable/ preferred futures (sometimes represented by 'visions'). **Foresight** is thus

- **structured**: it is a systematic approach by applying methods of futures research, science-based, and based on new theories of futures research
- **a debate** or **dialogue**: it includes interaction of relevant actors, active preparation for the future or different futures, and orientation towards shaping the future
- **complex**: it includes the consideration of systemic interdependencies, takes a holistic view
- **'futures' is plural**: it is an open view on different paths into the future with thinking in alternatives. But it also tries to see and work with the whole system (whole systems approach).

Using Foresight methods, we also envisage **different types of futures** and differentiate between **possible, probable and desirable** futures. Voros even adds potential and plausible futures (Voros 2003, p. 16-17) to the classification. When applying Horizon Scanning, we concentrate on **possible futures** first to detect ongoing trends from the past, new developments or even weak signals. What is relevant for FOSTER is decided by the consortium and here mainly by the Change Driven Initiatives, CDIs. That means, we have an inherent bias (Schirrmeister et al. 2020) towards their needs in the selection of topics. In the Horizon Scanning, we do not only search what they ask for but also search for signals new to them to make them aware of 'new things to come' by scanning the literature and discussing with different actors in the system. Not all developments are nice – but this depends on the perspective.

During the course of FOSTER, it was the task of the CDIs themselves to decide on their own desirable future (sense-making). For their further purposes, the Summer School in Barcelona 2023 was the place to learn some Foresight methods for imagining possible futures and in 2024, workshops for exploring and working with desirable futures, starting from the futures view, were offered, e.g. to use roadmapping on the way to planning.

Foresight takes the **long- and medium-term view** and encourages us to learn about the future impacts of our actions in the present. It is not prediction (Cuhls 2003, 2019) but rather a 'set of approaches to bringing longer-term considerations into decision-making, with the process of engaging informed stakeholders in analysis and dialogue being important alongside the formal products that can be codified and disseminated' (Miles 2008, p. 37).

The Horizon Scanning searches thus concentrated on opening up futures, finding issues in or parts of the food system that will change in the future, but this part of the project is not about applying a theory of change on an already known field of change (Balmann et al. 2016; Cantù et al.; Dinesh et al. 2021; Simeone et al. 2023). The sense-making is thus done within the CDI groups and by themselves. The FOSTER consortium supports with methods and facilitation.

How and what did we scan? We had several steps and different ways of searching for information about the horizon – and one part were the scenarios described in Deliverable 1.5. The Horizon Scanning started with a literature analysis of different food systems frameworks to define the boundaries of the system we are searching in and to define a search strategy. We considered food systems frameworks from the scientific literature like Bukeviciute et al. 2009, Eigenraam et al. 2020, Ericksen 2008, Hilmi 2019, Ingram 2011, Ingram et al. 2012; Ingram et al. 2018; Vallejo-Rojas et al. 2016; Voglhuber-Slavinsky et al. 2021; Westhoek et al. 2016; Zurek et al. 2022b and others, and of relevant organisations as in FAO 2014ff[5], the FAO High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security 2017, FAO 2018, different visualisations of IFST[6], Bizikova et al. 2021[7], Lomax 2018[8]. But most of them were too complex or too strongly aligned to the classical value chain in food production.

To use a practical approach and be in line with other EU projects, the framework concept from Foresight4Food was used in adapted form and changed further during the course of the different steps and based on the findings. Inherent in the framework is the food production value chain but the different outer layers of the frame include framework conditions, drivers and outcomes in a very straightforward way. We thus used this figure (figure 1) as a first entrance point to formulate a Horizon Scanning strategy and started in the steps of the food system chain, the outer part of the drivers and enhanced the collection of the drivers. The framework underwent several changes when we found new information, for example, we added Mobility as well as Resources & Energy as drivers. Moreover, we re-included Dietary Patterns and Societal & Cultural Patterns as they were originally subsumed under different headlines, but our research suggested they need specific attention, which is backed up by the new SCAR Foresight 6 Process (ongoing) that included for example 'Sustainable and Healthy Diets' as a specific focus area.

[5] https://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b10-value-chains/chapter-b10-2/en/.
[6] http://www.3keel.com/wp-content/uploads/reports/IFST%20Sustainable%20Food%20System%20Framework_0.pdf.
[7] https://www.iisd.org/articles/visual-representations-food-systems, visualisations based on scientific literature.
[8] https://resilientcities2018.iclei.org/wp-content/uploads/D4_Presentation_Lomax.pdf.

Figure 1 is the **concept frame used for the scanning**. Despite many discussions in the consortium on the pitfalls of this frame, we kept it for further searches and analysis but used it as a living document for changes.[9]

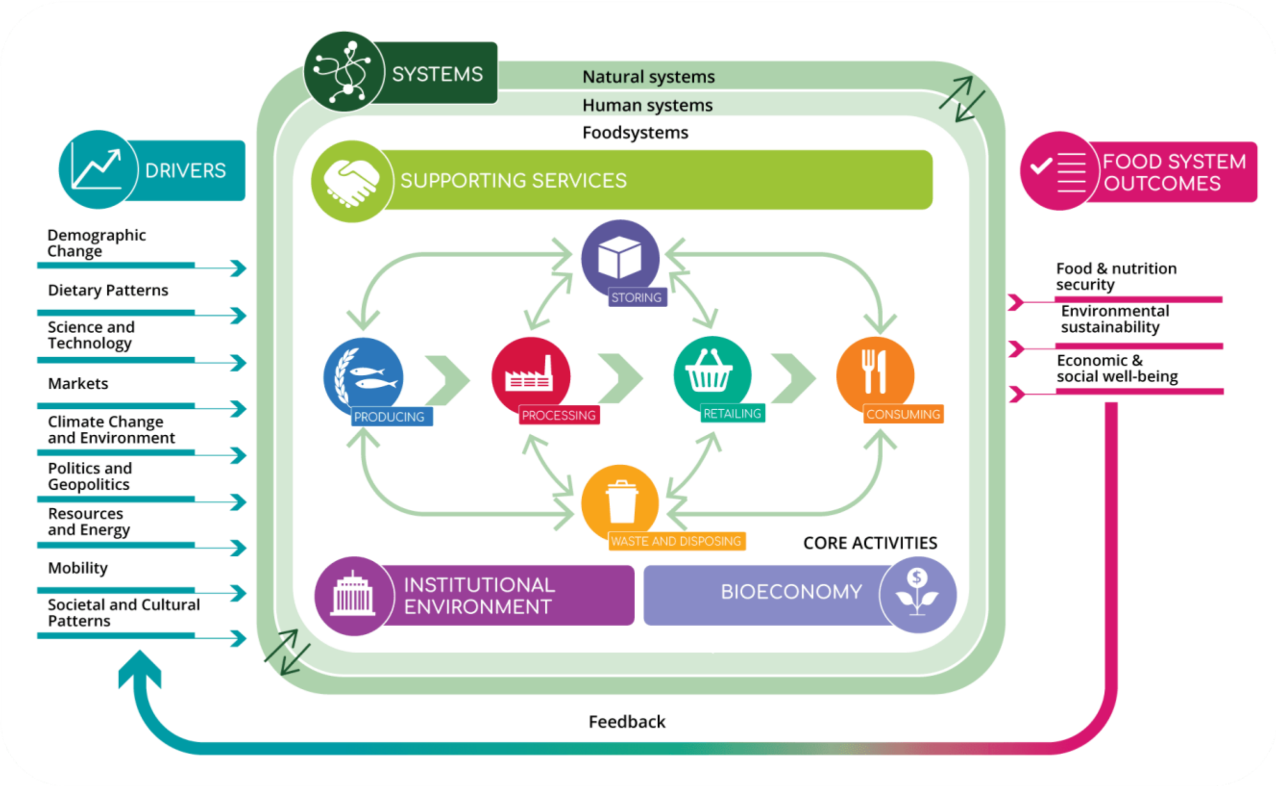

Figure 1 - The FOSTER concept frame
(adapted from Foresight4Food, see also first versions in Zurek et al. 2022b)

For the Horizon Scanning, we then began with the inner circle of the image – that is, the food system itself – with six categories or phases of the food supply chain: 1. Producing, 2. Processing, 3. Retailing, 4. Consuming. 5. Storing and 6. Disposing.

2.2 Methods of the Horizon Scanning Process

The process started methodologically with the definition of the scanning strategy based on the framework. **Criteria** for the search were:

1. Context of food systems (see figure 1),

2. Long-term developments or trends or signals that may have an influence on the system or parts of the system,

[9] On the website, the adaptations are also ongoing. When this report is written, the bioeconomy findings are inserted.

3. Issues in the sense of challenges/ problems or contradictions and new topics in the sense of upcoming technologies or the combination of driving forces.

4. We did not describe unchanged issues or pure 'trends'.

5. We did not describe issues or topics that were irrelevant for the CDIs.

Applying the criteria, we did a semi-automated search in several steps:

1. We searched for the titles in combination with food system(s) in Dimensions.ai.

2. We did a combined search of words that related to the area, e.g. production + emulsions + future

3. We analysed the findings to observe clusters (human scanning). We also collected other European Union projects and connected some of them on our digital platform https://fosterfoodsystem.eu/future-food-systems-knowledge/. An independent report supported the start (Achterbosch et al. 2019).

4. Additional findings were searched for directly in internet, journals, Dimensions.ai and Web of Science or specific journals related to the topic. The results are selectively described in Deliverable 1.2 and on the website https://fosterfoodsystem.eu/results-from-the-horizon-scanning-activities/. This report is a summary of the developments, drivers and signals we found.

5. All findings underwent an assessment by the CDIs and selected persons from the consortium: The first survey consisted of an Excel file where the CDIs could judge (give up to 5 stars for each finding, simulating a Likert scale) the importance of the topic. Then, they were asked for comments or changes in formulations and new sources. This served as a criterium for keeping the topic in the list or deleting it. Some topics were thus fused, shifted to a different area, reformulated or deleted (when there was no star/ no judgement that it might be important).

6. Even though the original idea was to stay within the food system with the analysis, the link to bioeconomy was obvious from the beginning. On request of some members from the consortium and one CDI, we included bioeconomy as a separate cluster into the framework as a link in and into the food system that is important for efficient resource use, the reduction of 'waste' as a resource for others within the food system or even for industry. Therefore, a search like in steps 2 to 4 was repeated for this cluster in 2024 and 2025 and the results were inserted into the webpage. This is very much coined with the findings in the 6th SCAR Foresight (not yet published). A summary can be found in this report.

7. Drivers: On the left-hand side of the framework, some current drivers of the food system are characterised. They are derived from broader overview studies, Foresight activities, own project work and different scenario reports (for the citation of the sources see Deliverable 1.2). The approach was similar to the '7 Drivers Model'

applied by NATO (NATO Allied Command Transformation 2023) and in many other Foresight and Horizon Scanning processes. Drivers are assumed to shape the food system of the future. They were also assessed by the CDIs in the first short survey. The original list of drivers (the clusters or headings) was based on the Foresight4Food initiative but modified according to our findings.

More details about the Horizon Scanning: The first step was a semi-automated Horizon Scanning approach using the database Dimensions.ai. This database contains scientific journals (like the Web of Science journals) and more recent publications that are trusted but not fully reviewed as well as some grey literature like reports. We started with the second category Processing (see Figure 1 above) as the number of hits to be checked was much lower compared to Production. For Processing, we defined key words for searches in discussion with experts and by reading some central journal articles. Key words were for example health food, functional food, personalised nutrition, bioactive compound, cellular agriculture, insect, algae, plant-based milk, cultured meat – just to mention a few of them, there were up to 100 key words. We combined them for the more precise search and a first selection of abstracts from the last 10 years in the database Dimensions.ai was automatically run and ranked according to some key indicators (e.g. frequency) in Excel files. In 'processing', we thus identified more than 674,000 papers. We started to cluster the first ones and build categories like 'starch-based products and processes', 'emulsions' or 'pigments, colours', but noticed soon, that this is much too detailed information for our further work in FOSTER, especially for the work of the CDIs, and that we have too many hits to cluster them. We tried another approach with topic modelling using the same abstracts and created some word clouds (one example see Figure 2 in Deliverable 1.2 Horizon Scanning). Despite this, in the discussion with our CDIs we came to the conclusion that we need a higher granularity level and a different and partly more practical angle of thought for the discussions with them.

That meant in addition to creating context scenarios (see Deliverable 1.5), we went on with **manual searches** partly based on the previous clusters and partly based on questions from the CDIs. We started to scan some of the consortium's own food-related projects and databases of other European food systems projects, for example: Fit4Food, Foresight4Food, FoodNavigator, Futures4Europe, DAKIS etc. We are aware that there are many more – other EU projects and their databases are already linked to the digital FOSTER Knowledge Platform, https://fosterfoodsystem.eu/other-eu-projects/.

These findings served as a starter and we then **screened through, overviewed and reviewed papers and databases** with statistics to deepen some of the findings or underline them with current data. We also read **single papers, newsletters** of food system or related communities, attended online **webinars** and the **Conference** of Food Systems 2030 in December 2023 in Brussels to take other issues into consideration and keep contact with the network (see https://fosterfoodsystem.eu/food2030-network/).

And we **re-clustered** some of the findings from the automated clusters mentioned above. But we did intentionally not evaluate the findings according to pre-described criteria as we did not want to impose our search biases or the biases of ‘experts’ into this search. We hosted all the findings in Excel files and provided them for the CDIs on our FOSTER SharePoint to assess them. The task of the CDI members was to add to the findings, reformulate them and assess if they were **interesting knowledge** (new or existing) to them at all. In this small survey, each file with one of the framework categories (drivers and inner circle, see figure 1) contained between 17 and 67 findings.

In February 2024, the **findings were selected according to the ‘survey’ assessments** of the CDIs, and single questions were discussed in a joint workshop on February 19, 2024. This means, the topics that remained in the list were highly selective according to the needs and interests of the CDIs but they are not assessed to other criteria – they are scanning results helpful for the scenario and CDI work. After a first review process, the findings and sources were updated in July 2024 and once more in Spring 2025 (manual search). The cluster or link to Bioeconomy was newly added after a detailed assessment (survey) by the CDI groups.

The following sections are summaries of the findings in the different clusters and the questions we derive from the search for the future of food systems. We do not display the individual findings themselves as they can be seen here: https://fosterfoodsystem.eu/results-from-the-horizon-scanning-activities/.

Chapter 3

European Food Systems change and are challenged

Chapter 3 – European Food Systems change and are challenged

3. European Food Systems change and are challenged

At the beginning, we would like to repeat some of the findings already described in the revised Deliverable 1.2 as they are essential for the understanding of the findings and the following summaries.

3.1 Importance of Food Systems

Food is essential for human beings; we cannot survive without food or water. This is often forgotten as we nowadays have enough food in the European Union. In most of the EU countries, food is available everywhere and always. The Covid-19 pandemic and the war in Ukraine have thus shocked Europeans and demonstrated that nothing can be taken for granted - and that food can become scarce, even here in Europe (Lang 2021). The reasons for this may be manifold: weather, war, politics, problems in logistics or energy supply or other external factors like natural disasters. Food system stability may not last forever. In many countries of the world, we do not see such relatively stable food systems as we have them in the EU and the latest report of FAO, IFAD, UNICEF, WFP and WHO 2025 gives some new figures. Worldwide, the absolute number of people who do not have access to enough or high quality food is increasing again (FAO 2023; Ingram et al. 2020). Some even warn that feeding all people of a still increasing world population (United Nations World Population Data 2024[10]) is impossible. Others are more optimistic and argue that 'feeding ten billion people is possible within four terrestrial planetary boundaries' (Gerten et al. 2020, see also Steffen et al. 2015a) or propose how it can be possible (Ranganathan et al. 2018).

As we are facing challenges like climate change – and thus new conditions for producing, processing, transporting or storing food – scientists warn that we will face many changes in the future (Cuhls et al. 2022; IPCC 2024; Kemp et al. 2022; Ripple et al. 2021; WMO 2025), some of them in a cascading way by one influencing the other, and a transformation of our food system is needed (FAO 2020, 2022, 2023).[11]

In this deliverable, we do not discuss the directionality of the transformation but describe the observations of what seems to be changing – in a selective and biased way from our co-created Horizon Scanning results. This does not mean that scientists fully understand the upcoming changes or their directions nor that the directions are fixed or we already know how to handle the challenges ahead. Many possibilities and scenarios exist so that we can embrace the changes and make use of opportunities or we can wait and see – but then, we lose

[10] see https://population.un.org/wpp/; https://www.un.org/development/desa/pd/.

[11] See Hölscher et al. (2018) for a deeper understanding of the terms transition and transformation and 'how the respective approaches and perspectives on understanding and interpreting system change can enrich each other.'

agency, the ability to act in time. This is why we describe our findings here, **selected under the perspective of the CDIs'** work.

But **what is a food system**? As described in Deliverable 1.2, a food system is the full system that provides us with food and spans the full range of activities that are related to producing, processing, distributing, retailing, preparing, and consuming food (Zurek et al. 2022a; Zurek et al. 2023), and in recent years, storing and waste management are also added to the food system functions. Many actors are involved in these activities, which are influenced by a range of policies, politics, governance, social developments, new technologies and single technical developments, markets, environmental or economic drivers as well as stress caused by single events or shocks (Braun et al. 2023; Ericksen et al. 2012; Grillitsch et al. 2019; Hansen et al. 2020; Hasnain et al. 2020; Hebinck et al. 2021; Ingram 2011; Ingram et al. 2018; Westhoek et al. 2016; Wiebe et al. 2015; Wiebe et al. 2018; Zurek et al. 2022a; Zurek et al. 2023). Figure 1 visualizes this framing of a food system, its drivers and its outcomes. Feedback loops in the figure show that the system permanently develops, changes, adapts, and that it is embedded in the human system and the natural system with economic developments at its core.

In this Horizon Scanning exercise, we concentrated on the food system activities to identify signals for change and possibilities for transformation activities in the sense of Hölscher et al. (2018). To clarify what we mean with the inner circle, we refer again to Zurek et al. 2022b, p. 420, with the arrows in the figure representing the relationships, knowledge flows and food transport within the system[12]:

- **Producing** food includes all activities involved in the production of the raw food materials. Key actors include farmers, hunters, fishermen, the multiple suppliers of production inputs including agrichemicals, agricultural labourers, and land owners.
- **Processing** and packaging food includes the various transformations that the raw food material (e.g. grain, vegetable, fruit, animal) undergoes before it is sent to the retail market for sale. Key actors include the middlemen who buy from producers and sell to processors; the managers and workers in processing and packaging plants; and trade organisations that set standards.
- **Retailing** and distributing includes a range of middlemen who go between the producers, processors, packers and the final markets, and the many actors involved in e.g. transport, delivery and warehousing operations, advertising, trading and supermarkets.
- **Consuming** includes all consumers themselves, and the varied actors that control what they consume, e.g., market regulators, advertisers, consumer groups.

[12] Storing and Disposing were added into this figure later by the Foresight4Food network and is already integrated in Figure 1 of Ingram et al. 2022.

- **Storing** in connection to food and food systems refers to the methods and practices used to keep food in conditions that maintain its quality, safety, and nutritional value over time. This can include refrigeration, freezing, canning, drying, using preservatives or changing already the resources for better storing. Effective food storage helps prevent spoilage, contamination, and waste, ensuring a stable food supply.
- **Disposing** in the context of food and food systems refers to the methods and processes used to manage and eliminate food waste and by-products. This can include practices such as composting, recycling, incineration, and sending waste to landfills. Proper disposal is crucial to minimize environmental impact, reduce waste, and promote sustainability within food systems. In this context, no or low waste is intended and circular approaches are more and more in the forefront so that the remainders are limited (European Commission 2020c; Fassio et al. 2019).

Therefore, the signals found in Chapter 6 resulted partly from our general literature analysis, from the automated search and additional clustering as described above, from manual searches in other Foresight exercises, or in findings from scientific papers or overviews. The descriptions contain several single sources.

3.2 From a more agriculture-based to an industrialised Food System

In Deliverable 1.2, we described the European Food system as changing from an agricultural system with farmers and fishers as the providers of food with short supply chains and minimal processing. Resources were scarce and dependent on weather, luck and know-how for good harvests. International trade routes developed and thus connected different food systems, different food providers and consumers as well as different local food systems (Barisitz 2017; Gurukkal 2016). Nowadays, with **efficiency and effectivity in the forefront,** the food system resembles more an industrial system running on economic criteria. 'The agri-food ecosystem is one of the fourteen industrial ecosystems identified in the updated New Industrial Strategy' is the starting sentence of a Commission Staff Working Document (European Commission 2023a), and new pathways for this industrial ecosystem are searched for (European Commission 2024c). Small-scale farming is belittled as 'unsexy' or and 'inefficient' and an increasing number of people left and is still leaving the sector. Agriculture thus became more and more intensified (Kelly et al. 2019) and industrialized, often regarded as a 'bad development'[13] so that many researchers demand a much more 'sustainable intensification of agriculture for human purposes' (Rockström et al. 2017). But human need is still central to thinking (anthropocentric thinking), their economy comes first, then the environment and animal welfare.

Worldwide, more and more people are living in urban areas (Ritchie et al. 2024; United Nations 2018), and also in the European Union (Giannakis et al. 2020), de-ruralisation is progressing leading to less attention to

[13] https://thehumaneleague.org/article/industrial-agriculture.

the rural areas, their infrastructures, cultures or ways of living. With the focus on urbanisation comes the hegemony of urban narratives about food, transport and political decisions[14]. There are small attempts in new European calls for proposals to work on this[15] but there are no signals that this situation is changing. During pandemic times, many people moved to the countryside (see the scenarios in Cuhls et al. 2022) but not all stayed there. We have no recent figures here but the development does not seem to be a permanent one as commuting to the cities is expensive and energy-intensive and many employers do only allow part-time home office or call their staff permanently back to office since 2024.

Despite many calls for more autonomy (Cagnin et al. 2021; Román 2023), the EU is not independent from food or feed imports. This lack of food sovereignty[16] is triggered by the demand for food that is not grown in Europe at all, by the demand for any food at any time and the high demand for meat often produced with imported feed from other regions of the world. EU countries imported about 23% of total feed proteins in 2022 (FEFAC 2024), which made the EU even more dependent on global value chains. The EU food system heavily depends on imports for its operations in the system and in processing food when agribusinesses import food commodities for producing processed food for exports. This caused massive disturbances in internal operations of the food system due to globalization, especially in a situation when geopolitical changes are driving the EU into new orders, relations and disruptions (see Deliverable 1.5 and the drivers below).

Demographic changes in the different EU countries remain a problem – even though one could think that it gets easier with less people in shrinking societies or with incoming migrants. But with ageing and super-ageing societies among the Member States (Gu et al. 2021)[17], the workforce is shrinking in sum and the average age of farmers in the EU has risen to nearly 60 years nowadays[18]. It is hard to find personnel with knowledge in farming or gastronomy and not many people are willing to do the exhaustive jobs. With minimum wage in agriculture in some countries, the problem gets worse as wage differences among EU countries are a factor to attract personnel – but not all can afford it. For smaller or medium-sized farms, it gets more difficult to be able to pay the higher minimum wages.

As hard work in this sector is required, not only the elderly but also young people leave the sector for more comfortable and less dirty jobs, even though automation and digital helpers make parts of the work better, easier and doable for ageing people. The progressive ageing of EU societies implies a significant reduction of

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[14] We thank our interim report reviewers for hinting at this point, see Giampietro et al. 2020.
[15] e.g. call HORIZON-CL6-2024-COMMUNITIES-01-2: Rural Life, see also https://ec.europa.eu/commission/presscorner/detail/en/ IP_21_3162.
[16] We thank our interim report reviewers for stressing this point.
[17] see also https://ourworldindata.org/population-growth; https://population.un.org/wpp/; https://www.populationpyramid.net/.
[18] There are countries, for example Japan, where the average age is even higher.

the economically active population and only few young farmers[19] remain: only 11.9 % of EU farm managers were under the age of 40 years old in 2020. There is less labour available for the food system, especially for the agricultural part, and there is loss in knowledge when people are leaving.

The IT sector in agriculture (Kepkiewicz et al. 2015; Klerkx et al. 2020) is already quite visible. Many processes are digitalised (Macpherson et al. 2022), connected and depending on external networks. The agricultural sector is quite advanced in using new technology, from precision farming (Kanter et al. 2019) to Agriculture 4.0 (Klerkx et al. 2020), from new biotechnology made possible with the means of new data use to precision fermentation, just to mention a few (see below).

The industrialisation of farming went along with another trend in the food system: pure, unprocessed resources like natural resources are not the only basis of our nutrition, anymore. The food system changed towards more and more processed, ready-made food, longer transport chains, different storing techniques and production, processing and logistic systems that are similar to industry, like in manufacturing, as much food is now dependent on being manufactured. 'Thus a significantly greater percentage of the final price paid by consumers is now garnered down chain rather than up chain over the last 20 years' (Cucagna et al. 2018). This citation is from 2018 and the trend went on. These 'industries' are the parts of the value chain that make the money (Afshin et al. 2019; Cucagna et al. 2018) without necessarily creating other values (Sadovska et al. 2020). Highly processed and convenient food intake is part of modern marketing, supported by influencers of all kind, e.g. in social media, and it is in vogue. Innovations around processed food thus generate new markets – how sustainable or healthy they actually are for individual consumers or society, or what added value they create, remains unclear and is not measurable. The generation of benefits for the environment within the food chains and consequently also the benefits for society are not valorised sufficiently (Ariane Voglhuber-Slavinsky et al. 2023). We do not have the knowledge, the will and means for doing so.

Food prices, true cost accounting and general inflation are a big issue in recent years: As some of the chains were broken during the pandemic, during the Ukraine war and by sanctions etc., food prices increased and some foods are too expensive for lower income households, means these people often go back to cheap food, often unhealthy, high fat and high sugar processed food (FAO, IFAD, UNICEF, WFP and WHO 2025). The processed products of a food industry geared towards high efficiency and maximum shelf life are often more appealing in terms of price, taste and convenience than fresh produce in the supermarket (associated with high labour costs and short shelf life), which still has to be turned into a tasty meal. This situation will not change even if food prices might decrease again for some time or some foods. In general, the trend seems to be higher increases in price for (especially fresh) food compared to other goods. If true costs are calculated,

[19] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farmers_and_the_agricultural_labour_force_-_statistics.

the price for food (especially for nutrient-dense foods like vegetables and fruits, see FAO, IFAD, UNICEF, WFP and WHO 2025:xiv) may rise even further.

A new notion came up in-between, Climateflation, which is the inflation caused by climate change – in fact by the extreme weather conditions that destroyed harvests or equipment and raises the costs of food and resources.[20] Climate-smart agriculture[21] and adaptation are therefore issues in agriculture and politics that are taken more seriously than before. Many consider new crops, plants, trees etc. that can sustain higher temperatures, longer droughts or more salt in soil. Inhouse farming even in cities is discussed more often as a solution to save transportation but mainly for escaping climate change effects. It is doubted that inhouse farming can produce enough to contribute a substantial amount of food and there are other problems like high energy use and environmental problems or contamination with systems like that. It thus remains open how long new developments may take here. As full circular systems cannot be feasible[22], new knowledge and many practical solutions are still needed that keep all resources in the loop as long as possible. And technologies will play a crucial role, too (see below or for an overview Serraj et al. 2018, the project DAKIS[23] and many others).

With new wars in the world, food security and nutrition for all remain a big issue. Europe is not safe, our situation can change, too (FAO, IFAD, UNICEF, WFP and WHO 2025). Some even see further evolution of 'polycrises', the different crises effecting each other or one even on top of the other, which are also called 'anthropocene traps' (Jørgensen et al. 2024). This means many challenges, sometimes even dystopian futures for food security. Europe is dependent on the world markets of food and feed, we are not independent, and although there are more claims for autonomy (Cagnin et al. 2021) or sovereignty (Edler 2024), a change will be ambivalent. The last food security report of 2025 sees Europe still well nurtured – but in many cases also overnurtured and still following unhealthy diets. What a (sustainable and) healthy diet is, remains under discussion. The current recommendations can be found on the website of the EAT Lancet Expert Group.[24] The Food System Economic Commission also summed up the challenges for the food systems and give some optimistic recommendations (Laderchi et al. 2024). This leads us to the major challenges for EU policy.

[20] Handelsblatt 30-7-2025.
[21] https://www.fao.org/climate-smart-agriculture/en/, https://unfccc.int/news/climate-smart-agriculture; https://www.worldbank.org/en/topic/climate-smart-agriculture, or platform https://www.sciencedirect.com/journal/climate-smart-agriculture.
[22] Be reminded that full circularity is impossible be it in open or closed systems. There are always inputs needed and outputs are manifold, some the intended ones, others unintended (like contamination of the system). The laws of thermodynamics tell us that a perpetuum mobile is impossible. But we can keep certain materials longer in our production circles, can recycle, re-use or use outputs as inputs for other systems that were 'waste" before.
[23] https://agrarsysteme-der-zukunft.de/konsortien/dakis.
[24] https://eatforum.org/eat-lancet-commission/eat-lancet-commission-2-0/, for the 2023 recommendations see EAT Lancet Expert Group 2023.

3.3 Challenges for the EU Food System and changing EU policies

Food security for all as an outcome of the food system (Ingram 2011) is one of the major aims to be achieved or secured, also in the future. It is regarded as one of the four highly valued features in a society (Walker 2020). Food security has many dimensions – and we see security in military dimensions as a much more prominent one, now in 2025. Already in 2017, the IPCC group that created Shared Socioeconomic Pathways mentioned the big drivers and warned with their quantitative scenarios that the changes in energy, land use and greenhouse gas emissions will have huge impacts on cropland, forests, pasture and other natural land (Riahi et al. 2017), a basis of our food system. But there are other challenges, from demographic change to climate change.

Environmental or Earth science studies provide new and more knowledge for food systems and their change, sometimes linked to the framework of Planetary Boundaries (Folke et al. 2021; Rockström et al. 2009; Rockström et al. 2023a; Rockström et al. 2023b; Steffen et al. 2015a; Steffen et al. 2015b; Willett et al. 2019). This demonstrates that there are external and internal factors having an impact on the food system itself as it is embedded in many different systems. These factors are often intertwined, as the Doughnut economy concept of Raworth (2016) demonstrates, which was brought to food system transformation discussions in several studies, e.g. in European Commission 2020c. Changes of the climate will further induce changes in the Earth system and the human system. Major challenges are the ecological limits to food production. When the famous 'Limits to Growth' report was published (Meadows et al. 1972), many thought of industry and the resources mentioned in this report. The Forrester model was the basis of the findings. But food systems have the same limits as industrial systems, and more and more, they become apparent.

Another changing factor is consumer lifestyle: people and their consumption are very distant from nature and some people even do not know, anymore, what they eat or how a cow really looks like. For hygienic reasons, pigs and other animals are separated on farms, which makes visits on farms and thus learning for pupils on the spot nearly impossible. Citizens have their values and those often change slowly, but some can be observed, one being **growing concerns for animals**, e.g. the growing importance of animal welfare in a food system when it comes to animal products. Consumers are more and more concerned about what they eat, how the animals were fed, what kind of life they had, and if they lived under adequate conditions. As many regard these conditions as bad, this forced supermarkets already to introduce labels or to sell meat with certificates. But it also brought consumers to decisions for veganism or at least reducing their meat consumption with many follow-up consequences for and within the food system. It is difficult to say how this might unfold as consumer thinking and food trends are more and more being influenced by social media – and it gets increasingly difficult to understand what is evidence-based and what is just influencer talk or AI/ chatbot repetition.

This new industry-based food system with very limited links to nature and without connections to the urban living places of people brings with it many trade-offs (FAO 2020, 2022, 2023; FAO, IFAD, UNICEF, WFP and WHO 2025; OECD/FAO et al. 2025), for example hygienic goals conflicting with plastic reduction (many foods are packed into plastic for hygienic reasons) or higher incomes for farmers that are directly translated into higher prices in the supermarket so that people on low incomes can hardly afford good food whereas at the same time, retail still profits. In the future, we will see many of these tensions. To find a balance will be part of the transformation towards a more sustainable food system. We need much more knowledge on all levels to handle trade-offs, conflicts and limited resources.

The growth paradigm is often criticized but not often in question (Giampietro et al. 2020; Raina et al. 2024). Even in our scenario work, we ended up with scenarios based on at least 'green growth' (see Deliverable 1.5) as the participants did not see a policy without growth upcoming. On the contrary, many policies of the European Commission are stressing growth, again, and demand for much more growth in economic terms (Draghi 2024; European Commission 2019, 2024a; Letta 2024).

The situation in food production, especially on the agriculture side, is at a serious tipping point now, and the future of human beings depends on the actions taken now when addressing the following major challenges:

1. Water (drinking water and aquifers) are under stress by droughts and changes in snow melting seasons (Nistor 2020; Peña-Angulo et al. 2022; Toreti et al. 2023), but also by poor water management and conflicts.

2. Soil health needs to be maintained (see European Mission[25]) and we still face soil loss (Halleux 2024; Panagos et al. 2024).

3. Pollution (especially N and P), pesticides residues, and especially the 'everlasting chemicals'. are negatively affecting the natural resource base underpinning our food supply and food quality.

4. Loss of biodiversity (Crenna et al. 2019; European Commission 2020c) and loss of habitat for many species is further increasing (IPBES 2019, 2022, 2023).

Often sustainability is demanded for, 'sustainable intensification of agriculture for human purposes' (Rockström et al. 2017) but this concept is very broad and needs clear and concrete targets to be reached. The anthropocentric view herein is challenged and collides with many targets of biodiversity protection (Frison et al. 2011) but it is an essential notion for feeding more human beings in a sustainable and just way and for protecting our spheres. The 5th SCAR Foresight Expert Group of the European Commission described three major challenges in a narrative (European Commission 2020c). The 6th SCAR Foresight took over these findings

[25] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/soil-deal-europe_en.

and is reviewing them from different perspectives. The focus areas are: Healthy and sustainable diets for all, Towards a 'circular' food supply[26], and Towards greater diversity.

The question thus is to figure out how the food system can adapt to the challenges and where there is room for manoeuvring. Demand for water, for resources and land is still increasing (also in the EU). Is feeding even more people on the planet a question of food distribution, of collaboration or are there physical limits? What are the transformations needed to address these challenges? Are small measures enough for a leverage effect? What does it mean for the EU and the food system, if we do not address these questions and do not manage our ecological systems?

Research may deliver some answers if well coined with peoples' needs and packed into usable knowledge. Science in many areas is also needed to create a foundation for this knowledge and to develop new technologies, new applications and their testing. Currently, research in the EU is quite strong and supported politically – this is a requirement for the future. We see many other tendencies in the world in many of our scenarios: scepticism in science, belief in non-scientific findings or emotional science but also the closing down of science-related institutions in the USA or the disbelief in empirical data. For example, the U.S. Department of Agriculture (USDA) will be reorganised, close its flagship and sees cuts in agricultural and forest research (Science Insider 2025).

These questions were the starting point of the CDIs activities in addressing small parts of the food system (knowledge) and in transforming food systems to be more sustainable and more resilient in the sense of transformative resilience (European Environment Agency 2019, 2024). Ranganathan et al. (2018) offer first starting points illustrated by figures, see also Searchinger et al. (2019), but they argue from the resources supply point of view. The Food 2030 group of the European Commission (Duncan 2025) recommends a very different approach linked to a new way of policy-making, one that is listening to very different stakeholder groups and takes a fundamentally new thinking as the starting point. In their report, the group argues that 'more attention can be devoted to how change is expected to happen' and change the narratives behind (Duncan 2025:12). Other recommendations are to adapt and align the European Food 2030 priorities, adapt and align pathways into the future (with mentioning 10 pathways) and embed the work much more across pathways and projects. There needs to be more inter- and intra-pathway coordination and collaboration for progressing the priorities. For food systems transformation, more enhanced and coordinated multi-actor approaches are recommended. The asymmetries of power play a big role in food systems so that structural

[26] The project team is aware of the problems with the term 'circularity' as full circularity is impossible – the scenarios are describing mainly how the system can be more efficient and waste of food is avoided or used as input for others to keep resources in the loop. The titles may therefore change (as of 2025).

barriers also including inequalities of all kinds (i.e. income inequalities, gender inequalities, regional or rural versus urban inequalities) can be overcome in the future (Duncan 2025:16).

But there are also other signals. The big reports for the European Commission of the last two years rather recommended a backwards tendency: back to more competition on world markets (Draghi 2024; European Commission 2024a), market forces and strengthening them (Letta 2024) and more defence-oriented policies (Niinistö 2024). The same influential reports (European Commission 2024a) demand acceleration in nearly everything but not all parts of the food system are able to change fast. The European Commission's strategic dialogue and vision-building activities[27] (European Commission 2024b) tried to start joint efforts but often on a highly aggregated level like 'reforming CAP' (the Common Agricultural Policy) or 'transformative resilience' (European Environment Agency 2024) which all need to be broken down to digestible knowledge and practical use for the stakeholders in the food system.

The European Commission's High-Level-Group on the science-policy interface already recommended stronger links between research, scientific evidence and policy but this link needs to go further and the demand for 'Strengthen the science-policy-society interface for food systems' was reformulated (Duncan 2025:17). The changes need to be monitored and evaluated (Duncan 2025:18). And it is exactly the science-policy-society or better science-policy-CDI triangle that is addressed in FOSTER and taken into account for making assumptions about future food system changes and where we are learning from each other during the last phase of FOSTER.

[27] https://agriculture.ec.europa.eu/overview-vision-agriculture-food/main-initiatives-strategic-dialogue-future-eu-agriculture_en and https://agriculture.ec.europa.eu/overview-vision-agriculture-food/vision-agriculture-and-food_en.

Chapter 4

Futures of the Framework of the Food System

Chapter 4 – Futures of the Framework of the Food System

4. Futures of the Framework of the Food System

This chapter summarises the findings on the environment of food systems, corresponding to the green ring around the system in Figure 1. At the beginning of the project, the environment of food systems was subcategorised in 'Supporting services' and 'Institutional environment'. However, during discussions at a workshop, it was decided that the category 'Bioeconomy' should be added as it marks the interface between agriculture, food consumption and further use of biomaterials.

The following sections review and describe the developments that will be relevant in the future and require new knowledge according to the Horizon Scanning and sense-making performed for this project on these categories.

4.1 Supporting Services

Food systems' supporting services refer to all services related to and serving the food systems. These include human-engineered infrastructure and services as well as ecosystem services[28]. Although historically scientists and environmentalists have discussed ecosystem services in their research, even if only implicitly, the lack of clarity made it difficult for their results to be considered by decision-makers. The term ecosystem services was only popularised in mid-2000 by the project Millennium Ecosystem Assessment (MA)[29], called for by the UN Secretary-General Kofi Annan. This popularisation and the realisation that human-engineered and ecosystem services can be evaluated equivalently significantly helped to inform and improve decision-making concerning ecosystem management and human well-being.

The human-engineered services supporting the food system are the built, institutional and technological layers that help and turn ecological productivity into food on plates. These include built infrastructure and logistics, production inputs and supply chains, institutional and digital systems, and mechanisation and farm equipment services.

Ecosystem services, in their turn, are grouped into four broad categories: provisioning, such as the production of food and water, regulating, such as the control of climate and disease, supporting, such as nutrient cycles and oxygen production and cultural, such as spiritual and recreational benefits.

[28] 'Ecosystem services are the many and varied benefits to humans provided by the natural environment and healthy ecosystems.' (Jeffers et al. 2015). Such ecosystems include, for example, agroecosystems, forest ecosystems, grassland ecosystems, and aquatic ecosystems. These ecosystems, functioning in healthy relationships, offer such things as natural pollination of crops, clean air, extreme weather mitigation, and human mental and physical well-being. Collectively, these are often integral to the provision of food and drinking water, the decomposition of wastes and the resilience and productivity of food ecosystems.

[29] https://www.millenniumassessment.org/.

The list of emerging services supporting the food systems found in the Horizon Scanning is shown in Table 1 below. Only results deemed relevant for and by the CDIs are shown. The services can be grouped to form four clusters: Food quality and supply chains (green), Ecosystem services regeneration and mimicking (blue), Agricultural appreciation, training and integration of community (ochre), and Technology and digitalisation services (grey).

Table 1: Relevant emerging services supporting the food systems found in the Horizon Scanning exercise
Background colours indicate cluster

Quality assurance and certification programs	Increased support for ecosystem services	A new (re-newed) appreciation of agricultural production
Food safety and traceability systems	Biodiversity services	New curricula and teaching
Supply chain optimisation and logistics management	Eatable landscapes - including co-villages	Consulting and advisory services for sustainable food practices
Dissemination and usage of shopping apps	Smart products as enablers	Training and education in the food industry
Ease of use	Online Shopping E-Commerce	Co-Creation and user input
Sales increase through Big Data	Simplified solution	P2P -based consumption decisions

Food quality and supply chains (green): The services in this cluster entail ensuring the safety and traceability of food products throughout the supply chain, optimizing the movement of food products from production to consumption for efficiency, and implementing systems to maintain consistent quality and obtain certifications for food products (Chkanikova et al. 2021; Jagtap et al. 2021; Yadav et al. 2022; Yu et al. 2022).

Agricultural appreciation, training and integration of communities (ochre): A renewed appreciation of agriculture and the work of farmers can be observed, especially since the Covid-19 pandemic, when suddenly food became a bottleneck. Many started to grow their own food and some traces of these movements remained. Additionally, the increase in urban gardening and farming along with the demand for sustainable agriculture may lead to a rising appreciation of farming methods and farmers in urban areas – but still not on a large scale (Project DAKIS 2019-2024). With the current demographic shift and search for next generation food producers, educational programs and training to improve skills and knowledge in the food industry are more demanded for and many curricula are currently being revised, e.g. systems thinking including systemic connections within the food system, sustainability or circular thinking (German Science And Humanities Council 2023b). Experts are trained who can provide advice and support for businesses adopting sustainable food practices. Additionally, the dominant factor in 'democratized consumption' are networks of people advising each other, usually through digital platforms. This is starting to be leveraged in food innovation to ask users to co-create and give input about new products (H2020 Fit4Food project 2017-2020; Project DAKIS 2019-2024).

Ecosystem services regeneration and mimicking (blue): Human activity has a negative impact on the world's biodiversity and ecosystems. This is why agricultural practices with more focus on protecting and aiding ecosystem services are gaining momentum. Solutions are being proposed to protect and regenerate biodiversity or to technologically provide ecosystem services that are being lost (Project DAKIS 2019-2024; Schaller et al. 2022). In addition, park-like landscapes with trees for fruits and other eatable plants are being established as parts of cities (Schaller et al. 2022).

Technology and digitalisation services (grey): Complicated devices are being replaced by more intuitive interaction interfaces and more simple solutions (less buttons, less functions). Technology is integrating itself into our everyday objects, where the only thing that remains visible of this integration are the interfaces, which exacerbate the ease of use and usability of technology. This ease of use together with the increasing presence of intelligent systems in smart homes start to provide functionalities to meet the needs of the users almost on demand and at the point of need (e.g. food delivered matching cooking recipes previously chosen). In addition, e-commerce, online shopping and the use of shopping apps have risen dramatically. This enables retailing companies to attempt to increase sales through the use of data and, with the help of the IoT, to automatise many sales processes (Project DAKIS 2019-2024; Ulwick 2017).

4.2 Bioeconomy

The bioeconomy applies biological resources, knowledge and biotechnology to make food systems more productive, 'circular'[30] and low-carbon. If done well, it reduces costs, needs less land and water, avoids waste and chemical footprints while improving shelf life, nutrition and farmer incomes. However, the bioeconomy is not a silver bullet. If mismanaged, it can lead to bad outcomes – and the expectations are high as the many EU projects on bioeconomy demonstrate.

Innovations in connection to food systems driving the bioeconomy include the development of bio-based materials, sustainable agricultural practices and biotechnological applications that enhance food security and environmental health as well as the use of smart technologies in agriculture. Biorefineries, particularly those of the next generation (D'Angelo 2023), are central nodes of the bioeconomy, converting streams of biowaste into energy and other value-added chemicals.

By integrating cutting-edge technologies, information management and circular economy principles, the bioeconomy is supposed to reduce dependency on fossil fuels, promote resource efficiency, resilience of the food system and contribute to the overall sustainability of economic systems. Carbon Management is one of the concepts driving the developments (OECD 2023a).

[30] Full circularity is impossible. With the notion of circularity, principles of more re-use, re-cycling or downcycling of material etc. is meant. Thus, the notion has to be used very carefully. The European Commission has an Action Plan for a Circular Economy: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en.

The findings shown in Table 2 below are not necessarily new inventions but are expected to be more visible or applicable in the future, and to have an influence on how the bioeconomy of the future may look like. These findings can be grouped to form three clusters: Circular economy for food, waste, valorisation and biorefining (green), Advanced technologies and processes in food systems (ochre) and Ecosystems health, from soil restoration to human health (blue).

Table 2: Relevant emerging bioeconomy topics and developments related to food systems
Background colours indicate cluster

Circular Economy for food, no waste	New food industry applications – example of hemp
Prevention and thus reduction of food waste with social and organisational innovations	Controlled environment agriculture, land-based aquaculture and co-culturing
Valorisation of agrifood side streams and 'waste'	Plants as chemical signal producers
Biomaterial and biorefining for a circular bioeconomy	Novel protein industry
Reconstructive practices and phytoremediation	Soil microbiome and plant microbiota
Paludiculture	Health effects of increasing amounts of microplastics in food, water and soil
Soil health - biochar and hydrochar	

Avoiding food waste, valorisation and biorefining (green) is one of the clusters. Following the waste hierarchy (prevention > reuse > recycling > energy), at first, food waste must be prevented (especially at household, retail and gastronomy level) and if there is waste, it needs to turn into a resource, used in cascades and be valorised as side streams across the chain. Prevention relies mostly on social and organisational innovation (coordination, trust in others, place-based logistics etc.) (European Commission 2020c; UNEP 2021). However, technology and digital tools (e.g. for demand forecasting) and regulation enabling safe upcycling and efficient side-stream use can significantly help prevent food and biological waste. A particularly significant way to valorise biological waste is with biorefineries, which can transform biomaterials into energy and other value-added chemicals (Narisetty et al. 2022; Tsegaye et al. 2021; Ubando et al. 2022). But they still need development, experimentation and practical knowledge as not all biomaterials can be used and running a biorefinery is not an easy task. A point to be vigilant with, here, is the dichotomy food versus fuel, which must be well managed.

Advanced technologies and processes between bioeconomy and food systems (ochre) are of course a part of a new bioeconomy. We can expect novel technology and processing solutions for the food system, some of which generate new applications from plant gene engineering or alternative proteins production to advanced cultivation methods and techniques that close nutrient loops but are energy-intensive (Espinosa-Ramírez et al. 2023; Fasolin et al. 2019; Flajšman et al. 2023; Mateos Fernández et al. 2022; Molfetta et al. 2022; Rischer et al. 2020; Schuman 2023; Sinke et al. 2023; Tian et al. 2023; van Huis et al. 2021; Vasdravanidis et al. 2022). The range of advancements in this cluster is wide but not all of them were deemed significant for the CDIs.

Ecosystems health, from soil restoration to human health (blue): This cluster integrates nature-based solutions with biological health management and contaminant risks. It focuses on rebuilding soil function, storing carbon and managing water, rehabilitating degraded or contaminated land and gives some hints how contamination affects human and ecosystems health – and what we can expect even more in the future. Because environmental remediation is difficult, upstream discharge reduction and monitoring across soil, water and food are paramount to improve soil and landscape health while safeguarding people (Dang et al. 2023; Erickson et al. 2021; Mandal et al. 2024; Putatunda et al. 2024; Roslan et al. 2024; Sachdeva et al. 2023; Singh et al. 2020; Sun et al. 2023; Tan et al. 2021; Williams et al. 2023; Ziegler et al. 2021).

4.3 Institutional Environment

The institutional environment of food systems is a complex web of formal and informal rules, organizations and governance arrangements that steer how food is produced, processed, distributed and consumed. The way how risk is managed or challenges are addressed in the food system is part of institutional work. Under the headline, we find market institutions, information systems and finance, all of which jointly determine who participates, who benefits and how sustainable and resilient the system is. In a nutshell, it is the framework that shapes all activities from 'farm to fork' (European Commission 2020a)[31].

It is worth noting that institutional actions often deliver bigger, longer-lasting wins than single technical fixes, as these institutions shape actors' incentives, power relations and transaction costs. If poorly designed institutional harm can also be substantial. For example, weaknesses like policy incoherence or weak enforcement can systematically exclude small actors or raise food loss and health risks as a consequence. In general, enforcement, inclusion and tailored governance matter more than paper reforms (nominal/legal changes) when fixing failures in the system.

The emerging institutions affecting the food system found in the Horizon Scanning and deemed relevant for and by the CDIs are shown in Table 3 below. They can be clustered in 5 topics: Policy regulations and power (green), Economy and finance (grey), Sustainability and natural environment (ochre), Digitalisation and Foresight (white) and Knowledge and advising (blue).

[31] See additionally: https://www.europarl.europa.eu/factsheets/en/sheet/293547/the-farm-to-fork-strategy.

Table 3: Relevant changes in institutions affecting the food system
Background colours indicate cluster

Innovation policy mixes to support food system innovation	Carbon footprint reduction and greenhouse gas emissions in the food industry
Stability of political environment	Considering time in agriculture, production, land use
Nudging as small-scale self-regulation of sustainable consumption	Transforming the food system into a regenerative, sustainable food system that works for all within planetary boundaries
Land use and land use policies	
Hygienic regulations and their impacts	New agribusinesses
Food policy and regulation	Biodiversity preservation and conservation farming with data and digitalisation
Land use and power	
Multiplier effects in local food system	Food Policy Councils in the world
Investments and developing finance	Agroecology as new paradigm

Policy, regulations and power (green) includes governance instruments, regulatory frameworks and power relations that shape food system outcomes. Legislation does not necessarily imply impact. Implementation and enforcement are needed. Power and governance shape outcomes, and it can be observed that rules need nuance to account for human behaviour (Geels 2011; Kern et al. 2018; Köhler et al. 2019; Project DAKIS 2019-2024; Turnheim et al. 2020).

Economy and finance (grey) covers the financial aspects and their consequences that enable food system change. Investing in food and agriculture is effective to reduce poverty and end hunger but we also see new models of financing (micro loans, crowdsourcing) solving some problems (Benedek et al. 2020; Project DAKIS 2019-2024).

Sustainability and natural environment (ochre) includes environmental targets and systemic transformation. It brings together explicit mitigation aims with a broader vision to transform the food system into a regenerative, sustainable system that operates within planetary boundaries and accounting for seasonality. It includes a call for action to implementing sustainability measures that show positive results (Earth4All; Leahy et al. 2020; Ritchie et al. 2024; Yakusheva 2019).

Digitalisation and Foresight (white) are means, digital tools and new business models to reshape farming. The environment is changing, so farming must adapt and raise efficiency by the use of new tools. For this to happen, digital information and technology are key, but also stability in the use of the tools (Dönitz et al. 2020; Project DAKIS 2019-2024).

Knowledge and advising (blue): form a new interface of advisory and knowledge-generation mechanisms between research, practice and policy. For example, the new academic discipline agroecology can provide the data and information needed to help councils and other advising bodies in formulating evidence-based recommendations to improve the food system improve the food system (European Commission 2022b; Gupta et al. 2018).

Chapter 5

Drivers shaping the Food System

Chapter 5 – Drivers shaping the Food System

5. Drivers that shape the future of food systems

Drivers are developments, strong or weak signals or existing and observable trends that have an influence on the food system. Drivers can come from within the system but are most often external. They often have historical backgrounds that need to be understood for understanding how they might unfold. Outcomes of the food system (see also figure 1) can develop as an answer to new drivers and vice versa. As Gupta, Zurek, Woodhill and Ingram recently stated, there is often a focus on historic trends and drivers, whereas the current and future developments hint at more specific challenges. 'Key drivers like labour migration, forced displacement, food affordability and level of digitisation remain understudied in terms of their plausible future trends, signalling a need for more forward-looking research' (Gupta et al. 2025:2). Drivers that develop slowly are difficult to identify as they often proceed invisible or cannot be found in the data because they change only marginally.

For each driver identified as significant for the food system, a list of emerging developments was listed in Deliverable 1.2. All relevant drivers found in the Horizon Scanning were also deemed relevant for and by the CDIs. They are presented, clustered and briefly summarised in the following section.

5.1 Demographic Change

There are emerging demographic changes affecting the food system found in the Horizon Scanning. The ones deemed relevant for and by the CDIs are shown in Table 4 below. They can be clustered in four topic groups: Demographic and social structure transitions (green), Migration and cultural food influences (grey), Global food systems and sustainability (blue); Ageing population and related challenges (ochre).

Table 4: Relevant emerging demographic changes affecting the food system
Background colours indicate cluster

Rise of urbanisation and its impact on food consumption	Changing food preferences and cultural influences	Ageing Society in Europe - differing in the Member States
Changing family structures and meal patterns	Migration and multicultural food trends	Old-age poverty leads to malnutrition in older population
Changing household structure & food	Migration to Europe and integration	Food delivery services for the elderly
Skilled personnel are missing	Sustainable food for all	Impact of nutrition on healthy ageing
Global demographic transition leads to structural changes in nutrition paradigm	New prospects for infant nutrition in emerging markets and developing countries	Ageing population and specialized dietary needs

Demographic and social structure transitions (green): Urbanisation and demographic transition caused many people in Europe to shift from agricultural to industrial work, separating families geographically and changing eating habits (Bruin et al. 2021; McCullough et al. 2016). This is not new but together with the rise of larger mechanised farms and nowadays even smart farming contributes to a significant decline in agricultural workforce. Machines, robotics and software solutions raised high expectations but also need investment and skilled workforce to make use of them. That is missing – human labour remains the bottleneck (Federal Statistical Office of Germany 2021). The discussion on women in agriculture[32] or 'careers' in agriculture seems to be still quite weak.

But also the structure of the workforce in food production is changing. Whereas agriculture is often family-related and includes people working on farms and outside, children learning at other places and new management of family life, e.g. evolving family dynamics affect meal planning, the rural areas lack more and more people and infrastructure and are less attractive for many (Sakemoto et al. 2004; Umberger 2015). As particularly, single-person households are rising worldwide, the new structures are creating distinctive food consumption behaviours (McCullough et al. 2016).

Migration and cultural food influences (grey): Migration remains a big issue in Europe. Looking at the figures, most migration occurs within the EU – but is not regarded as something positive (as we noticed in interviews in Africa, where migration equals positive mobility, Cuhls et al. 2020). However, international instability, poverty and climate change drive an increase of migration from the outside to Europe. This migration and their changing flow patterns affect European food preferences, cultures, eating habits and workforce, changing the demands imposed on the food system, which needs to adapt (Jeong et al. 2021).

Global food systems and sustainability (blue): The rising global population[33] (United Nations 2018) makes sustainable food systems fundamental to addressing migration, famine and obesity challenges. Meanwhile, despite the worrying pictures in news channels from war regions, average infant nutrition is improving (Project DAKIS 2019-2024).

Ageing population and related challenges (ochre): Healthy nutrition over the full lifespan is more critical for healthy ageing than generally recognized, and elderly populations require tailored dietary approaches to address their specific health and nutritional needs (Forum, Institute of Medicine Food 2010; Roberts et al. 2021; Sakemoto et al. 2004). However, Europe's ageing societies vary significantly between Member States in

[32] To find recent literature needs a separate attempt, first papers found are a bit outdated, e.g. from the FAO 2011b, and times have changed. There is a new focus on women in CAP (https://www.gov.ie/en/department-of-agriculture-food-and-the-marine/publications/women-in-agriculture/) and there are some campaigns, see for example https://europeanlandowners.org/publications/women-for-the-future-of-agriculture-2025/.
[33] https://population.un.org/dataportal/home?df=51e45653-641f-41f6-84e5-6474eedd13d3.

their characteristics and challenges. Poverty, and particularly higher age poverty, is a significant factor in food poverty and health deterioration across Europe[34].

5.2 Dietary Patterns

Emerging dietary patterns are affecting the food system. The topics and issues relevant for the CDIs are shown in Table 5 below. Diets are not necessarily changing towards the better – we see many negative implications of upcoming patterns in human diets with malnutrition not only meaning under- but also overnutrition with certain nutrients. The topics around dietary patterns can be clustered in four groups: Social and systemic food issues (green), Nutrition science, myths and guidelines (ochre), Food safety, processing and contamination (grey), Health conditions, regulation and interventions (blue).

Table 5: Relevant emerging dietary patterns affecting the food system
Background colours indicate cluster

Divided societies	Food safety and hygiene practices	Nutrition for better health and curing
Dependencies on Big Food (big companies, sugar, carbohydrates)	Highly processed foods increase dehydration risk	Nutritional guidelines and dietary recommendations
Food shortage	Packaging and health	Planetary health diet
Triple burden of malnutrition	Eating plastics	Nutrition myths: obesity
Food allergies and intolerances	Medication like Ozempic (against obesity) makes food restrictions unnecessary	Nutrition myths: plant-based
Regulation of food ingredients, especially fat and sugar		Nutrition labelling and transparency

Social and systemic food issues (green): A background of divided societies and income inequality creates significant nutritional disparities, where the have-nots face quantitative and qualitative undernourishment and food insecurity, even in Europe (Duncan et al. 2022; World Economic Forum 2024). This may lead to irreversible childhood developmental damage caused by malnutrition. In addition, a world in poly-crises means increasingly frequent disruptions in supply chains and thus temporal shortages of specific foods (Afshin et al. 2019; FAO 2022; Hugo Valin et al. 2021). On the other hand, international food corporations ('Big Food') permanently conquer new markets in emerging countries, which means that industrially manufactured products increasingly replace healthier food variants in those regions (Kruchem 2017). This is one of the drivers of the triple malnutrition burden (simultaneous existence of hunger, obesity and micronutrient deficiencies) leading to the rise in nutrition pattern diseases like diabetes and others (Afshin et al. 2019).

Food safety, processing and contamination (grey): The increasing variety of food options implies an increasing variety of food sectors and food or resource importers, which must be monitored and regulated (and must

[34] https://www.boell.de/de/2021/09/15/ernaehrungsarmut-wer-schlecht-isst-ist-nicht-selber-schuld.

comply) with food hygiene rules to guarantee food safety. Regulations must permanently adapt to the evolving environment[35]. Packaging and processing are central to improve food safety and prolong shelf-life but have their pros and cons, too (H2020 Fit4Food project 2017-2020). On the one hand, food contact materials can transfer chemicals to food with partly unknown effects, and on the other hand, ultra-processed foods often have low water content and higher content of salt, sugar and fat with all negative effects (Willig 2023). Not all processed foods are ultra-processed (see next section), not all are unhealthy, and there are many differences and innovation in food processing and packaging. Meanwhile, microplastics and plasticisers are one of the major problems being measurable in food and bodies, with rising evidence of possible health effects meaning that we humans automatically have unwanted substances on our dietary plan (Lockett 2023; McLendon 2023).

Nutrition science, myths and guidelines (ochre): On the one hand, it is widely known that good nutrition is key to have a healthy life. On the other, there is so much 'noise' in the field of nutrition (often commercially driven), with all kinds of myths, half-truths, misunderstandings and 'trends' spreading quickly by marketing, social media and influencers that it is difficult for lay people to know what a healthy diet is and what is not (Florença et al. 2021; König 2023; Lobo et al. 2021). Developing evidence-based guidelines and recommendations for healthy and balanced diets is as important as reaching the public with the recommendations (FAO 2024). Many diets need to be very personally adapted.

Meanwhile, the haves can afford to pay to access good quality knowledge, for additives and functional foods individually stylised if wished. But diets are not only individual, they can affect the environment and are thus a challenge for the whole society. This is why the EAT-Lancet Commission provided a guide with an evidence-based, healthy and sustainable diet[36]. In general, however, research gaps still exist. Better long-term, human studies on molecular mechanisms are needed and real-world affordability and effects must be studied further (Whitmee et al. 2015).

Health conditions, regulation and interventions (blue): Taxes on harmful ingredients (mostly sugar and fat) are on the rise to incentivise industry to reformulate their recipes of food and beverages (Rogers et al. 2024; Stanner et al. 2020). Ensuring clear and accurate nutrition information on food labels can help empower consumers to make more informed choices and address the growing prevalence of food allergies and intolerances (Freeman 2015; Winterová et al. 2021). The latter requires, in addition, suitable alternatives. New drugs like Ozempic help with weight loss but are expensive, require ongoing treatment and are not a substitute for food policy or lifelong healthy eating as they evoke the impression that unhealthy eating is just to be 'cured' (Canadian Agency for Drugs and Technologies in Health 2019).

[35] Food safety – Guidance platform: https://food.ec.europa.eu/food-safety/biological-safety/food-hygiene/guidance-platform_en.
[36] https://eatforum.org/eat-lancet-commission/.

5.3 Science and Technology

Many emerging science and technology applications are expected to drive the food system by combining very different fields of research (e.g. combinations with AI and robotics, new materials or genetics) or opening up completely new possibilities (like in geoengineering or bioengineering). Table 6 below includes some of the most interesting science and technology drivers from the point of view of the CDIs. They can be clustered in five groups: Digital technologies, automation systems and transport (green), Smart agriculture and sustainability (blue), Food innovation (grey), Seed resources and biological health management (ochre), Biotechnology and genetic innovation (white).

Table 6: Relevant emerging science and technology applications affecting the food system
Background colours indicate cluster

Predictive analytics and data-driven decision making	Blockchain and decentralised food supply chain management	Patents on seeds - seed monopolies
AI and machine learning in food industry applications	Renewable Energy generation for food production	Antimicrobial use in food-producing animals projected to increase
Robotics and automation in food production and processing	Integrating blockchain and IoT in precision agriculture	Genebanks & seed vaults to provide cheap access to a range of seeds
Advanced Manufacturing and Robotics	Precision agriculture and Smart farming increase agriculture productivity	Chronobiology - Light at the right time important for plants and animals (and humans)
Digital security and networks/ cybersecurity	Vertical farming enables better land use and local production	Genetic engineering (CRISPR & Co, gene editing)
Big Data and cloud computing	Development of sustainable soil-friendly fertilisers	Life and biological sciences as engines for bio-based innovation
Internet of Things (IoT)	Sensory tech. and flavour profiling	Agricultural gene drives
New digital technology for food transport	Beyond Meat & other synthetic foods incl. large-scale lab-grown meat	Space radiation to speed up plant breeding

Digital technologies, automation systems and transport (green): Applying AI and machine learning algorithms can improve various aspects of the food supply chain, be it in agriculture or in food industry. There are many ideas being developed but not much experience exists of how efficient AI really is and what works in practical applications (Project DAKIS 2019-2024; Van de Velde et al. 2023). In addition, Big Data and cloud computing can provide scalable data processing infrastructure for the entire food supply chain and the Internet of Things (IoT) real-time monitoring, quality control and operational optimization (Dadhaneeya et al. 2023; Misra et al. 2022). These can be leveraged by data analytics and predictive modelling to inform decision-making in the food industry or even to influence consumers (Baruchi 2022).

On top of this, robotics and automation can streamline food production, processing, sorting, handling and packaging operations without needing these data but they can also leverage it to become more efficient (Lipson et al. 2023; Van de Velde et al. 2023; Wakchaure et al. 2023). There are signs for both. The technologies implemented until now impact food transportation and the transportation needs are an important factor in the food system (Gharehgozli et al. 2017). The increasing digitalisation of the food supply chain makes cybersecurity critical (Latino et al. 2022). There are already new ways of attacking and impacting operations, distribution of foodstuff and spreading fear of food insecurity.

Smart agriculture and sustainability (blue): Smart farming is expected to make agriculture more sustainable, efficient and resilient at the same time. Precision farming is using GPS and other digital technologies to optimise crop production and, because of beeing more precise in watering, fertilising and using pesticides as well as seeding more precisely. This increases productivity, reduces environmental impact by using less fertilisers and pesticides, by producing less 'waste' of resources and it reduces manual work (Karunathilake et al. 2023). It is expected (but not without controversy) that these technologies will eventually be connected to blockchain for secure, transparent, decentralised and more autonomous management in agriculture (Frederik 2020; Liu et al. 2021; Torky et al. 2020). However, soil-friendly fertiliser development is anyway needed to address soil degradation and water contamination from intensive chemical agriculture (Ganesan 2024). Energy consumption in agri-food systems increased by more than 20% between 2000 and 2018. This makes it essential to adopt renewable energies for agri-food production (Gorjian et al. 2022; IRENA and FAO 2021). A promising approach, vertical farming, which enables urban food production with reduced transport costs, faces high energy consumption challenges, making the transition to clean energy even more important (Oh et al. 2023; Sowmya et al. 2024).

Food innovation (grey): Alternative protein sources including lab-grown meat and synthetic foods could revolutionize animal agriculture if it scaled up successfully (David et al. 2023; Xiang et al. 2023). In addition, advanced sensory technology can analyse and enhance flavour profiles in food products. The composition of new ingredients (odours, colours, flavours) from very different plant sources also raises high expectations. Many new food ideas stem from the use of algae but need good marketing for the consumers to accept them (David et al. 2023; Velasco et al. 2018).

Seed resources and biological health management (ochre): To meet the challenge of finding suitable plants for new climatic conditions, mankind needs a rich gene pool of varieties. However, seed patents and monopolies threaten the genetic diversity access needed for climate adaptation[37]. Gene banks and seed vaults like Svalbard provide a safe, cheap access to diversified seed varieties that can help for climate resilience (Crop Trust 2016). Plants, animals and humans have circadian rhythms that are influenced mainly by light. Adequate

[37] https://www.opensourceseeds.org/.

exposure to light is important for well-being, health, and for the timing of food intake also matters (Cuhls et al. 2024a). Mass livestock's commonly bad living conditions means that their health is heavily maintained via antimicrobial use, which continues to increase despite of resistance concerns, requiring better monitoring and stewardship policies (Mulchandani et al. 2023).

Biotechnology and genetic innovation (white): Genetic Engineering (GE) allows scientists to move desired genes from one plant or animal into another. This is a highly regulated field, particularly in Europe. Researchers are actively working to improve foodstuffs (Bakhshandeh 2023). A particularly controversial approach is gene drives, which force the inheritance of specific genes through populations, overriding natural selection. This approach could automatically spread engineered genes across ecosystems to control pests but at the same time pose irreversible ecological risks (Legros et al. 2021; Montenegro de Wit 2019). The process of creating GE foods is different from selective breeding, which involves selecting plants or animals with desired traits and breeding them or using radiation to induce DNA mutations. Space radiation is a variety of the latter that with microgravity and extreme temperatures may improve the process (FAO and IAEA 2023). Additionally, new knowledge from life sciences (e.g. synthetic biology) leads to new technologies and their application in the food system (Wydra et al. 2021).

5.4 Markets

The emerging market issues affecting the food system are shown in Table 7 below. They are especially relevant for the CDIs we asked and can be clustered in four groups: Food distribution and market development (green), Alternative and innovative food products (ochre), Consumer preferences and health consciousness (grey), Stakeholder awareness (blue).

Table 7: Relevant emerging market issues affecting the food system
Background colours indicate cluster.

Global food trade and emerging markets	Plant-based and alternative protein markets
Local and regional food systems	Food start-ups and entrepreneurship in the food industries
Direct-to-consumer sales and farmer's markets	
Discounter versus delicatessen and specialised trade	Insects - farming and eating as a new market
Increase in direct-to-consumer (DTC) online-ordering	Strict diets and food preferences
Use of food traffic lights as consumer information	Increased demand for food supplements and superfoods
Food waste awareness	Increasing demand for package-free foodstuff

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Food distribution and market development (green): The food system is growing in complexity, continuously evolving the old markets and developing new ones (OECD 2022). Still, the public's interest in local and regional food and in where the food comes from has increased (FoodPrint 2018). This contrasts with the trend of small local retailers, such as bakeries, butchers and greengrocers, being displaced by discounters, which offer all product categories under one roof and enable cheap and fast shopping[38]. This is probably one of the reasons behind the increase in direct-to-consumer (DTC) online ordering, which exploded with the Covid-19 confinements, and the re-invention of farmer's markets. Farmers attempt to sell directly, cut out intermediaries and reach out for customers. This give them much better feedback and the profit is higher (Greco et al. 2020; Helmer 2020).

Alternative and innovative food products (ochre): There is already a wide range of plant-based and alternative protein markets, including meat substitutes and synthetically produced foods. This development may expand in the future (EPRS 2024)[39], where alternatively produced foods could be the base of human and animal feed. One of the protein markets that is growing, is insects. Farming insects has an environmental impact which is lower than that of livestock species. Insects are easy to breed. However, eating insects could produce repulsion from consumers, bring a rise in allergies, in hygienic challenges, and legislation is also lagging behind (Kröger et al. 2021; Siddiqui et al. 2023; Yang et al. 2024). These and other innovations are being explored by food start-ups and innovative entrepreneurship in the industry. But consumers are hesitating and have less problems if the form of insects is already invisible.

Consumer preferences and health consciousness (grey): Consumer preferences determine the demand for foods and additives and how these are sold. Strict diets like vegan or for people with food allergies are on the rise (IFIC Food & Health Survey 2022). In addition, people (especially those with higher income) pay more attention to their nutrition, changing the diets and driving the increasing demand for food supplements and 'superfoods' (Fortune Business Insights 2025). The increasing demand for package-free foodstuffs and the proliferation of package-free stores create a positive feed-back loop that drives the rise in demand and availability, with upstream effects (e.g. the supply chain) (Fuentes et al. 2019). But it remains unclear how that unfolds as many supermarkets already gave up package-free foodstuff selling as the profits are not high enough and the demand is fluid.

[38] https://de.statista.com/themen/1291/lebensmittel-discounter/#topicOverview.
[39] NGOs, consultants and public institutions are already marketing 'alternative proteins' or raising expectations, here are a few examples: https://gfieurope.org/wp-content/uploads/2023/05/GFI-Europe-Alternative-Proteine-in-Deutschland-Full-Report.pdf; https://gfieurope.org/wp-content/uploads/2023/05/GFI-Europe-Sustainable-Proteins-in-Germany-Summary-EN.pdf. https://www.kern.bayern.de/recherche/312473/index.php. https://www.ernaehrungsradar.de/alternative-proteine-forschungsstand/..

Stakeholder awareness (blue) is a key first step in any field to drive change, and the food system is no different. The awareness that large amounts of food are currently being wasted could motivate producers, retailers and consumers to be more effective using their food (UNEP 2021). The use of food traffic lights educates citizens and influences their food purchasing decisions – and manufacturers adjust their recipes to game the system (Hagmann et al. 2020). Influencers seem to have positive or negative effects on eating – depending on the purpose (just selling products or making aware of something).

5.5 Climate Change and Environment

The structure of the findings for the driver Climate Change and Environment suggests a different approach to summarise them. During the Horizon Scanning phase, we and the CDIs identified twenty-five relevant environmental effects and research fields affecting food systems. In this analysis, we briefly summarize twenty of these findings[40] in a general summary, while examining three key areas separately: Climate change, Planetary boundaries and Water security.

General summary:

In the Horizon Scanning, the team identified a set of ways, in which climate change and environmental pollution will or are already reshaping food systems. Faster-than-average warming (notably in Europe), shifting seasonal patterns and hotspots are producing more frequent and intense heatwaves, droughts, heavy rains, floods, coastal erosion and wildfires. These hazards shorten growing seasons, destroy harvests and infrastructure, permanently remove arable land in some places and can create simultaneous multi-region crop failures that amplify global price shocks. In some regions, the change allows more harvests.

Climate stress also raises animal-disease risk and disrupts trade and logistics. Parallel contamination threats – persistent chemicals (PFAS, pesticides, pharmaceuticals), microplastics and their interactions with heavy metals – accumulate in soils, water and seafood, undermining health, market access and long-term productivity. Socio-economic pressures such as 'green grabbing' further threaten local food sovereignty by

[40] The individual future topics we found are: Temperature increase in Europe is higher than in other regions of the world, Climate-resilient crops and agriculture practices, Mitigation strategies for greenhouse gas emissions in the food industry, Adaptation to changing weather patterns and extreme events, Sustainable land management and soil conservation, Climate-smart agriculture and sustainable resource use, Weather extremes driven by a meandering jet stream cause multi-regional harvest failure at the same time, Future flooding and erosion as a consequence and further driver, 4 degrees increase of temperature until 2100, Forest and wildfires can destroy agricultural goods, Heavy rain and flooding can directly destroy agricultural goods, Heat protection measures for the population, Disruptive weather events related to climate change and animal disease outbreaks, Wheat harvest: El Niño could trigger a new food crisis, AMOC collapse could happen any time between 2025 and 2095 with a 95% confidence interval, Is a volcanic eruption fuelling global warming?, Green Grabbing, Forever Chemicals (PFAS) in the food chain, Addressing chemical residues in the environment (pharmaceuticals, pesticides, fertilisers…), Microplastic pollution (see https://fosterfoodsystem.eu/future-food-systems-knowledge/ or Deliverable 1.2).

commodifying land and ecosystems. Across all effects, poorer countries and smallholders are projected to bear the largest burdens (IPCC 2024; Ripple et al. 2024).

The research and policy agenda implications are wide and explicitly interdisciplinary: breeding and agronomy for climate-resilient crops, climate-smart agriculture, soil conservation and sustainable land management, engineering and nature-based adaptation for floods, erosion and heat protection, enhanced surveillance and control of animal disease as well as technological and biological solutions for contamination and pollution. Socio-economic research must tackle governance, land rights, incentives to reduce agro-chemical dependence and mechanisms to prevent exploitative 'green' land deals (Anderson et al. 2020; Rivero et al. 2022; Yue et al. 2017).

Uncertainties are obvious: explosive volcanic eruptions generally cause short-term cooling (via aerosols) rather than sustained warming (Euronews 2023b), uncertainties in climate overshoot (Schleussner et al. 2024), in consumer behaviour (Merz et al. 2023) and projections about an imminent AMOC collapse remain uncertain (SMC 2024).

Climate change:

'If climate change hits, it will have an effect on everything, everywhere and all at once' (Avampato 2023). Under such circumstances, other countries and regions cannot assist because they too would be affected. Some are responding to this with *different* standards especially for companies: 'We will keep fighting until we put a stop to ESG once and for all!'. ESG (Environmental, Social and Governance)[41] is a set of investment standards or criteria for corporate behaviour, in other words, it takes more than profit into account. The criteria are used to assess the sustainability and responsibility of companies with regard to the environment, social impacts and corporate governance. ESG was coined by the United Nations in 2005 with the original acronym GES because Governance was regarded as the most important of the three. The standards were not wrong at that time and they are not wrong now. They simply did not foresee the state of the environment and changes until 2025 and the application and effects are still unknown.

The situation worldwide and geopolitically changed during the last three years and even more since 2024, when especially the United States abandoned environmental protection in many areas. It is obvious that knock-on effects will follow. Even if all countries of the world achieved net zero today (no emissions), there is still no plausible way to keep global warming below 2 degrees Celsius (Paris Agreement is about 1.5 degrees). Above 2 degrees, we will see more intense storms, extreme and longer heatwaves, dangerous flooding, drought and fire conditions, crop failures, sea-level rise, increases in deadly diseases (plants, human and

[41] For a simple explanation, see: https://www.thecorporategovernanceinstitute.com/insights/guides/esg-a-comprehensive-guide-to-environmental-social-and-governance-principles/?srsltid=AfmBOopYmgQMvko3gxX6E1i8fVnIf44zAY6Xgh6ePNqhXpdQlKQQ2-KR.

livestock) and massive losses of biodiversity in flora and fauna. It remains a question if and how consumers will change their behaviour in the face of climate change and upon seeing its first symptoms.

Planetary boundaries: Planetary boundaries are a concept for estimating a safe operating space for humanity with respect to the functioning of the Earth System (Rockström et al. 2009). It presents nine critical Earth system processes that regulate our planet's stability and resilience, defining a 'safe operating space' for humanity. Scientists warn that humanity has already transgressed several of these boundaries, pushing Earth's systems beyond their stable ranges and threatening long-term habitability. It is still unclear how the food system will be impacted by these overshoots (Rockström et al. 2023b; Steffen et al. 2015a; Steffen et al. 2015b).

Water security: Water is already becoming the next frontier for comprehensive accounting and adaptation strategies – for food systems, too (EEA 2021; European Commission 2025; FAO/CIRAD 2024; Magagna et al. 2019; Roo et al. 2023; Scholten et al. 2025). Our increasingly threatened global water security demands that accounting for water use and risk rapidly acquires the same urgency with which we address carbon emissions (Famiglietti et al. 2022). Wars over water are already on the horizon. First cities and regions have water management plans or set limits to use water in drought times (quotas).

5.6 Politics and Geopolitics

Many new policy and geopolitics issues emerged during the last few years. They are affecting the food system and are immensely relevant for the CDIs, too. Some are shown in Table 8 below and can be clustered in two groups: Geopolitics and global supply threats (green), Policy, governance and market responses (ochre).

Table 8: Relevant emerging policy and geopolitics issues affecting the food system
Background colours indicate cluster

New world order	Trade agreements and international food governance
Hunger as a weapon - Ukraine war goes on	Food sovereignty and local food movements
War on resources	Public-private partnerships in food industry initiatives
Conflict China versus US concerning Taiwan is threatening food chains	Germany's Lieferkettengesetz with effects on food systems
	Regulation of food ingredients, especially fat and sugar
India's rice ban could trigger a global food crisis	The future of the Common Agricultural Policy (CAP)
Food security and access (to outcomes of the food system)	Policy support to food and agriculture

Geopolitics and global supply threats (green): There are different scenarios of how a new world order may look like for example the PostCovid scenarios (Cuhls et al. 2022), our FOSTER scenarios (Cuhls et al. 2024b), FOD 2nd strategic plan (Weber et al. 2023) or the JRC reference scenarios (Vesnic-Alujevic et al. 2023). USA, China and Russia are clear big actors but many other players are rising powers, also in food markets and within global food chains (Berger et al. 2022). Demographic dynamics may threaten food supply, leaving some on the verge of hunger. Hunger is more often used as a weapon, not only in wars but used as a threat by directing food supplies at will. Therefore, addressing issues related to food security and access to food or trade agreements are a key geopolitical issue currently (in 2025) even challenged by the politics of the USA. Some particular issues mentioned here are the conflict China versus the USA about the potential 'integration' of Taiwan and how it is threatening food chains in that region (Foreign Affairs 2023), the Ukraine war destroying the 'granary of the world' (Handelsblatt 2023) and the global issues arisen by India's ban of rice exports in an attempt to decrease domestic prices at home (Biswas 2023).

Policy, governance and market responses (ochre): In the EU, the Common Agricultural Policy (CAP) remains a cornerstone of European integration, see above. During its existence, it has undergone multiple changes and there are different possible paths into its future (European Commission). More about policy and governance in FOSTER Deliverable 4.1. Here, we only add some important additions: It is discussed with the view to the future to support the affordability of a healthy diet with food and agriculture policy (see Figure 1), particularly if policies drive a benefit for the consumers and support local food systems (FAO 2022; Sampson et al. 2021). It is discussed with the view to the future to support the affordability of a healthy diet with food and agriculture policy (see Figure 1), particularly if policies drive a benefit for the consumers and support local food systems (FAO 2022; Sampson et al. 2021). A rising upcoming approach is the taxation of particular food ingredients like sugar and fat (Popkin et al. 2021). Public-private partnerships in the food industry are an approach worth exploring (Smyth et al. 2021) as well as only trading with democracies like in Germany's Lieferkettengesetz (Çelik et al. 2022). This Supply Chain Act [42] came into force in 2023. The European Directive on corporate sustainability due diligence (Directive 2024/1760) came into force in 2024 to foster sustainable and responsible corporate behaviour in companies' operations and across their global value chains[43]. These directives are supposed to shorten supply chains.

[42] https://www.bmas.de/EN/Europe-and-the-World/International/Supply-Chain-Act/supply-chain-act.html.
[43] https://commission.europa.eu/business-economy-euro/doing-business-eu/sustainability-due-diligence-responsible-business/corporate-sustainability-due-diligence_en.

5.7 Resources and Energy

The emerging resources and energy issues affecting the food system are shown in Table 9. They can be clustered in four groups: Energy systems and food production interactions (green), Sustainable sourcing and supply chains (blue), Food security challenges (grey), Resource competition and scarcity (ochre).

Table 9: Relevant emerging resources and energy issues affecting the food system
Background colours indicate cluster

Relationship between energy price, automation and manual labour	Sustainable seafood sourcing and fisheries management	Competition for naturals
Energy production in competition with food production	Origin of the bio-based raw material and resources matter	Water as the next frontier - water security
Energy efficiency and renewable energy in the food industry	Sustainable sourcing of ingredients and raw materials	No land and competition for land
Rise in energy consumption	Food shortage	Resource utilisation increase
Energy shortage	Synergies between food and bioenergy industries	Specific resources missing or lagging for the energy transition
Competition between food and bioenergy industries		Fertiliser shortage

Energy systems and food production interactions (green): The energy-labour relationship was the foundation of the Industrial Revolution. Most technical processes started to use 'industrial energy' to replace the 'human energy' previously invested to do the same tasks manually. This automation has been possible due to the availability of cheap energy, which is crucial for most energy-intensive processes to be profitable or, at least, keep prices low – including most processes in the food system (Hagens 2020). Even though processes tend to become more efficient in time, global primary energy demand is expected to further increase in the next decades (H2020 Fit4Food project 2017-2020). This is why implementing energy-efficient technologies and utilizing renewable energy sources in food production and processing is key (Liczmańska-Kopcewicz et al. 2020). In addition, energy supply failures have far-reaching consequences for the food system along the entire value chain. Energy and food production compete for the same resources (Muscat et al. 2020). However, this competition creates opportunities for synergies in producing biogas (Lahiri et al. 2023; Teekens et al. 2016).

Sustainable sourcing and supply chains (blue): As companies replace fossil with bio-based resources, the demand for bio-based resources increases. Within the European Union, we do not have the land or the capacity in agriculture to satisfy this demand. Therefore, imports of bio-based foods will be necessary, even if the EU and its member states increase their effort to grow renewable resources (Project DAKIS 2019-2024). For this, promoting responsible sourcing practices is important, including for fishing practices and management of marine resources or in forestry (Scott 2018; Ziegler et al. 2016).

Food security challenges (grey): Food scarcity is not a problem in richer countries, at least not in the short term. Although inflation is still high and especially food is significantly more expensive in the EU compared to 2021, a long-lasting shortage of food is very unlikely during the next years. The current high prices are induced by energy costs mainly and costs are high for processed as well as unprocessed food[44]. However, crises may temporarily disrupt supply chains and some resources or foods may be unavailable. Economic inequality is the biggest problem when food is scarce and prices rise – lower income groups cannot afford enough healthy food, then (Pollard et al. 2019). And we are not sure how the future unfolds in food security.

Resource and land competition and scarcity (ochre): Projections for 2050 suggest the emergence of growing scarcities of natural resources for agriculture, which is not a new finding, as consumption of energy, water and other strategic resources is drastically increasing driven by population growth world-wide and economic development (Project DAKIS 2019-2024). Intensified competition for these resources could lead to overexploitation and unsustainable use, degrading the environment and creating a destructive loop, which would not only affect food supply but also the ways of making a living for farmers, foresters, pastoralists and fisher folk (Alexandratos et al. 2012). A factor to consider here is the competition of energy crops and photovoltaics versus land-use for agriculture (and versus land as investment) (Hertel et al. 2013), a question already discussed in the first SCAR Foresight published in 2006[45].

The factor time plays a big role here: despite the continued technological advancements and the possibility to replace materials, there may not be enough resources available in the time required for the energy transition when the demand for energy and other resources from all sides is increasing. Similarly, the competition of biomass energy generation and manure availability among other reasons may lead to a fertiliser shortage (Worstall 2013). Water is a particularly salient potential scarcity issue, as it is deemed to be the next big issue and progress on water tracking it is needed. A territorial governance of water that ensures sustainability of clean water supplies and sufficiency of water resources seems to be needed to minimise risk of conflicts over water resources even here in Europe (see above, water) (Mancosu et al. 2015).

5.8 Mobility

Mobility is a big driver for and within the food system. Without transport, there is no food in cities, no delivery service and no choice available in supermarkets. Table 10 below includes the identified and selected developments in mobility in the food system. They can be clustered in four groups: Last-mile delivery and solutions to bring food to customers (green), Sustainable transportation and environmental solutions (blue), Innovative and specialized systems (ochre), Examining food logistics and supply chain (grey).

[44] See What were the drivers of euro area food price inflation over the last two years? For data and reasons, also here: Real food inflation in Europe: Which countries are hit the hardest? | Euronews.
[45] https://scar-europe.org/scar-working-groups/foresight-task-force.

Table 10: Relevant emerging mobility issues affecting the food system
Background colours indicate cluster

Drone food delivery service	Electric and autonomous vehicles in food transportation	Mobile slaughterhouses & direct food commerce via alternative channels
Last-mile delivery and urban mobility solutions	Coupling photovoltaics with transport refrigerated units	New food delivery and waste collection system onboard commercial transport aircraft
Automated micro-vehicles	Cars as policy issue	Pipeline for food production & delivery
Pick-up points in E-Commerce	Reusable food containers	Food delivery platforms and gig economy
E-Hailing	Mobile food solutions and food trucks	New food logistics and transportation of food products on a small scale

Sustainable transportation and environmental solutions (blue): The means of transport, fossil fuelled cars particularly, are a controversial topic in many societies, and this significantly affects policy-making for sustainable transport, which also affects the food sector (Hrelja 2019). A novel idea to improve sustainability here is equipping refrigerated transports with photovoltaic panels on the rooftop of the vehicle to foster renewable energy penetration into the cold chain. Autonomous electric vehicles could help reduce emissions and enhance efficiency in food transportation but fully autonomous driving will still take time (Li et al. 2021). On another front, delivering food in re-useable containers is another approach to address environmental impact. Hygienic questions play a role here (Schuermann et al. 2022).

Innovative and specialized systems (ochre): More speculative are the assumptions about systems related to food mobility like a direct-to-home pipeline network installed on an outer wall of a building or adjacent to a smoke vent to transport freshly cooked food to customers (Patent 2014). Other ideas are a new food delivery and waste collection system onboard commercial transport aircrafts or the mobility of infrastructures (e.g. mobile slaughterhouses or direct food commerce via alternative channels) (Food System Change 2020).

Examining food logistics and supply chain (grey): Examining and improving the efficiency and sustainability of transportation and distribution networks on the food industry and employment has a significant impact potential but the data about real impact are unclear (Milkman et al. 2021; Paciarotti et al. 2021).

Last-mile delivery and solutions to bring food to customers (green) addresses the challenges of delivering food to and in urban areas and explores sustainable mobility options like air and ground drones (delivery robots) as well as the use of e-hailing services (Baum et al. 2019; Mucowska 2021; Wan Mohamad Yusoff et al. 2023). These services improve the process of collecting and sending orders from customers in a short period of time and they are already lucrative. Other options include flexible and innovative food service options like food trucks or developing pick-up points positioned at diverse locations throughout a city to provide an alternative to delivering to individual places (Food System Change 2020; Kalra et al. 2023; Masteguim et al. 2022).

5.9 Societal and Cultural Patterns

Many emerging societal and cultural patterns affecting the food system can already be observed and it can be assumed that most of the developments will be relevant in the future, also for the CDIs, see Table 11. The observations can be clustered in four groups: Consumer behaviour and food culture evolution (green), Socio-economic challenges and market pressures (ochre), Technology and systemic transformation (grey), Sustainability and environmental responsibility (blue).

Table 11: Relevant emerging societal and cultural patterns affecting the food system
Background colours indicate cluster

Spoiled consumers in some European countries	Divided Societies
Ethical and sustainable consumer choices	Inflation
Cultural food habits	Profit greed
Convenience-driven food products and snacking culture	Price sensitive consumers
Rise of alternative food channels (food trucks, pop-up restaurants)	Discounter versus Delicatessen and specialised trade
On-demand and personalized food delivery services	School Meals Coalition
Rise of food experiences and food tourism	Sustainable lifestyle
Society 5.0	Growing importance of animal welfare in the food system
Social innovation in the food system	Origin of the bio-based raw material and resources matter
Agribusiness in the future - future farmers	Greenhushing

Consumer behaviour and food culture evolution (green): Consumers expect every kind of food to be available anytime anywhere, regardless season or food growing needs (European Commission 2022a). Convenience-driven food products and snacking culture are hegemonic[46]. Consumers demand for fast, customized and convenient food delivery services[47] – what worked in pandemic times is expected to go on in European cities.

In addition, people tend to throw away perfectly good food because they buy or order too much or because they do not plan for what is really needed. This is in part driven by companies' leverage on what drives humans to buy more than they want. It is very difficult for humans to resist the call of some flavours and smells. Better research on these issues may empower policy-makers to set incentives for a change in food habits – but on

[46] https://de.statista.com/outlook/cmo/lebensmittel/convenience-food/deutschland#umsatz.
[47] https://de.statista.com/themen/3440/food-delivery-lieferdienste-lieferservice-portale/#statisticChapter.

the other hand, gives more manipulative power to marketing and influencers (European Commission 2020-2026). A growing number of consumers already factor in or even prioritise ethical and sustainable factors on their food purchasing decisions[48], but it remains unclear if this increase is really high and if it holds over time. There is also an increasing interest in immersive food experiences and culinary tourism[49] as well as alternative temporary food channels like food trucks or pop-up restaurants.

Socio-economic challenges and market pressures (ochre): Societies are becoming more divided[50] between haves and have-nots. Those without sufficient income cannot afford high quality food, sometimes not even enough food. This and factors like inflation or profit greed, which make prices increase, are dividing agriculture into micro farms (have-nots who cannot afford to buy food and grow what they can and where they can) and macro farms (large, automated companies, big farms). A large fraction of consumers are highly price sensitive, buying mostly the cheapest food without regard of origin, sustainability or worker conditions (Duncan et al. 2022; European Commission 2020c). This may also be related to the increasing use of discounters[51] instead of classic speciality retailers like butchers or bakeries. Buying cheap at discounters is not necessarily related to the income of the consumers. You can easily find a Porsche, Mercedes, BMW or Maserati parking in front of a discounter.

Countering food scarcity for school children is effective when there are school meals offered, but this does not exist in all EU countries and is not available during holidays. An example of a project to address the social (income) divide is School Meals Coalition, a project attempting to improve the quality and expanding the scale of school meals programmes globally as a platform to reach communities, feed children and enhance school attendance (Schindler 2015).

Technology and systemic transformation (grey): Societies in the 21st century are characterised by a high degree of digitalisation, which is changing the way people work and live, including their relationship with food and nourishment (Kanbara et al. 2022; Kravets et al. 2022). Social innovation plays a pivotal role in transforming the food systems towards being economically and socially feasible, sustainable and within planetary boundaries (European Environment Agency). New and young farmers tend to be well educated and equipped with technology. They have plenty of ideas to make use of technology and start to leverage the enormous potential in all areas of farming including crop protection. But we also see the danger that some of the farms are more and more dependent on big tech solutions (farms are often out of villages and depend on Starlink, what if this is switched off or increases costs?) and on energy supply (What happens if there is a

[48] eg. https://ethicalbutcher.co.uk/.
[49] http://kulinarischer-tourismus.de/forschungsergebnisse/.
[50] There is an explanation for the Netherlands: https://english.wrr.nl/topics/social-divisions. But not many studies are available for detailing the food divide in societies and different Member States, even though the division as such is obvious from the Agricultural Outlooks and FAO studies: OECD/FAO et al. 2025.
[51] https://de.statista.com/themen/1291/lebensmittel-discounter/#statisticChapter.

disruption in energy supply? Not all farms provide generators for this case). Redundancies rarely exist (Project DAKIS 2019-2024).

Sustainability and environmental responsibility (blue): Climate change and the numerous ecological problems push a part of the population towards a more sustainable lifestyle that includes changes in their nutrition habits, rising the demand for bio-based products[52] – which Europe is not able to fully provide (Project DAKIS 2019-2024). However, these preferences usually do not regard seasonality or origin of the products. This is why greenwashing is ubiquitous. Greenhushing is the bogeyman being used to stir up opposition against greenwashing regulations (Geilenkirchen 2023). Meanwhile, the fraction of consumers who take animal welfare into account for their purchases and nutrition is increasing, some of which turned vegetarian or vegan. This led companies to show some aspects of animal welfare in labels but the different labels in the EU are still confusing consumers, and trust in them does not seem to be high (Hild et al. 2019).

[52] UNEP: https://www.unep.org/explore-topics/resource-efficiency/what-we-do/sustainable-lifestyles.

Chapter 6

New Topics in Food Systems

Chapter 6 – New Topics in Food Systems

6. New Topics in Food Systems

This chapter summarises the findings on new themes, newly framed topics and upcoming issues in the food system, corresponding to the centre of the food system framework in Figure 1. The issues are summarised and were selected to serve for further work with the CDIs and in the consortium. They are not exhaustive.

6.1 Producing

This section synthesises the findings of the Horizon Scanning in the 'producing' part of the food system framework (Figure 1).

Land-based Innovations

Farming in Europe has been transformed over the last 70 years by policies, technologies and practices that sought to guarantee a stable supply of affordable food. But this has come at the cost of environmental degradation in some regions. Industrialisation of the food systems is the cause of the most severe health impacts for animals and humans. To meet health and nutrition goals, there are attempts for the diversification of key ingredients and sustainable agroecological systems (Frison et al. 2020), which can also address environmental issues. For example, agroecology supports sustainable agricultural production while maintaining robust stewardship of the environment by working with nature and ecosystem services. It has the potential to become a fundamental tool for the EU in its effort to promote sustainable farming (European Commission 2021).

Permaculture (holistic design methodology integrating ecological principles with agricultural practices) strives to design sustainable agricultural systems and human habitats that mimic the patterns and relationships found in natural ecosystems (H2020 Fit4Food project 2017-2020). Climate smart agriculture is designed to increase agricultural productivity and sequester carbon at the same time with natural or technological processes (Totin et al. 2018). And AI algorithms can optimize real-time irrigation practices by analysing several streams of data on soil, plants and weather to ensure efficient water usage. This improves crop health (Obaideen et al. 2022).

Controlled Environments in Agriculture

Indoor farming technologies involve agricultural production in buildings, where environmental conditions are precisely controlled. Growing crops in vertically stacked layers or urban settings enables efficient land use but does not provide large amounts of resources or food. 'Agriculture without land' is one of the attempts. Systems such as hydroponics or aquaponics grow plants in soilless nutrient solutions (Oh et al. 2023; Ramli et al. 2023). New technologies such as LED lights make production all year round possible, environmentally friendly but still energy intensive (Ramli et al. 2023). A further advantage of these growing systems is the controlled condition or the independence of access to soil. Partially underground greenhouses offer a controlled environment that protects crops from extreme weather and stabilise temperatures (Greenforges 2022). Underwater greenhouses may in the future represent an alternative system of agriculture useful in regions where cultivable land is scarce or plant growth extremely difficult for any reason (Pistelli et al. 2020).

Aquatic Food Systems

There is room for aquatic foods (fish, shellfish, aquatic plants and especially algae) to help end malnutrition while building a nature positive, equitable and resilient food system (European Commission 2022a). This is what the project *Aquatic and blue foods*[53] aims at. But this needs to be done implementing environmentally friendly practices in fish and seafood production as overfishing needs to be tackled (Proveg 2023). Aquatic food systems are not necessarily in the sea, they can also be installed on land or using existing ponds (H2020 Fit4Food project 2017-2020).

Most challenges affecting the aquaculture sector can be addressed by fully-closed systems, when there is a barrier between the cultivated organisms and the natural environment with no continuous water exchange (H2020 Fit4Food project 2017-2020). Although requiring significant investments, the transition from open to closed aquaculture has been demonstrated to be economically viable. Other ways to tackle overfishing is with cultivated fish of plant-based fish-like products (Proveg 2023).

Pesticide Paradox

Although pesticide use has increased 15-fold in the last 40 years (while agricultural land increased only around 10%) pests damage to crops have slightly increased, which makes it unclear how the real demand developed over time or how well applied pesticides are. Mostly aided by other factors such as the higher use of nitrogen fertiliser (almost 7-fold increase), increased irrigation (1.7-fold) and improved crop genetics, food production has increased 2-fold during the same time (Marmotian 2023).

Fertiliser Dependency

Among these contributing factors, fertilisers play a fundamental role in food security. Their production and costs are largely dependent on natural gas, a geostrategic resource used to produce ammonia (European Commission 2023b). Around 70% of the ammonia produced industrially is used to make fertilisers in various forms and composition. However, ammonia in pure form is also applied directly in the soil[54]. Sustainable fertiliser production and nutrient management (optimising the efficiency of fertiliser use and enhancing the recovery of nutrients from nutrient-rich side streams such as from manure, food waste or sewage sludge) can

[53] https://aquaticbluefood.org/.
[54] https://www.reportsanddata.com/report-detail/ammonia-market.

help European farmers produce healthier crops and higher yields while reducing impact and increasing resilience to climate change.

Many fertilisers are produced in Russia – this led to a shortage and higher prices on European markets during the last years. On the one hand, it reduced over-fertilisation, on the other hand, it made some products more expensive or fertilisers unavailable. Manure is a fertiliser that is available in Europe in huge amounts. Here, the problem of over-fertilisation and too much nitrogen remains. The EU is therefore pushing Member States into new ways of fertilising [55] (European Parliament and the Council of the European Union 2019).

Supply Chain Vulnerabilities

With the Covid-19 crisis, the possibility of having a disruption in the supply chain has emerged as a major concern (European Commission 2020c; OECD 2022; FAO 2022; OECD et al.; OECD/FAO 2019; OECD/FAO et al. 2025). In 2021, the obstruction of the Suez Canal by the Evergreen gave international trade a cold sweat and a bit later, the war in Ukraine has been causing dangerous tensions in food markets and food insecurity. This points to the need for assessing the impacts and supply chains of food production and for agricultural (re-) territorialisation, i.e. balancing the promotion of local products and international trade in Europe (Loodts et al. 2022). For this, multiple land use may help but cannot be the only solution. Multiple land use refers to the use of land for more than one purpose, e.g. grazing of livestock, recreation and timber production or photovoltaics and livestock grazing, and it may also apply to the use of associated bodies of water for recreational purposes, fishing and water supply (Butler 1985).

Water Competition in food production

Historically, in dry areas, there has been a competition for water between industry, agriculture and citizens (see also drivers). This competition has been increasing as industry and urbanisation expanded. Lately, some regions have been faced with a new actor in this competition: large information technology companies. Unknown to many citizens, these companies evaporate large quantities of water, especially for cooling purposes, which in some zones introduces significant tension in the competition for water (Li et al. 2023). Rivers and aquifers are suffering as a result as they are already suffering from the competition to energy production (a well known example is the cooling water for nuclear power plants). New water justice movements (NWJMs) are formed to fight for revitalising rivers in all senses and shape equitable and nature-based water governance (ERC 2023).

[55] For additions, a summary, reasons and amendments, see also https://www.ble.de/DE/Themen/Landwirtschaft/EU-Duengeprodukte/eu-duengeprodukte_node.html.

Dietary Diversification

Changing and diversifying our diets can be a way to reduce greenhouse gas emissions from food production, address the challenges of changes in land use and biodiversity loss while providing sufficient, nutritious, safe and affordable food to a fast-growing population (see drivers above). Many sources of proteins other than meat or milk exist (e.g. edible insects, cultured meat, fungi and microalgae), backed up by incipient use by the population (EPRS 2024; ERC 2023; Mancini et al. 2019; ÖAW-ITA and KIT-ITAS 2025; Surya Ulhas et al. 2023; Takefuji 2021; Yang et al. 2024). However, production and legislation still need to adapt to these dietary shifts. For example, the interest in insects as food and feed has been recently growing, mostly because the farming of insects has an environmental impact which is lower than that of livestock and because insects are easy to breed. In addition, there is an increasing number and amount of food additives used to improve conservation, flavour or other purposes. And one way to improve the nutritional quality of food crops is to biofortify them, for which there exist several techniques (Hassan et al. 2021).

6.2 Processing

In the original long list of new processing methods, there were many more very detailed methods for processing resources and food. The review by the CDIs revealed that this was too detailed for the purpose of the project FOSTER so that some findings were assessed as irrelevant to them. The findings in the resulting list are summarized below.

Definition of 'processed food'

The term 'processed food' is defined as any food that has been altered in some way from its raw state (OECD 2021). The processed food sector accounts for a significant share of income generation and employment and is essential to maintaining a steady global supply of safe, affordable and nutritious foods. The sector is thus key to supporting food security and nutrition. Notably, tomato paste is the most widespread industrial product (not just foodstuff!) worldwide, distributed mostly by few big companies from China, California and Europe (Mahlke 2019:30-31).

Processing taxonomies and regulation

Food can be classified according to the extent of processing or in terms of nutrient content. The Nova classification (FAO 2019) defines the following groups: unprocessed or minimally processed foods, processed culinary ingredients, processed foods, ultra-processed foods. Food processing must guarantee food hygiene and a set of rules mandated by different administrative levels and geographies try to ensure it (Dwinger et al. 2007). The number of ingredients in processed foods seems to matter when it comes to healthy diets and allergens-free food.

Many consumers demand more transparency and monitoring of complex supply chains, which have become non-transparent due to increased specialization and international division of labour. The rise of Industry 4.0 and IOT, however, produces an enormous amount of data, which allows tracing the entire production process, logistics and subsequent processing of the products (Project DAKIS 2019-2024). In the food sector, customers could gain greater access to information about the products supply chain and processing – if these data are available and digestible for them.

Novel and functional foods

Novel food has entered the food market over the last two decades, means 'novel' is not necessarily 'new' here. Novel food is based on different innovations like new isolated food ingredients, micro-organisms or novel animal ingredients like insects or new production processes. Despite interest in the EU due to nutritional and environmental added value, novel food products also have very high product failure rates (H2020 Fit4Food project 2017-2020). Examples of novel food are alternative protein sources. Producing enough conventional animal-based protein to meet future global food demands in a sustainable way represents a challenge (see above). Edible insects, plant-based, (precision) fermented or cultured meat and micro-algae have recently been proposed as alternative protein sources that can be produced in a more sustainable way and contribute to ensuring global food security (EPRS 2024; Good Food Institute; H2020 Fit4Food project 2017-2020; ÖAW-ITA and KIT-ITAS 2025; Surya Ulhas et al. 2023; Takefuji 2021).

Cultured meat (lab-grown or in vitro meat) utilizes technology to grow meat from animal (stem) cells. It is an emerging technology still in its infancy but has the potential to customise the biochemical composition of meat – it is possible to grow almost any type of cell, thereby obtaining healthier animal products while not killing any animal (Good Food Institute; H2020 Fit4Food project 2017-2020). Another example of a novel food is a caffeinated brew that uses 'superfoods' and plant-based waste ingredients to mimic the molecular structure of coffee (Euronews 2023a).

Functional food is food containing health-giving additives, i.e. improving health and well-being and/or reducing the risk of disease beyond their nutritional effects, which makes functional food very appealing to consumers. Under the headline of 'functional food' we find pre- and probiotics, omega-3 fortified drinks, collagen snacks, vitamin-enriched foods and many other combinations (H2020 Fit4Food project 2017-2020). Historically, fermentation has been used for food preservation but it is also used to transform inedible or unpalatable food into acceptable food, broadening and improving dietary options. Food fermentation is the intentional use of microorganisms to manufacture or modify food. Two approaches dominate the field: classic and increasingly precision fermentation and biotechnological fermentation (WebMD 2024).

Both novel foods, as foodstuffs or ingredients, and the labelling of health claims on food require legal review prior to market launch.

Emerging processing technologies

Thermal processing (pasteurization, ultra-high temperature, blanching…) has been traditionally used to preserve food. However, such processes tend to lose nutrients and freshness. Preserving food can also be achieved by using high pressure or high-intensity ultrasounds, alone or in combination with other methods, or even with minimal processing technologies (Cacace et al. 2020; Chavan et al. 2022; Nabi et al. 2021). While these are not particularly mild processing methods, they follow the broader tendency in modern food technology toward milder processing and the use of natural preservatives to keep high food quality with high nutritional values for health, which is often better than the nutrient loss from thermal processing (H2020 Fit4Food project 2017-2020).

3D food printing is a commercially available technology for creating edible and customized food items (Verma et al. 2023). Going further, 4D food printing adds the time dimension to the process, where the printed item changes after printing thanks to stimulus-responsive materials. This technology is at its initial stage. Going even further, 5D and 6D food printing are proposals to print complex structures with improved strength and less material than do 3D and 4D printing (Ghazal et al. 2023). Another example of advanced techniques to process food is applying nanoscale materials and processes to enhance food quality and safety (Jayaweera et al. 2023).

Such advanced processing is difficult in short supply chains, where customers and producers are proximate and the scale of producing is usually rather small and where producers lack the capacity to use an advanced infrastructure. Collaboration can serve as to make processing equipment more accessible in these situations. For example, collaboration can enable the use of a high-level aseptic filling machine in small-scale food processing (van Parys et al. 2023). This kind of 'do-it-together' approaches and other social innovations related to local food production and consumption (such as urban gardening) can promote the sustainable use and design of (urban) public spaces in communities and the cultivation of food in cities (Project DAKIS 2019-2024). In rural areas, the joint use of machines has a rather long tradition and is sometimes organised ('Maschinenring').

'Circular' opportunities

Processing food generates streams of by-products. If these are treated as waste, a lot of value can be lost. Using by-products for other use can generate new streams of revenue and decrease costs, while avoiding the use of new raw materials and decreasing waste. Agricultural by-products cannot only contribute to nutrition but also to the production of energy and materials (German Science And Humanities Council 2023a). An example of nutrient recovery is the use of aquafaba as raw material (Erem et al. 2023).

6.3 Retailing

Pricing

A big issue in retailing is the pricing. Consumers usually do not pay the full prices for agricultural products. These products include the use of commons (water, air, environment etc.), nobody is paying for, there are many subsidies and some products generate (unfavourable) externalities like environmental harm. All of them do not appear in the balance sheets of the producers but need to be addressed – or better: paid – by society. A part of these costs is paid by the individuals in society in other forms (taxes, worse health, odours or noise…), and a part becomes deferred costs for subsequent generations (True Price 2019). Another issue with pricing and retailing is that fair prices and fair distribution of food are far from the norm, neither in Europe nor in many countries of the world[56]. There is no research about retailers and their design of pricing or the way they pay for their resources – retail is the 'elephant in the room', here. There are attempts to improve the situation with different economic thinking, in which trust, system balances, commons and the way to work are interpreted in a different way.

Product information

Conveying product information is key in retailing. However, consumers express a lack of understanding and confusion about on-pack claims and labels (Project DAKIS 2019-2024; World Business Council for Sustainable Development 2018). The existing transparent labelling initiatives attempt to tackle this problem. Some of them are corporate-led, some consumer-led and they are mainly trying to standardize labels (Project DAKIS 2019-2024; World Business Council for Sustainable Development 2018). Clear trustful certification helps consumers to make informed choices, but often, people trust each other more than any other source of information and increasingly turn to the internet to find 'trusted' information (World Business Council for Sustainable Development 2018), which is again sometimes misleading or marketing. Implementing technologies like blockchain for transparent and traceable food supply chains could help regain public trust (Caro et al. 2018). Aiding this with AI and IoT to achieve a personalized and interactive shopping experiences (Zimmermann et al. 2023), particularly leveraging the popularity of online shopping, may make it more attractive and trustable for the end consumers (Charlebois et al. 2021).

Supply chains and retailing

The growing trend to shorter supply chains leads to social innovations in local food production and consumption. Local high quality food system networks like Food Circles shift food production and retail from centralized structures towards decentralised, partially autonomous nutrition systems. This paves the way for bottom-up innovations and can decrease the market share of big players. Local niches for the delivery of

[56] https://www.smallfarmincomes.in/.

distinct food services can lead to innovations and an efficient customer response (Moller et al. 2019; Nemes et al. 2021; Project DAKIS 2019-2024). Vending machines are a good example for this, selling the products of several producers at place or close to the place of production. Another example is direct marketing in cooperative shops, farm shops and at farmers' markets. This avoids external retailers and is thus less expensive and more independent in prices and earnings for the producers (McKean 2019). However, consumers may find it less convenient to need various stops to buy their food instead of just going to a supermarket. Short supply chains may suffer from convoluted logistics. Integrated logistics networks may help coordinate and optimise logistics to reduce transport distance, time spent in transportation, with the collateral benefit of reducing emissions (Paciarotti et al. 2021).

6.4 Consuming

Global food security and resource management

With the still rising global population, food scarcity and mounting evidence that many of today's whole foods aren't as packed with vitamins and nutrients as they were 70 years ago (Colino 2024), the question about how to feed the world arises. Increasing food availability is an important need and an important challenge (see the drivers above). A sustainable food system is fundamental in solving many of the global issues, such as mass migration or the triple burden of famine, malnutrition and obesity, as well as avoiding future wars. This is a global issue that does not stop at national borders (Project DAKIS 2019-2024). Europe does not have the space or the capacity to satisfy the rising demand for bio-based food resources by herself. Imports of bio-based foods will be necessary, even if the EU and her Member States increase their effort to grow agricultural practices, reversing the trend of decreasing agricultural area (Project DAKIS 2019-2024).

Additives, packaging and health

Colours and sweeteners are two of the most common additives used to give food a marketable quality. There are several hundred food additives allowed on the EU market in 2025. However, recent findings suggest that several additives have harmful effects on human health. Individual exposure to food additives is found to be related to obesity, cancer, cardiovascular diseases and mortality (ERC 2023; European Commission 2020-2025) and of course allergies. On top of that, the packaging of food itself can be harmful. For example, plastic-sealed food and drinks are hygienic but one of the highest human exposures to microplastics (Fleming 2023). Some chemicals contained in food packaging such as phthalates can be harmful for humans (some have hormonal effects) and are transferred to food by contact in some circumstances (Avery 2021). The use of 3D printed food that can be consumed immediately may help avoiding some of these issues coming with packaging and transport (Horn-Muller 2023) but here again, it is dependent on the ingredients of the printer.

It is expected that in the mid-term lab-grown flavours – mostly from fungus – will dominate the flavour additives domain replacing many natural flavours. Similarly, the smells added to most foods and drinks can be created in yeast-brewing tanks rather than being extracted from plants or synthesized in laboratories. Research is already active in genetically engineering yeast to produce flavour molecules. This could eventually lead to entirely new and unfamiliar tastes – but we do not know the influence on health, now (Kramer 2023). It is expected that consumers will be influenced by marketing to test new products and companies have an interest in making them addicted to new flavours, smells or odours so this a severe consumer issue (Kruchem 2017).

The typical Western-style diet includes less fluid than it should. This happens at a time when adequate hydration is key to surviving the heat waves striking multiple countries. Sweltering temperatures have led to much more focus on staying hydrated with liquids but few headlines focus on the role diets play in hydration. Highly processed foods, with a low water content to extend shelf life at the store and save transport costs, are rapidly replacing more traditional, water-rich foods, which should contribute at least 20% of total daily water (Willig 2023). A silver lining, however, is that an increasing fraction of the population is embracing plant-based diets and alternative proteins (Surya Ulhas et al. 2023; Tay et al. 2023). These are ethical (they do not involve animal suffering), mostly sustainable, and usually they contain more water and are more healthy.

Climate-friendly dieting

Food consumption is among the main drivers of environmental impacts. On the one hand, there is the need to fulfil a fundamental human need for nutrition, and on the other hand, this poses critical threats to the environment. Different diets have distinct effects on the environment. The EAT-Lancet Commission (EAT Lancet Expert Group 2023; Hirvonen et al. 2020; The Lancet 2020) has presented a global planetary health diet that is healthy for both people and planet. This specific diet has some controversial aspects (Hirvonen et al. 2020), but in general, consumers can become healthier while improving their environmental footprint just by switching diets[57]. In the same way, healthy diets can cause negative environmental effects, when only reduced to a nutrition factor (WUR 2023). In general, it is understood that consumption in the future must pay attention to more than just the end result, the food, and consider the whole delivery chain. But in daily life, this is difficult for consumers to follow.

[57]Our Wold in Data: https://ourworldindata.org/food-choice-vs-eating-local; https://ourworldindata.org/environmental-impacts-of-food.

Market forces and consumer behaviour

Food consumption behaviours result from a combination of drivers but it is possible to identify the drivers that seem to influence consumers the most (Nicolau et al. 2021). For example, there is a trend toward smaller family units (Moller et al. 2019). These small households tend to cook less and demand more easy and hassle-free meals. A counter-argument is that consumers will always tend to consume what is most easily available and this is mainly 'dictated' or provided by the market, particularly the big corporations, less from agriculture (see the problem of season-dependence of food). Big food producing companies are increasingly conquering markets even in emerging or developing countries and influencing consumption towards a standard global food choice (there was even the notion of 'McDonaldisation of the world'). Unhealthy food dominates markets and suppresses the production of smaller scale and healthier food approaches. Sugar and carbohydrate are omnipresent and eaten too much in all countries, now (Kruchem 2017).

Consumer groups and consumer organisations sometimes attempt to put pressure on supermarkets or retailers to change something, often with pricing or by offering some kinds of products (e.g. Foodwatch made a campaign pressuring supermarkets to change their cereal product to pesticide-free production) but with mixed results (Food Watch 2022). Price sensitivity seems to be the major possibility to influence consumers in most of the EU countries – when buying, first comes price, then quality (see also the scenarios in Deliverable 1.5). France seems to be an exception where quality comes first and where consumers are ready to pay more for quality. In most countries, the share of consumers looking for the price first, is higher, and for some people, it is a necessity because of their low income. Price-sensitive consumers are good examples to increase consumer engagement with local products when they are reasonably priced. Hungarian or German consumers for example are very price sensitive – tell us our CDIs. How do you get consumers in other countries to consume more local, regional products – only if they are cheaper, or are there quality arguments? What marketing and sociological methods are available to drive more quality-driven choices? Many consumers have a low income and are thus price-sensitive – how can they be able to buy cheap but high quality food? These questions stay unresolved.

6.5 Storing

Detection technologies and storage solutions

Spoilage of vegetables and fruits is particularly concerning, causing health problems and resulting in economic losses for the sector. Spoilage may arise from insect damage, enzyme activity and physical damage or by microbial contamination. Although some techniques and detection methods for determining spoilage are currently available, implementing cutting-edge technologies could improve food storage and shelf life. Recent innovative techniques include biosensors, electronic noses, electronic tongues, smartphone-based technologies to avert the deterioration or early detection of spoilage and prolong the shelf life (Amit et al. 2017; Kaushik et al. 2023).

Besides these technologies, the storage structures used also strongly influence food preservation. One example is controlled atmospheric storage, which creates optimal storage conditions by controlling or modifying the gas composition around food (Kaur et al. 2021). Minimal processing techniques, such as hurdle technology, can also help obtain safe products with extended shelf life and acceptable palatability (Berdejo et al. 2023; Tsironi et al. 2020). Real-time monitoring enabled by the IoT can turn data into actionable insights about the condition of food, ensuring food is stored within the required conditions (Maheshwari et al. 2021; Mohammed et al. 2022). Coupled with smart food packaging, it could even provide real-time information on the food-quality (Jafarzadeh et al. 2023; Nature Reviews Bioengineering Editorial 2023).

Packaging innovation

Advances in processing techniques, preservation and packaging have enabled the food industry to consistently supply consumers with a wide array of healthy and fresh products all year round. Food packaging contributes to preserving the quality and to protecting food, ensuring convenience in distribution and handling (H2020 Fit4Food project 2017-2020). Not only this, applying anti-microbial and anti-spoilage coatings to food packaging helps to prevent food spoilage (Du et al. 2023). One example is chitosan[58], essential oil coatings (Zhang et al. 2021). In addition, there are many new ideas to extend shelf life with active packaging that actively monitors food, such as new surfaces or silk proteins, and packaging 4.0. Packaging 4.0 goes beyond active and intelligent packaging, it allows digital connectivity and new functionality that can even engage the consumer via an app. Intelligent packaging solutions will communicate actively within the value chain, manufacturing, distribution and the consumer's home environment (H2020 Fit4Food project 2017-2020).

Environmental challenges

Plastic is an important and ubiquitous packaging material but it harms the environment and potentially the health of many living organisms including humans. Responsible consumers ask for a reduction of packaging in general, and plastic in particular (H2020 Fit4Food project 2017-2020). Regulators and companies started regulating and rethinking packaging materials taking sustainability into account. For example, there has been an increasing trend towards using either biodegradable or semi-biodegradable materials, like replacing conventional fossil-based plastics with bioplastics[59] (Weligama Thuppahige et al. 2022). A possible solution

[58] Chitosan is a linear polysaccharide composed of randomly distributed β-(1→4)-linked D-glucosamine and N-acetyl-D-glucosamine used for coating.
[59] According to European Bioplastics (European Bioplastics), a plastic material is defined as bioplastic if it is either bio-based (materials created using renewable biomaterial sources), bio-degradable, or features both properties.

but with challenging real-world realisation is packaging that can be eaten on the go, without a need for waste collection, processing, recycling, or disposal (Kumar et al. 2022).

When plastic is unavoidable, recycling or upcycling the plastic to produce new food packaging may help lower the pressure on landfills (Jung et al. 2023). Even better is re-using packaging before/instead of throwing it away (Camps-Posino et al. 2021). Reusing both, primary packaging (those with direct contact with foods) and secondary packaging (e.g. carrier bags) significantly reduces waste. However, a complex interplay of environmental, economic, social and technological factors affects the implementation and efficacy of reusable packaging. In addition, the switch from a single use to a reusable packaging system is a food safety concern and need the change of some regulation (Bradley et al. 2023).

One step further is avoiding packaging altogether. Package-free stores and supermarkets are starting to be common in bigger cities. Even some conventional supermarkets are starting to encourage shoppers to bring their own containers and to trial refill stations. Despite the obvious environmental benefits of limiting single use packaging, the package-free movement must pay attention to the undesired increase in food waste due to the shorter shelf life of some foodstuffs (Fuentes et al. 2019). This caveat is generalisable to alternative packaging materials: they do not necessarily make the packaging solution more sustainable if they end up producing more food waste. Another problem are the habits of consumers. They need specific awareness for this: not to forget their boxes and clean them properly and use the recycling containers in the intended way.

6.6 Waste and Disposing

Food waste prevention and reduction strategies

The FAO estimates that each year approximately one third of food produced for human consumption in the world is lost, degraded, contaminated or wasted (FAO 2011a). Biological waste generates methane emissions, which have much larger greenhouse effect than CO_2. Without a change in dietary habits and the reduction of food waste, the expected growing population and incomes is projected to lead to an increase in demand for agricultural products of up to 50 % by 2050 (OECD 2022; OECD/FAO 2019; OECD/FAO et al. 2025), but it is very difficult to calculate as there are different places where food waste can occur (Goodwin et al. 2025). Detailed projections are displayed in the Statistical Annex of OECD/FAO et al. 2025 for different countries and different kinds of food and feed.

Continuing waste of food will contribute to increasing food insecurity and hindering nutrition, in a world, where one in nine people are already undernourished (ERC 2023). In addition, food losses and waste often translate into economic losses for farmers and other stakeholders within the food value chain resulting in higher prices for consumers (European Commission 2020b; Project DAKIS 2019-2024).

A glance at where food is lost makes it clear that food loss is generated in all stages of its supply chain. Shortening supply chains has, therefore, the potential to help reduce the amount of food wasted. However, this is understudied and the effects on the amount of food wasted may largely depend on the specificities of each implementation (Dominic 2023). Reasons on the customer side can be packaging sizes but also short expiration dates, the misunderstanding of expirations dates[60], different food aspects and specifities or ignorance about the shelf life of food – however, prices do not seem to be a significant factor.

The Food Recovery Hierarchy (H2020 Fit4Food project 2017-2020; Teigiserova et al. 2020) prioritises actions organisations can take to prevent and divert wasted food. Each tier focuses on different management strategies for the food wasted. The benefits for the environment, society and the economy decrease with each level. The first level is avoidance of waste. Redistributing surplus food to those in need through charity organisations and community programmes is one top-down approach as well as using it to produce biofuels or biopolymers (EU Platform on Food Lossesand Food Waste 2019). A variety of social and private initiatives have also evolved. From using vegetables not fitting the standard due to appearance, shape or size to waste cooking or up-cycling of non-food waste. Cooking too much in households when hungry adds to the problems. There also exist corporate initiatives like tracking and ensuring freshness along the supply chain, e.g. with the help of IoT or apps to distribute not-good-looking or left-over food (Oddbox 2021). Some German discounters have initiatives to buy products that are 'too good to go' or 'ugly' ('ugly apples').

Packaging innovations and alternatives

Developing eco-friendly packaging materials that reduce their environmental impact is a way to minimise the issues of disposing of it, from biodegradable packaging to edible packaging (Kumar et al. 2022; OECD 2023b; Weligama Thuppahige et al. 2022). Plastic is a vital and widespread material but the ways it is used and particularly discarded frequently undermine the economic benefits of a circular, sustainable system and plastics damage the environment. Packaging 4.0 goes beyond this and would have the capacity to communicate within the value chain and with the consumer's home environment, which would allow reminding the user of expiry dates of their products early enough to use them before, for example (H2020 Fit4Food project 2017-2020).

The increasing demand for package-free foodstuffs and the proliferation of package-free stores creates a positive feed-back loop that drives the rise in demand and availability. Despite the obvious environmental benefits of not producing – and hence, not having to waste – packaging, consumers are responsible for the

[60] For example, the German word 'Mindesthaltbarkeitsdatum' is often misunderstood as the date when food 'expires', but in fact it only says that the food hast to be good until then – and normally much longer. But many people just throw it away at that day.

majority of food waste from the whole supply chain. Thus, the package-free movement must pay attention to the undesired increase in food waste due to the shorter shelf life of some foodstuffs (Fuentes et al. 2019).

Circular economy and waste valorisation

'Circular economy' approaches in the food industry are being discussed at various levels and forms, embracing sustainable practices that minimise waste and promote resource utilisation. The notion is a bit misleading as it is not an economy of completely closed loops but at keeping resources as long as possible in the circles and in use (see above). The activities towards a circular economy range from policies and regulations to voluntary initiatives, to halve food waste by 2030 in Europe and reduce food losses by at least 25%, to local initiatives (Bisoffi et al. 2021; European Commission 2022a; Mouat 2022).

Biorefineries represent a transformative approach to the food system by converting agricultural and food processing waste streams into valuable products and energy. These facilities take byproducts like crop residues, fruit peels, vegetable trimmings, spent grains from brewing and food manufacturing waste, and transform them through various biological and chemical processes into biofuels, bioplastics, animal feed, fertilisers and high value biochemicals. Biorefineries create a circular economy model that maximizes resource utilization while reducing environmental impact. This waste-to-value approach provides additional revenue streams for food producers and processors. It contributes to food security by making the entire system more efficient and sustainable (Narisetty et al. 2022). On a smaller scale, vermicomposting is a process that relies on earthworms and microorganisms to help stabilize active organic materials and convert them to a valuable soil amendment and source of plant nutrients (Enebe et al. 2023).

A large fraction of solid waste from the food system ends up in the toilet, although it is not considered food waste but sanitary waste. This waste could, in principle, be used to fertilise crops in the form of biosolids. Waste treatment plants can use chemical processes to treat this waste, with the goal of eliminating dangerous bacteria that could pose threats to human health. However, the treatment methods aren't 100% effective. Class A biosolids, the result of waste treatment, are supposed to be free of dangerous bacteria but DNA testing shows that there are a significant number of virulent genes in the material. And when biosolids are added to soil, the level of virulence genes increases even further, which could potentially lead to damaging crops that are grown on that soil. In order to use biosolids as manure, scientists and government groups need to monitor their impact on the microbes in the soil, to prevent food contamination (D'Angelo 2023; Westreich 2023).

Chapter 7

Outlook: Contradictions, Questions, Tensions….

Chapter 7 – Outlook: Contradictions, Questions, Tensions….

7. Outlook: Contradictions, Questions, Tensions….

The future food system in the EU is facing many challenges and the direction, in which it will develop, is rather unclear. Currently, many exogeneous factors, the drivers of change in and on the system, are changing. Here, we have to mention especially climate change with extreme weather, hotspots also in Europe, droughts and floods, heavy rain etc. and the demographic change with new citizens from other countries in Europe, especially driven by the war in Ukraine but also climate refugees, those fleeing wars in other regions or those who seek for better opportunities for their lives. Most European societies are ageing and have low birth rates. The newcomers are often young – but their next generation adapts the birthrates. The number of people in Europe only remains constant if there is influx of people, which means a much more heterogeneous population also in the food system. This challenges cultures, ethics, eating habits, living together or the workforce but brings the opportunity of keeping the food systems agile, bring in new food ideas and provide the knowledge of growing plants that can grow in the new weather conditions. To accept these new conditions is very hard for the people in the rather conservative agricultural sector.

Our food systems in Europe have developed into more industrialised systems in some countries with many actors thriving for profit, mass sales and high margins, and other producers thriving for more organic, natural, culturally bound or regional provision of food and ingredients. Farmers as the major providers of the resources in the system have demonstrated their power in demonstrations in 2023 and 2024 but in fact the major part of the food system is dominated by big producers and retail so that farmers are not in the situation to get fair prices or high incomes. Farmers are the ones who have to consider more and more regulation and sell their products in high competition that often comes from outside the EU or other EU countries who can produce at lower costs. Even the quality of products differs very much in the regions of Europe. That sets farmers under stress and from the few remaining farms, many will be given up as they are not economically viable, anymore.

On top, there are opportunities and challenges upcoming with new technologies that allow for many changes in agriculture and production through digitalisation and artificial intelligence, but also genetic engineering, new breeding and new ways of doing business. These changes need a lot of investment in knowledge – time that is not available when economic considerations and the daily work on farms are in the forefront.

Food and food systems are a matter of geopolitics – visible in the Ukraine war and the war in Gaza. Food is used as a weapon, for extortion or threatening civil societies with non-delivery or shortage of food. It is a part of wars (Messer et al. 2024) and war is back. Food security for all cannot be taken for granted, anymore. In Europe, we are not directly threatened in 2025 but even that can change.

In 2025, when this report is written, policies and regulation are changing again – back to less sustainable production, more resilience and more autonomy. Reality does not show this autonomy, on the contrary, even more feed is imported and the reliance on energy and specific global partners is rather higher than in 2021, when the Covid-19 pandemic started. One approach to counter this development is keeping resources as long as possible in the loop, avoiding what is called 'waste' and using it as a resource for others or use material in cascades. The different concepts here are 'circular economy' and 'bioeconomy'.

The European Commission has published its vision towards the future[61] but it is still unclear how far it will be applied and brought into effect, how many policies will base on the vision or derived from it and how the new strands of policies will unfold. Nobody expects the Common Agricultural Policy (CAP) to be abolished as it is at the heart of the European Union but changes are usual and expected. How far they go still remains unclear and is under discussion when this report is written. There are several questions: What will happen when the differentiation of the Common Agricultural Policy[62] with its three pillars changes to one pillar only? In each version, the CAP focused on a set of objectives, mobilised a series of policy instruments and allocated budget. There are different paths into the future of the CAP imaginable and the direction from now on is still undecided. The Farm to Fork Strategy from 2020 of the European Commission is not mentioned, anymore. More about policy and governance can be found in Deliverable 4.1 (Tsvetkov et al. 2025).

The strategic dialogue organised by the European Commission[63] and the Vision for Agriculture and Food[64] are a first step into the direction of integrating more and other stakeholders into the food system and debates about it but in these strategic talks, the actors mainly stemmed from the agricultural sector and less from the more powerful industrial actors in the food system who often dictate prices and have much power in the system. Actors from 'the other side of the food system', means nature, plants, animals who are often suffering from our anthropocentric view are also missing in the vision. Our too anthropocentric view might have negative consequences when we humans directly and indirectly reduce biodiversity, exploit and waste natural resources or try to modify ecosystems. This can bring many effects, from better harvests by new technologies over introducing invasive species to monocultures or desertification of landscapes that are becoming useless for food production. Ex ante impact assessments and Foresight are necessary to anticipate and avoid potential damage.

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[61] https://agriculture.ec.europa.eu/overview-vision-agriculture-food/vision-agriculture-and-food_en.

[62] https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-glance_en.

[63] https://commission.europa.eu/topics/agriculture-and-rural-development/strategic-dialogue-future-eu-agriculture_en or https://multimedia.europarl.europa.eu/en/video/timeline-the-common-agricultural-policy_N01-AFPS-210920-TCAP.

[64] https://agriculture.ec.europa.eu/overview-vision-agriculture-food/vision-agriculture-and-food_en.

Creating more European Agency – not only in industry or defence - but also in food security is essential. As the well-known US Brookings institute is already titling: Will Donald Trump make European tech great again?[65] they argue that the current US policies may fire back and lead to a more independent and autonomous Europe. This is a question not only to be taken seriously by European industry but also by agriculture and other players of the food system. We have our chance, we have the knowledge, and we can also welcome researchers from the USA and other countries to learn from and with them.

At the end of our brief outlook, we have more questions than answers, many tensions and contradictions are collected and we can state that the future is neither bright nor dark. It is what we make out of it. The CDIs and academic partners in FOSTER are small puzzle pieces in the large food system – but with good ideas and future visions as well as ideas to improve or even change the system in these small areas, a leverage effect may occur. It is not only money that changes a system, but money is helpful. It is not only power that changes a system. It is the interplay of the different actor groups that shape the future. They are all citizens with rights and with the need to eat food.

The information and futures knowledge pieces of this document will be used as background information or input for the work of CDIs and consortium in the last phase of the project FOSTER and beyond. We welcome all readers to make use of this kind of futures knowledge for the own project or purpose. Other details can be found on https://fosterfoodsystem.eu/.

[65] https://www.brookings.edu/articles/will-donald-trump-make-european-tech-great-again.

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Chapter 8 – Bibliography

8. Bibliography

This bibliography contains the literature cited in this Deliverable 1.4. The detailed links for findings can also be found on the website fosterfutures.eu, where they are integrated into the FOSTER digital Knowledge platform and updated until the end of the project FOSTER in 2026.

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