Monitoring the twin transition of industrial ecosystems

AGRI-FOOD

Analytical report

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Executive summary

Measuring performance and monitoring change within an industrial ecosystem are vital components that enable policymakers and industry stakeholders to track progress over time and obtain valuable feedback on whether the system is moving in the desired direction. This report is a contribution to the 'European Monitor of Industrial Ecosystems' (EMI) project, initiated by the European Commission's Directorate General for Internal Market, Industry, Entrepreneurship, and SMEs, in partnership with the European Innovation Council and SMEs Executive Agency (EISMEA). Its primary objective is to present the current state and the advancements achieved over time in terms of the green and digital transition of the Agri-Food Industrial Ecosystem.

The agri-food industrial ecosystem is essential to Europe. In 2019, 16 million people were employed in the industrial ecosystem, compared to 21.5 million in the entire food supply chain, and the value-added was roughly €603 bn (or 6.4% of the EU total). The agri-food ecosystem is typically formed by SMEs, with 99% of food and drink enterprises being SMEs, and more particularly, micro-enterprises. The EU agri-food ecosystem is known for providing high-quality and safe products, and the EU is the number one food and drink exporter in the world. However, the ecosystem is subject to several challenges and is historically known for its high environmental impact in terms of greenhouse gas emissions (GHG) and energy consumption.

The **agri-food industrial ecosystem is witnessing a shift towards a EU sustainable food system**, powered by green and digital technologies such as biotechnology, advanced materials, advanced manufacturing and robotics and Internet of Things (IoT), to support the twin transition.

In this project, the green and digital transition of industrial ecosystems have been analysed based on a tailored monitoring framework and dataset. The data include a business survey, text mining of company websites, startup data, patent applications, trade and production, investments, online job advertisements and job profiles and environmental impact data. The methodology of the data calculations is included in report on the conceptual and methodological framework.

Key findings about the green transition

Technological trends underpinning the green transition in the agri-food industrial ecosystems have been analysed based on patent statistics and startup data. Within the green transition technologies, **biotechnology, advanced sustainable materials and air & water pollution reduction related technologies lead the patent share within the EU total in the agri-food domain.** The EU27 and USA are on equal level in terms of relative share for these technologies, leading China in all instances.

Biotechnology remained the most important technology that **agri-food tech startups** used related to the twin transition and for innovating within the industry over the period since 2010. Circular economy, production of healthy food and precision agriculture make up for the top-three business models in the startup data set over the indicated period. Further topics related to nutrition as well as alternative proteins round out the top five. Within circular economy business models, startups include firms that address food waste, such as platforms that monitor and reduce waste during production, or AI-based solutions that reduce or valorise food waste. In addition, companies that valorise food/agricultural waste to energy are also included in the category, together with waste valorisation for uptake in other industries. There has been also an increasing number of scaleups in agri-food linked to green transition objectives.

The business survey conducted as part of the project and the text mining of company websites in the agri-food ecosystem found that a significant portion of companies in the agri-food ecosystem has been actively embracing the green transformation.

- 29% of agri-food companies text mined have been found to reference the adoption of green transformation technologies
- 53% of the respondents reported a positive increase in their investments dedicated to the green transition and environmental sustainability over the past five years
- 34% indicated having adopted energy saving technologies
- 32% confirmed that they use recycled materials and 32% any other recycling technologies
- Regarding food waste, 26% of the respondents indicated that they took actions to reduce food waste.

The **agri-food industrial ecosystem is particularly challenged by decreasing investment trends**, related to sector specific challenges in obtaining finance. While the need for modernisation of production is evident, the profit margins themselves are relatively low, reducing incentive for investment and preferring investment in fixed assets. Crunchbase and Net Zero Insights data indicates that private equity and venture capital investment in agri-food tech companies linked to the green transition have been volatile over the past decade. The green technologies attracting investment include **biotechnology and related agri-tech with over €1 bn in investment**, as well as **recycling technologies** with €272 m. Public intervention through Horizon 2020 in the area of *Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy* accounted for €488 m (13% of the total funding).

Workers in the agri-food ecosystem are often low skilled, ageing workers or third-country nationals, sometimes with lower qualification levels. There is an increasing need for high skilled workers such as agronomists, machinery and contact material specialists, C-level employees, sustainability experts, circular and biotech experts, food scientists, food technologists, and high craftsmanship in the different sub-sectors. Many initiatives are taken to address this labour and skills shortage, including education and training, social protection policies, immigration, supporting collaborations, developing partnerships and platforms to share knowledge and best practices including the Pact for Skills. The **supply and demand of skilled professionals relevant for the green transition** has been captured based on LinkedIn data. Within the registered professionals on LinkedIn employed in the agri-food industrial ecosystem, 3% indicated to have environmental protection related skills (green skills). Circular economy is the most important green skill followed closely by low carbon, energy saving technologies and renewable energy. The most popular environmental skills on job advertisements have been corporate social responsibility, energy efficiency and environmental legislations.

Key findings about the digital transition

The digital transition in agri-food is less apparent in technological trends related to the development of patents but show an increase over time. Digitalisation, automation, and the use of new and advanced technologies have proved to enable efficiency gains, sustainability, and circularity in the agri-food ecosystem. For the technologies underpinning the digital transition patenting, advanced manufacturing and robotics as well as Internet of Things (IoT) have the highest relative share.

Agri-food tech startups have played a key role in the transition of the agri-food ecosystem by developing and providing digital tech solutions for agriculture and food production. **Artificial Intelligence** and online platforms have gained ground and witnessed a sharp relative increase at the expense of other software services developed in agri-food tech startups. **Online platforms and mobile applications** have been another popular form of using digital technologies in the agri-food industry and gained further importance since the Covid pandemic period. **Robotics** technology has become more and more important over time as the number of agri-food tech startups established shows, even if the relative importance of the technology compared to others such as AI shifted. Business models related to the digital transition, while less prevalent than the green transition, include precision agriculture, smart sensors agri-food/Internet of Things, and advanced manufacturing and robotics.

With regard to the digital transition, the text mining of company websites found that **approximately 25% of agri-food companies have adopted at least one digital transformation enabling technology**. The business survey with agri-food SMEs provided the following insights:

- 48% of SMEs increased their investment into digital technologies over the past five years
- 35% of the respondents invested between 5 and 9% of revenue in digital transformation.
- 30% of SMEs adopted online platforms
- 27% of agri-food SMEs used cloud technologies
- Big data and related data analytics were applied by 17% of the survey respondents, while Artificial Intelligence was pointed out to be used by 11% of the respondents
- Robotics technologies have been taken up by 11% of the SMEs in the ecosystem
- Internet of Things solutions have been already adopted by 10% of the respondents.

The **supply and demand of skilled professionals relevant for the digital transition** has been captured based on LinkedIn data. Within the registered professionals on LinkedIn employed in the agri-food industrial ecosystem, 6% indicated to have one type of advanced digital skill (including technological knowledge such as IoT, AI, connectivity, big data, advanced farm management software etc). Digital skills are led by **advanced software** for farm management or food production, followed by **cloud** related skills and **artificial intelligence**.

In addition, the **skills demand in the agri-food industrial ecosystem** was analysed based on the skills intelligence insights of Cedefop. Online job advertisements that can be related to the digital transition were analysed for the main digital skills including both general and more advanced digital skills. The top five digital skills that appeared most often over the period from 2019-2022 include **office software, technical drawings, business ICT, but also database and programming** related skills.

1. Introduction

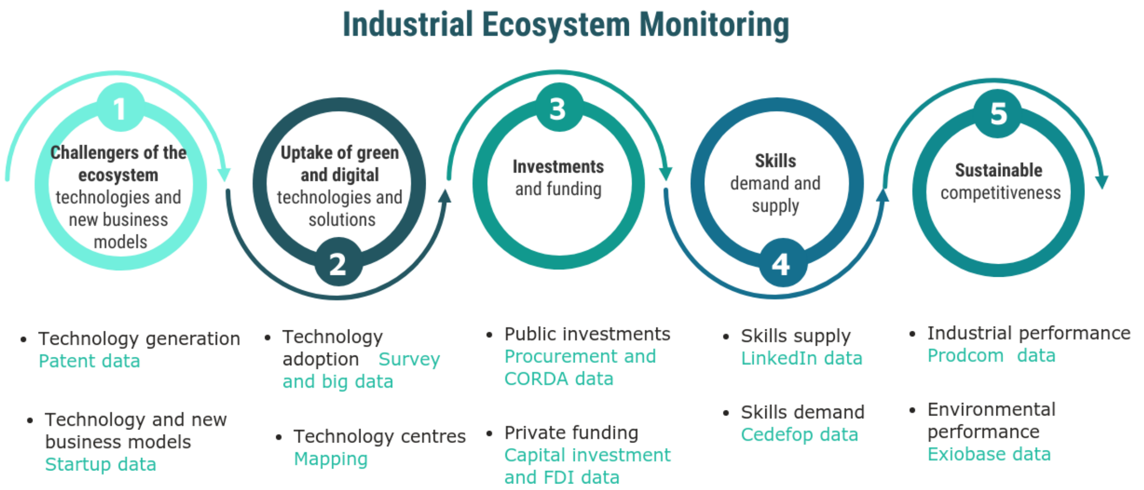
1.1. Objectives

This report has been prepared within the '**European Monitor of Industrial Ecosystems' (EMI)** project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and SMEs Executive Agency (EISMEA). The overall objective of the project is to **contribute to the analysis of the green and digital transformation of industrial ecosystems** and progress made over time.

The EU's updated industrial strategy[1] has identified 14 industrial ecosystems[2] – one of them being **'Agri-food'** - that is in the focus of this report. The industrial strategy defined industrial ecosystems as encompassing all players operating in a value chain: from the smallest startups to the largest companies, from academia to research, service providers to suppliers. The notion of ecosystems captures the complex set of interlinkages and interdependencies among sectors and firms across the EU. Industrial transition is driven by technological, economic, and social changes, and in particular by green and digital technologies and the shift to the circular economy. The process is however characterised by complex, multi-level, and dynamic development. To make transition sustainable, technological change needs to be coupled with new business models, the necessary investments, skills, regulatory framework conditions and behavioural change across the ecosystem.

Measuring performance and change is vital to allow policymakers and industry stakeholders to track progress over time and get feedback whether the system is moving in the desired direction. To measure performance, a dedicated **monitoring and indicator framework** has been set up for the purposes of this project with an aim to capture them in regular intervals (see the overview of the monitoring framework in Figure 1).

Figure 1: Overview of monitoring industrial ecosystems and relevant data sources



Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

[1] European Commission (2020). A New Industrial Strategy for Europe, COM/2020/102 final and European Commission (2021). Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery, COM(2021) 350 final
[2] The 14 industrial ecosystems include: construction, digital industries, health, agri-food, renewables, energy intensive industries, transport and automotive, electronics, textile, aerospace and defense, cultural and creative culture industries, tourism, proximity and social economy, and retail

The indicator framework includes a **set of traditional and novel data sources that allow shedding new light on ongoing transformation patterns.** The novelty of the analysis lies in the exploratory and innovative data sources used across the different chapters. Due to its effort to analyse industrial ecosystems using a more or less standardised set of indicators, the study cannot address all aspects of the green and digital transition. Therefore, additional analysis and industry-specific data sources should be used to supplement a full assessment.

The **methodological report** that sets the conceptual basis and explains the technical details of each indicator is found in a separate document uploaded on the EMI website. Moreover, some of the specific industry codes used throughout this analysis have been also included in Appendix B. The green and digital technologies considered in this study are presented in Figure 2.

Figure 2: Main technologies monitored in the project

Green transformation
Advanced Sustainable Materials
Biotechnology
Energy Saving technologies
Clean Production technologies
Renewable Energy technologies
Solar Power
Wind Power
Other (geothermal, hydropower, biomass)
Recycling technologies
Circular business models

Digital transformation
Advanced Manufacturing & Robotics
Advanced Manufacturing
Robotics
Artificial Intelligence
Augmented and Virtual Reality
Big Data
Cloud technologies
Blockchain
Digital Security & Networks/ Cybersecurity
Internet of Things
Micro- and Nanoelectronics & Photonics
Online platforms

Source: Technopolis Group, IDEA Consult and Fraunhofer ISI

This report contributes to the analysis of the **key pillars put forward in the 'Blueprint for the development of transition pathways'**[3] of the Industrial Forum developed in 2022.

1.2. Definition of the ecosystem

This section highlights the definitions used to **delineate the agri-food industrial ecosystem** (see Figure 3).

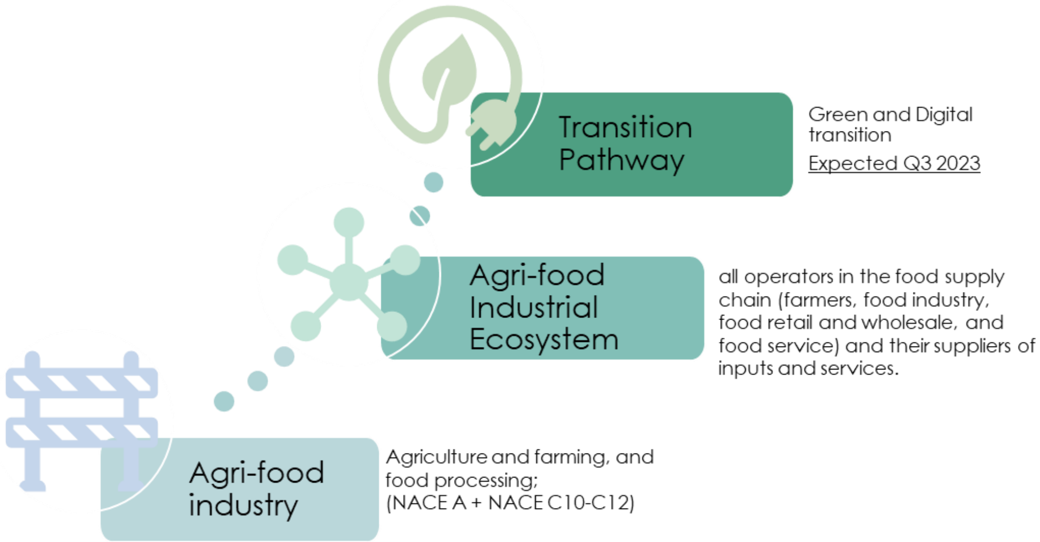
The agri-food industry typically refers to both agriculture & farming (NACE A) and food processing activities (NACE C10-12). For the purpose of this study, we focus on the agri-food industrial ecosystem as it is outlined in the Industrial Strategy[4] and Annual Single Market Report[5].

According to the European Commission's Annual Single Market Report 2021, the agri-food industrial ecosystem "covers all operators in the food supply chain (farmers, food industry, food retail and wholesale, and food service) and their suppliers of inputs and services

[3] https://ec.europa.eu/docsroom/documents/49407/attachments/1/translations/en/renditions/native
[4] European Commission European Industrial Strategy https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en
[5] European Commission (2022) Annual Single Market Report 2022 https://ec.europa.eu/docsroom/documents/48877

(seeds, pesticides, fertiliser, machinery, packaging, repair, transport, finance, advice and logistics). The ecosystem hence has a very long border – and overlaps – with the Tourism and the Retail ecosystems."[6]

Figure 3: Positioning of the agri-food industrial ecosystem definitions



Source: IDEA Consult based on the definition of the agri-food ecosystem as described in the Annual Single Market Report (2022)

Practically following this definition, this report will, in data collection and analysis, focus on activities in agriculture and farming, and food and beverages. In doing so, the following activities will be excluded:

- Forestry & logging
- Cannabis
- Equestrian
- Transportation related to food delivery and logistics
- Industrial equipment and machinery related to agri-food
- Chemicals, especially pesticides, fertiliser and other agricultural chemicals
- Hunting & trapping
- Cooking and recipes

For each of the fourteen industrial ecosystem, a pathway for the green and digital transition, i.e., a transition pathway, is or will be developed. For the agri-food ecosystem, this transition pathway is planned for Q4of 2023.[7],[8]

[6] European Commission (2021) Annual Single Market Report 2021 https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[7] Transition pathways for European industrial ecosystems. https://single-market-economy.ec.europa.eu/industry/transition-pathways_en
[8] European Commission (2023) Annual Single Market Report 2023. https://single-market-economy.ec.europa.eu/system/files/2023-01/ASMR%202023.pdf

1.3. Industry state of play

The agri-food ecosystem is essential to Europe. In 2019, 16 million people were employed in the industrial ecosystem[9], compared to 21.5 million in the entire food supply chain[10], and the value-added was roughly €603 bn (or 6.4% of the EU total).[11] On average, the agri-food industrial ecosystem has marginally reduced its total employment between 2015 and 2019 and increased its gross value-added growth, yet to a modest extent when compared to the other industrial ecosystems[12]. The agri-food ecosystem is typically formed by SMEs, with 99% of food and drink enterprises being SMEs, and more particularly, micro-enterprises. While only 1% of food and drink companies are leading large enterprises, they employ 40% of the workforce and generate more than half of turnover of the sector (€442 bn total). While farms are not classified as SMEs in business statistics, many of them are, however, small: only 1% of the EU farm holdings have an annual turnover of over €500 000.[13]

Production performance of the agri-food industrial ecosystem can be represented in many different ways and can give insight into the economic performance of the sector or ecosystem depending on the dataset in question. When available across time series, production performance allows to position the overall evolution of the sector or industrial ecosystem. While primary agricultural and fishery production can be represented in the form of e.g. crop production, livestock population, meat production, milk production or marine fishing areas catch, the food part of 'agri-food' is much wider, covering the preparation, distribution and service of food and drink.[14] The food and drink industry is a leading manufacturing industry in the EU in turnover, value added and investment.[15] The value of sold production in the EU and experienced a roughly 14% increase in activities from 2011 to 2021.[16]

The **total production value for the agri-food industrial ecosystem gives insight into the production performance of the overall ecosystem**. Data on production were extracted from Eurostat.[17] Prodcom statistics reveal the total values of production of manufactured goods carried out by enterprises located in EU27 over 14 years (from 2008 until 2021). The agri-food industrial ecosystem is delineated by the NACE 2 classification and weights identified in the Annual Single Market Report.[18] Results depicted in Figure 4 present the weighted sum of production of manufactured goods aggregated at NACE 2-digit level for the agri-food industrial ecosystem (thousands of euros).

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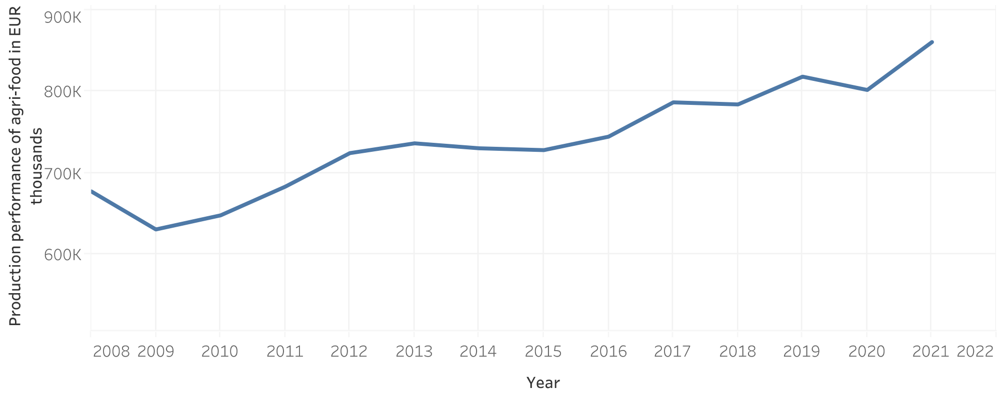
[9] European Commission (2022) Annual Single Market Report 2022. https://ec.europa.eu/docsroom/documents/48877
[10] Food Drink Europe (2022) Data & trends EU Food and Drink Industry https://www.fooddrinkeurope.eu/wp-content/uploads/2023/01/FoodDrinkEurope-Data-Trends-2022-digital.pdf
[11] European Commission (2022) Annual Single Market Report 2022. https://ec.europa.eu/docsroom/documents/48877
[12] European Commission (2022) Annual Single Market Report 2022. https://ec.europa.eu/docsroom/documents/48877
[13] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[14] Eurostat (2022) Key figures on the European food chain – 2022 edition.
[15] Food Drink Europe (2022) Data & trends EU Food and Drink Industry https://www.fooddrinkeurope.eu/wp-content/uploads/2023/01/FoodDrinkEurope-Data-Trends-2022-digital.pdf
[16] Eurostat (2022) Industrial production statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Industrial_production_statistics#The_five_largest_manufacturing_activities
[17] Eurostat Prodcom https://ec.europa.eu/eurostat/web/prodcom/data/database
[18] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf

Figure 4: Production performance of agri-food industrial ecosystem in EUR thousands for 2008-2021



Source: IDEA Consult based on Eurostat [prom]

Continuous growth of the production value underlying the agri-food industrial ecosystem can be observed over the indicated period, highlighting the increasing importance of agriculture and food for internal consumption and exports. The years 2009 and 2020 show minor dips, which can be associated with the financial crisis and the COVID-19 pandemic, however the growth trend outweighs them.

During the **COVID-19 pandemic**, the agri-food ecosystem suffered from sudden challenges (especially during the first wave), but has proven to be resilient overall[19],[20]. Some important challenges that arose were the sudden changes in consumption patterns and the disappearance of key outlets. For instance, in high-income countries, consumers became platform clients contributing to shifting towards more digital transactions[21], the sales of frozen and packaged foods increased steeply[22], the demand for healthy and local food increased, and, at some moments, there were issues with panic buying and stockpiling by consumers. Also, while the supply chains of the food industries remained relatively resilient, there were bottlenecks due to the closed borders, which caused distortions in the supply of inputs and transport of goods, and a shortage of labour.[23] [24] In the end, the production levels and turnover in the industry decreased slightly, but less than in many other industries, and recovered fairly well. Currently, the **war in Ukraine** poses serious threats for many countries in terms of food security given the excessive dependence on essential products, such as grains, fertiliser and energy.[25]

Challenges for the industry

The EU agri-food ecosystem is known for providing high-quality and safe products, and the EU is the number one food and drink exporter in the world.[26] However, the ecosystem is subject to several challenges and is historically known for its high environmental impact in terms of greenhouse gas emissions (GHG) and energy consumption (as further analysed in Chapter 5).

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[19] European Commission (2021) Annual Single Market Report 2021.
[20] European Parliament. Policy Department for Economic, Scientific and Quality of Life Policies. (2021). Impacts of the COVID-19 pandemic on EU industries.
[21] Food and Agriculture Organisation (FAO). (2022). Future of Food.
[22] European Parliament. Policy Department for Economic, Scientific and Quality of Life Policies. (2021). Impacts of the COVID-19 pandemic on EU industries.
[23] European Parliament. Policy Department for Economic, Scientific and Quality of Life Policies. (2021). Impacts of the COVID-19 pandemic on EU industries.
[24] FoodDrink Europe. (2020). Economic Bulletin Q2 of 2020. https://www.fooddrinkeurope.eu/resource/economic-bulletin-q2-of-2020/
[25] Food and Agriculture Organisation (FAO). (2022). Future of Food. https://www.fao.org/documents/card/en/c/cc0959en
[26] European Commission (2021) Annual Single Market Report 2021.

When it comes to labour productivity and innovation, the EU food industry is lagging slightly behind. The ecosystem is known for its dispersed innovation research and the EU food and drink industry has a lower R&D investment intensity than some of its global competitors[27],[28]. That being said, innovation in agri-food is needed in order to meet the food demands of the future (increasing pressure per hectare), while contrasting the consistently high emissions due to the use of non-renewable energy sources in agri-food chains. Both public and private R&I investments are needed in order to foster the necessary developments.[29]

Overall, the agri-food ecosystem is using more and more digital, technologies yet this may still be regarded as insufficient. This is because for many farmers (who are often confronted with price variations and low incomes[30]) and agri-food companies (of which 99% are SMEs) the economic feasibility of investing in technologies like robotics and sensors remains a significant hurdle. On top of that, many farmers and food processors are not aware or motivated to take up new technologies as it drastically changes the way they work and the gains of such technologies are often insufficiently demonstrated.[31] At the same time, the ecosystem struggles to attract high-quality staff, and the digital skills of farmers and food processors (which may go hand-in-hand with the aging of the workforce) are often insufficiently developed.[32]

Globally, the growing world population, high urbanisation rates, and climate change are rapidly posing a series of grand challenges to the agri-food industry. These societal changes make that securing sufficient and safe food inclusively and sustainably will require major transformations in the whole food system. Particularly, natural resources will need to be used more efficiently and processes will need to be optimized, thereby expanding the output and significantly reducing food waste and losses and environmental impact. [33]

At the same time, food prices have significantly increased in recent years, with food being around 30% more expensive than in the 1990s, and consumer food prices have increased faster than the general price index between 2000 and 2020.[34] This is mainly caused by inflation, high energy prices, and increasing transport, packaging, machinery, and labour costs as well as rising costs of animal feed and fertilizers.[35] Additionally, consumers are shifting demand towards more environmentally and socially responsible, nutritious, and quality products, creating space for innovations in food, such as the use of alternative proteins to replace meat.[36] [37] [38]

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[27] Food Drink Europe. (2022). Data & Trends of The European Food and Drink Industry 2022. https://www.fooddrinkeurope.eu/resource/data-trends-of-the-european-food-and-drink-industry-2022/

[28] European Commission (2021) Annual Single Market Report 2021.

[29] European Commission (2023) Food systems Research and innovation investment gap study: Policy report https://op.europa.eu/en/publication-detail/-/publication/1747dc15-be80-11ed-8912-01aa75ed71a1

[30] European Commission (2021) Annual Single Market Report 2021.

[31] European Commission (2020). Advanced Technologies for Industry. Sectoral Watch. Technological trends in the agri-food industry. https://ati.ec.europa.eu/reports/sectoral-watch/technological-trends-agri-food-industry

[32] OECD (2023). Labour and skills shortages in the agro-food sector. https://www.oecd.org/publications/labour-and-skills-shortages-in-the-agro-food-sector-ed758aab-en.htm

[33] Food and Agriculture Organisation (FAO). (2022). Future of Food. https://www.fao.org/documents/card/en/c/cc0959en

[34] Food and Agriculture Organisation (FAO). (2022). Future of Food. https://www.fao.org/documents/card/en/c/cc0959en

[35] Food Drink Europe. (2022). Economic Bulletin on Input Costs up to June/July/August 2022. https://www.fooddrinkeurope.eu/resource/economic-bulletin-on-input-costs-jun-aug-2022/

[36] The European Consumer Organisation (2020). One Bite At A Time: Consumers And The Transition To Sustainable Food. Analysis of a survey of European consumers on attitudes towards sustainable food. https://www.beuc.eu/sites/default/files/publications/beuc-x-2020-042_consumers_and_the_transition_to_sustainable_food.pdf

[37] EIT Food (2021). The top 5 trends for the agrifood industry in 2021. https://www.eitfood.eu/blog/the-top-5-trends-for-the-agrifood-industry-in-2021#3_-alternative-proteins-continue-to-gain-grounds-with-consumers

[38] EIT Food (2023). Top 5 European food trends in 2023. https://www.eitfood.eu/blog/top-5-european-food-trends-in-2023

2. Challengers of the industry: green and digital technological trends

Key findings

Maintaining sustainable food systems is imperative for future security and a healthy society[39]. Technologies including digital technologies and clean technologies that reduce or eliminate negative environmental impact promise to increase safe and healthy food production and save natural resources. Technological trends related to the twin transition in the agri-food industrial ecosystems have been analysed based on patent statistics and startup data. These two metrics yield different types of information.

The EU27 had the highest share of the world patent applications in agri-food in 2020, although its leadership has been continuously declining since 2010. This relative decline is due to the increasing patenting activity in China and South Korea. The USA has managed to keep its position more or less stable over the past years.

The green transition in agri-food has been enabled by a high number of patent applications most related to **biotechnology, advanced materials and water pollution reduction**. Digital technologies are less apparent in patents but show an increase over time. **Digitalisation, automation, and the use of new and advanced technologies have proved to enable efficiency gains, sustainability, and circularity** in the agri-food ecosystem. For the technologies underpinning the digital transition patenting, **advanced manufacturing and robotics as well as Internet of Things** have the highest share.

On the other hand, tracking startup data has provided valuable insights into the innovation portfolio within the agri-food sector. Results have indicated indiating that they play a key role in the transition of the agri-food ecosystem by developing and providing digital and clean tech solutions for agriculture and food production. **The creation of agri-food tech startups related to the twin transition has increased sharply since 2013,** more in the field of digital technologies than for environmental solutions. Despite these positive figures, digitalisation in the agri-food ecosystem is increasing is still regarded as insufficient.

Biotechnology remained the most important technology that agri-food tech startups used related to the twin transition and for innovating within the industry over the period since 2010. **Artificial Intelligence and online platforms have gained ground** and witnessed a sharp relative increase at the expense of other software services developed in agri-food. **Circular economy, healthy food and precision agriculture** make up for the top-three business models in the startup data set over the indicated period. Further topics related to nutrition as well as alternative proteins round out the top five.

Within **circular economy business models**, startups include firms that address food waste, such as platforms that monitor and reduce waste during production, or AI-based solutions that reduce or valorise food waste. In addition, companies that valorise food/agricultural waste to energy are also included in the category, together with waste valorisation for uptake in other industries.

Business models related to the digital transition, while less prevalent than the green transition, include **precision agriculture**, **smart sensors agri-food/Internet of Things**, and **advanced manufacturing and robotics**.

[39] see https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

Technological trends in the agri-food industrial ecosystem are driven by the need for a green and digital food system that sustainably responds to the needs of a growing world population.

Green transition in the agri-food industrial ecosystem is driven by the vital need to reduce the environmental impact of the industry by improving energy and natural resource efficiency, reducing emissions, decreasing food waste and losses while exploring innovations such as alternative proteins and sustainable packaging to improve the environmental impact. This is apparent from the use of green technologies, such as recycling technologies, energy saving technologies and renewable energy technologies as well as biotechnology. The latter, food biotechnology, is an umbrella term covering a vast variety of processes for using living organisms—such as plants, animals, microbes, or any part of these organisms—to develop new or improved food products.[40]

Digitalisation, automation, and the use of new and advanced technologies are indispensable to improve the efficiency, sustainability, and circularity in the agri-food ecosystem. For instance, advanced manufacturing and robotics are indispensable for smart food processing, hence increasing productivity and food safety.[41] Several recent reports forecast a Compound Annual Growth Rate (CAGR) of more than 10% until 2028 in food robotics.[42] Other digital technologies are projected to have a great impact on the agri-food ecosystem and food processing in the industry, namely big data, Internet of Things (IoT), use of digital twins and blockchain. Systems of connected sensors, devices, machinery, and data analytics are helping the sector to improve efficiency, quality, and safety while reducing costs, waste, and time to market. This revolution is formalized by the concept of Industry 4.0 of which the derivative 'Factory 4.0' refers to such smart factories with automated processes, digitised operations, and connectivity throughout the factory floor for real-time monitoring through data collection and analysis.

While the recent figures acknowledge that digitalisation in the agri-food ecosystem is increasing, it is still regarded as insufficiently high.[43] Several challenges are hindering the uptake of digitalisation, such as the high costs of robotic equipment, and lack of awareness, skills and education on the latest technological developments.

The Methodological Report of the European Monitor of Industrial Ecosystems (EMI) project outlines the core technologies considered as a part of the green and digital transition in this project, with industry specific technologies highlighted for the agri-food industrial ecosystem.

In the next sections, technological trends and new business models in the agri-food ecosystem have been captured by a range of different indicators, stemming from different data sources, such as patent and startup data. In addition to the data presented here, there are other sources that report on startups, including EIT Food. More details about the startups mapped and the programmes available can be found on their community website for startups.[44]

[40] The Food Industry Association (2013). Food Biotechnology. https://www.fmi.org/blog/view/food-safety-backgrounders/2013/04/01/food-biotechnology-general-scientific-principles-safety-and-regulations
[41] European Commission (2021). Advanced Technologies for Industry – Product Watch Robotics for food processing and preparation. https://ati.ec.europa.eu/reports/product-watch/robotics-food-processing-and-preparation
[42] Knowledge Based Value (2023). Europe Food Robotics Market Size, Share & Industry Trends Analysis Report By Application. https://www.kbvresearch.com/europe-food-robotics-market/; Report Linker (2020). Europe Food Robotics Market Forecast 2019-2028. https://www.reportlinker.com/p05914897/EUROPE-FOOD-ROBOTICS-MARKET-FORECAST.html
[43] European Commission (2021) Annual Single Market Report 2021. https://commission.europa.eu/system/files/2021-05/swd-annual-single-market-report-2021_en.pdf
[44] EIT Food (2023) Startups https://www.eitfood.eu/community/startups

2.1. Technological trends

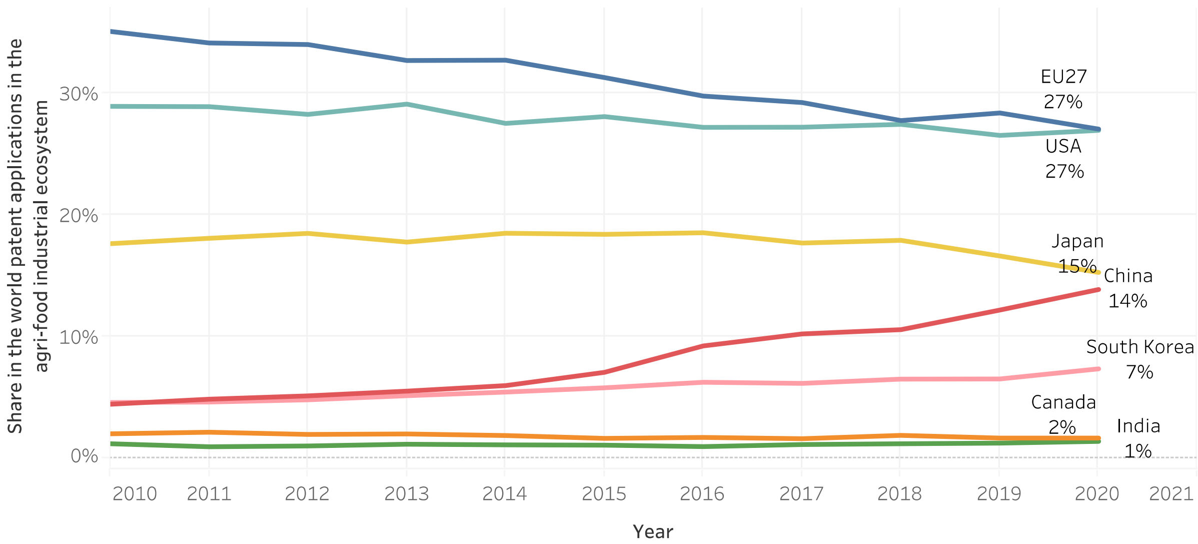
Technology developments has been tracked by patenting activities related to the specific sectoral activities based on patent-based classifications. The analysis is based on 'transnational patents' (Frietsch/Schmoch, 2010) (i.e. PCT/WIPO filings or direct applications at the EPO, excluding double counts) and was conducted on an extended version of the EPO's Worldwide Patent Statistical Database that Fraunhofer ISI implemented locally. Technologies-relevant-to-ecosystems, in this case the agri-food industrial ecosystem, are defined based on a search that refers to patent classifications (IPC) and/or use keywords to identify relevant applications across classes. The detailed methodology is presented in the Methodological Report.

In the agri-food sector, the number of patents tends to be lower compared to other ecosystems. This can be attributed to many companies choosing to protect their innovations through trade secrets, recipes, and know-how instead of seeking patent protection. As a consequence, patents are typically concentrated in specific technological fields such as digitalization, biotechnology, or processing technology.

In fact, according to a focus group with FoodDrinkEurope carried for a recent DG RTD report, only 10% of R&I undertaken by companies in the food sector is patented[45].

Figure 5 presents the trends in the evolution of patent applications related to the agri-food industrial ecosystem as a share of world patent applications and shows a general reduction over time.

Figure 5: Trends in the evolution of patent applications related to the agri-food industrial ecosystem as shares in the world patent applications



Source: Fraunhofer calculations, Patstat

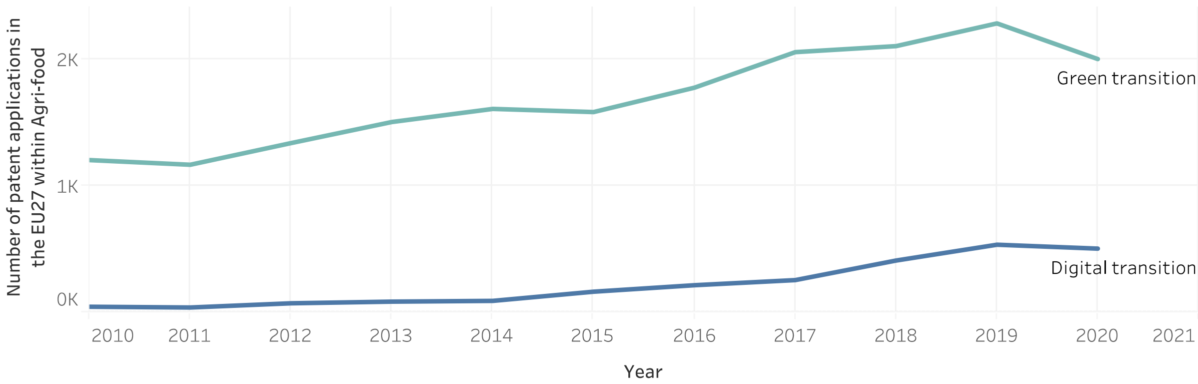
A more detailed analysis was done linked to the digital and green transition. The analysis of digital and green patent applications related to the agri-food industrial ecosystem was based on the analysis of the 2022 edition of the OECD REGPAT database. The industrial ecosystem was classified into a set of Cooperative Patent Classification (CPC) categories. A text mining algorithm was used to search for key words and their specific association in the text of patent documents as well as in the Cooperative Patent Classification nomenclature. By using this approach, we can representatively capture the patenting

[45] European Commission (2023). Food Systems. Research and innovation investment gap study: policy report. Available at: https://op.europa.eu/en/publication-detail/-/publication/1747dc15-be80-11ed-8912-01aa75ed71a1

activity in agri-food and observe trends in distribution and development as indicated in this section. The classification of green transition technologies builds upon the OECD green patents classification that we augmented by including additional technologies particularly relevant to the ecosystems and extended the CPC association. The identification of digital transition technologies builds on earlier work on Industry 4.0 (Balland and Boschma 2021) and includes additional technologies particularly relevant to the ecosystem.

Building on this, Figure 6 shows the number of green and digital patent applications over the years from 2010 onwards. Overall, it can be seen that the trends over time for green transition are considerably higher than for the digital transition in the agri-food industrial ecosystem and the related patenting activity. That being said, 2020 shows a decline for the number of patent applications related to the green transition within agri-food which could potentially be attributed to COVID-19.

Figure 6: Trends over time



Source: Balland, 2022 based on PATSTAT

Zooming in on the specific technologies related to the green and digital transition, Figure 7 shows the distribution of patents by digital and green transition related technologies applied in the agri-food industrial ecosystem. Within the green transition technologies, **biotechnology, advanced sustainable materials and air & water pollution reduction** related technologies lead the patent share within the EU total in the agri-food domain. The EU-27 and USA are on equal level in terms of relative share for these technologies, leading China in all instances. For the technologies underpinning the digital transition patenting, **advanced manufacturing and robotics as well as Internet of Things (IoT)** have the highest relative share. The EU27 leads for IoT in the share of patenting activities.

Figure 7: Patents distribution in agri-food by digital and green transition related technologies

Technologies	EU27 share of tech within EU total	USA comparison	China comparison
Green transition			
Biotechnology	48,07%		
Advanced sustainable materials	13,68%		
Air & Water pollution reduction	5,99%		
Waste management	4,38%		
Biofuels	2,82%		
Water related adaptation technologies	2,49%		
Recycling technologies	2,21%		
Batteries	1,01%		
Solar energy	0,88%		
Greenhouse gas capture	0,28%		
Hydrogen	0,28%		
Other energy storage	0,24%		
Wind energy	0,20%		
Geothermal energy	0,04%		
Marine & hydro energy	0,04%		
Digital transition			
Advanced manufacturing and robotics	9,13%		
Internet of Things	3,91%		
Artificial intelligence	1,49%		
Cloud computing	0,36%		
Smart grids	0,16%		
Cybersecurity	0,12%		
Blockchain	0,08%		

Legend: Lower relative share — Higher relative share

Source: Balland, 2022 based on PATSTAT

2.2. Tech startups linked to the twin transition in the agri-food ecosystem

Trends in agri-food tech startups have been captured by analysing the Crunchbase and Net Zero Insights[46] data sources. In the context of this report, agri-food tech startups have been defined as any company providing a solution or technology that supports the green and digital transition of the Agri-food ecosystem.

Net Zero Insights is a database specialised in capturing environmental sustainability driven startups, while Crunchbase collects data primarily on venture capital-backed tech companies. Digital and green technologies have been linked to startups within agri-food and are described in the methodological report (the selected industry tags and technologies please see in Annex A).

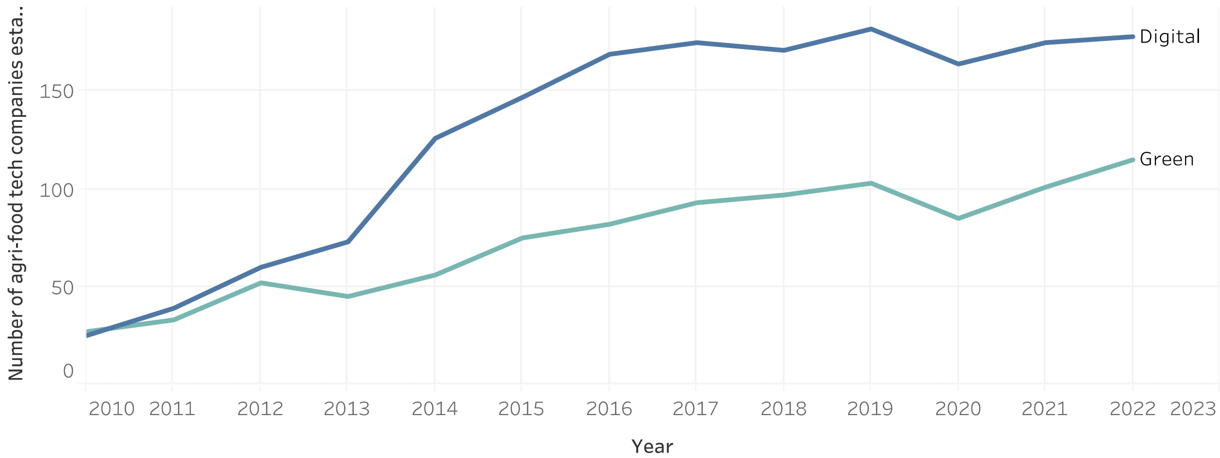
Figure 8 presents the creation of these agri-food tech companies over time, where 2 748 digital and green startups have been identified over the period from 2010 to 2022. Digital tech startups in the agri-food context include companies that address a particular challenge in the industry with the help of digital technologies (such as using Internet of Things to enhance productivity in agriculture or offering real time data analytics specifically in food production). Green-tech startups have a focus on environmental sustainability and provide a clean, less polluting solution such as reduction of food waste with sorting technologies or

[46] https://netzeroinsights.com/ and www.crunchbase.com

a software to make better predictions in farming. It is not surprising that a growth can be observed over time in the number of both types of companies, in particular since 2013. Digital technologies witnessed a stronger increase but are closely followed up by green-tech companies most recently. A dip in the year 2020 can be also observed which can be attributed to COVID-19.

Please add a sentence on where the eco-system stands compared to other eco-systems

Figure 8: Evolution in the number of green and digital agri-food tech companies established over time

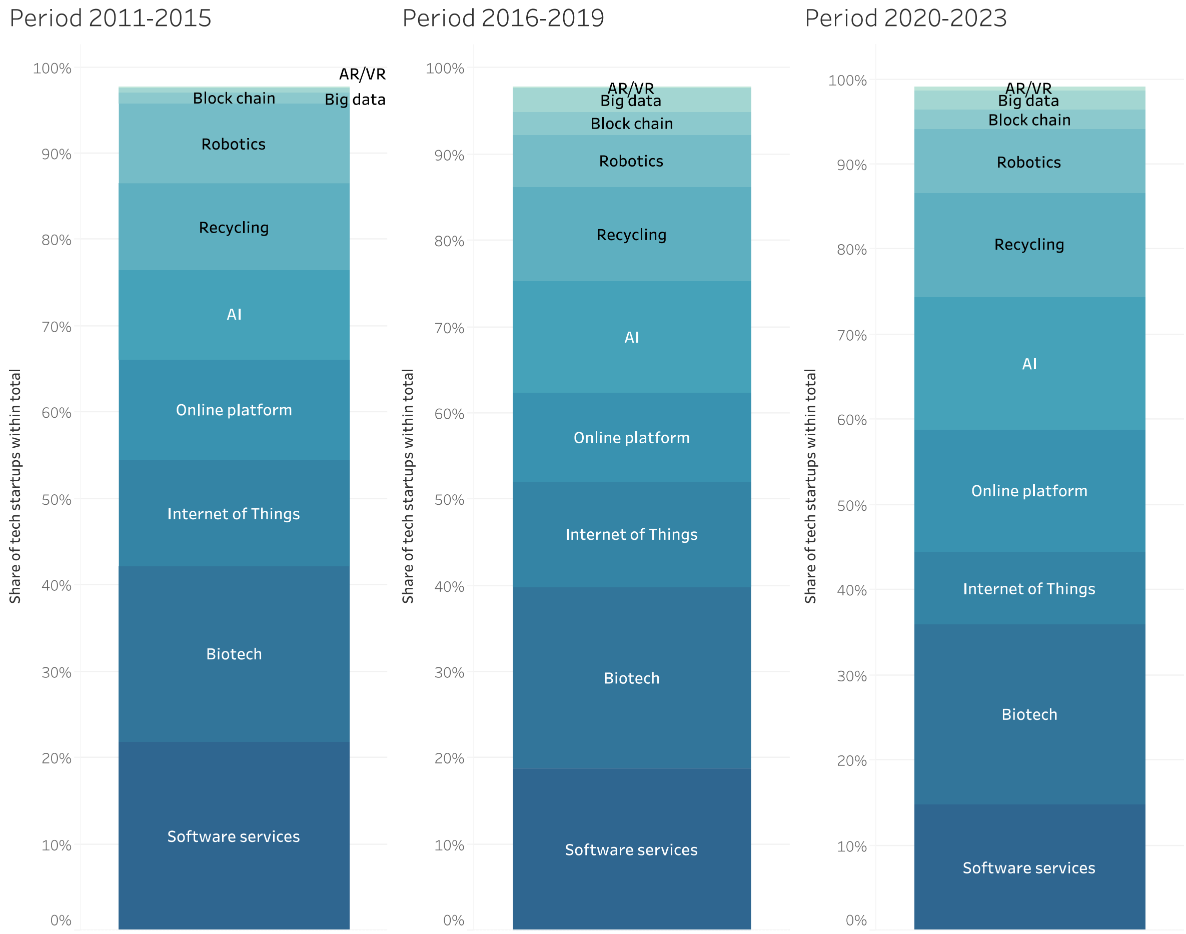


Source: Technopolis Group based on Net Zero Insights and Crunchbase, 2023

Zooming in on the specific technologies related to the green and digital transition, Figure 9 presents the share or agri-food tech startups per technology. Three periods of observation are presented in order to depict change in the relative importance of technologies over time. The picture shows that the type of digital/green/other technologies relevant for agri-food remained the same but their relative importance changed. Artificial Intelligence and online platforms increased in importance significantly over time. Blockchain and augmented and virtual reality solutions although still niche have also gained some more ground.

Biotechnology has been the most important technology applied within agri-food among others also for sustainability purposes and creating healthier food. For example, knowledge of advanced emulsions, micro-encapsulations and cell culture are being used to create alternative solutions for a healthier and environmentally sustainable nutrition.

Figure 9: Share of agri-food tech startups per technology established over three selected periods (2011-2015; 2016-2019 and 2020-2023) within total number of agri-food tech firms in the database



Source: Technopolis Group based on Net Zero Insights and Crunchbase, 2023

Artificial Intelligence is increasingly explored by agri-food tech startups in various new applications throughout the agri-food value chain. AI allows farmers and food production companies to turn data such as on soil quality, crop yields, production volumes or prices into insights and better decisions. Based on Crunchbase 105 AI startups have been identified established after 2010 and with headquarters in the EU27, where **62% of these companies are serving agriculture and 38% the food and beverage production** industries.

Most of these startups use AI to analyse agricultural data and can for example determine the amount of fertilisers, fungicides and pesticides needed per land or make forecasts about crop development and allow for traceability. AI is usually linked to sensors.

Many of these startups are developing autonomous robots using deep learning-based computer vision for example for weed elimination or vineyard crawling. They are often linked to precision farming solutions.

In the field of food production, AI is used as part of food data science and food data monitoring. It allows gathering intelligence about targeted food market segments and provide insights into the taste of customers. It is also used for logistics management and supply chain management in combination with Internet of Things technologies.

A large share of these AI solutions promise to solve inefficiencies in the food system, climate management, disease prevention, energy use, natural disaster response. Several startups are related to food waste, where AI is used for better planning and elimination of waste during the food production process.

Box 1: Artificial Intelligence for environmental sustainability and the circular economy in agri-food[47]

Connecterra[48] is a software developer from the Netherlands specialised in the dairy industry. It created Ida, an AI that connects farmers along the value chain to identify issues on the farm, recommend solutions and support farmers to make the transition to sustainable farming.

SPRK[49] is a developer of an AI-based distribution platform addressing the food waste challenge. It offers a reduction in food disposal costs and an artificial intelligence-based online food distribution system to produce and procure food for cities and surplus food for the poor by establishing a pragmatic and functioning circular economy.

Foodforecast[50] is a German tech company that uses AI to reduce food waste. It analyses historical bakery store sales and combines them with influencing factors to create an automated sales forecast for the next order.

Online platforms and mobile applications have been another popular form of using digital technologies in the agri-food industry and gained further importance since the Covid pandemic period. These firms have developed online marketplaces and trading platforms for farmers and contractors, or more targeted for regenerative agriculture. Linkinfarm[51] offers farmers the opportunity to outsource the management of their land in order to maintain and transmit their assets. Other examples include mobile applications that allow tracking the origin of ingredients and verifying the certificates of organic products. Other apps create healthy meal plans and share food product recommendations.

Robotics has a range of use cases in agriculture and food production such as in picking, packing and transporting of fruit, vegetables and other food products. It allows sophisticated automation in food processing. Robotics technology has become more and more important over time as the number of agri-food tech startups established shows, even if the relative importance of the technology compared to others such as AI shifted.

Box 2: Robotics tech startups in agri-food

Naio Technologies[52] develops and markets machines for agriculture and viticulture. It features electric tools for weeding, hoeing, and harvesting that help farmers collect and harvest their products. The company specialises in agriculture, AI and robotics. Naio Technologies was founded in 2011 and headquartered in France.

Odd.Bot [53]develops weed removal robots that provide a higher yield and allow for reducing the use of polluting chemicals.

Business models present the patterns related to the underlying technologies, where in some cases one business model will rely on a combination of technologies (e.g., precision agriculture relies on a combination of sensors, IoT, platforms, etc.). Figure 10 presents the share of agri-food tech startups per main business model over the period 2018-2022. Circular economy, healthy food and precision agriculture make for the top-three business models in the startup data set over the indicated period. Further topics related to nutrition as well as alternative proteins round out the top five.

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[47] The companies presented in Box1 have been selected to show three different AI applications that enable the green transition of the agri-food ecosystem.
[48] https://www.connecterra.io/about/
[49] https://sprk.global/
[50] https://foodforecast.com/ueber-foodforecast/
[51] https://www.linkin.farm/
[52] https://www.naio-technologies.com/
[53] https://www.odd.bot/

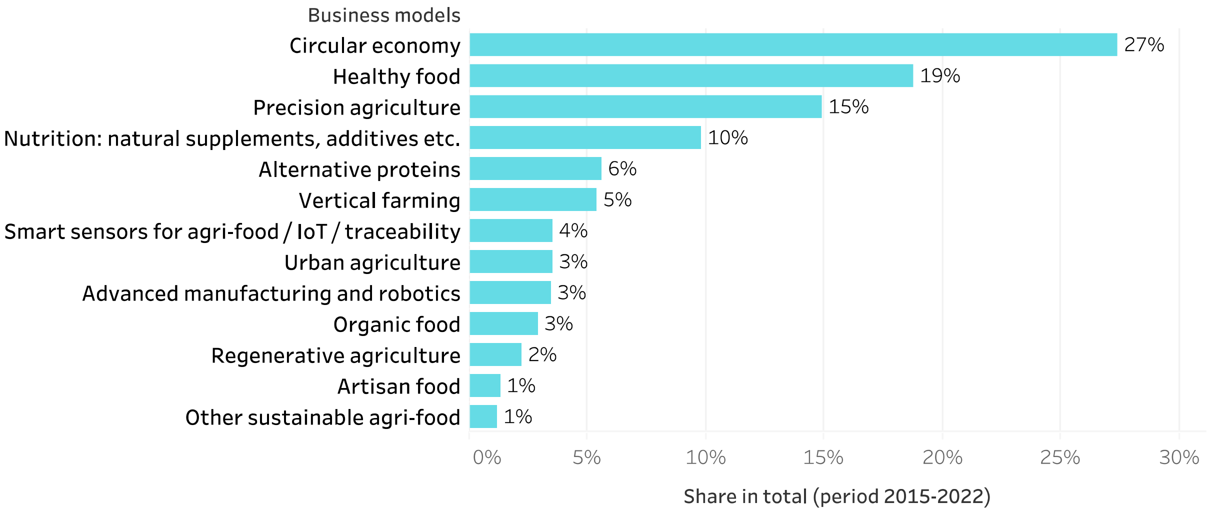
Within the **circular economy business model**, we find diverse companies. There are firms that address food waste, such as linkee[54], an association that collects and surplus food to people in precarious situations. There are also platforms that monitor and reduce waste during production, or AI-based solutions that reduce or valorise food waste.

In addition, waste to energy valorisation companies are also included. For example, BIO2CHP[55] is company that offers micro-scale bio-based energy production units for small and medium agro-industries with organic wastes. Other circular economy business models focus on waste valorisation for uptake in other industries, such as textiles cosmetics or construction. As an example, Yellow Pallet[56] is a company that produces and sells shipping pallets and blocks made from 100% sustainable agri-fibres, including banana, bamboo, coconut, and pineapple waste.

The **healthy food business model** relates to the use of ingredients, human health, organic food as well as supplements and additives. A selection of examples of companies includes the seller and developer of nature-based ingredients Fluxome (acquired by Evolva)[57], and the protein food focused Goodlife company[58] and MyLab Nutrition Group[59].

Alternative proteins as a business model includes a growing number of firms is innovating using high-value insect protein or natural, plant-based meat alternatives. In some examples, food products like gels, powders and dietary fibres are made from specialised proteins obtained from water lentils. EntoCube presents a Finnish example of farming insects.[60]

Figure 10: Share of agri-food tech startups per main business model over the period 2015-2022



Source: Technopolis Group based on Net Zero Insights and Crunchbase, 2023

Business models related to the digital transition, while less prevalent than the green transition, include **precision agriculture**, **smart sensors agri-food/Internet of Things**, and **advanced manufacturing and robotics**. Examples of precision agriculture

[54] See https://linkee.co/a-propos/
[55] See https://www.bio2chp.com/about-us.html
[56] See https://www.yellow-pallet.com/
[57] See https://evolva.com/
[58] See https://www.goodlife-company.de/
[59] See https://www.mylabnutrition.net/
[60] See https://entocube.com/en/

startups include Dilepix[61], Agrirobotica[62] and Polariks[63], enabling vision and monitoring tools for farmers. In the area of **robotics**, Nordluft Automation[64] and Vitalgia Labs[65] develop drones and systems for heated greenhouses, respectively.

2.3. Scaleups in agri-food

Young firms that are scaling up are key drivers of innovation and potential disruptions in any industrial ecosystem including agri-food. They challenge the status quo and push other industrial firms to adapt their production and operation models. This is why they play a key role also in digitalisation and the green transition. As a recent JRC report concluded, the number of scaleup businesses and unicorns in the EU lags behind the US and China[66]. Europe hosts only around 10% of the world scaleups as concluded by recent researchers[67]. In comparison with the USA, scaling up is a challenge in the EU and the number of unicorns is still low even if the number of startups has increased significantly over the past years[68]. There are various definitions for scaleups and unicorns. The OECD defines a scaleup "*as a company that has achieved 20% annual growth in headcount or revenue over the past three years*". Other researchers define scaleups according to growth funding and other expansion criteria. The European Scaleup Monitor[69] adopted a definition "*as young fast-growing companies 10 years old or younger that have received at least €1 million within the past 10 years*".

Following the above definition, this study identified 293 active scaleups in the agri-food industrial ecosystem in the EU27 based on Crunchbase data (data retrieved in June 2023). This number represents 5% of all agri-food startups in the database. As a comparison, the number of scaleups was 675 in the USA, which is 6% of all US startups.

Key examples of scaleups include the following:

- Infarm that builds and distributes efficient vertical farms throughout cities (and was already cited above).
- InnovaFeed is a biotech company that produces a new source of protein from insect rearing for animal feed and aquaculture in particular.
- yfood Labs is a food-tech startup which designs smart food solutions for a modern generation. The product portfolio currently compromises ultra-convenient and complete-nutrition drinks, drink powders and bars.
- Matsmart sells surplus food online in order to address the challenge of food waste. As it is claimed on their website, in 2017, Matsmart saved 2022 tonnes of food from going to waste. Matsmart was founded by Karl Andersson, Erik Södergren and Ulf Skagerström, and launched in Sweden in 2014. Since then, the company has also expanded to Norway and Finland.
- Meatable is a food production company that produces guilt-free meat. Meatable is a company that creates manufactured meat using stem cell technology.

[61] See https://www.dilepix.com/en/
[62] See https://www.agrorobotica.it/
[63] See https://polariks.com/
[64] See https://www.nordluftautomation.com/
[65] See www.vitalgia.com or https://www.crunchbase.com/organization/vitalgia-labs
[66] European Commission JRC (2022). Tackling the Scale-up Gap
[67] Vlerick (2022)
68 See the analysis of ATI 2021
69 European ScaleUp Monitor (2021). European scaleups got knocked down, but are up again, Erasmus Centre for Entrepreneurship, available at: https://www.eur.nl/media/100543

3. Uptake of green and digital technologies and business models

Key findings

A business survey was conducted as part of the project about the status in the uptake of digital and green technologies and related business models in SMEs operating in the agri-food ecosystem. In addition, company websites in the agri-food ecosystem have been text mined and analysed in terms of their technology uptake. The results of both analysis indicate that **a significant portion of companies in the agri-food ecosystem has been actively embracing the green transformation**.

- 29% of agri-food companies text mined have been found to reference the adoption of green transformation technologies
- 53% of the respondents reported a positive increase in their investments dedicated to the green transition and environmental sustainability over the past five years.
- 34% indicated having adopted energy saving technologies. This finding is not a surprise since energy-saving has become very important since the start of soaring energy prices in 2021.
- 32% confirmed that they use recycled materials and 32% any other recycling technologies
- Regarding food waste, 26% of the respondents indicated that they took actions to reduce food waste.

With regard to the digital transition, the text mining of company websites found that approximately **25% of agri-food companies have adopted at least one digital transformation enabling technology**.

- 48% of SMEs in the EMI survey responded that they had increased their investment into digital technologies over the past five years.
- 35% of the respondents invested between 5 and 9% of revenue in digital transformation.
- 30% of SMEs adopted online platforms
- 27% adopted cloud technologies
- Big data and related data analytics were applied by 17% of the survey respondents
- Artificial Intelligence was pointed out by 11% of the respondents
- Internet of Things solutions have been already adopted by 10% of the respondents

3.1. Survey

With the objective of monitoring the status in the uptake of digital and green technologies, a large-scale business survey has been implemented in the framework of this study. The survey collected data about the progress towards the green and digital transition of European SMEs across industrial ecosystems such as Agri-food and gather information about the related investments. The survey was based on using Computer Assisted Telephone Interviewing (CATI). The final sample included 3 900 companies in all industrial ecosystems and **1 045 interviews for Agri-food in particular.** The mainstage fieldwork was conducted between 15 January and 15th May 2023. A prerequisite for each reach-out and interview was to have a respondent with adequate capacities and knowledge to answer the questionnaire (for more details please see the methodological report of the project).

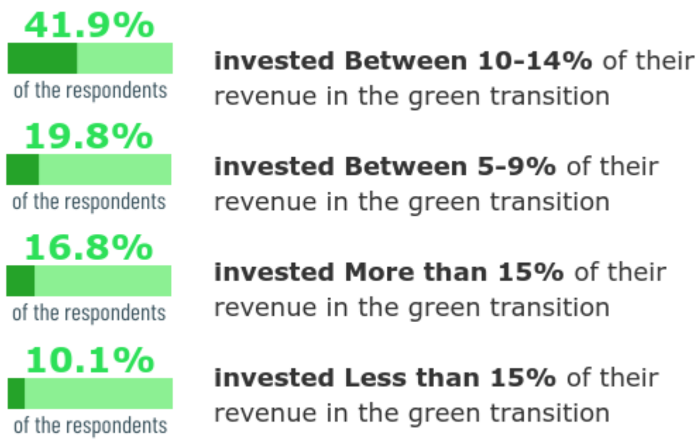
Complementing the survey, technology uptake was also monitored by text mining company websites. The objective of the big data analysis in the agri-food ecosystem was to provide empirical evidence on the adoption of green and digital technologies. This exercise relied on large volumes of data which enabled regular and up-to-date monitoring of the adoption of sustainable practices and innovations using digital technologies by the industrial ecosystem. The analysis covers a sample of 29 051 companies comprising a total of 4 963 412 webpages. This sample is further divided into 9% large companies and 89% SMEs from the agri-food industrial ecosystem.

3.1.2 Green transformation

Both the survey and the text mining of company websites found that companies in the agri-food ecosystem had progressed towards green transition objectives to varying degrees.

In terms of adoption rate approximately **29% of companies text mined have been found to reference the adoption of green transformation** technologies. As part of the EMI survey, SMEs in the agri-food ecosystem were asked about their investments towards the green transition and environmental sustainability over the past five years. Results indicate that **53% of respondents reported to increase their investments into environmental sustainability actions**. Furthermore, the survey inquired about the percentage of annual revenue allocated by agri-food companies for green transformation. The findings reveal that the majority of SMEs (41.9%) invested between 10% and 14% of their revenue annually. This indicates that a significant portion of companies in the agri-food sector are actively embracing these technologies.

Figure 11: Share of revenue invested in green transformation by SMEs in the agri-food industrial ecosystem on average annually



Source: Technopolis Group and Kapa Research, 2023

The detailed survey results demonstrate that SMEs in the agri-food industrial ecosystem are concerned about their energy use and **34% indicate having adopted energy saving technologies**. This finding is not a surprise since energy-saving has become very important since the start of soaring energy prices in 2021. The Flash Eurobarometer found that 57% of SMEs in agri-food adopted measures including non-technological actions to save energy.

Figure 12: Adoption of green technologies within the agri-food industrial ecosystem

	Status	
Technology	Already using	Planing to adopt
Energy saving technologies	33,6%	12,6%
Recycled materials	32,3%	5,2%
Recycling technologies	31,7%	2,3%
Clean production technologies	28,6%	3,4%
Renewable energies	27,9%	8,2%
Advanced sustainable materials	27,5%	5,3%
Water reduction technologies	27,4%	4,6%
Food waste reduction	26,6%	7,3%
Waste reduction technologies	23,3%	7,4%
Biotechnology	20,4%	1,6%
Sustainable fuel	16,3%	2,4%
Additive manufacturing	13,3%	1,3%
Hydrogen	12,4%	0,4%
Carbon capture technologies	11,8%	3,4%

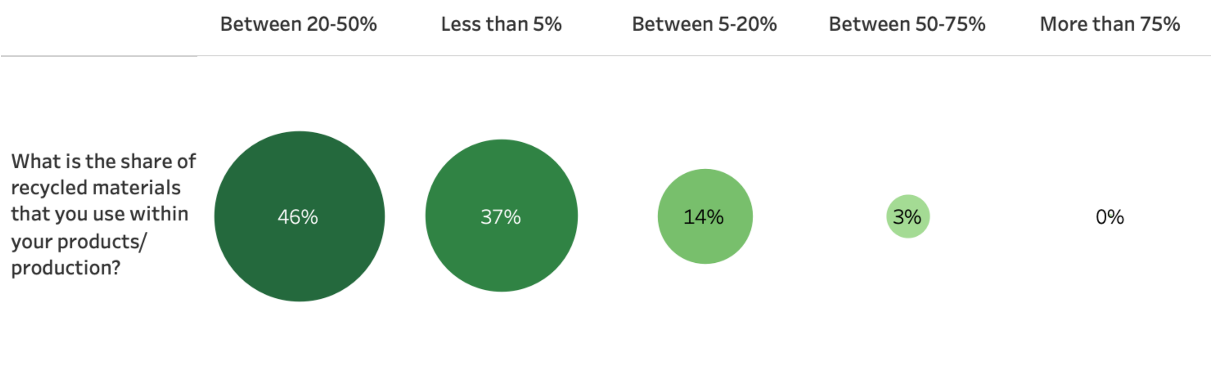
Source: Technopolis Group and Kapa Research, 2023

Recycling

The survey results show that **32% confirmed that they use recycled materials and 32% any other recycling technologies.** A further question investigated the proportion of recycled materials that is used within production or the products of those that have adopted recycling. As shown in the Figure below, close to half declared to be using between 20% and 50% of recycled materials.

Regarding food waste, 26% of the respondents indicated that they took actions to reduce food waste and recycle them.

Figure 13: Share of recycled material that is used within production by SMEs in agri-food that adopted this technology



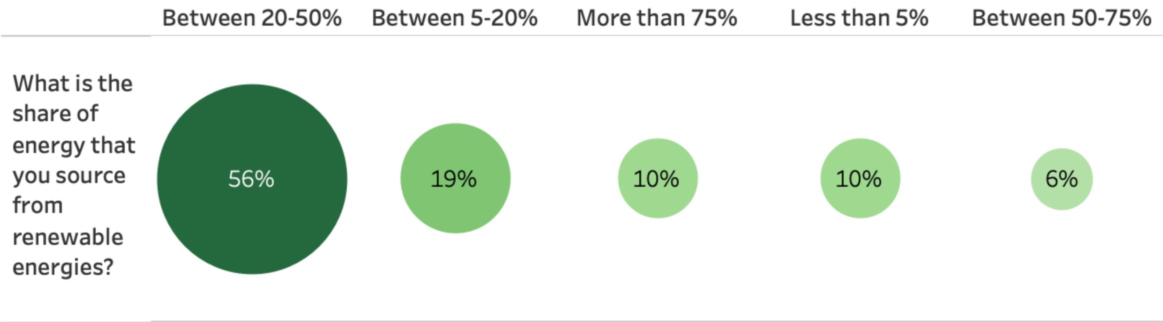
Source: Technopolis Group and Kapa Research, 2023

Sustainable packaging were referenced on 11% of the company websites with practices often involving the utilisation of eco-friendly materials such as biodegradable or compostable packaging, recycled content, reduced packaging waste and international standards such as ISO 9001. Advanced technologies enable the design and manufacturing of packaging solutions that minimise resource consumption and pollution. These include innovative designs to optimise space utilisation, lightweight packaging to reduce material usage, and efficient distribution systems to minimise transportation-related emissions. Moreover, intelligent packaging technologies, such as QR codes or RFID tags, facilitate better supply chain management, reducing overstock and food waste.

Renewable energy

The EMI survey found that 28% of the respondents invested in renewable energy technologies, and 56% of those cover between 20 and 50% of their total consumption with renewable energy.

Figure 14: Share of renewable energy use within total energy consumption



Source: Technopolis Group and Kapa Research, 2023

The adoption of renewable energy technologies has been also pronounced on company websites with 16% of companies in the sample referencing it. Solar energy and the utilisation of organic materials for energy production are the dominant sources cited by companies on their website. Hydrogen, geothermal, wind and nuclear are present but comparatively to a lesser extent.

In solar energy several companies have installed photovoltaic systems on rooftops and open spaces which represents a mature technology with widespread adoption. Organic materials include for instance companies which have incorporated biomass technology, using organic materials for heat generation and power production. Wind power includes wind turbines being employed to generate clean electricity. Geothermal energy systems are utilised for heating and cooling purposes, showcasing an innovative approach to energy efficiency. The adoption of advanced technologies like microbial fuel cells and LED lighting further underscores the industrial ecosystem's capacity to innovate and environmental stewardship. In addition, various aspects of heating, cooling, and energy efficiency are frequently referenced associated to technologies that aim to improve energy efficiency and promote sustainability.

Advanced sustainable materials and alternative proteins

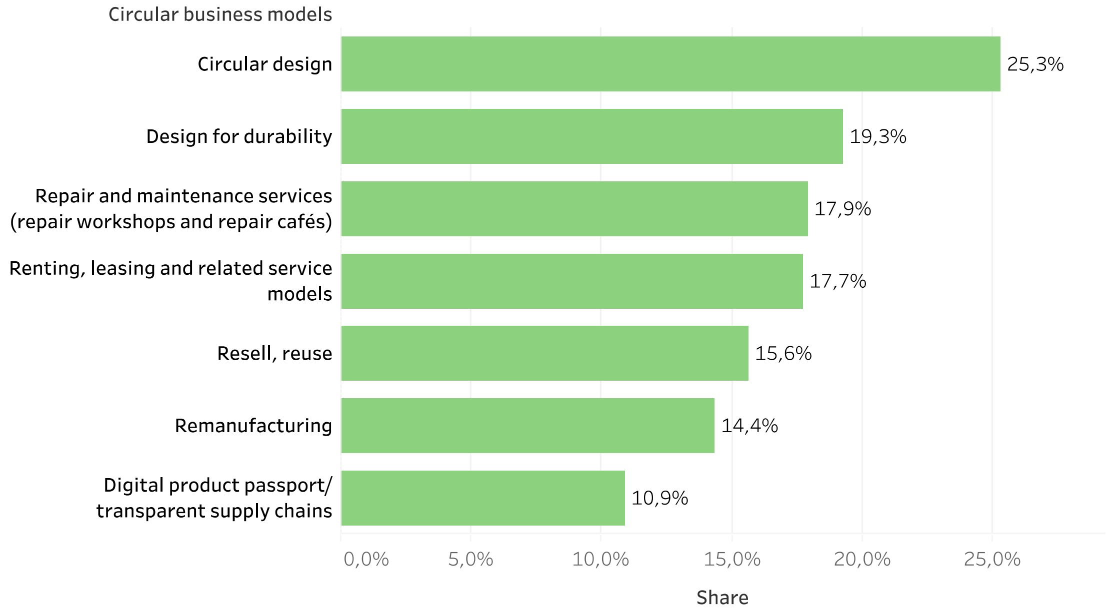
Advanced sustainable materials were indicated by 27% of the SMEs participating in the EMI survey. More specifically, the text mining of company websites found that **alternative proteins have been highlighted on 15% of the websites.** Several cutting-edge technologies are driving innovation in the alternative protein sector. These advancements include hydrolysis and purification processes to create bio-functional animal proteins. In addition, 3D food printing technology is being employed to produce plant-based alternatives. Bacteriophages are also gaining prominence for their potential to combat health challenges in aquaculture through targeted interventions. Further innovations involve the use of mycoprotein as a novel ingredient in aquaculture feeds, aiming to enhance sustainability. Notably, methane inhibitors are being developed to reduce greenhouse gas emissions from livestock, and fish oil alternatives derived from algae offer a sustainable option for aquaculture feed.

Circular business models

Agri-food SMEs were surveyed about the **adoption of circular business models and other circular practices** such as repair, renting, leasing or design for durability. The results indicate 25.3% pays attention to circular design, 19.3% of the respondents adopted design for durability followed by repair and maintenance services (18%).

Renting, leasing and related service models were taken up by 18% of the respondents. Taking actions regarding transparent supply chains was indicated by 11% of the respondents. Digital product passports as highlighted in the sustainable products initiative[70] of the European Commission will be the norm for all products with tags identified and linked to data relevant to their circularity and sustainability.

Figure 15: Adoption of green business models and non-technological solutions within the agri-food ecosystem



Source: Technopolis Group and Kapa Research, 2023

Using digital technologies for environmental sustainability

The role of **digital technologies in mitigating the environmental impact of agri-food** includes IoT devices, data analytics, automation, and smart packaging solutions, as found by the analysis of company websites. These are utilised to optimise agricultural processes, minimise resource consumption through real-time data monitoring, streamline manufacturing operations for energy efficiency, and enhance traceability to reduce plastic waste and promote recycling.

Advanced technologies to reduce water consumption include irrigation control systems, precision irrigation techniques, water recycling, and sustainable water resource management. Controlled release fertilizers with polymeric coatings optimise nutrient release and reduce water usage. Innovative farming solutions, sensors, and precision irrigation systems further contribute to significant water savings. Recirculation systems and specialised diets are utilised in aquaculture to lower water consumption. Reverse osmosis systems are employed to ensure clean water quality in pools while conserving

[70] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en

water. Additionally, advanced testing methods and recirculating water systems are applied in aquaculture research to monitor health and welfare while minimising water use.

Modern technologies for soil health and fertility include precision irrigation systems such as drip irrigation and satellite imaging for real-time monitoring and efficient water management. They utilise organic and natural fertilisers, practicing cover cropping, green manure, and composting to promote soil nutrient enrichment and biodiversity. Implementing regenerative agriculture techniques such as minimum tillage, crop rotation, and mechanical soil management helps in maintaining soil structure and preventing erosion. Additionally, some companies explore innovative approaches like biochar usage to enhance soil quality and carbon sequestration, while others focus on sustainable practices in dairy farming and vineyard management to improve soil health and overall environmental impact.

Companies are incorporating **digital technologies to support the circular economy** by developing high-performance materials, utilising waste for renewable energy, implementing organic farming practices, adopting eco-friendly packaging, optimising resource usage through automation and data analytics, conducting research to reduce waste, collaborating with educational institutions for knowledge exchange, extending food shelf life through preservation methods, offering clean label ingredients, and embracing ethical values for responsible consumption and production.

Environmental standards

When asked about the certification on any environmental standards, 46% of the respondents indicated that they had been certified (see Figure 16).

Figure 16: Percentage of agri-food SMEs stating that they have been certified on environmental standards

Source: Technopolis Group and Kapa Research, 2023

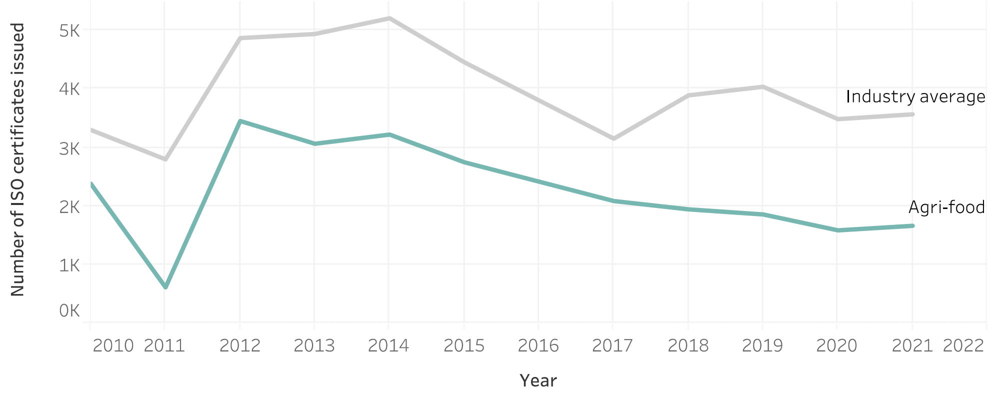
The agri-food ecosystem is guided by different sets of environmental definitions and guidelines, including ISO standards. ISO 14001 is a set of standards that any company can follow to implement an effective environmental management system. By adopting the good practices suggested by the standard, firms can substantially reduce their environmental footprint. The number of environmental certificates issued in the industry indicates the progress towards the application of environmentally friendly business practices and production methods. For the purposes of this report, ISO data were accessed via the ISO survey of certifications to management system standards[71].

The analysis of the data shows that companies operating in the agri-food ecosystem obtained less and less ISO environmental certificates over time. Since reaching the peak

[71] ISO (2022) ISO Survey of certifications to management system standards. Accessed on https://isotc.iso.org/livelink/livelink?func=ll&objId=18808772&objAction=browse&sort=name&viewType=1

in 2012, the number of companies using environmentally friendly standards has steadily decreased. **The annual ISO survey indicates that there were 1,660 certificates issued to agri-food companies in the EU27 in the year 2021,** which is a **decrease** compared to 2,380 certificates issued in 2012 and which is below the industry average.

Figure 17: Number of environmental certificates issued



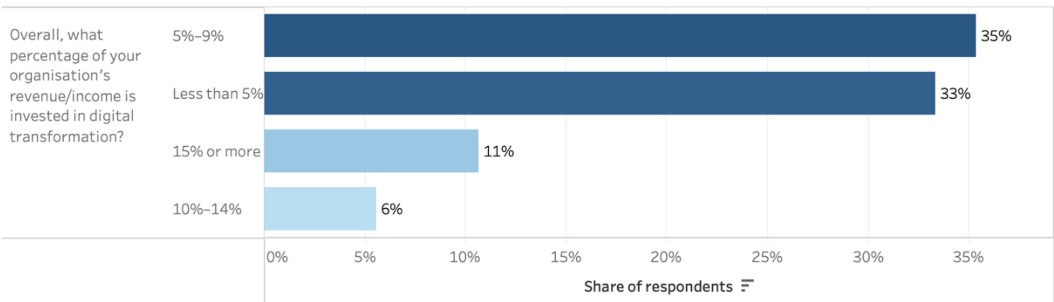
Source: Technopolis Group, 2022, based on ISO

3.1.2 Digital transformation

In terms of overall adoption rate, the text mining of company websites found that approximately 25% of companies in the investigated sample have adopted at least one digital transformation enabling technology. This indicates that **a quarter of companies in the agri-food sector are actively embracing these technologies.**

When asking agri-food SMEs, whether they had increased their investments dedicated to digital technologies during the past five years 48% responded positively. A further question was related to the percentage in terms of revenue that retailers had invested in digital transformation on average annually. As shown in Figure 18 below, the responses show that **35% of the respondents invested between 5 and 9% of revenue** in digital transformation, and altogether 74% invested less than 15%.

Figure 18: Share in revenue is invested in digital transformation on average annually



Source: Technopolis Group and Kapa Research, 2023

The Figure below details the level of adoption of specific digital technologies. The detailed results demonstrate that besides the popularity of **online platforms** (used by 30% of the respondents), SMEs **have adopted cloud software and computing (27%).** This is also reflected in Eurostat[72] data, where the survey on ICT usage and e-commerce in enterprises found 30% of food and beverage manufacturing companies[73] had bought computing services used over the internet in 2021. From a technological perspective, traceability, food safety and precision agriculture are gaining traction among both large companies and SMEs.

Figure 19: Adoption of digital technologies within the agri-food industrial ecosystem

	Answer	
Digital technologies	Already using	Planing to adopt
Online platform	30,3%	5,0%
Cloud software and cloud computing	26,8%	6,0%
Big Data	17,2%	4,0%
Robotics (eg. weeding robot, robotic agricultural or food production machi..	11,2%	2,4%
Artificial Intelligence	11,2%	3,0%
Internet of Things	10,3%	1,0%
Digital twin	9,3%	0,4%
Augmented and virtual reality	7,1%	2,0%
Blockchain and digital traceability (and other distributed ledger technologies)	4,6%	0,6%

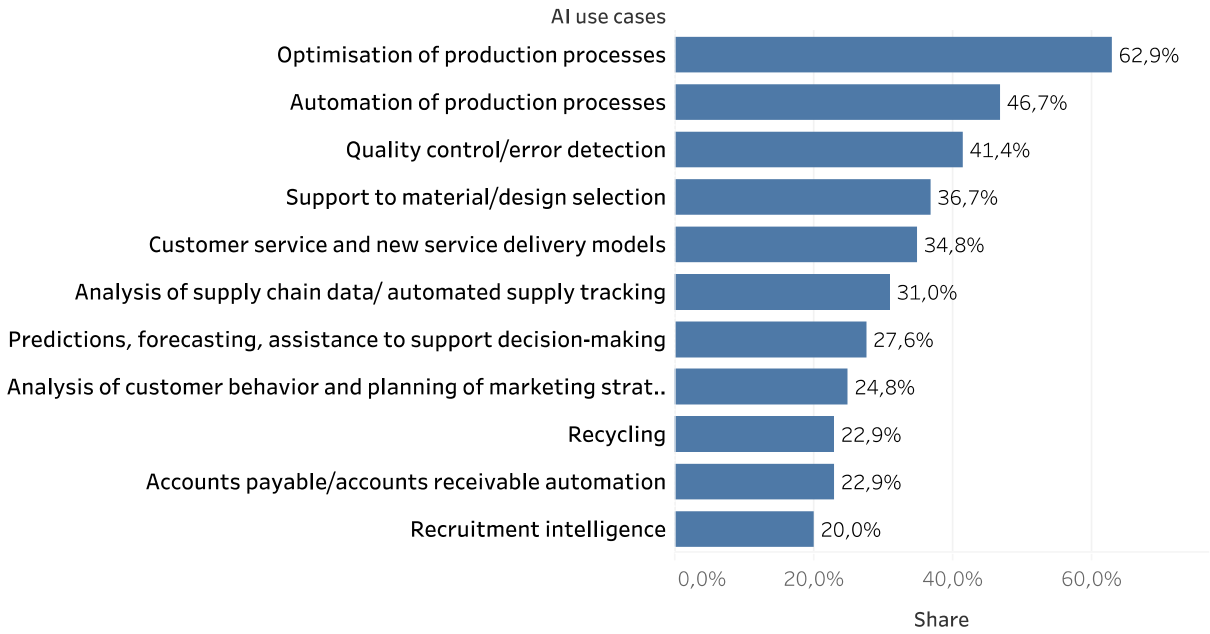
Source: Technopolis Group and Kapa Research, 2023

The use of **Artificial Intelligence was pointed out by 11%** of the respondents. Moreover, according to the survey results, **Internet of Things solutions have been already adopted by 10% of the respondents**. A higher share of use emerges in the ICT survey[74], where 29.5% of the surveyed companies indicated to be already using some form of IoT.

Further questions revealed the **areas where Artificial Intelligence have been focused in the agri-food ecosystem**. The highest share of the responses includes optimisation and automation (indicated by 63% of SMEs) and quality control and error detection (41%). Moreover, AI technologies have been adopted with the objectives of supporting material sourcing, analysis of supply chain data, and predictions, forecasting and assistance to decision making.

[72] https://ec.europa.eu/eurostat/databrowser/view/ISOC_CICCE_USEN2__custom_6885490/default/table?lang=en
[73] Data available correspond to NACE codes C10, C11 and C12.
[74] https://ec.europa.eu/eurostat/databrowser/view/ISOC_EB_IOTN2__custom_6886017/default/table?lang=en

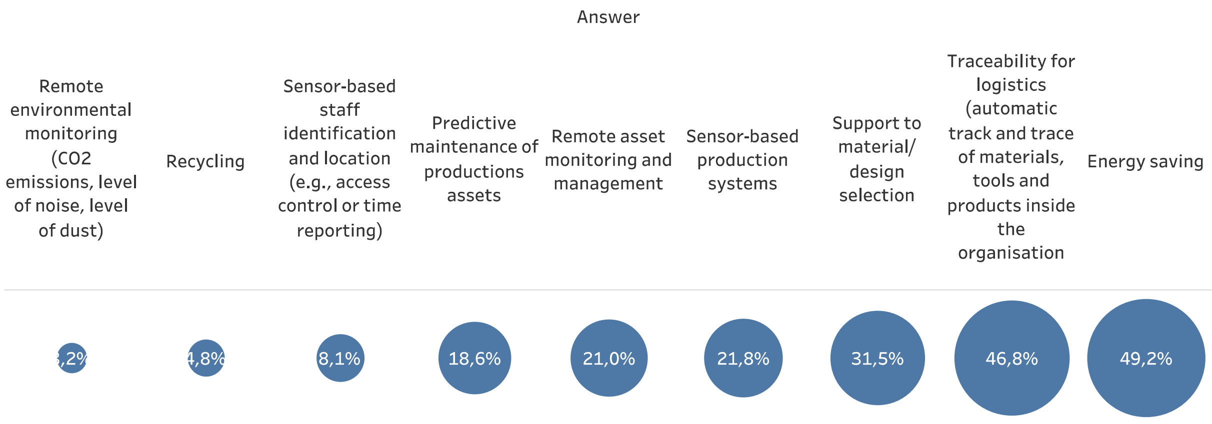
Figure 20: Use cases of AI



Source: Technopolis Group and Kapa Research., 2023

Survey results indicated that **the Internet of Things is used by 10% of the respondents**. IoT is used for energy efficiency (49%) and traceability for logistics (47%). Other common applications include sensor-based production systems and remote asset monitoring and management, as shown in Figure 21 below.

Figure 21: Use cases of Internet of Things



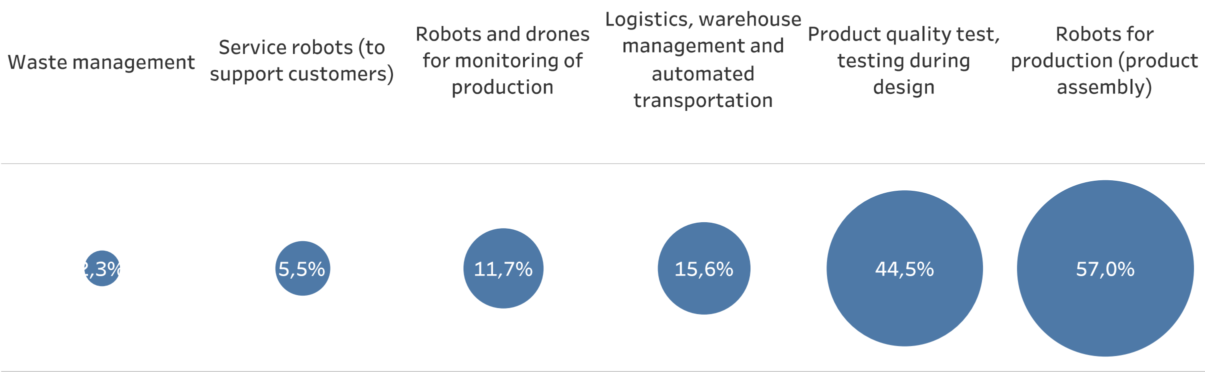
Source: Technopolis Group and Kapa Research, 2023

Various agricultural enterprises are harnessing the power of remote sensing technologies to revolutionise their operations. By integrating IoT sensors, drones, and satellite imagery, these businesses are gaining insights into environmental factors like humidity, temperature, and crop health. This data-driven approach enables optimised irrigation, fertilizer usage, and pest management, while also reducing waste and minimising environmental impact. Precision farming techniques, guided by remote sensing technologies, provide accurate mapping of crops and fields, enhancing growth monitoring and decision-making. These advancements establish the foundation for sustainable practices, ensuring efficient resource utilisation, higher yields, and improved overall quality across the agri-food supply chain.

Digitalisation and precision agriculture were present on 13% of all company websites. The agri-food ecosystem has been adopting precision agriculture through various advanced technologies. These include the use of sensors, drones, geographical information systems, software, remote-controlled underwater vehicles, image analysis, AI, satellite tech, and hyperspectral cameras. These technologies enable real-time monitoring, data collection, and analysis to optimise crop management, reduce environmental impact, enhance animal welfare, ensure product quality, and improve overall efficiency and sustainability throughout the agricultural process.

Robotics technologies have been adopted by 11.2% of the SMEs in the broader agri-food industrial ecosystem. According to Eurostat, 10% of companies that manufacture food products, beverages and tobacco products (10 persons or more) declared to have used industrial or service robots in 2022.

Figure 22: Use cases of robotics



Source: Technopolis Group and Kapa Research, 2023

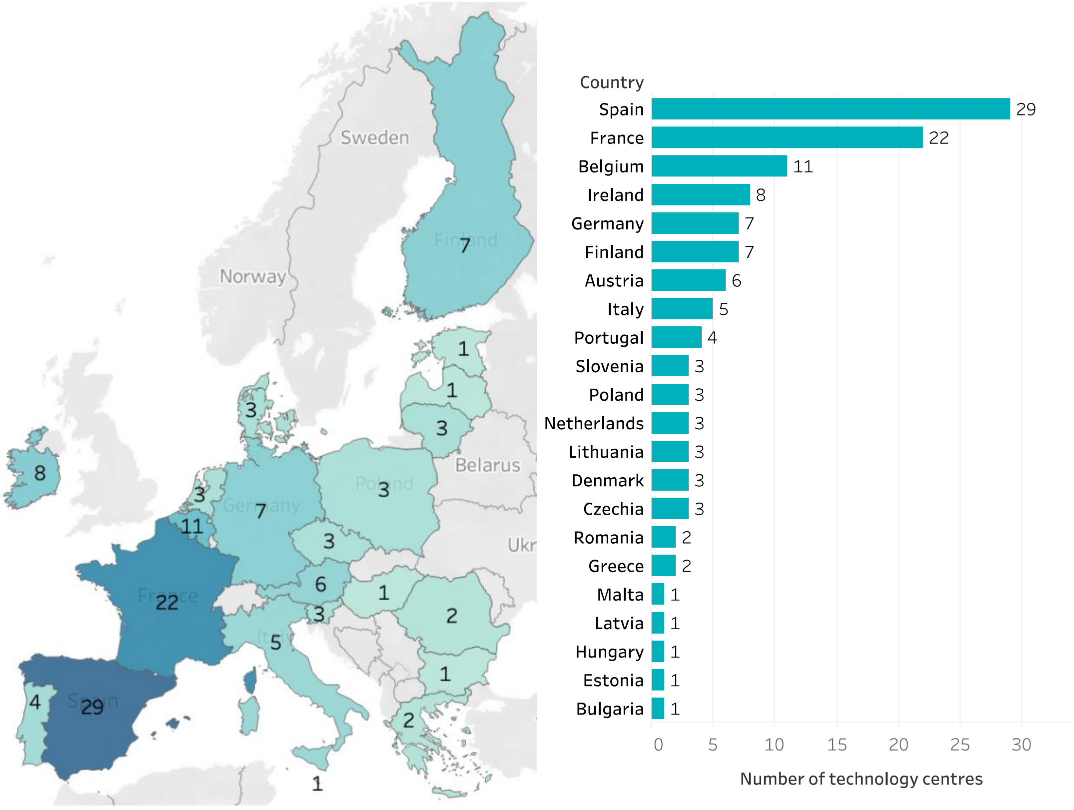
Augmented and virtual reality has been mentioned by a lower number, notably **7%** of the respondents. The top three applications on the use of AVR are inventory visualisation and management (indicated by 78% of respondents), virtual material sourcing (76%) and workflow management (73%).

Although **blockchain technologies were indicated by only 4% of the respondents, the analysis of company websites identified a higher importance dedicated to traceability and food safety, accounting for 18% of all companies**. Agri-food SMEs can leverage digital technologies such as blockchain, QR codes, real-time monitoring, and traceability systems to ensure food safety and enhance transparency throughout their supply chains, underscoring their commitment to quality and sustainability.

3.2. Technology centres supporting SME's access to technology

Innovation actors are at the core of industrial ecosystems and gathering and sharing information about them in a structured way is crucial to detect gaps, improve collaboration, foster innovation and strengthen innovation ecosystems. The Technology Centre Mapping comprises information on technology centres that are key actors in innovation ecosystems due to their technical expertise and their ability to bring together and steer collaboration among various types of actors in their own ecosystems and beyond. Figure 23 presents the number of technology centres (TCs) that are active in the agri-food industrial ecosystem per European country and shows that Spain (29) is the country with the highest number of technology centres in the EU, followed by France (22) and Belgium (11). These countries might host additional technology centres active in the agri-food industrial ecosystem, which are currently not registered to the technology centres mapping.

Figure 23: Technology centres per country – agri-food



Source: Analysis based on Advanced Technologies for Industry Technology Centre Mapping, 2023

The following examples serve to illustrate the activities and scope of technology centres active in agri-food, their links with the broader ecosystem as well as examples of recent activities in which they are involved. They include the following three cases Center of Bioimmobilisation and Innovative Packaging Materials (PL) (see Box), CMYK Ingredients (BG) (see Box), VTT industrial biotechnology, synthetic biology, and food processing (FI) (see Box).

Box 3: Example Technology Centre: Center of Bioimmobilisation and Innovative Packaging Materials, CBIMO (PL) [75]

Name of the Centre	**Center of Bioimmobilisation and Innovative Packaging Materials, CBIMO (PL)**
Location and scope	
CBIMO is a self-financing entity, located in the region of Western Pomerania in Poland. The centre operates under the Faculty of Food Sciences and the Faculty of Fisheries of the West Pomeranian University of Technology in Szczecin, but it is considered an independent body of this one. The centre not only focuses on the packaging itself, but also on the production and operation of the packaging materials. Therefore, CBIMO is specialised in the following fields: modern technologies and packaging, innovative materials, and new immobilization techniques, such as immobilization of cells, bacteria, and particles.	

[75] CBIMO (2023) Centrum Bioimmobilizacji i Innowacyjnych Materiałów Opakowaniowych (CBIMO) https://cbimo.zut.edu.pl/

Main services and equipment
CBIMO offers various technological services in the formation, modification, testing , and characterization of packaging materials. CBIMO, has, among others, a service for characterization of basic and functional properties, devices for biotechnological research and bioimmobilization processes, a laboratory device for obtaining functional materials and specialized in research and measurement equipment, including pilot-scale trials, and a service for obtaining, modifying, and purifying new substances of biological origin. CBIMO has also experience in the preparation and joint implementation of research projects with economic partners and research and development units co-financed from various sources (national: Ministry of Science and Higher Education, National Center for Research and Development, departmental, structural funds, and EU framework projects). Finally, CBIMO offers a service for the commercialization of research results.
Recent projects related to the green and digital transition in agri-food
CBIMO is involved in several international and national projects, contributing to the development of innovative, environmentally friendly solutions with a potential for industrial applications. A few examples include: • HumidWrap The objective of this project is to use active packaging materials for storage and release of water to achieve the proper humidity level of paper and plastic packages in order to optimally conserve the goods freshness, shelf life, self-value, and quantity.[76] • FreshInPac seeks to develop bio-based packaging for perishable foods (fruits, vegetables, and flowers) with multiple functionalities (ethylene scavenging, rejection of plant-based antimicrobials, control of water vapour condensation). The uniqueness of this project lies in the way the packaging development is carried out by digital simulation, which rarely has been done before for these multifunctional packaging materials.[77] • ActInPak: the Action intends to create a knowledge-based network on sustainable, active, and intelligent fibre-based packaging in order to optimise the supply value chain and to promote the consumer awareness of food usage.[78]

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023, CBIMO 2023 and IVLV 2023

Box 4: Example Technology Centre: CMYK Ingredients (BG) [79]

Name of the Centre	CMYK Ingredients (BG)
Location and scope	
CMYK Ingredients is a food-tech development centre located in Bulgaria. Its mission is to develop more healthy and tasty products available for retail and on grocery shelves, in supermarkets and online, and in a wide range of packaging formats. CMYK implements food-tech solutions and develops new foods (functional, organic, nutraceutical and microbiome supportive) for different kinds of consumers, including food minorities (i.e., those with food allergy, diabetes, sugar intolerance, KETO diet, among others).	
Main services and equipment	
The services of the CMYK are based on two major technological focal points: ingredient fermentation and sprouting. Therefore, CMYK has a fermentation research laboratory for the development and improvement of fermentation related production processes with diverse	

[76] IVLV HumidWrap https://www.ivlv.org/en/project/humidwrap/, accessed on 18 April 2023
[77] IVLV FreshInPac https://www.ivlv.org/en/project/freshinpac/, accessed on 18 April 2023
[78] http://www.actinpak.eu/
[79] CMYK (2023) CMYK Ingredients https://www.cmykingredients.com/

equipment for cultivation of microbial cultures, incubators and laboratory fermentation reactors, and a pilot plant with large chambers for scale-up studies and small productions, as well as other necessary equipment for innovative techniques in fermentation and extraction of compounds for food, cosmetic and pharmaceutical industries. The Centre also has a Department for Research and Patents accessible for large food retail corporations, SMEs, and startups. Finally, CMYK has specific facilities for developing its own prototyping production.
Recent projects related to the green and digital transition in agri-food
CMYK is a global top 500 food-tech innovative company. Examples of the activities of CMYK in relation to the green and digital transition include: • In 2019, CMYK Ingredients was rated by Forward Fooding for its contribution into the environmental footprint reduction. • Excellence in Innovation 2021 Awards (Bulgaria): In 2021 CMYK was awarded by the President of Bulgaria as one of the seven most innovative companies. • SIAL Innovation selection: Four of CMYK's final products have been selected by SIAL Paris Innovation Awards 2020.

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023 and CMYK, 2023

Box 5: Example Technology Centre: VTT industrial biotechnology, synthetic biology, and food processing (FI) [80]

Name of the Centre	**VTT industrial biotechnology, synthetic biology, and food processing (FI)**
Location and scope	
VTT is a research institution located in Finland. It is a limited liability company that is fully owned by the Finnish state and runs under the Ministry of Economic Affairs and Employment. VTTs mission is to create and design sustainable solutions through research, service activities, reporting and internal operations. Within VTT, 'industrial biotechnology, synthetic biology, and food processing' is a multidisciplinary team that conducts research in biotechnology looking at the interface with industrial processes.	
Main services and equipment	
In the area of Food Industry, VTT has built the so-called concept Food Economy 4.0. This vision involves: - promoting circular economy nutrients, energy, and water as an integral part of primary production and the manufacturing industry, - the utilization of food raw materials in a versatile way, - the fostering of more sustainable food solutions which support health and well-being and - the evolution of the food value chain into a service with smart packaging and agile logistics. To put this vision in practice, VTT provides research infrastructure for industrial biotechnology, synthetic biology, and food processing. The research facilities are equipped with a comprehensive	

[80] VTT (2023) VTT: Welcome to VTT https://www.vttresearch.com/

set of bioreactors such as high-throughput screening robotic station, over 50 advanced laboratory scale fermenters, and a pilot plant with food pilots including a malting and brewing pilot, a pilot bakery as well as pilot facilities for dry and wet grinding, fractionation, drying and extrusion. VTT also has state-of-the-art analytical tools, in-house databases for comparative genomics and cell sorting, culturing, and imaging facilities (flow cytometers, imagers, spinning disk and other microscopes).
Recent projects related to the green and digital transition in agri-food
VTT carries out several projects and activities in support of the green and digital transition. Some examples include: • VTT participates in the EU-funded CANMILK[81] research project exploring the use of plasma technology to capture the methane in barn air and break it down into carbon dioxide. In Finnish conditions, the methane emissions generated in conjunction with milk production account for about 50 percent of milk's carbon footprint. The goal of the research project is to develop equipment that can convert the greenhouse gas methane that is captured from barn air into less harmful carbon dioxide. • The Food without Fields project[82], coordinated by VTT, examined the possibilities and challenges of new food production methods in Finland. These methods included cellular agriculture, i.e., harnessing microbes and plant cells to produce feed and food, as well as the production of new protein-rich crops under controlled conditions, such as in greenhouses and vertical farming environments. With these new methods and renewable energy, food could be produced with less emissions. Agricultural land use could be reduced by over 90%, which would free up land for carbon sequestration by other means. • The demands on food packaging are growing: the Single-Use Plastics Directive (SUPD) requires natural polymers to be used, and a review of the Packaging Waste Directive (PPWD) is coming. VTT and other research institutes have risen to the challenge and are actively searching for SUPD-compliant solutions. The challenge is to combine several desirable properties, such as recyclability combined with strength, heat-sealability, and oxygen and grease barrier properties. • On the digital transformation VTT offers both producers and consumers tools for gathering and monitoring information on the consumption habits of individuals, specifically, an application that monitors dining rhythm is currently under development at VTT. Indeed, the "Snacktracker"[83] application recognises and records the times of eating, eating speed, time spent eating, and the location. Its purpose is to guide individuals towards more balanced eating habits.

Source: Advanced Technologies for Industry Technology Centre Mapping, 2023 and VTT, 2023

[81] See https://www.vttresearch.com/en/news-and-ideas/valio-and-vtt-researching-use-plasma-technology-convert-barn-air-methane-carbon

[82] See https://www.vttresearch.com/en/news-and-ideas/recent-study-introduction-new-food-production-technologies-would-lead-finland

[83] See https://www.vttresearch.com/sites/default/files/pdf/visions/2017/V10.pdf

4. Investment and funding

Key findings

The agri-food sector is particularly challenged by decreasing investment trends, related to **sector specific challenges in obtaining finance**.

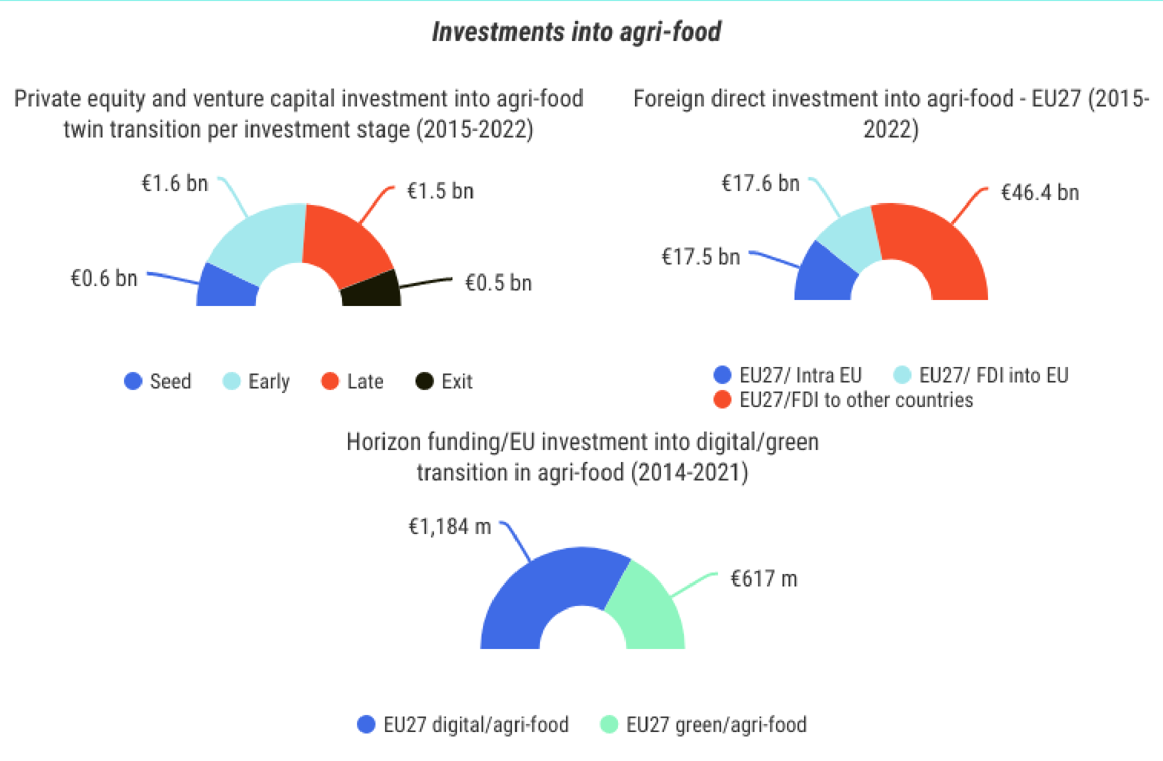
Private investments in new and advanced technologies aiming at digitalising and greening the sector have generally been **on the rise**. For instance, investments in the agri-food tech industry have grown steadily, with a record amount of investment in 2021.

Crunchbase and Net Zero Insights data indicates that **private equity and venture capital investment in agri-food tech companies** linked to the digital and green transition have been **volatile over the past decade**.

Foreign direct investment Outwards EU27 investments from EU27 countries are considerably higher than the intra EU and foreign direct investment into the EU27 over the observed period. While foreign direct investment into the EU27 is comparably high in 2017, it remains otherwise low. Outward EU27 investment from EU27 countries is variable, though clearly on the rise from 2020 onwards into 2022.

Under Horizon 2020, a total funding of **€3.8 bn is attributed to the agri-food industrial ecosystem**. The digital and green transition related projects accounted for €1.7 bn. Among the funded projects, ICT projects accounted for 18%, followed by food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy (13%).

Technologies such as renewable energy technologies (wind, solar and other (geothermal, hydropower, biomass) power; 15%), and advanced manufacturing & robotics (11%) make up important segments in terms of technological focal areas.



Source: Technopolis Group based on investment data, 2023

Investments play a central role in transforming agri-food systems. According to the 'Financial needs in the agriculture and agri-food sectors in the European Union' summary report, the agri-food sector is particularly challenged by decreasing investment trends, related to sector specific challenges in obtaining finance. While the need for modernisation of production is evident, the profit margins themselves are relatively low, reducing incentive for investment and preferring investment in fixed assets. Five drivers of the demand for finance in the agri-food sector include efficiency, capacity expansion, compliance, product differentiation and working capital (see Figure 24).[84]

Figure 24: Drivers of demand for finance in the agri-food sector

EFFICIENCY	CAPACITY EXPANSION	COMPLIANCE	PRODUCT DIFFERENTIATION	WORKING CAPITAL
• Automation • Digitalisation • Upgrades	• Competitiveness • Export markets • Fixed cost regression	• Regulation • Retail standards	• Branding • Promotion • New products development	• Inventory • Payment of liabilities

Source: European Investment Bank, 2020

The recent FAO report on the Future of Food85 indicates that, globally, investments in the agri-food system are growing since the 2008 food price crisis especially thanks to private investments which constitute the bulk of investments in the sector. Also 'new' private actors, such as pension funds, specialised investment funds, endowment funds, and impact investors, are entering the sector. Indeed, private investments in new and advanced technologies aiming at digitalising and greening the sector have generally been on the rise. For instance, investments in the agri-food tech industry have grown steadily, with a record amount of investments in 2021. Especially the US dominates the investments in the agri-food tech sector, followed by Asia.[86] The report also indicates that there is increased investor attention to climate solutions; and that in 2022, the alternative protein segment has declined in terms of investments (but is still rather large).

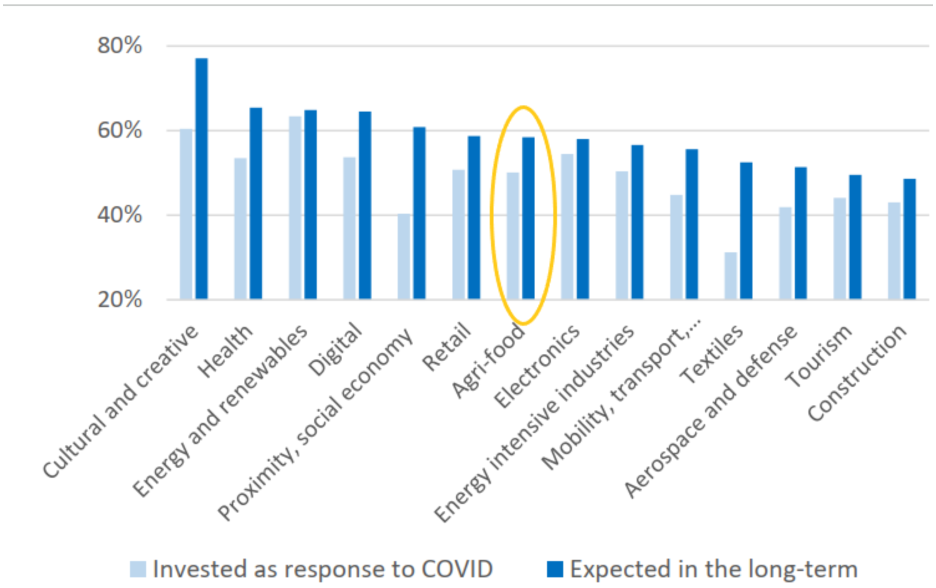
With regard to the public investments, the Food and Agriculture Organisation (FAO) report shows that the global share of the government expenditure on agriculture slightly increased from 1.7% in 2001 to 2.2% in 2020. However, in Europe and central Asia, the percentage decreased from 2.5% to 1.7%. In general, the proportion of public resources allocated to the sector is limited, especially compared to the sector's weight in the economy. The report forecasts that private investments will continue to make up the bulk of the total investments in the sector.

The Annual Single Market Report (2022)[87] highlights that the agri-food ecosystem is quite in the middle compared to the other industrial ecosystems with regard to investments related to the digital transition (see Figure 25) as well as the green transition (Figure 26). Particularly, with regard to the digital transition, about 50% of the firms in the ecosystem

[84] European Investment Bank (2020). Financial needs in the agriculture and agri-food sectors in the European Union: Summary report. https://www.fi-compass.eu/sites/default/files/publications/financial_needs_agriculture_agrifood_sectors_eu_summary.pdf
[85] Food and Agriculture Organisation (FAO). (2022). Future of Food. https://www.fao.org/documents/card/en/c/cc0959en
[86] Agfunder (2023). Global Agri-foodTech Investment Report 2023. https://agfunder.com/research/agfunder-global-agrifoodtech-investment-report-2023/
[87] European Commission (2022) Annual Single Market Report 2022. https://ec.europa.eu/docsroom/documents/48877

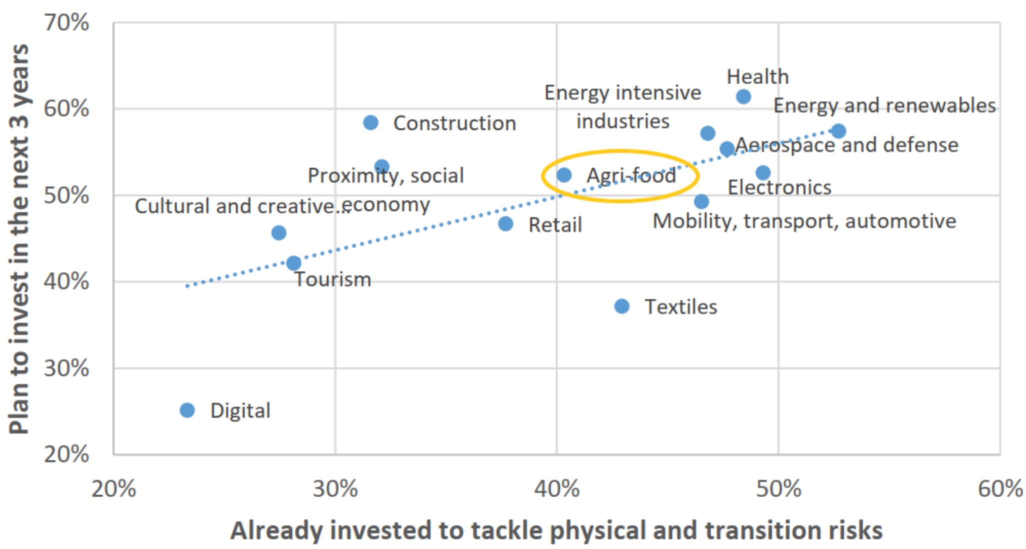
have invested in digitalisation as a response to the COVID-19 crisis and almost 60% are planning investments in the long term. On the green transition, more than 40% of the EU firms in the ecosystem have already invested in efforts to mitigate the impact of physical and transition risks and reduce carbon emissions, which approximately coincides with the percentage of EU firms across all industrial ecosystems. Additionally, over 50% have plans to make such investments in the next three years, which is slightly higher than the percentage of firms across all industrial ecosystems.

Figure 25: Digital investment and long-term investment expectation (share of firms in %), by industrial ecosystems



Source: European Commission 2022, Annual Single Market Report and sources therein

Figure 26: Investment plans to tackle climate change impact, by industrial ecosystem



Source: European Commission 2022, Annual Single Market Report and sources therein

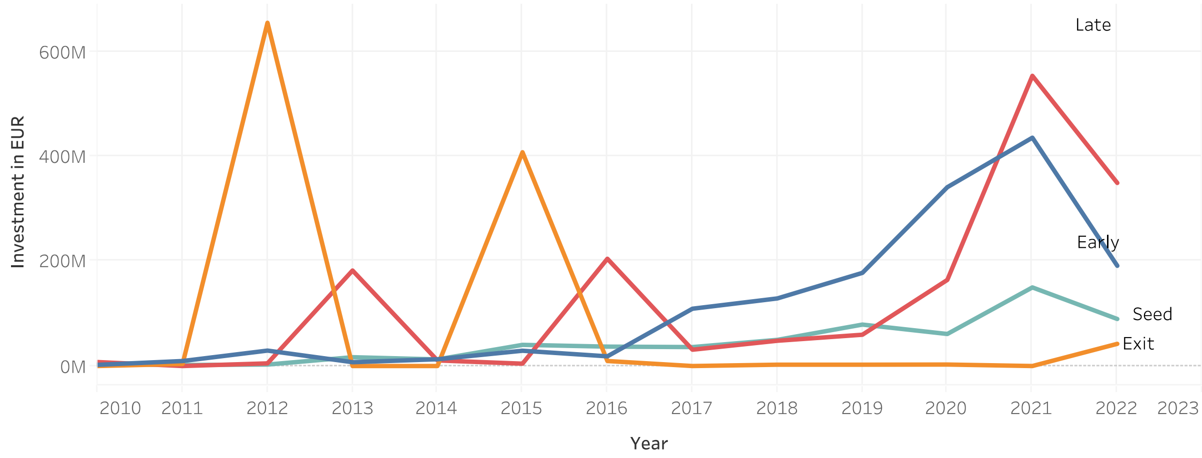
4.1. Venture capital and private equity investments

The scale of venture capital and private equity investment in agri-food tech companies that focus on digital and green technologies and business models has been calculated using a combined data set from Net Zero Insights and Crunchbase sources[88].

Crunchbase and Net Zero Insights data indicates that private equity and venture capital investment in agri-food tech companies linked to the digital and green transition have been volatile over the past decade.

Figure 27 below presents the picture of annual private equity and VC funding into EU27 agri-food tech startups per main investment type (seed, early, late and exit)[89]. The picture of investment by subclass is equally volatile, though with late-stage funding attracting the most important amount of investment for agri-food tech startups and especially in the recent years, early, seed and exit having considerably lower investment amounts comparatively.

Figure 27: Private equity and venture capital investment into EU agri-food tech companies per main investment type (2010 onwards)



Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2022

Looking at the technologies attracting investment, not surprisingly biotechnology and related agri-tech leads the way with over €1 bn in investment, followed by online platforms (€400 m) and recycling technologies (€272 m) the latter is explained by the capital intensity of such investments, see Figure 28.

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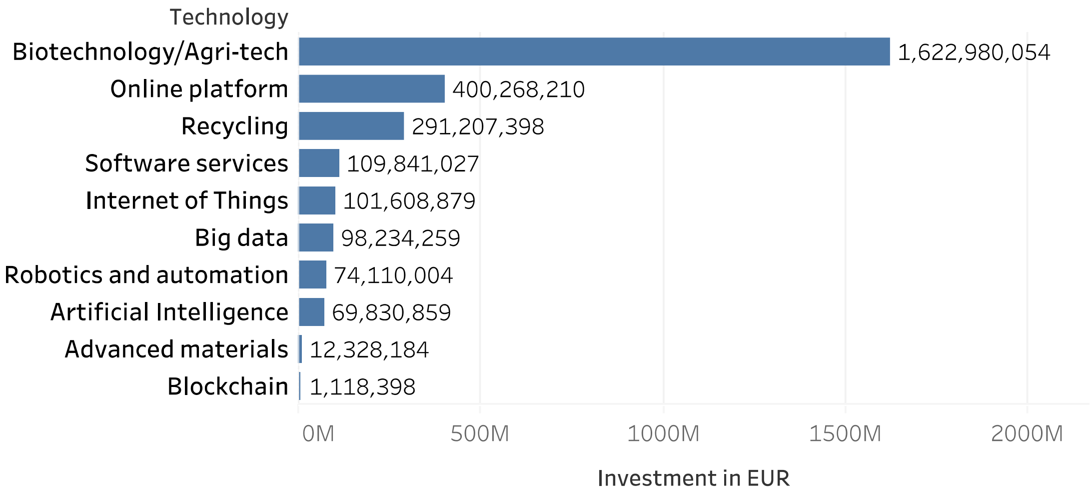
[89] For the purpose of this study, we classify funding arounds according to the following considerations:

- Seed. This stage includes all funding instruments that occur in the early phase of development of startups. Types of funding under this stage include: Pre-Seed, Seed, Angel, Accelerator/incubator, Product Crowdfunding, Equity Crowdfunding, Crowdfunding, Award/Prize
- Early Development. Here we include early Venture Capital investment rounds (up to €20 million), Convertible Note, Series A, Corporate and Private Equity (up to €20 million)
- Late Development. Operations within this stage include advanced VC rounds (>€20 million), starting from Series B.
- Exit. Here we include operations for very well establish startups, including offering corporate shares to the general public, acquisition and merger operations.

Figure 28: Distribution of private equity and VC investment into agri-food tech companies by type of technology (2010-2022)



Source: Technopolis Group calculations based on Crunchbase and Net Zero Insights, 2023

In addition, the data reveal information on the number of **unicorns in agri-food tech** by world region. Over the indicated time period, the EU27 recorded 15 agri-food tech unicorns compared to 85 in the USA and 32 in China. A few examples include:

- Flink Food,[90] an online platform for grocery products
- InFarm,[91] developing technologies for vertical farms
- HelloFresh,[92] bringing pre-portioned ingredients to people's homes on a subscription basis

4.2. Foreign direct investment in agri-food

Figure 29 presents the total capital investment over time of foreign direct investment (FDI) agri-food projects (from EU or to EU). The figure showcases the evolution over time of total capital expenditure of agri-food FDI projects from or to EU member states. Three categories of movement are visible: Intra EU (FDI projects from EU27 countries to EU27 countries), foreign direct investment from non-EU countries into the EU27, and outwards EU27 FDI from EU27 countries.

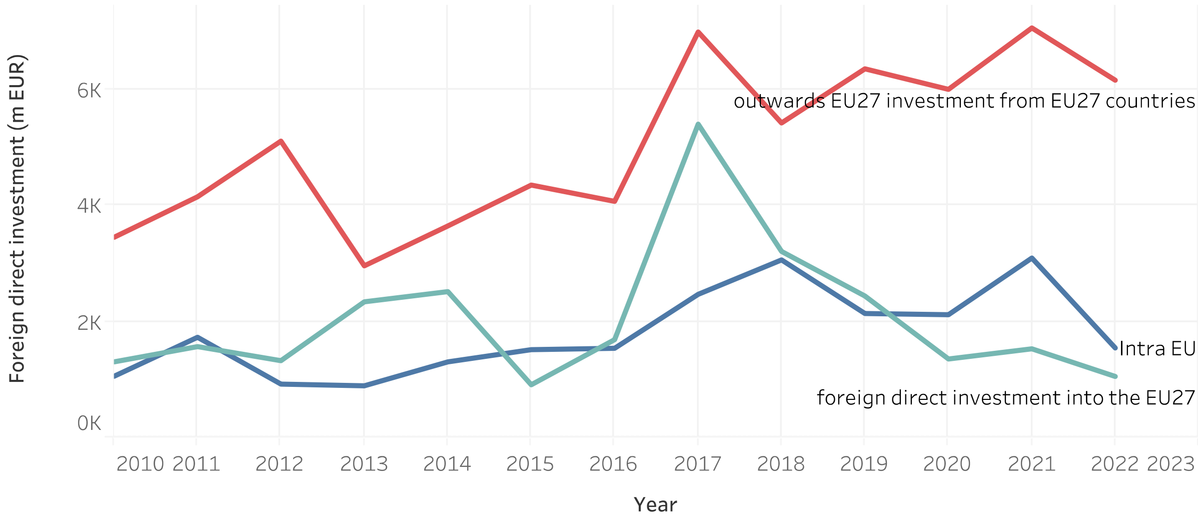
fDi intelligence[93] is a data tool that tracks cross-border greenfield investment both intra EU, extra EU and globally, covering the **agri-food industrial ecosystem. It provides real-time monitoring of investment projects**, capital investment and job creation with powerful tools to track and profile companies that are active investors in the agri-food industrial ecosystem. The data source tracks projects that are expected to create new jobs and do not cover merges and acquisitions as these are already part of the venture capital data analysis above.

Outwards EU27 investments from EU27 countries are considerably higher than the intra EU and foreign direct investment into the EU27 over the observed period. While foreign direct investment into the EU27 is comparably high in 2017, it remains otherwise low.

[90] See https://www.goflink.com/en/
[91] See https://www.infarm.com/
[92] See https://www.hellofresh.be/
[93] https://www.fdiintelligence.com/

Outward EU27 investment from EU27 countries is variable, though clearly on the rise from 2020 onwards into 2022.

Figure 29: Foreign direct investment in agri-food



Source: Technopolis Group calculations based on fdiInsights

4.3. EU research and innovation funding into agri-food

A recent study **'Food systems: Research and innovation investment gap study: Policy report'** highlights the public and private expenditure when it comes to food systems and food-related innovation activities. In terms of EU funding for food systems, €18.4 bn is estimated to have gone to food systems related projects between 2007 and 2020, with €2.1 bn going to the primary production sector. Based on an analysis of company data related to patenting activity, the study estimates €93 bn have been invested in food-related innovation by the private sector between 2012 and 2018[94], the majority of which in Germany and the Netherlands, and largely related to 'climate smart and environmentally sustainable food systems'.[95]

In this study, Horizon 2020 funding data was further analysed with regard to digital and green transition related investments within agri-food. Horizon 2020 was the European Union's multiannual research and innovation programme for the period 2014-2020. According to data from the Community Research and Development Information Service (CORDIS), **the programme funded 955 projects classified under the agri-food industrial ecosystem with a total funding of €3.8 bn in 2014-2020.**

The digital and green transition related projects accounted for €1.7 bn.

Among the funded projects, ICT projects accounted for 18% of the total funding according to the coding available in CORDA[96], followed by food security, sustainable agriculture and

[94] The study also acknowledges the inherent difficulties in tracking private investments in the agri-food sector, highlighting that this value might be underestimated.

[95] European Commission (2023) Food systems Research and innovation investment gap study: Policy report https://op.europa.eu/en/publication-detail/-/publication/1747dc15-be80-11ed-8912-01aa75ed71a1

[96] CORDA data is a private version of CORDIS data. It includes the NACE code of the beneficiaries, therefore allowing to a sector-based analysis.

forestry, marine and maritime and inland water research and the bioeconomy (13%) see Table 1.

Zooming in on the technologies as defined in the Methodological Report of the Monitoring industrial ecosystems (EMI) project, Table 2 outlines the total cost per technology related to the agri-food industrial ecosystem. With more specific technologies such as renewable energy technologies (wind, solar and other (geothermal, hydropower, biomass) power; 15%), and advanced manufacturing & robotics (11%) making up important segments in terms of technological focal areas.

Table 1: CORDA EU R&I funding in EUR in agri-food - High level technology area coding

Technology - High level (coded in CORDA)	Total Cost	FP Contribution	Other investment	Share
Climate action, environment, resource efficiency and raw materials	73.504.569	67.202.580	6.301.988	2%
Food security, sustainable agriculture and forestry, marine and maritime and inland water research and the bioeconomy	488.609.891	450.461.171	38.148.720	13%
ICT	685.414.196	462.692.702	222.721.493	18%
Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing (NMBP)	410.762.643	313.340.372	97.422.272	11%
Smart, green and integrated transport	15.892.994	12.319.193	3.573.800	0,4%
Space	85.055.777	170.104.209	- 85.048.432	2%
Total investments in twin transition projects	1.759.240.070	1.306.016.018	368.168.274	45%
TOTAL Agri-Food	3.890.269.015	6.483.115.398	644.986.127	100%

Source: Technopolis Group based on CORDA, 2022

Table 2: CORDA EU R&I funding in EUR in agri-food – Technology based classification

Technology & IE	Total Cost	FP Contribution	Other investment	Share in total (using Total cost)
Advanced Manufacturing & Robotics	335.742.243	237.326.116	98.416.127	11%
Artificial Intelligence (& Machine Learning & Computational intelligence)	310.911.984	198.638.204	112.273.780	10%
Digital Security & Networks/ Cybersecurity	12.189.427	11.457.756	731.670	0,4%
Digital Tech for Mobility	152.582.250	129.208.896	23.373.354	5%
Internet of Things	221.122.006	153.236.532	67.885.473	7%
Micro- and Nanoelectronics & Photonics	71.429	50.000	21.429	0%
Advanced Materials and Nanotechnology	-	-	-	0%
Biotechnology including Medical Biotechnology	134.194.852	117.382.958	16.811.894	4%
Energy Saving Technologies	9.092.902	7.582.768	1.510.134	0,30%

Hydrogen technologies	2.191.134	2.180.663	10.471	0,07%
Wind, Solar and other (geothermal, hydropower, biomass) Power	464.588.999	357.039.040	107.549.959	15%
Recycling technologies relevant for the circular economy	146.480.840	131.758.268	14.722.572	5%
TOTAL	**3.013.558.360**	**2.404.169.376**	**609.388.984**	100%

Source: Technopolis Group based on CORDA, 2022

5. Skills

Key findings

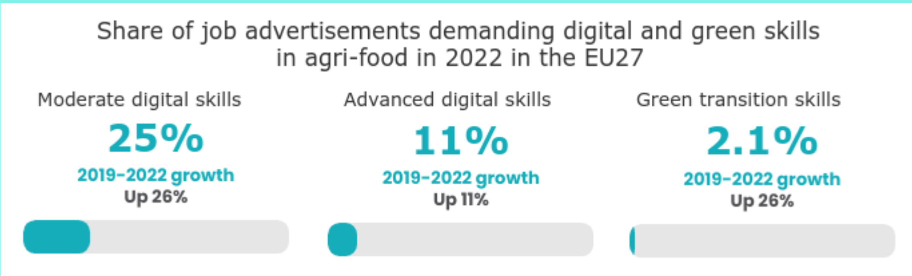
Workers in the agri-food ecosystem are often low skilled, ageing workers or third-country nationals, sometimes with lower qualification levels. There is an **increasing need for high skilled workers such as agronomists, machinery and contact material specialists, C-level employees, sustainability experts, circular and biotech experts, food scientists, food technologists, and high craftsmanship** in the different sub-sectors. Many initiatives are taken to address this labour and skills shortage, including education and training, social protection policies, immigration, supporting collaborations, developing partnerships and platforms to share knowledge and best practices including the Pact for Skills.

The supply of skilled professionals relevant for the green and digital transition has been captured based on LinkedIn data. Within the registered professionals on LinkedIn employed in the agri-food industrial ecosystem, **6% indicated to have one type of advanced digital skill** (including technological knowledge such as IoT, AI, connectivity, big data, advanced farm management software etc), and **3% to have environmental protection related skills** (green skills).

Digital skills are led by **advanced software** for farm management or food production, followed by **cloud** related skills and **artificial intelligence**. **Circular economy** is the most important green skill followed closely by **low carbon, energy saving technologies and renewable energy**.

Skills demand in the agri-food industrial ecosystem was analysed based on the skills intelligence insights of Cedefop. **Online job advertisements that can be related to the digital transition represented 25% of all job ads in agri-food in 2022 in the EU27.** This share is 11% for advanced digital technologies. Regarding the green transition, 2.1% of job vacancies were found requesting a green skill in 2022.

Figure 30: Share of job advertisements with a reference to digital or green skills



Source: Technopolis Group calculations based on Cedefop, 2023

The top digital skills that appeared most often on agri-food job advertisements over the period from 2019-2022 include **office software, technical drawings, business ICT, but also database and programming** related skills. The most popular environmental skills on job advertisements have been **corporate social responsibility, energy efficiency and environmental legislations**.

The agri-food ecosystem is facing critical labour and skills shortages that may impede the sector's productivity growth, resilience and sustainable development.

Labour and skills shortages and the strong skills mismatch in the industry are a major concern in the agri-food sector across OECD countries. Particularly, workers in the agri-food ecosystem are often low skilled, ageing workers or third-country nationals, sometimes with lower qualification levels.[97] These challenges are compounded by the perceived unattractiveness of the sector, with low wages and limited career prospects, [98] and the transformations the sector is facing with regard to technological and economic change, climate change, and global value chains, requiring workers to develop new knowledge and skills.[99] As such, there is an increasing need for high skilled workers such as agronomists, machinery and contact material specialists, C-level employees[100], sustainability experts, circular and biotech experts, food scientists, food technologists, and high craftsmanship in the different sub-sectors.[101] Yet, an important characteristic of the agricultural labour force is the relatively low interest and investment in formal education, with a strong preference for informal and experimental pathways to acquiring skills via learning on the job and within the environment of the farm.

The nature of skills required in the agri-food ecosystem varies substantially depending on the technology intensiveness of the sector. For instance, in regions with more a technology intensive agri-food sector, there is a high demand for highly skilled workers who can operate these technologies. In regions with more traditional production technologies, demand for medium-skilled workers may be more frequent.[102] Yet, in general, stronger digital skills are needed in the agri-food workforce to allow for the uptake of advanced technologies required for a digital and green transition.[103] To foster the development of digital skills and encourage younger highly qualified workers to the sector, targeted investment in skills and jobs programmes and support will be needed.

As a response, many initiatives are taken to address this labour and skills shortage, including education and training, social protection policies, immigration, supporting collaborations, developing partnerships and platforms to share knowledge and best practices etc. Importantly, the EC has launched the Pact for Skills[104], a flagship action under the European Skills Agenda[105], which is a shared engagement model for skills in Europe. Particularly, for the agri-food sector, the Pact for Skills represents an opportunity to upskill and reskill the workforce and make the agri-food ecosystem more attractive to young people, while providing career and life-long learning perspectives to both employers and workers.[106] It brings together various stakeholders including social partners, training and educational organisations including Vocational Education and Training (VET), companies, trade associations and public authorities among others.[107]

Specific projects also seek to tackle the modernisation of skills and competences needed for the future in the agri-food industrial ecosystem, such as askfood[108], as well as fields[109]

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[97] Pact for skills – Agrifood. https://ec.europa.eu/social/BlobServlet?docId=25257&langId=en#:~:text=Its%20objective%20is%20ensuring%20the,including%20the%20agri%2Dfood%20ecosystem.

[98] OECD (2023). Labour and skills shortages in the agro-food sector. https://www.oecd.org/publications/labour-and-skills-shortages-in-the-agro-food-sector-ed758aab-en.htm

[99] Assembly of European Regions (2021). Digital Transformation & Skills in the Agri-food Sector. https://aer.eu/upskilling-agri-food/

[100] Persons in charge of certain departments with a 'chief' designation such as Chief Executive Officer, Chief Technical Officer, etc.

[101] Pact for skills – Agrifood. https://ec.europa.eu/social/BlobServlet?docId=25257&langId=en#:~:text=Its%20objective%20is%20ensuring%20the,including%20the%20agri%2Dfood%20ecosystem.

[102] OECD (2023). Labour and skills shortages in the agro-food sector. https://www.oecd.org/publications/labour-and-skills-shortages-in-the-agro-food-sector-ed758aab-en.htm

[103] European Commission (2020). Advanced Technologies for Industry. Sectoral Watch. Technological trends in the agri-food industry. https://ati.ec.europa.eu/reports/sectoral-watch/technological-trends-agri-food-industry

[104] European Commission Pact for Skills https://pact-for-skills.ec.europa.eu/index_en

[105] European Commission European Skills Agenda https://ec.europa.eu/social/main.jsp?catId=1223&langId=en

[106] Pact for skills – Agrifood. https://ec.europa.eu/social/BlobServlet?docId=25257&langId=en#:~:text=Its%20objective%20is%20ensuring%20the,including%20the%20agri%2Dfood%20ecosystem.

[107] Food Drink Europe Agri-food pact for skills https://www.fooddrinkeurope.eu/agri-food-pact-for-skills/

[108] askfood https://www.askfood.eu/project

[109] fields https://www.erasmus-fields.eu/home-2/

which aims to address future skills needs related to sustainability, digitalisation and the bioeconomy in agriculture. Both projects co-funded by the ERASMUS+ programme of the European union.

5.1. Green and digital skills in the agri-food industry

This section aims at analysing trends in the supply and demand of skilled professionals relevant for the green and digital transition based on LinkedIn data. LinkedIn is the largest professional network platform with rich information like profile summary, job title, job description and field of study, which can be used for the identification of skilled professionals in advanced technologies and both in digital and green transition. It represents the single most comprehensive source currently available for the construction of technology-specific skills related indicators. To harvest the data from LinkedIn, keywords capturing skills by advanced technology have been defined and reviewed by technology experts. Queries have subsequently been constructed to filter the database by location and industry.

To capture the agri-food industrial ecosystem the following LinkedIn tags have been used: dairy, fishery, wine & spirits, ranching, farming, food production, food & beverages. In order to capture the number of professionals working in the sector, occupations related to the industrial ecosystem have been taken into account.

Green skills have been identified as skills related to environmental protection, environmental services, environmental policy, environmental sustainability, environmental standards, low carbon technologies, renewable energy, the circular economy including circular design and recycling, and clean production technologies and business models related skills.

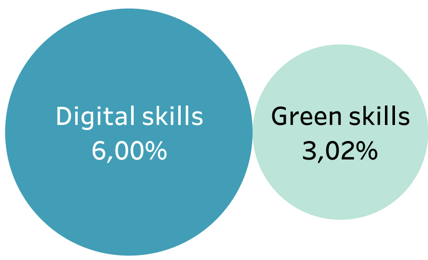
Advanced digital skills have been defined in the context of the main digital technologies captured in this project notably in artificial intelligence, cloud computing, connectivity, robotics, Internet of Things, augmented and virtual reality and blockchain, but in additional advanced software technologies have been also included that are relevant for the industrial ecosystem (such as farm management software).

Green and digital skills

Based on the analysis of LinkedIn data, a picture of the supply of professionals with green and digital technological skills relevant to the agri-food industrial ecosystem be obtained. Within the registered professionals on LinkedIn employed in the agri-food industry, **3% indicated to have one type of green skill and 6% to have an advanced digital skill** (see Figure 31).

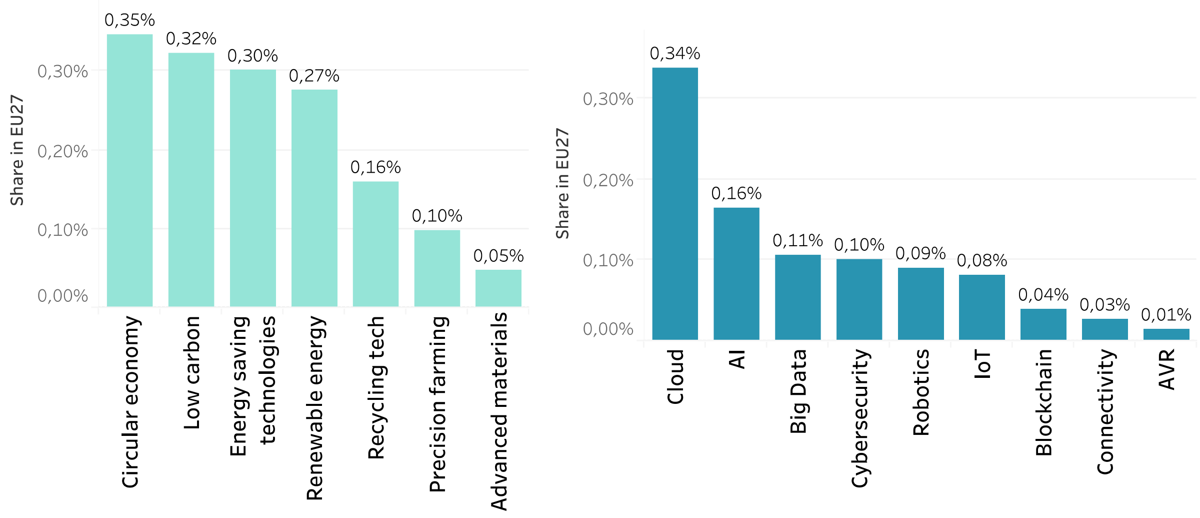
Notably within the green and digital skills breakdown (Figure 32), several skills are placed within a similar range of importance. Digital skills are led by cloud related skills followed by skills related to artificial intelligence. Circular economy leads the way, followed closely by low carbon, energy saving technologies and renewable energy.

Figure 31: Share of professionals with specific green and digital skills employed in agri-food and with a profile on LinkedIn



Source: Technopolis Group calculations based on LinkedIn, 2023

Figure 32: Breakdown of green and digital skills by type



Source: Technopolis Group calculations based on LinkedIn, 2023

Progress over time

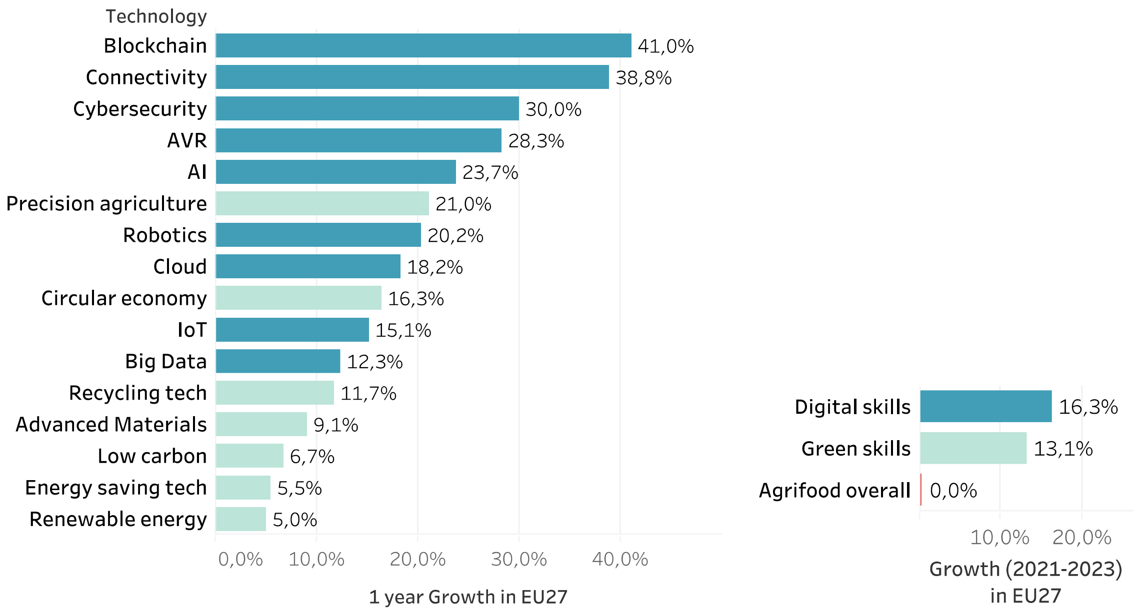
The change in the number of professionals with digital or green skills have to be put in the context of the overall employment patterns. As highlighted above, the total number of professionals in agri-food on LinkedIn has decreased over time and in particular during the pandemic period, which is in line with official statistical figures. Compared to this, the share of professionals with digital or green skills has witnessed a steady growth over the past years.

There have been 16% more professionals in the agri-food industrial ecosystem claiming to have an advanced digital skill and 13% more with a green transformation skill in March 2023 than in 2021. In a broader context, available Eurostat figures show that the number of ICT specialists in the EU grew by 50.5 % from 2012 to 2021, almost eight times as high as the increase (6.3 %) for total employment[110].

Figure 33 presents the trends in the number of professions with green and digital skills in terms of growth in the EU27 (from 2021 and 2023). For the digital skills, blockchain (41%), connectivity (38.8%), cybersecurity (30%), augmented and virtual reality (28.3%) and artificial intelligence (23.7%) make up the greatest fragment of growth. Green skills are led by precision agriculture (21%), circular economy (16.3%) and recycling tech (11.7%), but are considerably less important in the recent growth figures than the digital technologies.

[110] Eurostat https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_specialists_in_employment

Figure 33: Trends in the number of professionals with green and digital skills employed in the agri-food industrial ecosystem and with a profile on LinkedIn



Source: Technopolis Group calculations based on LinkedIn, 2021 and 2023

5.2. Skills demand

Skills demand in the agri-food industrial ecosystem has been analysed following the skills intelligence insights of Cedefop. This dataset covers 28 European countries and is based on the collection and analysis of more than 530 online job advertisement sources (424 distinct websites) which are open-access sites. The dataset provides information on most requested occupations and skills across European countries based on established international classifications, e.g., ISCO-08 for occupations, ESCO for skills, and NACE rev. 2 for sectors.

Specific to the agri-food industrial ecosystem[111], **there were 826 009 unique job advertisements from companies between 2019-2022 in the EU.** The number of online job advertisements within agri-food in EU27 countries amounts to 268 954 in the year 2022. Skills have been analysed related to the green and digital transitions. The European multilingual classification of Skills, Competences, Qualifications and Occupations (ESCO) is used as follows:

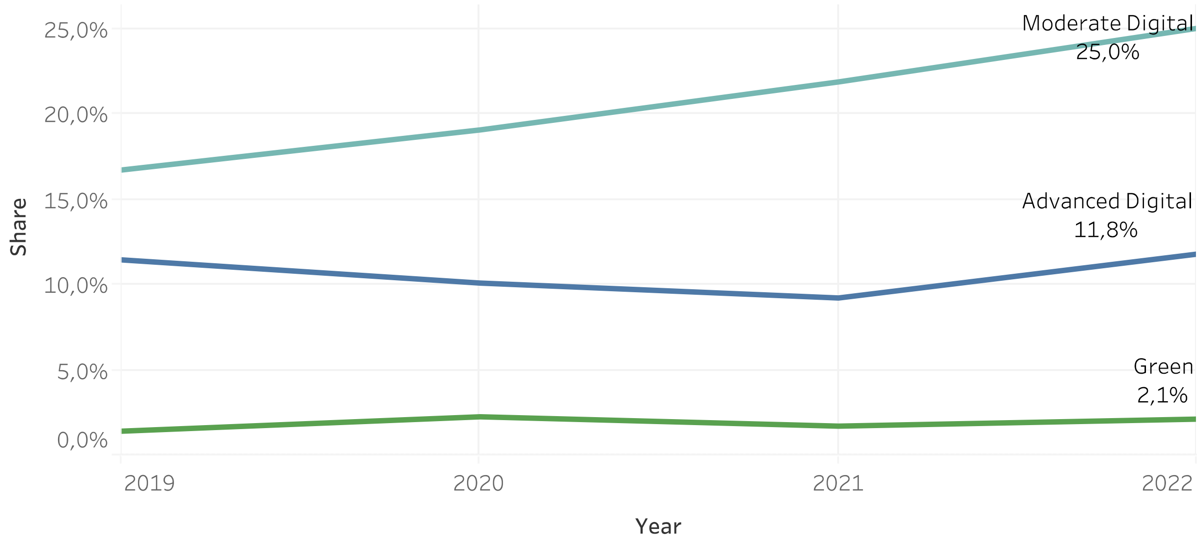
- **Green transition related skills** (ESCO v1.1.) are those knowledge and skills which reduce the negative impact of human activity on the environment.
- **Moderate and Advanced Digital skills** (ESCO v1.1.1 which is currently being updated) are competences which involve the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society. Within digital skills, we distinguish between moderate digital skills (that do not include basic Microsoft office skills but include specialised software used in the industry, the use of statistical software etc) and advanced digital skills (a category that is filtered for digital technologies highlighted in the methodological

[111] In the case of the tourism industrial ecosystem the dataset was filtered for the NACE industries as defined in the Annual Single Market Report for agri-food

report including AI, big data, robotics, IoT, cloud, augmented and virtual reality, blockchain).

The share of online job advertisements that required any form of **moderate digital skills (excluding basic IT office skills) was 21.07%** over the period from 2019-2022 (25% in 2022), while this percentage was **10% for advanced digital skills** (11.7% in 2022). Requirements related to the **green transition** appear less often on the advertisements notably in a very small share **1.89%** of the cases (2.1% in 2022). Both the number and share of job ads with digital and green skills requirement increased over time.

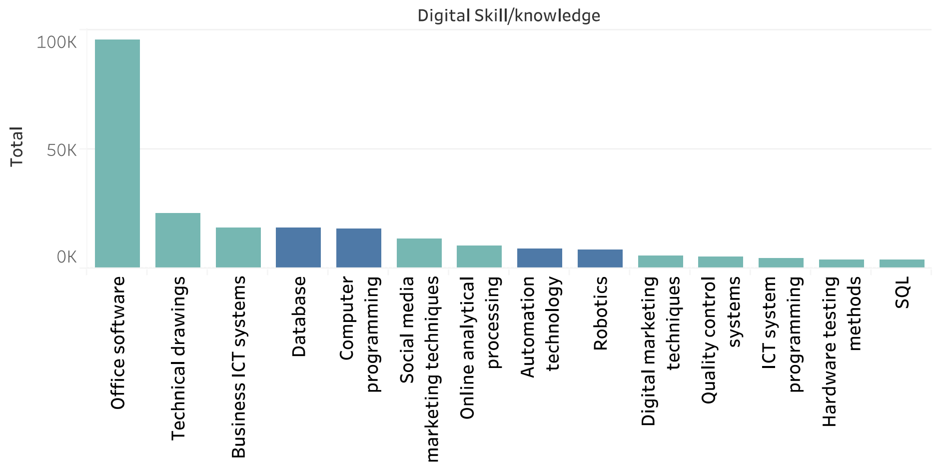
Figure 34: Share of online job advertisements in agri-food with a requirement for digital or green skills within total in the EU27



Source: Technopolis Group calculations based on Cedefop SkillsOvate data, 2023

The top 15 digital skills including both general and more advanced digital skills that appeared most often on agri-food job advertisements over the period from 2019-2022 are presented in the Figure below:

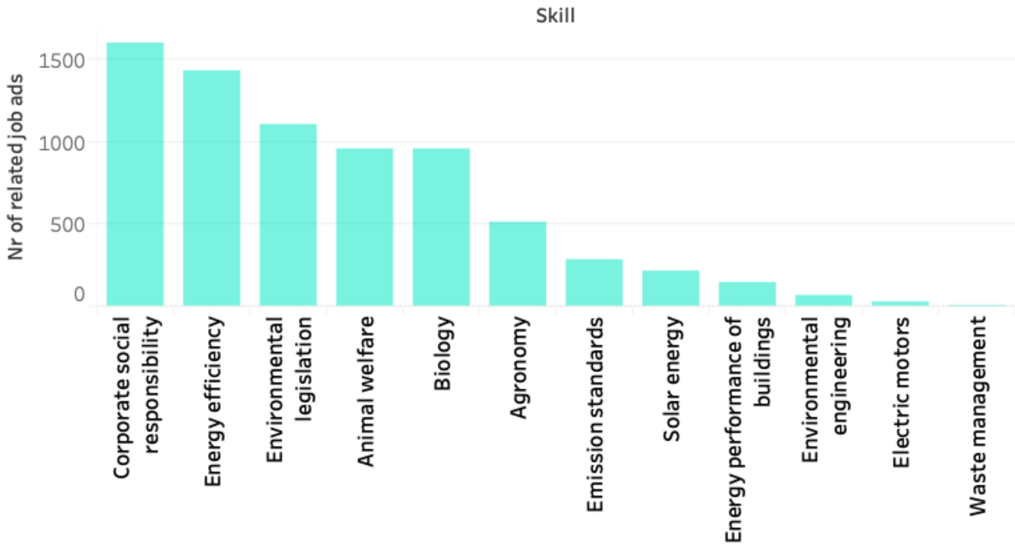
Figure 35: Top 15 digital skills on job advertisements in agri-food (2019-2022) in the EU27



Source: Technopolis Group calculations based on Cedefop SkillsOvate data, 2023

The green skills are significantly more limited compared to digital. The more sought-after green skills are:

Figure 36: Top green skills on job advertisements in agri-food (2019-2022) in the EU27



Source: Technopolis Group calculations based on Cedefop SkillsOvate data, 2023

6. Green performance of the ecosystem

Key findings

The agri-food ecosystem is traditionally known for its large environmental impact and its conspicuous use of (natural) resources.

Resources utilisation is captured with **four main dimensions** which are considered in cross-industry comparisons. The four dimensions are namely, embodied land use, water consumption, material consumption, and the energy mix supplied to the industrial activities. In terms of environmental impacts, there are **two additional dimensions monitored**: air emissions (incl. GHG), and damage to the ecosystem.

Materials extraction has been decreasing until 2015 and has, since then, shown an upward trend. Furthermore, it is noticeable that the absolute values of resource use for the agri-food ecosystem are well above the industrial ecosystem averages.

Water and land use of the agri-food ecosystem make up more than half of the total water and land use of all industries and the material extraction in the agri-food industry represents almost a third of the material extraction of all industries.

The **greenhouse gas emissions** of the agri-food industrial ecosystems are consistently high over time with a slight decrease in 2015. Additionally, the emissions of the agri-food industry are more than twice as high as the IE average.

ISO 14001 includes a set of standards that any company can follow to implement an effective environmental management system. **The annual ISO survey indicates that there were 1 660 certificates issued to agri-food companies in the EU27 in the year 2021,** which is a **decrease** compared to 2 380 certificates issued in 2012 and which is below the industry average.

The agri-food ecosystem is traditionally known for its large environmental impact and its substantial use of (natural) resources. Specifically, the agri-food sector, and especially agriculture[112], negatively impacts the environment by the combined use of a range of natural resources and input, such as land, fresh water[113], pesticides, fertilisers, and energy, hereby affecting biodiversity, depleting natural resources, and leading to water and air contamination, soil erosion, deforestation, and greenhouse gas emission.[114],[115] Recent data show that food processing, packaging and transport tend to be only a small part of a food's carbon footprint, and that the bulk of the carbon footprint is attributable to meat (especially beef) production.[116] The Annual Single Market Report (2022) indicates that the energy intensive industries and the agri-food ecosystem had by far the highest level of GHG emission intensity in 2019 compared to the other industrial ecosystems.[117] At the same time, the agri-food ecosystem can also have positive impacts on the environment

[112] OECD (2022). Environmental impacts along the food supply chain. https://www.oecd-ilibrary.org/agriculture-and-food/environmental-impacts-along-food-supply-chains_48232173-en
[113] 70% of global freshwater withdrawals are used for agriculture (FAO. 2011. The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London.)
[114] OECD. Agriculture and the environment. https://www.oecd.org/agriculture/topics/agriculture-and-the-environment/
[115] European Environment Agency (2023). Food security and environmental impacts. https://www.eea.europa.eu/themes/agriculture/greening-agricultural-policy/food-security-and-environmental-impacts
[116] https://ourworldindata.org/environmental-impacts-of-food?insight=food-emissions-local#key-insights-on-the-environmental-impacts-of-food
[117] European Commission (2022) Annual Single Market Report 2022 https://ec.europa.eu/docsroom/documents/48877

for instance by trapping greenhouse gases within crops and soils, and mitigating flood risks through the adoption of certain farming practices.[118]

In recent years, there have been some encouraging signs that the agriculture sector of OECD countries is capable of addressing its environmental challenges and mitigating its environmental impact. For instance, in the last decade, progress was achieved reducing phosphorus balances, ammonia emissions, nitrogen balances, GHG emissions intensities[119] and the use of renewable energy applications along the agri-food chains[120]. However, a lack of progress was observed in reducing GHG emissions.[121]

6.1. Resource consumption

As the agri-food industrial ecosystem heavily resource-dependent, time series on resource use in the agri-food industrial ecosystem are particularly interesting to examine and provide insights into the progress of the ecosystem with regard to the green transition. Several sources can be consulted to capture distinct elements of the environmental impact of the industrial ecosystem. The data to monitor the green transition is drawn from the Eurostat and Exiobase 3.8[122] data sources. Whilst Eurostat represent the official European statistics, Exiobase is a legitimate source of information referred to for example by the European Environmental Agency[123], the EC/JRC community[124], Eurostat[125], and by the European Commission to propose the regulation on carbon border adjustment mechanisms[126]. Pressure to environments refer to trade-embodied resources utilisation, and trade-embodied impacts.

Resources utilisation is captured with **four main dimensions** which are considered in cross-industry comparisons. The four dimensions are namely, embodied land use, water consumption, material consumption, and the energy mix supplied to the industrial activities. In terms of environmental impacts, there are **two additional dimensions monitored**: air emissions (incl. GHG), and damage to the ecosystem.

Figure 23 shows the summary of green performance indicators at EU level and its change from 2010 to 2020.

It is noticeable that the absolute values of resource use for the agri-food ecosystem are well above the industrial ecosystem averages. Particularly, the **water and land use of the agri-food ecosystem make up more than half of the total water and land use of all industries and the material extraction in the agri-food industry represents**

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[118] OECD. Agriculture and the environment. https://www.oecd.org/agriculture/topics/agriculture-and-the-environment/

[119] OECD (2022). Measuring the Environmental Performance of Agriculture Across OECD Countries. https://www.oecd.org/publications/measuring-the-environmental-performance-of-agriculture-across-oecd-countries-4edcd747-en.htm

[120] The International Renewable Energy Agency (IRENA) & The Food and Agriculture Organization of the United Nations (FAO). (2021). Renewable energy for agri-food systems. https://www.fao.org/3/cb7433en/cb7433en.pdf

[121] OECD (2022). Measuring the Environmental Performance of Agriculture Across OECD Countries. https://www.oecd.org/publications/measuring-the-environmental-performance-of-agriculture-across-oecd-countries-4edcd747-en.htm

[122] Exiobase is a time series of environmentally extended multi-regional input-output (EE MRIO) tables. Its coverage is by country and industry from 1995 to 2021 and has EU and extra rest of the world coverage. Source: Stadler, Konstantin, Wood, Richard, Bulavskaya, Tatyana, Södersten, Carl-Johan, Simas, Moana, Schmidt, Sarah, Usubiaga, Arkaitz, Acosta-Fernández, José, Kuenen, Jeroen, Bruckner, Martin, Giljum, Stefan, Lutter, Stephan, Merciai, Stefano, Schmidt, Jannick H, Theurl, Michaela C, Plutzar, Christoph, Kastner, Thomas, Eisenmenger, Nina, Erb, Karl-Heinz, … Tukker, Arnold. (2021). EXIOBASE 3 (3.8.2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5589597

[123] EEA 2022. Visit 12/10/2022. https://www.eea.europa.eu/data-and-maps/data/external/exiobase

[124] Beylot, A., Secchi, M., Cerutti, A., Merciai, S., Schmidt, J. and Sala, S., 2019. Assessing the environmental impacts of EU consumption at macro-scale. Journal of cleaner production, 216, pp.382-393. https://doi.org/10.1016/j.jclepro.2019.01.134

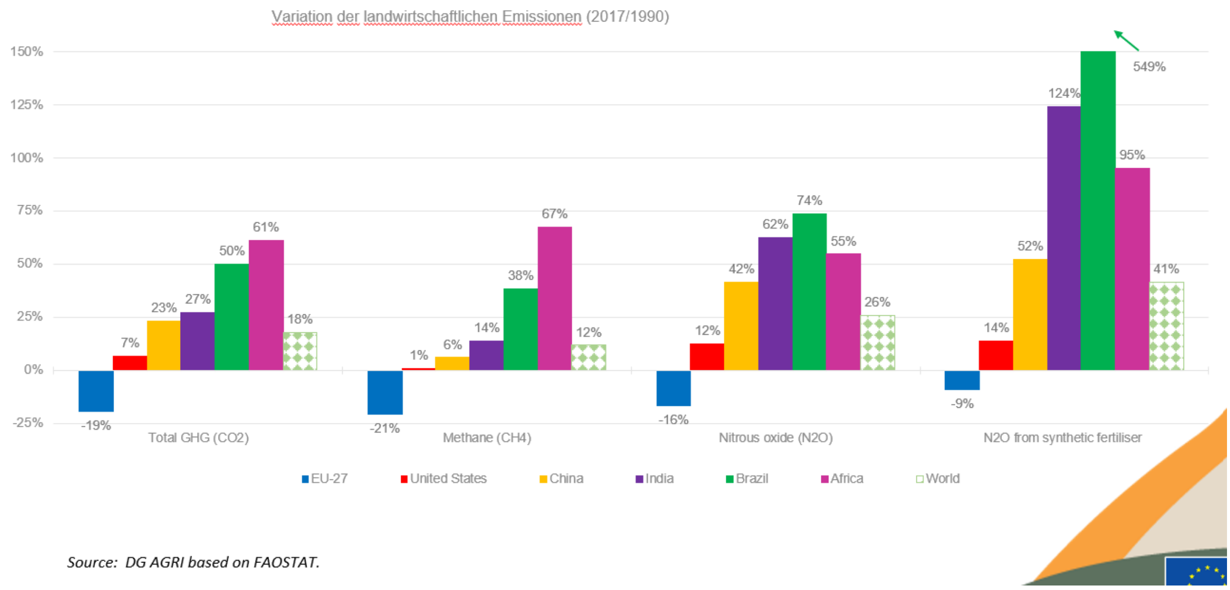
[125] Remond-Tiedrez, I. and Rueda-Cantuche, J.M. eds., 2019. EU Inter-country Supply, Use and Input-output Tables: Full International and Global Accounts for Research in Input-output Analysis (FIGARO). Luxembourg: Publications Office of the European Union.

[126] EC (2021) REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Establishing a carbon border adjustment mechanism. COM(2021) 564 final.

almost a third of the material extraction of all industries. Land use and water consumption show increasing trends, associated with increasing environmental impact. Materials extraction has been decreasing until 2015 and has, since then, shown an upward trend.

The global emissions of the agri-food industrial ecosystem have remained consistently high over time with a slight decrease in 2015.

Figure 37: Agricultural emissions



Source: DG AGRI based on FAOSTAT.

Additionally, emissions of the ecosystem are more than twice as high as the IE average. Agri-food systems consume about 30% of the world's energy[127], and a third of agri-food systems' emissions of greenhouse gases stem from energy use worldwide.[128] Particularly, in 2019, the ecosystem had the second highest level of GHG emission intensity compared to the other industrial ecosystems.[129]

The damage to the ecosystem, which covers biodiversity loss, shows a slightly increasing trend since 2014, yet shows signs of levelling off or even reversing in 2019-2020.

[127] The International Renewable Energy Agency (IRENA) & The Food and Agriculture Organization of the United Nations (FAO). (2021). Renewable energy for agri-food systems. https://www.fao.org/3/cb7433en/cb7433en.pdf

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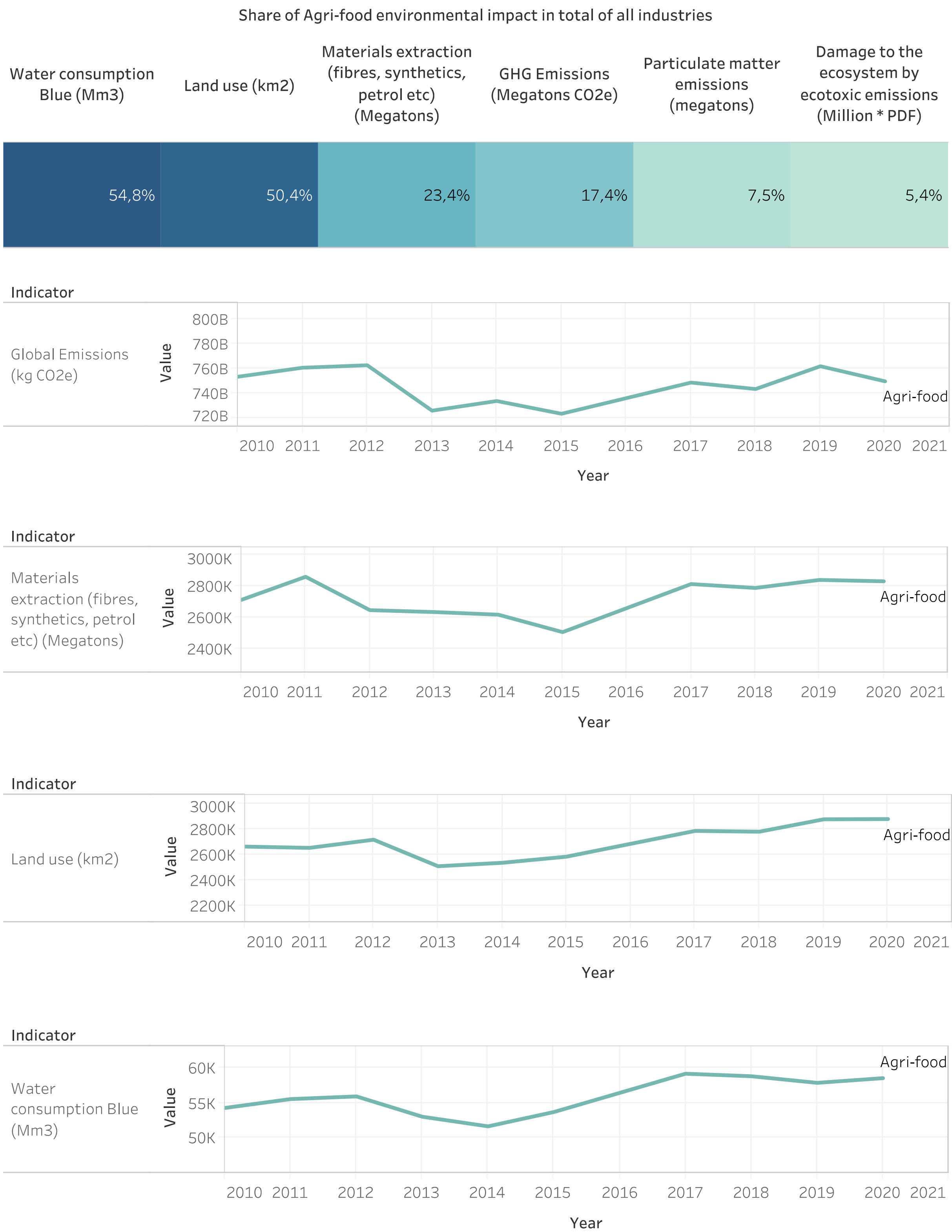
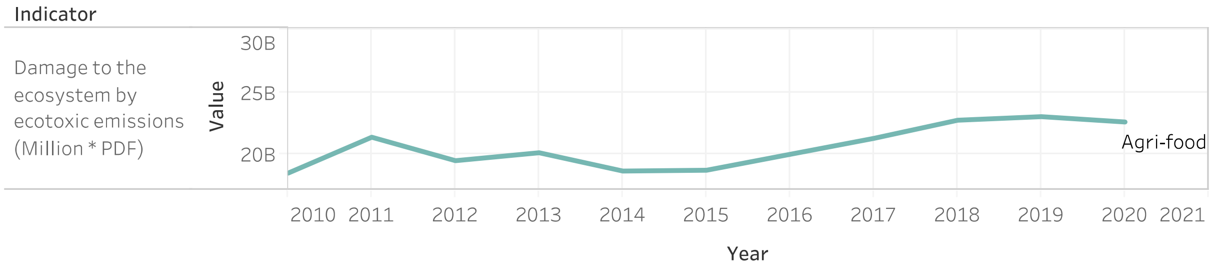
Figure 38: Indicators to capture the green transition of the agri-food industrial ecosystem in the EU, Exiobase





Source: Technopolis Group based on Exiobase, 2022

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Appendix B: Methodological notes

Crunchbase and Net Zero Insights

Tags used in the analysis:

- **Agriculture and Farming** Agriculture, AgTech, Animal Feed, Aquaculture, Farming, Horticulture, Hydroponics, Livestock,
- **Food and Beverage** Bakery, Brewing, Catering, Coffee, Confectionery, Craft Beer, Dietary Supplements, Distillery, Farmers Market, Food and Beverage, Food Delivery, Food Processing, Food Trucks, Fruit, Grocery, Nutrition, Organic Food, Seafood, Snack Food, Tea, Tobacco, Wine And Spirits, Winery, Restaurants

FDI

fDi intelligence[130] tracks cross-border greenfield investment both intra EU, extra EU and globally, covering the agri-food industrial ecosystem among other industries. It provides real-time monitoring of investment projects, capital investment and job creation with powerful tools to track and profile companies that are active investors in the field. The data source tracks projects that are expected to create new jobs and do not cover merges and acquisitions (already part of the VC data analysis above).

FDI sectors and sub-sectors selected for the analysis:

- **Food & beverages** Fruits & vegetables & specialist foods, Animal food, Food services, Tobacco, Soft drinks & ice, Food & beverage Stores, Seasoning & dressing, Coffee & tea, Breweries & distilleries, Crop production, Bakeries & tortillas, Snack food, Other (Food & Beverages), Dairy products, Sugar & confectionary products, Wineries, Animal production, Seafood products, Fishing, Animal slaughtering & processing

Survey

The table below presents the overview of the sub-sectors included in the sampling frame, with corresponding sections according to the NACE industrial classification.

Table 3 Survey sampling

NACE		Sample size of the survey
A	Agriculture, forestry and fishing	506
C10	Manufacture of food products	275
C11	Manufacture of beverages	264

Source: Technopolis Group and Kapa Research, 2023

Big Data analysis

The analysis employs the OPIX platform, which utilises a selection of models specifically tailored to the Agri-Food industrial ecosystem and the technological scope of the project.

[130] https://www.fdiintelligence.com/

The main data source for the analysis is the websites of companies within the Agri-Food ecosystem, namely the sectors of agriculture, forestry and fishing and manufacture of food products, beverages and tobacco products. The analysis covers a sample of 29,051 companies comprising a total of 4,963,412 webpages. This sample is further divided into 9% large companies and 89% SMEs from the Agrifood industrial ecosystem.

The thematic scope of the green and digital transition pillars covered by the analysis is derived from a scoping exercise of policy documents, scientific literature and industrial practices on technologies related to the green and digital transition of the Agrifood ecosystem.

In digital transition, the statistics on the adoption of AI, 3D printing, robotics and cloud computing services, already covered by Eurostat in the annual survey on ICT usage and e-commerce in enterprises are used in this report where available and hence for manufacture of food products, beverages and tobacco products.

In the Table below, the high-level categorisation is described for green and digital transition. Each category is further broken down in a number of High Priority Clusters.

Table 4: Technological Scope for the agri-food Big data analysis

Green transition	Digital Transition
Modern technologies to improve soil health and fertility Advanced technologies used to reduce water consumption The role of I4.0 technologies in mitigating climate change Renewable energy Sustainable packaging Alternative proteins	Digitalisation and precision agriculture Remote sensing technologies in agriculture Digital technologies to improve traceability and food safety Emerging technologies supporting agri-food supply chain management Digital technologies in support of the circular economy Augmented and virtual reality

Source: Technopolis Group, based on Opix's big data services.

The methodological approach of the analysis is supported by models that utilise scientific and industry data corpuses specific to the agri-food industrial ecosystem. These models are designed to provide detailed insights into the scope of the green and digital transition pillars.

The models generate a list of High Priority Clusters (HPCs) that frame the green and digital transition pillars using key terms. This approach enables a high level of granularity in the analysis, allowing for a more precise understanding and interpretation of the activities undertaken by companies in the Agri-Food sector.

By utilising HPCs and their corresponding key terms, the analysis can set minimum thresholds for the presence and frequency of these terms within HPCs. These thresholds serve as qualifying criteria for companies, determining their inclusion within the Green and Digital transition pillars. The team conducting the analysis can adjust the level of stringency by setting specific thresholds for key terms, ensuring that companies meeting the criteria are considered in the analysis.

Overall, the use of models based on scientific and industry data corpuses, combined with the identification of HPCs and key terms, provides a robust and systematic approach to analyse the green and digital transition pillars within the Agri-Food industrial ecosystem. This approach contributes to obtaining high quality results and addresses risks associated to green washing in companies' websites. Combined with other evidence such as sustainability certifications or eco-labels etc. the results can contribute to the regular monitoring of twin transition technological uptake in the agri-food industrial ecosystem.

Environmental certificates

ISO annual surveys report the number of companies/organisations with environmental certificates. Environmental certificates were the ISO 14000, which was updated requiring more stringent standards and practices in the year 2015. The new standard was then named ISO 14000/2015. Holders of the ISO 14000, starting from the year 2015, had to be re-certified to gain the new ISO14000/2015 certificate. New sustainability and environmental practices had to be put in place; with organisational change and financial requirements implied. Accreditation bodies had also to adopt new verification procedures, with their corresponding time lag. This may explain the drop in number of certified companies/organisations from 2015 to 2017.

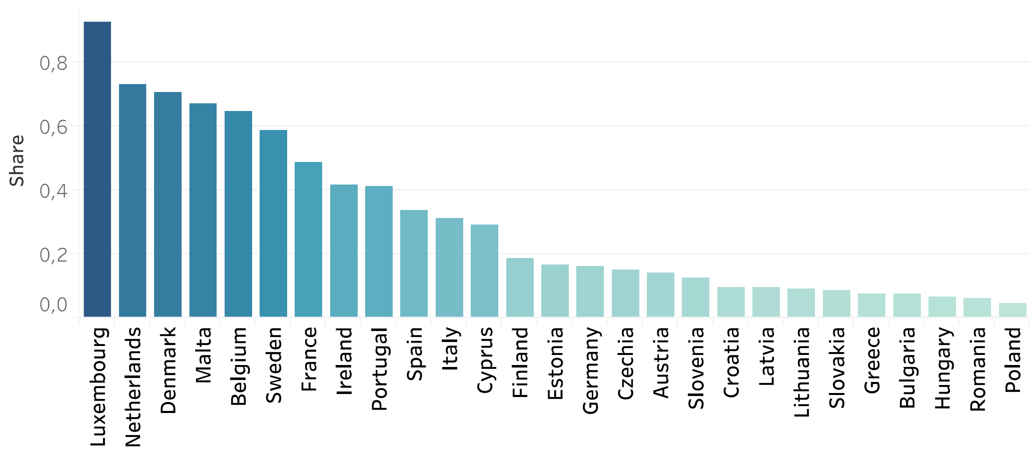
Exiobase

Exiobase is a time series of environmentally extended multi-regional input-output (EE MRIO) tables. Its coverage is by country and industry from 1995 to 2021 and has EU and extra rest of the world coverage. Source: Stadler, Konstantin, Wood, Richard, Bulavskaya, Tatyana, Södersten, Carl-Johan, Simas, Moana, Schmidt, Sarah, Usubiaga, Arkaitz, Acosta-Fernández, José, Kuenen, Jeroen, Bruckner, Martin, Giljum, Stefan, Lutter, Stephan, Merciai, Stefano, Schmidt, Jannick H, Theurl, Michaela C, Plutzar, Christoph, Kastner, Thomas, Eisenmenger, Nina, Erb, Karl-Heinz, … Tukker, Arnold. (2021). EXIOBASE 3 (3.8.2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.5589597

LinkedIn Representativeness

To perform a representativeness analysis of LinkedIn, the available industry-specific dataset has been compared to Eurostat figures regarding the active population in the industrial ecosystem. The results show that countries such as Luxembourg and the Netherlands, as well as Denmark, Malta and Belgium have a higher amount of persons active in the agri-food industry active on LinkedIn as compared to countries such as Greece, Bulgaria, Hungary, Romania and Poland.

Figure 39: Representativeness of agri-food industry professionals on LinkedIn compared to Eurostat statistics on persons employed in agri-food



Source: Technopolis Group calculations based on LinkedIn vs Eurostat - annual enterprise statistics for special aggregates of activities (NACE Rev. 2)