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IDENTIFYING TECHNOLOGICAL CHANGES AND SKILL NEEDS IN THE WESTERN BALKAN AGRI-FOOD SECTOR: EU TRENDS REPORT

DRAFT

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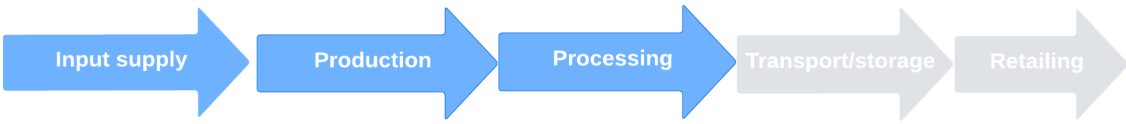
1. Introduction

The study *Identifying technological changes and skills needs in the Western Balkan agri-food sector*, seeks to identify current and emerging technological changes and skills needs in the three niches of the agri-food value chain in the Western Balkans (WB). These niches are digitalisation in agri-food, biochemical and microbial products for agri-food, and organic and functional foods. As part of the study, this report serves to identify current and emerging technological changes and skills needs for the three niches in the European Union (EU).

The agri-food value chain comprises agriculture and food processing[1] at the chain's input, production, processing, transport/storage, and wholesale/retail levels. The three niches stand at different levels of the agri-food value chain. Therefore, they do not represent the whole value chain but rather its different levels. For example, the niches of digitalisation in agri-food and biochemical and microbial products for agri-food stand at the **input** supply level of the value chain. For the purposes of this study, the organic and functional food niche captures two levels of the agri-food value chain: **production** and **processing**.

The niches of digitalisation in agri-food and biochemical and microbial products deal with the production of inputs such as, inter alia, digital software for agri-food and (bio)fertilisers and (bio)pesticides. The niche of organic and functional foods deals with the production and processing of organic and functional foods and beverages, and food supplements. In Figure 1, we show the flow of the agri-food value chain and mark the levels at which the three niches operate in light blue.[2]

Figure 1. The three niches within the agri-food value chain.



The agri-food value chain is an essential part of the EU's economy and policy landscape. To illustrate this, the broad agri-food value chain provides over 44 million jobs in the EU, including forestry, agriculture, the food industry and retail food services, as well as the production of inputs such as fertilisers, machinery and crop protection.[3] In terms of policy, the EU Common Agricultural Policy (CAP) is one of the most important and, at 60 years, oldest EU-level policies relating to agri-food.[4] It represents roughly 40% of the overall budget of the EU.[5] Since the EU is one of the leading exporters of agri-food production globally, the CAP's role in consolidating the EU's agri-food market in the face of various crises (e.g. Russia's war against Ukraine) helps the EU's agri-food sector provide food security and access to high-quality food to Europeans, while also exporting high-quality food outside of the EU.[6] The CAP's size, therefore, reflects the relevance of the whole agri-food sector to the EU.

The EU's agri-food sector is a sector in change. Currently, the sector is undergoing significant transformations in the context of digitalisation and the green transition. The green transition is the European Commission's (EC) policy priority, as reflected in the European Green Deal[7] and the Climate Law.[8] These significantly reflect on the entire agri-food value chain because it is highly polluting. Globally, agriculture makes up around 13.5% of total anthropogenic greenhouse gas (GHG) emissions.[9]

[1] de Velde E. V. & Kretz D. (2020). Advanced Technologies for Industry (ATI) – Sectoral Watch. Technological trends in the agri-food industry. Available here. p. 5.
[2] Although there are companies operating at the transport/storage level, for the purposes of this study, we focused on the highlighted levels of the agri-food value chain.
[3] European Commission (2017). The Future of Food and Farming. Available here.
[4] European Commission (2022). The common agricultural policy at a glance. Available here.
[5] European Commission (2019). Glossary: Common Agricultural Policy (CAP). Available here.
[6] European Commission (2022). Feeding Europe: 60 years of common agricultural policy. Available here.
[7] European Commission (2022). A European Green Deal. Available here.
[8] European Commission (2020). Proposal for a Regulation of the European Parliament and of the Council establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law). Available here.
[9] IFOAM, also Soto, E. I., Barnes, A., Balafoutis, A., Beck, B., Sanchez, F. B., Vangeyte, J., Fountas, S., Van, D. W. T., Eory, V., & Gomez, B. M. (2019). The contribution of precision agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU. *JRC Publications Repository*. https://doi.org/10.2760/016263. p. 6.

In the EU, agriculture makes up approximately 10% of total GHG emissions, particularly methane (CH_4) and nitrous oxide (N_2O), which are by-products of animal farming and fertilisers.[10] At the same time, EU agriculture is the only 'major system in the world' that has reduced GHG emissions by 20% since 1990.[11] To further the reduction in the agri-food sector's GHG emissions, the EC has put it at the core of its green initiatives, which we discuss below.

As part of the European Green Deal, the EC has proposed the Farm to Fork (F2F) Strategy and the European Biodiversity Strategy. The F2F, for example, highlights the need to make food systems more climate-resilient and sustainable in the face of climate change related insecurities, in particular by calling to protect soil nutrients by reducing their loss by 50% and ensuring that there is no deterioration in soil fertility.[12] In this context, the F2F aims to reduce the overall use and risk of chemical and hazardous pesticides by 50% and reduce fertiliser use by 20% by 2030.[13] The Biodiversity Strategy for 2030 emphasises the need to protect natural areas on land and sea. Conserving marine stocks, for example, could 'increase annual profits of the seafood industry by more than EUR 49 billion.'[14] In addition, the Green Deal includes provisions for a CAP reform, proposed in 2018, which substantially affects the implementation of the aforementioned strategies. The reformed CAP specifically focuses on supporting the agricultural sector by increasing the contribution of EU agriculture to climate change mitigation and adaptation, improved management of resources used for agriculture, sustainability of food systems and more robust protection for biodiversity.[15]

To achieve its green goals in relation to the agri-food sector, the EU has combined its green transition priorities with the priorities of the digital transition. The green transition requires the sector to become more resource-efficient. This is also in part because of the future lack of available land for food production. As the global population rises to around 8 billion people this year and is projected to grow to 10.4 billion by the end of this century,[16] increasing food security will depend on the efficiency of the use of the available agricultural land.[17] Hence, the agri-food sector will require a higher intensity of precision technologies for better land use to sustain such a population. The uptake of precision technologies is a core feature of digitalisation in the agri-food sector.

Digitalisation, alongside the green transformation, is one of the EU's policy priorities, with its scope going beyond the agri-food sector. The European Digital Decade's targets, expected to be achieved by 2030, include the digital transformation of businesses, secure and sustainable digital infrastructures, and digital skills development.[18] Digitalisation is a way of making agriculture greener, thus helping to facilitate the European Green Deal by making input use and production processes in the agri-food sector more precise.[19] Therefore, the EC increasingly focuses on supporting the development of digital and data solutions to help cut down carbon emissions and optimise agri-food production practices.[20]

The three niches of the agri-food sector are directly impacted by the proposed changes in the context of the EU's policy initiatives, as well as market and consumer trends relating to technology innovation in the agri-food sector, which we will discuss in the next section. These initiatives and trends drive new demand for occupations and skills in the three niches. To understand more precisely how the development and uptake of new technologies facilitates changes in the three niches of the agri-food sector, as well as what kind of occupational and skills needs it gives rise to, this report is divided into

[10] European Commission (2020). Farm to Fork Strategy. Available here. p. 10.
[11] Farm to Fork Strategy. p. 5.
[12] Farm to Fork Strategy. p. 4, p. 9.
[13] Ibid, p. 9.
[14] European Commission (2020). Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU Biodiversity Strategy for 2030 Bringing nature back into our lives. Available here.
[15] European Commission (2020). Analysis of links between CAP Reform and Green Deal. Available here. p. 4.
[16] Roser, M., & Rodés-Guirao, L. (2013). Future Population Growth. *Our World in Data*. Available here.
[17] Spanaki, K., Karafili, E., Sivarajah, U., Despoudi, S., & Irani, Z. (2022). Artificial intelligence and food security: Swarm intelligence of AgriTech drones for smart AgriFood operations. *Production Planning & Control*, *33*(16), 1498-1516. https://doi.org/10.1080/09537287.2021.1882688. p. 1.
[18] European Commission (2019). Europe's Digital Decade: Digital targets for 2030. Available here.
[19] Loudjani P. et al. (2020). AIA: Artificial Intelligence and EU Agriculture. *Joint Research Centre.* Available here. See also European Parliament. (2014). Precision agriculture: An opportunity for EU farmers: Potential support with the CAP 2014-2020. Available here.
[20] Salas M. (2021). What's on the 'Horizon' for agriculture? *Euractiv*. Available here.

three main chapters, each of which is divided into sections that provide a general overview of the niches, discuss the main technological trends and the trends in occupational profiles and company skills needs.

The analysis in this report focuses on discussing the general profiles of the agri-food sector and the selected market niches in the EU, while also paying close attention to key economic indicators (e.g. trends in growth and productivity) and key employment indicators, such as levels of (in)formality and average salary levels in the relevant NACE sectors and groups. The report also addresses the question of what kind of profiles in occupations, qualifications and skills are in demand. Finally, the report offers an estimation of the capacity of formal and non-formal training providers to match evolving labour requirements in the short and medium term. Details on the study methodology can be found in Annex I. Methodology, and the interview questionnaires for each niche are presented in

Annex II. Interview questionnaires

2. Digitalisation in agri-food

Companies operating in the niche of digitalisation in agri-food in the EU can be seen to belong to the input supply level of the agri-food value chain. These companies produce equipment and software for agri-food production, processing, transport and storage, and retail. They thus facilitate digitalisation of the value chain and help drive new occupational and skills demand trends.

In this chapter, we provide an overview of the market niche in general. We also discuss technological and market trends in the niche, as well as the occupational and skills needs of the companies active at the **input** level of the agri-food value chain (see Figure 2 below).

Figure 2. Digitalisation in the agri-food market niche within the agri-food value chain

In the following sections, we first provide an overview of digitalisation in the agri-food niche in the EU, presenting the main market and consumer trends. Then, we discuss the main technological trends. Finally, we reflect on the trends in occupational profiles and skills needs in the niche.

2.1 Overview of the market niche

This section provides a general overview of the niche of digitalisation in the agri-food sector in the EU and discusses some challenges and trends this niche faces. The niche of digitalisation in agri-food encompasses economic activities classified under the following NACE sectors:

- C28.3: Manufacture of agricultural and forestry machinery
- C28.9.3: Manufacture of machinery for food, beverage and tobacco processing
- M72.1: Research and experimental development on natural sciences and engineering
- J62: Computer programming, consultancy and related activities
- J63: Information service activities

The agri-food value chain is a resource-intensive value chain. Agricultural and food production operates on a large scale to satisfy consumer demand.[21] Agri-food is, therefore, a highly polluting sector, as discussed earlier. The digitalisation of the agri-food sector is seen as helping optimise resource use, for example, by allowing more precise and selective treatment of agricultural land.[22] In this vein, the rise of advanced technologies is undeniably changing the agri-food industry in the EU.

Higher uptakes of advanced technologies in the agri-food value chain, such as cloud computing and Artificial Intelligence (AI), help improve production efficiency by making resource use smarter and more precise, which is why this process is referred to as Precision Agriculture (PA).[23] PA is part of an umbrella term for Smart Farming (SF) and Smart Agriculture (SA), which are management concepts that refer to the technological revolution in agriculture and food production.[24] While PA, and its synonym, Precision

[21] Interreg Europe (2021). The Agri-Food Circular Economy E-Book. Available here. p. 8.
[22] Pallottino, F., Biocca, M., Nardi, P., Figorilli, S., Menesatti, P., & Costa, C. (2018). Science mapping approach to analyze the research evolution on precision agriculture: World, EU and Italian situation. *Precision Agriculture*, *19*(6), 1011-1026. https://doi.org/10.1007/s11119-018-9569-2
[23] Moysiadis, V., Sarigiannidis, P., Vitsas, V., & Khelifi, A. (2021). Smart Farming in Europe. *Computer Science Review*, *39*, 100345. https://doi.org/10.1016/j.cosrev.2020.100345. See also European Parliament. (2014). Precision agriculture: An opportunity for EU farmers.
[24] Moysiadis et al. (2021). Smart Farming in Europe. p. 2.

Farming (PF), refer more specifically to farm and field management,[25] SF and SA refer more broadly to managing agricultural and food production by digital technologies, such as real-time data-gathering, processing and analysis, as well as machine intelligence, the Internet of Things (IoT), robotics and other automated or semi-automated technologies.[26] For the sake of simplicity, we use the term Smart Agriculture (SA) to refer to recent trends in technology adoption in the agri-food value chain.

SA helps agri-food producers achieve greater sustainability by reducing waste and monitoring environmental impact during all stages of agri-food production.[27] Hence, the European Joint Research Centre (JRC) estimates that SA can make a substantial CO_2 saving contribution to European agriculture by 2030 by cutting down the production inputs, such as water, fuel and fertilisers.[28] Furthermore, the Scientific Foresight Study, published by the European Parliament (EP), argues that agricultural data management and PA can facilitate the implementation of EU regulations, especially within the Common Agricultural Policy and connected policies.[29]

The usefulness of SA, both for facilitating various regulations and for enabling the agri-food sector to increase precision and efficiency, drives its popularity in the EU. This sector is predicted to grow by 12% at a compound annual growth rate (CAGR) during the period 2022-2030.[30] Furthermore, a report by Mordor Intelligence predicts that the European precision farming market will experience a 15.3% CAGR growth during the period 2022-2027.[31] It is no surprise, then, that skills that have shown the highest growth in the niche are skills in AI, security, blockchain, IoT and Big Data skills.[32]

Given the growth of the SA market and the skills in the niche of digitalisation in agri-food, it is important to contextualise employment levels in the relevant economic sectors for this niche. Unfortunately, there is no niche-specific information. In addition, data disaggregation is not available for NACE sub-groups. To adjust for these gaps, we analysed data for the upper-digit NACE values for industries relating to the niche. Hence, in the absence of disaggregated data, the data below presents the broad context for the niche. The information on the total number of persons employed in the relevant economic sectors is presented in Figure 3 below.

As we can see, most people are employed in ‘Computer programming, consultancy and related activities’, and ‘Manufacture of machinery and equipment’. In computer programming, consultancy and related activities, and manufacture of machinery and equipment n.e.c., the number of men is more than twice that of women. For other sectors, the discrepancy is lower, although men predominate.[33] We also note a steady growth in employment across the years for J62 (Computer programming, consultancy and related activities) and a slight decrease for C28 (Manufacture of machinery and equipment n.e.c.).

[25] Pedersen, S. M., & Lind, K. M. (2017) Precision Agriculture – From Mapping to Site-Specific Application. In S. M. Pedersen & K. M. Lind (Eds.), *Precision Agriculture: Technology and Economic Perspectives* (pp. 1-20). Springer International Publishing. https://doi.org/10.1007/978-3-319-68715-5_1. p. 2.

[26] Kamilaris, A., Gao, F., Prenafeta-Boldu, F. X., & Ali, M. I. (2016). Agri-IoT: A semantic framework for Internet of Things-enabled smart farming applications. *2016 IEEE 3rd World Forum on Internet of Things (WF-IoT)*, 442-447. https://doi.org/10.1109/WF-IoT.2016.7845467, p. 442., see also McFadden, J., Casalini, F., Griffin, T., Anton, J. (2022). The digitalisation of agriculture: A literature review and emerging policy issues. *OECD Publishing.* Available here. Also see Pedersen and Lind. (2017). Precision Agriculture.

[27] EIT Food (2021). The top 5 trends for the agrifood industry in 2021. Available here; de Velde E. V. & Kretz D. (2020). Advanced Technologies for Industry (ATI) – Sectoral Watch. Technological trends in the agri-food industry. Available here.

[28] Lamborelle A. & Alvarez L.F. (2016). Farming 4.0: The future of agriculture? Available here.

[29] Kritikos, M. (2017). Precision agriculture in Europe: Legal, social and ethical considerations. *European Parliamentary Research Service.* Available here.

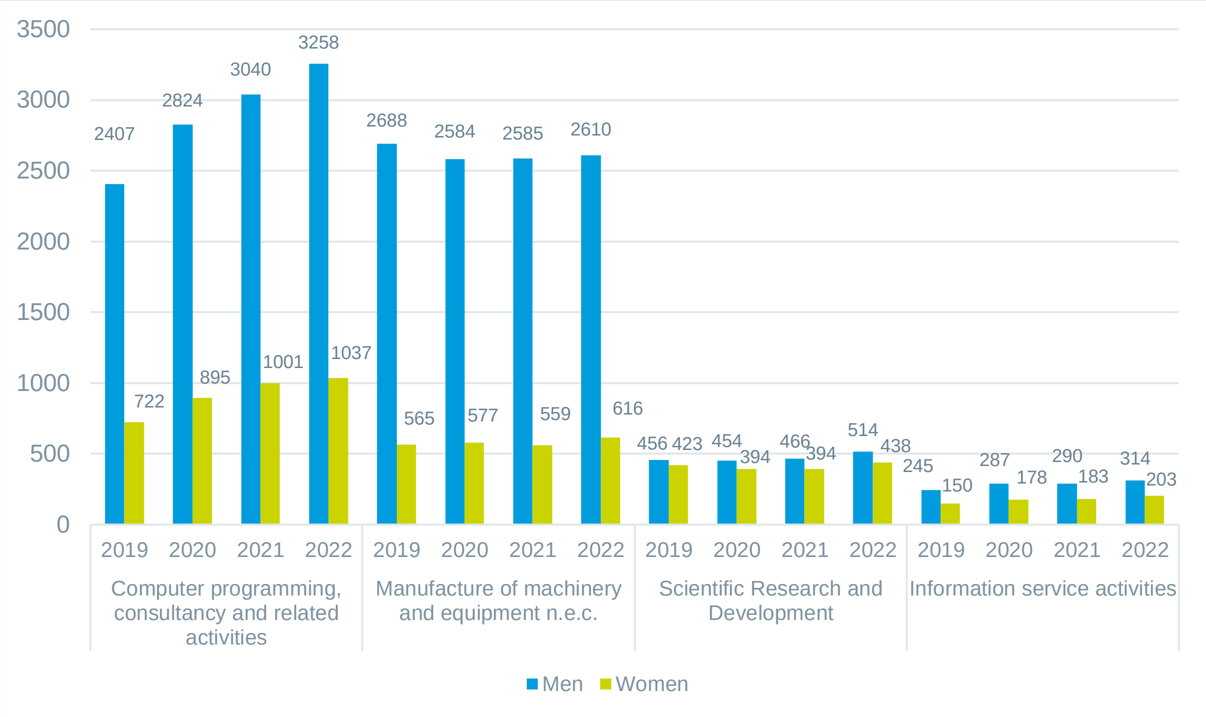
[30] Straits Research (2022). Europe Smart Agriculture Market. Available here.

[31] Mordor Intelligence (2021). Europe precision farming market – growth, trends, COVID-19, and forecasts (2022-2027). Available here.

[32] de Velde E. V. & Kretz D. (2020). Advanced Technologies for Industry (ATI) – Sectoral Watch. Technological trends in the agri-food industry. p. 14.

[33] The predominance of men in the niche was also emphasised by a senior researcher for digitalising agri-food in a leading German technology research centre. In fact, the interviewee’s assessment is that men comprise around 90% of workers in agriculture engineering. Although the interviewee has emphasised that the food industry is more gender-balanced (close to 50-50% in distribution), they have stressed that men predominate in the niche.

Figure 3. Total number of persons employed (in 1000) in the NACE sectors C28, M72, J62 and J63. EU-27



Source: Eurostat [LFSQ_EGAN22D]

Table 1 below shows the breakdown of the number of companies in the EU based on economic activity relevant to the niche and size for 2019 and 2020. Overall, the most activity is recorded for the smallest SMEs (0-9) of which there are over 700 000 and growing. The strongest sector is 'Computer programming, consultancy and related activities', which also employs the highest total number of workers. It had 728 484 companies in 2020, thus being more than five times larger than the next biggest sector, which in 2020 was 'Information service activities' (J63). This suggests that sector J62 will remain the most popular sector relevant to the niche of digitalisation in agri-food at least in the mid-term, while also indicating that SMEs will be an important driver of innovation in the niche as well.

Table 1 Number of companies based on economic activity and size (EU-27)

Economic activity (EU-27)	Manufacture of agricultural and forestry machinery		Manufacture of other special-purpose machinery		Computer programming, consultancy and related activities		Information service activities		Scientific research and development	
Size / year	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Total	6 000	6 000	24 000	24 000	697 995	728 484	136 000	140 000	67 759	69 893
0-9 employees	no data	4 120	14 589	15 537	659 435	688 749	no data	133 700	61 800	64 085
10-19 employees	800	736	3 672	3 325	18 100	18 000	3 300	3 160	2 322	no data
20-49 employees	636	647	3 109	3 051	12 500	13 027	1 784	1 817	1 779	1 822
50-249 employees	478	475	2 160	2 101	6 470	7 000	1 074	1 050	no data	1 230
Over 250 employees	no data	110	no data	458	1 408	1 466	249	243	277	282

Source: Eurostat [SBS_SC_SCA_R2]

Note: data marked in red are marked as 'low reliability' in Eurostat's dataset. Cells where there are no data have been marked 'confidential' by Eurostat. There was no data disaggregation for C28.9.3 and M72.1, so we used higher-level aggregations, such as C28.9 and M72.

Although there are varying levels of informality regarding employment in the agri-food sector in the EU in general,[34] there is a lack of niche-specific information. Nevertheless, this niche is less exposed to informality, compared to other levels of the agri-food value chain, due to the structure of the companies operating in it and the nature of the work they do. Developers of technologies for the agri-food sector tend to be start-ups mainly located in France, Germany and Spain, as well as in Italy, the Netherlands and Ireland,[35] which generally receive venture capital (VC) and private investment or are funded through national or EU-level programmes, such as 'Horizon Europe'.[36] Furthermore, since they develop technologies for the agri-food sector, such SMEs need a specialised labour force, trained usually at the level of ISCED 6 or above, as we discuss in the section on occupational profiles and skills needs, which suggests less likelihood for informality.

Digitalisation in agri-food is driven by certain factors, such as strategic policy priorities, consumer trends and market developments.[37] At the same time, there are many barriers to digitalising agri-food, such as the digital divide and matching technological developments to end users' needs (i.e. farmers). We will overview some main drivers in the niche before discussing the barriers and trends.

Regarding strategic policy priorities, as we have seen, the EU sees digitalisation as facilitating the green transition, especially in the agri-food sector. It is the EC's priority to bring the reformed CAP, for example, into the Green Deal framework. In this context, digital transformation and tools are seen as 'enablers of the changes' for clean energy supply across the EU's industry, including 'food and agriculture.'[38] Furthermore, the F2F Strategy envisages using digital solutions to deliver better climate and environmental results, increase climate resilience and reduce and optimise the use of production inputs.[39] The F2F Strategy and the Green Deal foresee bringing 100% fast broadband internet to rural areas by 2025.[40] The F2F further envisages EUR 10 billion of investments in research and innovation in agri-food under 'Horizon Europe', emphasising the development of digital technologies to be used in this field.[41] Additional initiatives by the EC also include large-scale pilots to drive digitalisation in Europe. These pilots focus on R&D in the deployment of digital technologies for the agri-food sector. For example, more than EUR 80 million has been assigned to various projects, such as the 'Internet of Food and Farm 2020' and DEMETER, both of which focus on deploying interoperable smart farming platforms.[42]

Apart from the policy effort and public funding priorities, consumer and market trends also drive innovations in the sector. The sector is witnessing an increase in online shopping and the digitalisation of logistics. The most common field for start-ups in food and beverage processing and production during the period 2009-2019 was e-commerce, internet-related activities and apps.[43] Therefore, the need for digital tools is an important driver for start-up creation in the niche. For example, the European online grocery market is expected to experience a CAGR growth of 16.5% between 2022 and 2027, thus demonstrating the trend.[44] Digitalising in the niche is also connected to the shift in consumers' dietary preferences. As EIT Food reports, consumers increasingly prioritise waste management and sustainability in their food choices.[45] Moreover, around 67% of European consumers in the European

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[34] See ILO (Ed.) (2018). Women and men in the informal economy: A statistical picture (Third edition). *International Labour Office*. Available here; Arsić, M., & Krstić, G. (2015). Effects of Formalisation of the Shadow Economy. In G. Krstić & F. Schneider, F., Morkunas, M., & Quendler, E. (2022). An estimation of the informal economy in the agricultural sector in the EU-15 from 1996 to 2019. *Agribusiness*, agr.21774. p. 2; Schneider, Formalizing the shadow economy in Serbia: Policy measures and growth effects (pp. 101-109). *Springer*. p. 102.

[35] de Velde et al. ATI sectoral watch. p. 13.

[36] As argued by de Velde et al. ATI sectoral watch. See also European Commission. (2022). Horizon Europe. Available here. For more specific funding calls, see European Commission. (2022). Digitisation of the European Agricultural Sector: Activities in Horizon 2020. Available here.

[37] As emphasised in an interview with representatives from an innovation technology cluster.

[38] European Commission (2020). Analysis of links between CAP Reform and Green Deal. Available here. p. 8.

[39] Farm to Fork Strategy, 8.

[40] Farm to Fork Strategy, 16. See also European Commission. (2021). Connectivity: key to revitalising rural areas.

[41] European Commission (2019). EU Member States join forces on digitalisation for European agriculture and rural areas. Available here.

[42] European Commission (2022). Large-scale pilots in the digitisation of agriculture. Available here.

[43] De Velde et al. ATI sectoral watch. p. 13.

[44] IMARC (2021). Europe Online Grocery Market: Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027. Available here.

[45] EIT Food (2021). The top 5 trends in the agrifood industry in 2021. Available here.

Consumer Organisation's (BEUC) report expressed readiness to develop more environmentally friendly eating practices.[46] Digitalisation is seen as helping to facilitate that shift.

At the same time, the trend of digitalisation in the agri-food sector is not equally reflected across the sector.[47] Although our primary focus is on developers of technologies for the niche, it is important to mention the users of those technologies, because technology development as a market trend is influenced by the demand for digitalisation in agriculture. Furthermore, the relevant literature and our interview findings emphasise the divergence between technology development and adoption, thus pointing to conflicting needs and expectations between developers and different types of farmers.[48] In this sense, our interviewees emphasised that innovative applications in agri-food often elude both farmers and consumers. The latter, for example, are not aware of what technologies are used to produce their food.[49] Regarding farmers, the situation is slightly more complicated, as we discuss below. These factors contribute to the slow adoption of innovative technologies in the agri-food sector, which slows down the sector's digitalisation.

Important factors relating to why farmers are slow to digitalise are farm size, age, education levels and the cost of new technologies. Many smaller farmers are reluctant to digitalise because they see no clear benefits to their business, while larger farms embrace digitalisation to optimise productivity.[50] Farmers' age and education levels are 'significant' predictors of the adoption of SA technologies in farming.[51] Additionally, research has pointed to the digital divide[52] between rural areas and urban areas as a significant factor of adoption. New technologies, such as broadband internet in rural areas, can boost connectivity and the adoption of robotics. However, the digital divide in the EU prevents their uptake. In that vein, only 60% of EU rural households have high-speed internet access, the EU average being 86%.[53] In fact, only 48% of rural residents have at least basic digital skills, which further illustrates the difficulties surrounding the digitalisation of agri-food.[54]

Companies developing technologies in agri-food face their own challenges. While generally, these companies are also SMEs, mainly start-ups,[55] they have not yet captured the market where many large companies, such as John Deere or Syngenta, have started developing their own technologies for SA. Furthermore, there are gaps in connecting start-ups to agri-food-producing SMEs. These gaps relate to difficulties in connecting farmers and developers[56] and the poor internationalisation of companies in the sector in the EU, where legislative differences across Member States (MS) hamper technology scale-up.[57]

In addition, SMEs face challenges in finding a skilled workforce for agri-food technology. Although skills and occupations in digital technologies are becoming increasingly popular in the EU, which we discuss

[46] The European Consumer Organisation (2020). One bite at a time: Consumers and the transition to sustainable food. Available here. At the same time, many expressed opposition to high-tech foods, such as lab-grown foods, expressing a preference instead for plant-based alternatives. (Ibid, 16)
[47] De Velde et al. ATI sectoral watch. p. 19.
[48] As emphasised in the interviews with the representatives of a non-profit industry association engaged in agriculture technology and a non-profit NGO researching digitalisation in agriculture.
[49] As emphasised by the two interviewees mentioned above.
[50] De Velde et al. ATI sectoral watch. p. 19. This information was also confirmed in an interview with a representative of a non-profit industry association engaged in agriculture technology and in an interview with a representative of a government agency in Germany that manages a fund for financing R&D projects for the development and application of digital solutions in agriculture. See also McFadden, J., Casalini, F., Griffin, T., & Antón, J. (2022). The digitalisation of agriculture: A literature review and emerging policy issues. See also Blasch, J., van der Kroon, B., van Beukering, P., Munster, R., Fabiani, S., Nino, P., & Vanino, S. (2022). Farmer preferences for adopting precision farming technologies: A case study from Italy. *European Review of Agricultural Economics*, *49*(1), 33-81. https://doi.org/10.1093/erae/jbaa031.
[51] Barnes, A. P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S., van der Wal, T., & Gómez-Barbero, M. (2019). Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land Use Policy*, *80*, 163-174. https://doi.org/10.1016/j.landusepol.2018.10.004, p. 165.
[52] Chandra, R., Collis, S. (2021). Digital Agriculture for Small-Scale Producers. Communications of the ACM, December 2021, Vol. 64 No. 12,. p. 81. Also Schroeder, K., Lampietti, J., & Elabed, G. (2021). What's Cooking: Digital Transformation of the Agrifood System. *World Bank*. p. 5.
[53] European Commission (2021). Connectivity: Key to revitalising rural areas. Available here.
[54] Ibid.
[55] Ibid.
[56] Which was emphasised in an interview with a representative from a non-profit NGO researching digitalisation in agri-food as well as interviews with representatives of a company providing equipment and solutions for technical education and a research institute for organic agriculture.
[57] European Commission (2021). Connectivity: Key to revitalising rural areas. Available here.

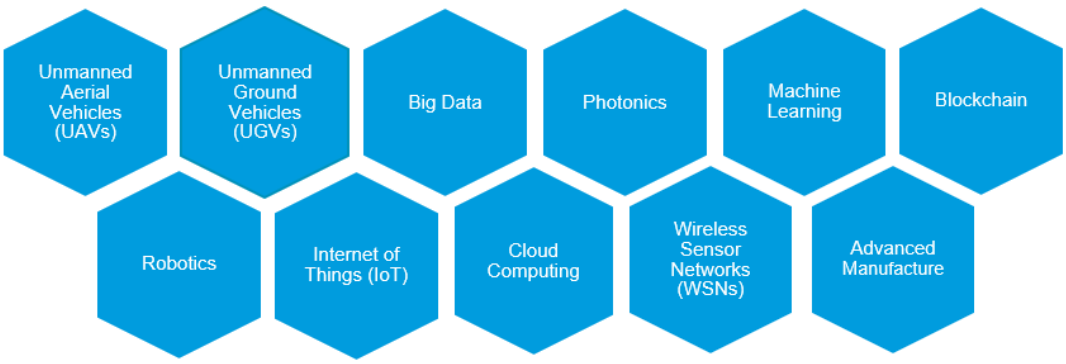
below, there is a lack of formal education for agri-food technologies in the EU, thus making it harder for SMEs to find skilled labour quickly.[58] Non-formal education is also lacking in the niche, especially training seminars for employees and opportunities for bringing technology developers and agri-food SMEs together.[59] Furthermore, interviewees mentioned low salaries and a lack of awareness of recent graduates that their skills may be applied and needed in the agri-food sector as additional important challenges for companies that need a skilled workforce.[60]

The general profile of the agri-food sector thus reflects a sector undergoing a twin change towards digitalisation and greening. The developments in SA and the EC's own priorities in the context of the New Green Deal and Europe's Digital Decade will require a shift from large mechanised systems in agriculture to more specific, precise and selective modes of production. At the same time, several technological trends are helping to facilitate the transformation of the agri-food sector. Understanding them is key to understanding what skills are needed in the market. We therefore discuss some main technological trends below.

2.2 Main technological trends

Technology and its impact on agri-food productivity have been long documented.[61] Today, technologies in the agri-food sector are used to increase both the quality and quantity of production and optimise human labour use[62], while minimising waste. Their main goal is fine-tuning decision-making[63] and improving the precision, management and sustainability of agricultural production processes.[64] Because of the wide scope of activities that Smart Agriculture (SA) encompasses, it requires the use of various technologies. In Figure 4 below, we present a non-exhaustive list of some prominent technologies that make up SA.

Figure 4. Smart Agriculture Technologies (non-exhaustive)



Source: Own elaboration, based on the most prominent technologies identified by the ATI sectoral watch (2020), Moysiadis et al. (2021), and Chandra and Collis (2021).

In the EU, the SA technologies are already being streamlined into agricultural instruments. For example, as of 2016, between 70% and 80% of the new farm equipment sold in Europe included components that

[58] As confirmed by interviewees with a representative of a non-profit industry association engaged in agriculture technology and with a representative of a company providing equipment and solutions for technical education.
[59] The former was highlighted as essential by a representative of a non-profit industry association engaged in agriculture technology, and the latter was emphasised by an interviewee from a non-profit NGO researching digitalisation in agri-food.
[60] As emphasised in interviews with a representative of a research institute for organic agriculture and a representative of a non-profit industry association engaged in agriculture technology.
[61] Schroeder, K., Lampietti, J., & Elabed, G. (2021). What's Cooking: Digital Transformation of the Agrifood System. World Bank. p. 17.
[62] IoT-NGIN (2021). Implications of IoT system on European lives. Available here.
[63] Kritikos, M. (2017). Precision agriculture in Europe.
[64] International Society of Precision Agriculture (n.d.). Precision Ag Definition. Available here.

enable the use of SA.[65] Nevertheless, many of these components have yet to be actively used in the agri-food sector due to the uptake limitations discussed above. Indeed, SA is based on a concatenation of technologies from Figure 4. Smart Agriculture Technologies (non-exhaustive)Figure 4.[66] In this context, some technologies can capture the market demand better than others. For example, while technologies such as blockchain promise trustless[67] and safe communication standards, the initial hype around them was not followed by sustained interest, thus limiting their growth potential.[68] By comparison, the IoT, AI, Big Data, drones and robotics technologies are major trends driving innovation in the niche. This sub-section focuses on outlining the most prominent technological trends in the agri-food value chain. We first present these technologies and then discuss more specific barriers and drivers concerning their future development.

- One of the most important technologies in this regard is the **Internet of Things (IoT)**.[69] IoT enables farmers to create networks of connected agricultural machines, farms and even wineries, such as tractor sensors and farmers' phones.[70] IoT devices and sensors allow agri-food producers to receive, send, generate and process production data and synchronise it between data portals.[71] This way, IoT technology enables better decision-making[72] and optimises machine operation and field management with the help of location-based services such as GPS and real-time information exchange.[73] The IoT market spending in Europe was estimated to reach EUR 184 billion in 2021 and experience double-digit growth through 2025.[74] The expected growth in IoT spending, as well as the expected growth of the SA market, indicates a notable trend in the adoption of IoT technologies in the sector.
- **Drones**, or Unmanned Aerial Vehicles (UAVs), also known as Remotely Piloted Aircraft Systems (RPAS),[75] are the most popular technology in the niche. Drones are small, light, slow and endurant, they can easily be controlled and they can fly very low, up to one metre from the ground while producing high-resolution images of agricultural land.[76] They also have GNSS satellite-positioning receivers that enable location tracking and can be programmed for autopilot, which means that they can stay in the air for long periods of time, thus capturing swathes of data.[77] Drone technologies can be applied in delivery systems and pesticide dispersion.[78] Since the reduction in the use of pesticides and their risks is one of the EU-wide targets to be achieved by 2030,[79] drones can help by providing more targeted and precise inputs, thereby increasing safety for the environment and the operators.[80] Future drone application in the agri-food sector is expected to involve drone fleets[81] or swarms[82] for collectivising agri-food production or delivery. Although barriers to drone adoption remain (as we discuss below, slow policy developments affect drone use in agri-food),[83] the drone market for agri-food is expected to grow at least 20% CAGR by 2027, thus pointing to a notable growth trend.

[65] Soto, et al. (2019). The contribution of precision agriculture technologies. p. 39. See also Lamborelle A. & Alvarez L.F. (2016). Farming 4.0: The future of agriculture?
[66] Kritikos, M. (2017). Precision agriculture in Europe.
[67] Trustless technology is a feature of blockchain communication standards. Trustless technologies require no third party to operate between transactions (e.g. banks). In being trustless, they are safer because they do not involve middlepersons and therefore keep transactions irreversible. For more on 'trustless,' see Cryptopedia (2022). What Does Trustless Mean? Available here.
[68] Chandra, R., Collis, S. (2021). Digital Agriculture for Small-Scale Producers. p. 77.
[69] Bonneau, V., Copigneaux, B., Probst, L., & Pedersen, B. (2017). Industry 4.0 in agriculture: Focus on IoT aspects. *Directorate-General Internal Market, Industry, Entrepreneurship and SMEs.* Available here. See also Kamilaris et al. Agri-IoT.
[70] European Commission (2019). Cultivating the Internet of Things in farming. Available here.
[71] CEMA (2017). Digital Farming: what does it really mean? Available here.
[72] European Commission (2022). The Digitisation of the European Agricultural Sector. Available here.
[73] Bonneau, et al. Industry 4.0 in agriculture. p. 3-4.
[74] CBI (2022). The European market potential for (Industrial) Internet of Things. Available here.
[75] Veroustraete, F. (2015). The rise of the drones in agriculture. *EC agriculture* 2(2), 325-327.
[76] Soto, et al. (2019). The contribution of precision agriculture technologies. p. 82.
[77] Ibid.
[78] Foote, N. (2020). EU farmers: Unlock potential of agricultural drones or risk falling behind. *Euractiv*. Available here.
[79] European Commission (n.d.). Farm to Fork targets – Progress. Available here.
[80] Foote, N. (2020). EU farmers: Unlock potential of agricultural drones or risk falling behind. *Euractiv*. Available here
[81] Spanaki et al. (2022). Artificial intelligence and food security.
[82] Mazur, M. (2016). Six Ways Drones Are Revolutionizing Agriculture. *Technology Review*. Available here.
[83] Foote. (2020). EU Farmers: Unlock potential of agricultural drones.

- The challenges of recent years, such as the COVID-19 pandemic, have demonstrated the need for faster automation adoption in the sector.[84] **Robots** are seen as a promising way of automating the sector.[85] Robotics reduces farmers' dependency on unstable labour markets and increases safety and sustainability due to more efficient calculations of the necessary inputs.[86] With robots, farmers can optimise animal management and animal exploitation (e.g. milking) while reducing animal harm, they can improve food management (e.g. decoration and assembly of food products)[87], spray trees more efficiently, monitor crops constantly and improve the production of bio-based products (e.g. by smarter use of enzymes).[88] This necessitates the use of smart sensors and actuators that optimise micro-level processes.[89] In addition to drone technologies, automation and robotics are considered some of the most disruptive technologies in the agri-food sector.[90] Although agricultural robots are still in the early stages of innovation,[91] they have been established in the dairy industry, and future applications are expected in harvesting, picking and weeding.[92]
- **Artificial Intelligence (AI)** and **Big Data** are some of the most recognisable technologies in general. AI and Big Data technologies are relevant for agri-food because they can be trained to recognise crop disease or even animal conditions and quickly notify farmers.[93] AI systems can aid in the administration of agri-food production by reducing and preventing food waste, and enhancing food safety, transparency and traceability.[94] In particular, these systems can aid in analysing soil and weather patterns to ensure ideal conditions for crop planting or the use of biochemical and microbial products, as well as help determine which microbes are essential for specific farm ecosystems.[95] Furthermore, data processing also helps with accountability and auditing because data processing infrastructures provide more complete and trusted information to consumers and auditors.[96] Although Big Data and AI technologies in agri-food are currently past their peak of innovation,[97] the future expectations are that they will be increasingly incorporated into robotics, drones, IoT and other technological ecosystems.[98]

It is expected that future technological trends in the sector will remain connected to these four technologies. However, there are indeed differences in the prominence of particular technological trends. Robotics is still mainly in the innovation and experimentation phase in the sector, which means that the future use of robots is not yet determined and is subject to experimental trials. Although robotics are established in dairy farming, and high expectations for their use in particular activities of the agri-food sector (e.g. weeding, harvesting) exist, it is still unclear how able robots are to deal with variations of agricultural land and food products.[99] In addition, robots are a costly technology, with some costing

[84] Robs4Crops (n.d.). New EU project set to accelerate the shift to robotics and automation and fundamentally shake up the agrifood landscape. Available here.
[85] Lytridis, C., Kaburlasos, V. G., Pachidis, T., Manios, M., Vrochidou, E., Kalampokas, T., & Chatzistamatis, S. (2021). An Overview of Cooperative Robotics in Agriculture. *Agronomy*, *11*(9), Article 9. Available here. See also Yaghoubi, S., Akbarzadeh, N. A., Bazargani, S. S., Bazargani, S. S., Bamizan, M., & Asl, M. I. (2013). Autonomous robots for agricultural tasks and farm assignment and future trends in agro robots. *International Journal of Mechanical and Mechatronics Engineering*. 13(3).
[86] Ibid.
[87] de Velde et al. ATI sectoral watch. p. 10.
[88] Bergerman, M., Billingsley, J., Reid, J., & van Henten, E. (2016). 'Robotics in Agriculture and Forestry.' In B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics*, 1463-1492. *Springer International Publishing*, see also de Velde et al. ATI sectoral watch. p. 10.
[89] de Velde et al. ATI sectoral watch.
[90] Yahya, N. (2018). Agricultural 4.0: Its Implementation Toward Future Sustainability. In N. Yahya, *Green Urea,* 125-145. Springer Singapore. p. 132.
[91] As argued by Chandra, R. & Collis, S. (2021). Digital Agriculture for Small-Scale Producers: Challenges and Opportunities. Available here. p. 77.
[92] DLL Financial Solutions (2021). Three Trends That Will Shape the Food Industry Going Forward. Available here.
[93] Loudjani P. et al. (2020). AIA: Artificial Intelligence and EU Agriculture. p. 10.
[94] Higuera, A. G. (2022). What if AI could make the agri-food sector more resilient? *European Parliamentary Research Service.*
[95] Bengtsson-Palme, J. (2020). Microbial model communities: To understand complexity, harness the power of simplicity. *Computational and Structural Biotechnology Journal*, 18, 3987-4001.
[96] European Commission (n.d.). Smart Specialisation Platform: Traceability & Big Data. Available here. See also European Commission (2022). Special report 16/2022: Data in the Common Agricultural Policy – Unrealised potential of big data for policy evaluations. Also Foote N. (2022). EU auditors urge Commission to move into digital age on agri data collection. *Euractiv*.
[97] As presented by Chandra, R., Collis, S. (2021). Digital Agriculture for Small-Scale Producers. p. 77.
[98] Loudjani P. et al. (2020). AIA: Artificial Intelligence and EU Agriculture. p. 10-13.
[99] Wang, Z., Hirai, S., & Kawamura, S. (2022). Challenges and Opportunities in Robotic Food Handling: A Review. *Frontiers in Robotics and AI*, *8*. Available here.

upwards of EUR 500 000 in 2021.[100] These factors limit their penetration into the agri-food value chain, especially regarding applications in smaller agricultural holdings.[101]

Future expectations for technologies such as AI, IoT and drones in the agri-food value chain are their deeper integration and penetration into different chain levels.[102] IoT technologies do not require significant investment such as robotics technologies but promise work optimisation to agri-food producers.[103] The adoption of AI and Big Data processes in the value chain is often treated as a necessity due to the sheer volume of data generated by agri-food activities. Hence, there is a strong indication that IoT and AI technologies will remain important technological trends in the agri-food value chain in the short and medium term. This does not, however, resolve some problems with the uptake of these technologies in the chain, such as how ready agri-food SMEs are to adopt them and whether they understand how to operate them. For example, six out of 10 European agri-food companies did not use AI solutions in their business in 2021.[104] This problem was also highlighted in the interviews, where participants identified IoT, AI and Big Data solutions as the most important technological trends in the agri-food value chain but also stated that many agri-food SMEs are simply not using them because they do not see their benefits clearly.[105]

Drones are similarly popular to IoT and AI and are easy to use. The difference is that the barriers to access for drones are related to policy. Agri-food producers see great value in using drones for pesticide dispersal or field monitoring, but this is not yet entirely reflected in the EU policies.[106] For example, EU Regulation 2022/0196 on sustainable use of plant protection products prohibits aerial application of plant protection products, but it also calls for specific criteria to exempt certain types of drones from that prohibition. Simultaneously, the EU's Drone Strategy 2.0 calls for the unleashing of growth and sustainability potential for drones, including in agri-food.[107] However, it is unclear how policy developments will impact drones in the agri-food value chain. What is certain, however, is that drones will remain a major trend in agri-food in the future.

The growth of SA requires not only a major development and roll-out of digital technologies for the agri-food value chain; it also drives new demand trends for occupational profiles and related skills. The development of digital skills and knowledge remains crucial for making agriculture truly smart, especially in the context of the EU's own strategies for reforming the sector. To understand what kinds of occupations and associated skills will be in demand in the short and medium term, we discuss the trends in skills needs and occupational profiles below.

2.3 Trends in occupational profiles and company skills needs

As discussed above, there is a trend of growth and proliferation of start-ups focused on developing technologies for agri-food. This, together with large companies turning towards technology development, is driving specific trends in occupational profiles and skills demand in the sector. Below, we discuss which skills demand trends are linked to which occupational profiles, and how they will develop in the short and medium term.

We first explored the ISCO and ESCO classifications to identify the most prominent occupations in digitalisation in the agri-food niche in the EU. The most relevant ISCO codes we identified were 1 (managers), 2 (professionals), 3 (technicians and associate professionals) and 4 (clerical support workers). We then conducted desk research of relevant job portals for different EU countries and organised relevant occupations based on the lower ISCO or, where possible, ESCO codes. To discuss

[100] DLL Financial Solutions (2021). Three Trends that Will Shape the Food Industry.
[101] As the representatives of an innovation technology cluster pointed out in an interview, high prices are an important challenge to adopting digital technologies in agri-food.
[102] Chandra, R., Collis, S. (2021). Digital Agriculture for Small-Scale Producers. p. 77.
[103] Pincheira, M., Vecchio, M., & Giaffreda, R. (2022). Characterization and Costs of Integrating Blockchain and IoT for Agri-Food Traceability Systems. *Systems*, *10*(3), Article 3.
[104] EIT Food (2021). 6 out of 10 European agrifood companies do not use artificial intelligence solutions, according to experts at the Food4 future in Bilbao. Available here.
[105] As indicated by interviews with a representative of a non-profit industry association engaged in agriculture technology and a representative from a non-profit NGO researching digitalisation in agriculture.
[106] Foote (2020). EU Farmers: Unlock potential of agricultural drones.
[107] European Commission (2022). A Drone Strategy 2.0.

these, we will begin by outlining occupations that are in demand, as well as ISCED levels relating to those occupations. Then, we will discuss in-demand hard (technical) and transversal (non-technical) skills for those occupations.

Managers

Among **managers** (**ISCO 1**), there is a high demand for administrative and commercial management (ISCO 12) and production and specialised services management (13). People hired for these positions must usually have higher levels of education, at **ISCED 7-8**. Regarding administrative and commercial management profiles (ISCO 12), there is a demand for managerial occupations that support commercialisation, marketing, digital marketing and sales (ESCO 1221.3.2, 1221.5 and ESCO 1221.3.2.1), and product development (ESCO 1223.2.1).[108] Generally, the **hard skills** required for these positions are an understanding of agriculture and especially precision agriculture, and having a background in agronomy, marketing and business. The company profile looking for such skills are companies directly working with farmers to develop digital solutions, such as remote sensing technologies or AI applications.[109] Demonstrable communications and digital skills, and excellent knowledge of operationalising social networks is also an added requirement for marketing positions.[110] Further hard skills relevant for ISCO 12 profiles involve having substantial experience in data analysis and digital product development, as well as an agri-tech background and demonstrable experience working with user interface (UI) / user experience (UX) design. The latter, for example, was required by Biome Makers, a company that develops technologies for soil biology. Hard skills in geospatial product development and launch, as well as skills in data in agriculture and software development for agriculture, are required by companies making more specific products, such as satellites for geospatial imagery[111] or crop monitoring.[112] For the latter, added skills are advanced knowledge of soil science, ecology, agronomy, project management and computer science skills, especially data analysis for and operational excellence in agriculture.

Among managers in **production and specialised services management (ISCO 13)**, there is a demand for chief data officers (ESCO 1330.1), product managers[113] (ESCO 1330.6), supply chain managers[114] (ESCO 1324.8) and manufacturing managers (1321), where agrovoltaic managers[115] are prominent. Generally, these occupations require **hard skills** in software product management experience, geospatial product development, GIS understanding, and forestry and carbon accounting knowledge, especially for companies developing geospatial technologies.[116] Furthermore, skills in financial modelling and familiarity with energy markets and renewable energy are required, as well as skills in data science, farming, UI/UX and consumer app development. There is also a need for experience with supply chains and industrial economics. Much like with ISCO 12, the companies seeking such occupations are those working with farmers directly to develop agri-tech solutions. Although start-ups predominate, there are larger companies, such as Syngenta or Sencrop, also present in the market. This indicates that both start-ups and big companies are looking for marketing and development of their products, thus pointing to the novelty of the market niche.

Professionals

Professionals in the ISCO 2 group are usually required to be educated at higher levels, such as **ISCED 6 or above**, but with a stronger emphasis on occupation-specific skills. Furthermore, in our analysis, we noted the highest demand for professionals (ISCO 2) in comparison with other ISCO groups in the niche. Professionals in the ISCO 24 group (business and administration), such as business development professionals[117] (ESCO 2431.5), product and service managers (2431.15), and marketing

[108] Biome Makers, US/Spain. Head of digital product development.
[109] Such as Yara, Germany. Marketing manager.
[110] Syngenta, France. Communication and digital manager.
[111] Space4Good, Netherlands. Geospatial product manager.
[112] Regrow, France. Director of environmental strategy.
[113] Apollo Agriculture, Netherlands. Product manager.
[114] JLT Computers, Sweden. Supply chain coordinator.
[115] BayWa, France. Agrivoltaism manager. Also juwi Group, Germany. Agrivoltaism/Agri-PV Manager.
[116] Space4Good, Netherlands. Geospatial product manager.
[117] Kubota Holdings Europe, the Netherlands. Business development and Intellias, Germany. Digital business developer.

and sales professionals[118] are in high demand for this niche. There is also a demand for CRM managers (ESCO 2431.15). The **hard skills** required from these professionals range from understanding PR and marketing techniques and having an academic background in marketing to needing skills in data science, agronomy, finance and economics. Skills necessary for C-suite roles, consultation experience and sales experience are also in demand. Regarding company profiles for these occupations and skills, we noted a balancing-out of start-ups and larger companies, further indicating the higher demand for below-managerial positions. At the same time, the job ads list was limited, and we noticed that some companies have multiple listings. This is consistent with the narrow scope of this niche and the fact that the market for digital producers is still in the early stages of development.

We noticed a high demand for the ISCO groups of science and engineering professionals (21) and ICT professionals (ISCO 25), as well as the ISCO sub-group of life science professionals (213). In terms of the ISCO 21 group, we see a demand for installation engineers (ESCO 2149.2.5), mechanical (2144.1) and mechatronics (2144.1.11) engineers, as well as computer hardware (2152.1.1) and satellite (2152.1.14) engineers. There is also a demand for geospatial data engineers (2165.3), especially from companies working on drone or satellite imaging technologies.[119] In addition, there is a demand for robotics engineers (2149.15). Engineering skills are some of the most demanded **hard skills**. More specifically, experience with 3D design tools and printers,[120] skills in product-oriented design,[121] CAD tools,[122] and knowledge of actuators are in demand.[123] Further skills needed include working with embedded systems[124] and power electronics.[125] Skills in computer vision,[126] vehicle kinematics[127] and real-time systems programming are also relevant,[128] as are skills in 3D mathematics and geometry,[129] Geographic Information System (GIS) or equivalent, ETL pipelines, Python, geoinformatics[130] and geomatics, knowledge of MediatR and implementation of CQRS,[131] knowledge of QGIS,[132] experience with satellites, radars and/or radiosondes.[133] The profiles of companies looking for such skills are companies developing digital solutions for agri-food based on UAVs and satellite images, as well as companies working with indoor (and vertical) farming, companies developing sensory solutions for animal welfare management, and companies developing machine learning tools for agri-food. We also noticed large companies, such as John Deer, Syngenta and Sencrop seeking engineers with the foregoing skills, thus suggesting their stronger involvement with the niche.

For ICT professionals (ISCO 25), there is a demand for developers such as application developers (ESCO 2514.2), software developers (e.g. full stack developers and user interface developers in ISCO 2512), and ICT system configurators (ESCO 2522.1), such as system performance engineers. Data scientists and analysts (ESCO 2511.3 and 2511.4,) are also in high demand. Professionals in ISCO 2 are usually required to be educated at the level of **ISCED 7 or above**. The **hard skills** relevant for the **ISCO 25** group are knowledge of cloud-based app development and services,[134] SQL,[135] Git,[136] Web API[137] and UI/UX design, and an understanding of AWS or GCP/Azure[138], Linux skills[139] and CSS. Generally, knowledge in one or more programming languages such as Java Script, HTML, CSS, Python,

[118] Agroknow, Greece. Marketing research & engagement specialist.
[119] See Constellr GmbH, Germany. Lead Mission Architect. See also Jua.ai, Germany. Geospatial Data Engineer.
[120] Aquacorp, Spain. Multiple postings.
[121] Bilberry, France. Mechatronics engineer.
[122] Bilberry, France. Mechatronics engineer.
[123] VitiBot, France. Mechatronics engineer.
[124] Aquacorp, Spain. Multiple postings.
[125] VitiBot, Mechatronics engineer.
[126] Agrointelli, Denmark. Mobile Robotics Engineer.
[127] Ibid.
[128] Ibid.
[129]Augmenta, US/Greece.
[130] KWS Group, Germany. Project manager/Data architect.
[131] Supper&Supper, Germany. Full Stack Developer. Head Aerospace, China/France/Netherlands. Geomatic and remote sensing engineer.
[132] RSS Solutions, Germany. Software developer.
[133] Jua.ai, Germany. Geospatial Data Engineer.
[134] Supper and Supper, Germany. Full Stack Developer. See also KWS Group, Germany. Full Stack Developer.
[135] CrowdFarming, Spain. Software developer. Sencrop, France. Software engineer.
[136] RSS Solutions, Germany. Software developer. Ecobloom, Sweden. Data engineer.
[137] See VetVise, Germany. Frontend SW developer. Supper&Supper, Germany. Full Stack Developer
[138] Apollo agriculture, Netherlands. Devops engineer.
[139] Ibid.

C++ or R is also required.[140] Programming in general was also identified as a very important skill in the interviews. Further skills in high demand are management of cloud infrastructure and machine learning,[141] text processing and data visualisation,[142] and skills in high-performance computing and Parallel Filesystem.[143]

In terms of **life science professionals** (**ISCO 213**), there is a notable demand for agronomists (ESCO 2132.2) and digital agronomy experts. Professionals in these occupations are expected to be educated at the level of **ISCED 6 or above**. The **hard skills** involved are skills in agronomy, where skills in precision technologies are emphasised. Experience in crop physiology, crop protection and fertilisation are also stressed as important. In addition to the foregoing skills, skills such as project management and experience with marketing and commercialisation of products are also required.[144]

Technicians

In comparison to ISCO 2 (professionals), there is a **less pronounced** demand for **technicians (ISCO 3)** and **no identifiable demand** for **clerical and support workers (ISCO 4)** in the niche of digitalisation in agri-food in the EU**.** The job ads reviewed showed a demand for installation technicians (ESCO 3115.1), field service technicians (ISCO 3115), and agricultural sales technicians (3322). There is also a need for other types of installation and support technicians (3114), as well as service technicians (3115) for agricultural robots (e.g. milking robots). Technicians are usually required to have educational levels matching **ISCED 3-6**, although the requirements can sometimes be lower: for instance, one posting for an installation technician[145] required **ISCED 2**.

Pay levels

To investigate average salary levels for occupational profiles across all sectors in digitalisation in agri-food niche in the EU, we selected nine EU countries and profiled salaries for professions by using the job portal, Glassdoor[146] (see Annex I. Methodology for more details). In **Error! Reference source not found.**Table 2 below, we present estimated salaries for occupations relevant to the niche of digitalisation in agri-food. No single country predominates in terms of salary levels in the EU, although a significant number of salaries is in the 10th decile, standing at or above EUR 34 323 in 2021. Countries with such salaries are Belgium, Germany, the Netherlands and Sweden, and these are paid for occupations such as R&D managers, manufacturing managers, business development managers, sales and marketing managers, as well as machine learning engineers. Greece, Italy and Poland pay the least for these professions, and in general. The stakeholders interviewed stated that salary oscillations across the EU slow down digitalisation in agri-food. Since agri-food businesses generally pay less than ICT businesses (see Table 4 and Table 5 for more information on salaries), it is much harder for them to attract skilled ICT workers.[147]

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[140] VitiBot, France. Frontend developer. Climate Farmers, Germany. Junior data analyst/R programmer. Supper&Supper, Germany. Senior Devops engineer.
[141] Ecorobotix, Switzerland. Cloud engineer. ActCon, Germany. Senior backend developer. See also Apollo agriculture, Devops engineer.
[142] MDN Labs, Greece. AI Python developer.
[143] e-GEOS, Italy. HPC systems engineer.
[144] Zeiss Group, Germany. Chief agronomist. Syngenta, France. Digital agronomy expert – Disease control.
[145] See Intelligent Growth Solutions (IGS), Sweden/Remote, Installation Technician.
[146] Glassdoor uses machine learning to make salary estimations based on salary data from Glassdoor as well as the latest governmental sources. Please see here.
[147] This was also argued by the academic researcher interviewed from Poland.

Table 2. Estimated total pay (year) – median values, adjusted for net salary average (in EUR)

Occupation	BE	DE	EL	ES	FR	IT	NL	PL	SE
Manufacturing manager	97 293	55 601	38 618	37 088	31 429	35 048	56 620	no data	26 567
Business development manager	57 585	37 093	54 175	33 312	35 017	30 284	49 896	50 880	94 862
R&D manager	35 974	39 974	no data	34 141	25 335	33 894	102 288	no data	no data
Machine learning engineer	39 702	36 854	23 479	27 926	28 835	19 985	44 144	24 959	100 517
Sales and marketing manager	39 277	40 880	8 832	35 636	40 405	36 543	58 539	37 990	33 607
Digital marketing manager	38 366	30 037	22 727	33 311	29 384	26 081	46 415	27 334	76 505
Data engineer	34 259	36 416	22 074	23 673	25 440	18 127	41 376	34 927	53 472
IT consultant	28 030	31 659	17 425	19 789	22 976	16 603	49 426	26 670	55 338
Robotics engineer	22 694	78 399	7 254	23 950	18 852	15 487	30 280	9 913	no data
Computer programmer	34 128	34 581	25 431	15 621	21 677	16 069	41 103	15 765	25 486
Application developer	14 391	35 119	9 449	14 097	26 731	15 656	31 475	29 068	52 611
IoT developer	no data	28 399	no data	29 725	no data	16 408	27 679	no data	no data
Electronics engineer	18 202	35 160	19 689	21 167	25 808	19 490	34 130	23 811	25 148
Web designer	14 248	24 597	8 523	16 896	21 083	31 285	61 615	20 264	19 769
Mechatronics Engineer	17 923	31 358	6 836	18 695	20 853	18 424	56 561	7 250	24 928
Agronomist	14 032	31 685	7 285	24 689	22 321	25 164	31 494	21 155	no data

Source: Glassdoor
Note: Salary estimations are not filtered by industry and level of experience due to data availability. Glassdoor provides gross salary estimations, which is why we used the OECD's 'Average personal income tax and social security contribution rates on gross labour income'[148] for relevant countries to adjust and estimate net annual salaries. Salaries that belong to the 10th decile of Eurostat's 'Distribution of income' [ILC_DI01] table are in dark teal. Estimations in light teal fall into the 9th and 8th deciles, while the estimations in white fall into the 7th decile or lower. Values marked in red indicate lower levels of confidence. In such cases, a salary estimation on Glassdoor did not have a 'high confidence' or 'very high confidence' label, meaning that it was calculated based on a limited number of salaries.

General trends

Overall, we see **two specific** short and medium-term skills trends for this niche. One, the demand for occupational profiles in the ISCO 2 group (Professionals) is rising in the sector, as employers need professionals to help develop technologies for agri-food. This will likely continue in the short term, driving the skills demands needed for those occupations. Second, employers may start needing more technicians (ISCO 3) to help maintain devices in the medium term, which will presumably drive skills demand for skills from this ISCO group. In this context, for instance, the interviewees identified the increasing need to develop skills in hydroponics, especially for indoors and vertical agriculture, which we will discuss further in the chapter on organic and functional foods.[149] Hydroponics technicians or specialists are usually skilled workers, educated at the level of **ISCED 5 or above.** Skills required for hydroponics technicians or specialists are specialised knowledge of agriculture, experience in data collection and visualisation, agriculture and agronomic technology, knowledge of indoor agriculture, and plant physiology.

While technical knowledge remains the most sought-after skill in the niche, there is a growing importance of **transversal**, or **non-technical**, skills. The most frequently mentioned transversal skills are language skills. This indicates that intercultural exchange and internationalisation are very relevant to the niche. These are prominent across all ISCO groups considered. Apart from English, languages such as French,

[148] OECD (2021). Average personal income tax and social security contribution rates on gross labour income. Available here.
[149] As was emphasised in an interview with a representative of an industry association for indoor agriculture.

Spanish and German are most frequently required. Generally, employers favour language fluency and independence of expression. Furthermore, independence in knowledge acquisition, a high interest in and affinity for new technological developments and their application to agriculture, and intercultural skills are emphasised. Other important transversal skills are critical thinking, the capability to multitask, communication, leadership, analytical and problem-solving skills, and experience in communicating and interacting with agricultural growers.

In general, there are no higher education programmes targeting digitalisation in agri-food, or smart agriculture, in the EU. Most programmes focus either on the fields of agriculture or ICT, without offering specific skills that can cut across fields. However, we see a presence of formal CVET initiatives at universities in Spain and Sweden, such as summer courses on hydroponics and distance learning courses by private education providers.[150] The two universities offering summer courses also offered EC credits for them, 10 credits at the University of Almería for a 4-week course on hydroponic systems in 2021, and 15 at the Swedish University of Agricultural Sciences for a 2-month course in hydroponics, which is recurring.

Interviewees emphasised the importance of VET education in developing the niche, while also stressing the lack of niche-specific initiatives in this regard.[151] While the interviewees emphasised the general lack of VET initiatives in the niche, we found examples of attempts to provide offers in this regard. For example, the representative of the industry association for indoors agriculture stated that their association had participated in the Ponics VET project, which was funded as part of an Erasmus+ ECVET framework.[152] As part of the project, they developed a pilot training course for hydroponic technicians. Initially, the course was localised to Latvia, Greece, Italy, Belgium and Bulgaria, and it offered ECVET[153]-compliant certification to students. It was intended for young farmers and would-be farmers in the EU and aimed to offer them comprehensive training in hydroponics. While the course itself was successful, it was difficult for the interviewee's organisation to fund the maintenance of the course, which was cancelled after partners unexpectedly pulled out. Indeed, the course's website is still online, although it has no content.[154] The shutting down of the project was described by the interviewee as confusing, thus suggesting that some educational initiatives for innovative technologies in agri-food are still in the early stages and are facing precarity.

Another example of VET initiatives relevant to the niche in the EU was the SATI (Smart Agriculture and Training Implementation) VET initiative. It was launched by the European Parliament and the European Commission in 2021.[155] The aim of the initiative was to produce a comprehensive training platform for VET module courses in smart agriculture. The platform engaged topics such as photogrammetry, field scouting, crop health analysis, Unmanned Air Systems (UAS) and new trends in policies in environmental science and agriculture. The project ran until the end of February 2023. The platform should become operational after the project's completion. The platform development suggests that VET opportunities for the niche in the EU are becoming more prominent, although we cannot yet comment on the effectiveness of this initiative in addressing the skills demand gaps.

Overall, the niche of digitalisation in agri-food is specific in that it is still a developing sector in the agri-food value chain. Interviews with professionals dealing with digitalisation in agri-food showed that some of the main problems relating to matching evolving labour market requirements in the short and medium term are the lack of educational opportunities for digitalisation in agri-food, as discussed above, inadequate connections between technology developers and farmers, and low levels of entrepreneurial skills with young innovators. For example, a representative of a non-profit organisation which supports youth initiatives and entrepreneurship in agriculture emphasised that business skills, entrepreneurial skills and internationalisation are some of the most important and most needed skills for young start-

[150] Mainly done by universities, such as the University of Almería in Spain, see here, and the Swedish University of Agricultural Sciences, see here, or specialised providers of training in agri-food, such as here. Although the latter is an Australian company, its services are developed for remote delivery.
[151] Interviewees such as an academic researcher and a representative of the industry association for indoors agriculture.
[152] For more information, see FarmTech Society (2019). FarmTech Society is Partnering with the EU Ponics VET Project. Available here.
[153] The European Credit System for VET.
[154] Hydroponics VET. Available here.
[155] SATI. Available here.

ups developing technologies for agri-food. The interviewee stressed that while young innovators have a comprehensive understanding of how to solve a particular problem using new technologies, they fail to consider the global market, competition and the business opportunities and gaps there. They also lack transversal skills such as public speaking skills, negotiation skills, networking and communication skills. Hence, many young developers lack a sense of how to develop their innovative ideas and technological prototypes into sustainable businesses.

Apart from business skills, the interviewees stressed the importance of bringing technology developers and users together. They emphasised that without relevant knowledge in agronomy and experience working on farmland or with farmers, many technology developers risk creating technologies that are not useful or appealing to users. In this context, however, the interviewees also spoke about the lack of educational funding initiatives for agriculture in general and for digitalising agriculture in particular (e.g. agricultural programmes are rarely financed by Erasmus). The experts interviewed pointed to how most agricultural holdings are usually family businesses which lack serious management infrastructure. This can become a problem for digitalisation and the demand for digital innovations for agriculture, as such a structure is not very permeable to innovation and learning to innovate on the job.

Additional challenges emphasised by the interviewees include making agri-food education open to cross-cutting forms of knowledge, thereby making it attractive for agri-food producers to integrate that knowledge in their holdings. In this context, CVET education was mentioned as essential for developing cross-cutting skills for digitalising agriculture. On-the-job learning specifically was identified as important for technological skills, especially in agri-food production.

Overall, the niche of digitalisation in agri-food faces many challenges, from the digital divide and technology adoption to policy frameworks, the social structure of the agri-food sector, education levels, and distribution of salaries and funding. There is a lack of formal training that could help intensify the digitalisation of agri-food in the EU. At the same time, opportunities for VET and informal forms of training, such as on-the-job learning, are stressed as essential for helping technology developers and users create a common language and adopt necessary skills that would help modernise the agri-food sector. In addition, the development of VET and CVET forms of learning, bringing technology producers and users together, as is done by one interviewee's organisation, will be an important way of matching labour market demands and fostering digital skills in agri-food.

Based on the foregoing analysis and research, we can conclude that, in the short and medium term, the skills needed in the niche will be mainly technical skills connected to the most relevant technologies in the niche, in addition to skills in business, commercialisation and marketing. Technologies such as IoT, drones, AI and Big Data will become even more prominent in the short term, while technologies such as robotics can be expected to become more prominent in the medium and long term. Technical skills connected to such technologies that will become prominent in the niche in the short and medium term include the following skills, among others:

- programming;
- mechatronics;
- Big Data analytics;
- data visualisation;
- text processing;
- cloud management and computing;
- IoT skills;
- real-time systems programming;
- GIS and geo-spatial programming skills;
- remote sensing;
- marketing;
- digital product development;
- agronomy;
- e-commerce and sales;
- consultation;
- project management.

3. Biochemical and microbial products

The interest in and demand for biochemical and microbiological products are growing, together with the European authorities' and farmers' ambition to ensure a sustainable, healthy and environmentally friendly food system. The cultivation of these products is considered to be an effective measure in crop protection and such products are considered to be a safer substitute for the commonly used chemical pesticides that are widely applied to protect plants against pests and diseases. Given that the use of biochemical and microbial products helps overcome genetic and abiotic[156] limitations, maximise productivity and quality, and, overall, concerns improvement in production, this niche mainly represents the **input supply level** of the agri-food value chain in the EU (see Figure 5 below).

Figure 5. Biochemical and microbial market niche within the agri-food value chain

In the following sections of this chapter, we first provide an overview of the niche of the biochemical and microbial products in the EU, presenting the main market and consumer trends. Then, we discuss the main technological trends. Finally, we reflect on the trends in occupational profiles and skills needs in the niche.

3.1 Overview of the market niche

This section provides a general overview of the niche of biochemical and microbial products in the EU and discusses some of the challenges and trends this niche faces. The production of biochemical and microbial products falls under the following NACE sectors:

- C20.1.5: Manufacture of fertilisers and nitrogen compounds
- C20.2: Manufacture of pesticides and other agrochemical products
- A1.6.1: Support activities for crop production
- A1.6.3: Post-harvest crop activities
- M72.1.1: Research and experimental development on biotechnology

Similar to conventional products applied in the agri-food sector, biochemicals and microbials include several categories of products, with pesticides and fertilisers being the most prominent. While **pesticides** (also known as plant protection products, 'PPPs') are used to control and protect plants from weeds, diseases and insects, **fertilisers** are used to feed the soil and/or plant with essential nutrients. Figure 6 below provides some examples of microbial and biochemical products in these two categories.

Figure 6. Examples of biochemical and microbial products applied in the agri-food sector.

PPPs	Fertilisers
Biostimulants	Minerals
Biocontrols	Organic acids
Biofungicides	Crop probiotics
Plant growth extracts and regulators	Soil improvers

Source: Own table.

[156] A non-living chemical or physical factor in the environment.

The difference between conventional PPPs and fertilisers and those considered biochemical and microbial is that the latter category is based on microorganisms and natural products. They originate from nature, and control pests by non-toxic mechanisms, thus posing less harm to humans and having only a minimal impact on the environment. By contrast, conventional fertilisers, and pesticides especially, are generally synthetic materials that directly kill or inactivate the pest and can be toxic to non-target plants. They are also linked to negative human health effects.[157]

The use of biochemicals and microbials is addressed by several regulations, legal acts[158] and investment programmes at the EU level. Given the potential harm, EU pesticide laws are considered the strictest in the world. Unlike in the other systems where regulators focus on whether products are harmful or not, in the EU, PPPs must be marked safe in order to be sold.

Evidence collected through desk research and interviews shows that such strict regulation creates potential obstacles to the further growth of this biochemical and microbial products market niche.[159] This mostly concerns the long timelines for registering PPPs. Therefore, recent amendments to existing regulations have focused on simplifying the approval and authorisation of biological PPPs (or pesticides) containing microorganisms.[160] Fertiliser producers and users, meanwhile, are confronted with the EU Fertilising Products Regulation (FPR) that came into force in the summer of 2022. This regulation replaced Regulation (EC) No 2003/2003 of the European Parliament and of the Council relating to fertilisers,[161] which exclusively covered fertilisers from mined or chemically produced, inorganic materials.[162] The new regulation, in turn, opened the market for new and innovative organic fertilisers (including biochemical and microbial products) by defining the conditions under which these can access the EU Single Market.[163] Although the FPR provides strict rules on safety, quality and labelling, these are considered less stringent than those proposed by the previous EU Fertiliser Products Regulation.[164]

Policy initiatives such as the European Green Deal,[165] the Farm to Fork (F2F) Strategy[166] and the EU Chemicals Strategy for Sustainability further aim to reduce dependency on chemical plant protection products. The European Green Deal itself foresees at least EUR 1 trillion in investment to improve the health of citizens and future generations, with EUR 279 billion to come mainly from the private sector. Although investment concerns not only the agri-food sector, F2F within the Green Deal draws attention to sustainable agricultural solutions and the application of biochemical and microbial products.[167] In addition to investments in this market niche as part of the policies mentioned, another EUR 60 million is expected to be spent in the next 5 to 10 years in the EU on dedicated field studies of various selected microbials.[168]

The efforts taken by the EU authorities and Member States to provide farmers with tools to substitute chemical PPPs and fertilisers are driven by several factors, namely: ensuring a healthy food system; reducing the environmental footprint; and helping mitigate the economic losses due to climate change and the decline of biodiversity.[169] Their pursuit is likely to drive up the demand for alternative biochemical and microbial products. This argument is further supported by the fact that organic farming is a key sector of EU agriculture. In 2019, there were almost 330 000 organic farmers in the EU, cultivating up

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[157] IFM (n.d.). Exposure to Pesticides, Herbicides & Insecticides: Human Health Effects. Available here.
[158] Regulation (EC) No 1107/2009, available here; Regulation (EC) No 396/2005, available here; Directive 2009/128/EC on the sustainable use of pesticides, available here; Commission Regulation (EU) 2022/1438, amending Annex II to Regulation (EC) No 1107/2009, available here; Commission Regulation (EU) 2022/1439, amending Regulation (EU) No 283/2013, available here; Commission Regulation (EU) 2022/1440, amending Regulation (EU) No 284/2013, available here; Commission Regulation (EU) 2022/1441, amending Regulation (EU) No 546/2011, available here; Regulation (EU) 2019/1009, laying down rules on the making available on the market of EU fertilising products – the FPR, available here.
[159] Interview with an international biocontrol organisation representative; also EBIC (n.d.). The EU Fertilising Products Regulation should allow microbial plant biostimulants to access the EU market in a way that fosters innovation. Available here.
[160] European Commission (2022). Questions and answers: Farm to Fork: new rules for micro-organisms used in plant protection products. Available here.
[161] European Commission (2003). Regulation (EC) No 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers. Available here.
[162] Nutriman (2022). The new fertiliser regulation – consequences for farmers. Available here.
[163] Ibid.
[164] Fertilizers Europe (2022). Fertilizing Products Regulation. Available here.
[165] European Commission (2022). A European Green Deal. Available here.
[166] European Commission (2020). Farm to Fork Strategy. Available here.
[167] Harvey, F. And Rankin, J. (2020). What is the European Green Deal and will it really cost €1tn? Available here.
[168] Schreiber, S. (2022). Biobased agri-innovation with microbiome products – EU lags behind US, Brazil, and New Zealand, say microbiome researchers. Available here.
[169] European Commission. Questions and answers: Farm to Fork.

to 20% of its farming area (with the goal of reaching 25% by 2030).[170] Based on this, the market research agency Mordor Intelligence estimates that the European agricultural microbials market will witness a compound annual growth rate (CAGR) of 15% from 2016 to 2026. Germany is expected to be the fastest-growing market during the period forecast since it holds the largest European agricultural microbial market share.[171]

Bayer, BASF SE and Corteva are among the leading companies in the agricultural solutions market in the EU countries. Operating in this market niche, they notice an increase in the sales of biochemical and microbial products. For example, one of the market leaders, the German multinational chemical company BASF SE, observes EUR 8.16 million worth of sales (26% of which to Europe) for agricultural solutions in 2021, a 6% increase compared to 2020.[172] Furthermore, this company announced peak sales potential of more than EUR 7.5 billion for its innovation pipeline of agricultural solutions (including the use of biochemical and microbial products).[173] By 2029, the company expects to launch more than 30 critical projects, including novel seeds and traits, chemical and biological crop protection, digital products and new formulations. BASF SE also invested around EUR 900 million in R&D in the agricultural solutions segment in 2021, representing around 11% of the segment's sales.[174] Meanwhile, another key player, the German company Bayer, expects their investment in agricultural solutions containing the application of biochemicals and microbials to translate to a peak sales potential of nearly EUR 30 billion.[175] The company has also reported that, compared to the second quarter of 2021, sales in the agricultural business overall rose by 25.8% in the third quarter of 2021.[176] The American company Corteva is further developing its biologicals portfolio to complement existing farm practices. The company has recently acquired microbiological technologies leader Symborg[177] to establish itself as a leader in this market niche which they perceive to be rapidly growing.[178]

Some start-ups specialising in producing biochemicals and microbials also focused their resources on the development of this market niche. For example, the Danish insect pheromone start-up BioPhero raised EUR 14.2 million to replace chemical insecticides. Meanwhile, the French company Micropep raised EUR 8.5 million to develop innovative small peptide solutions for agriculture. In addition to changes in business metrics and structure, companies in this market niche also seem to be dedicating their research centres, engineering and digital services divisions to the implementation of relevant research activities on how to innovatively implement their solutions relating to the application of biochemicals and microbials.[179] Altogether, such trends confirm the rapid growth in the demand for biochemical and microbiological products in the agri-food sector.

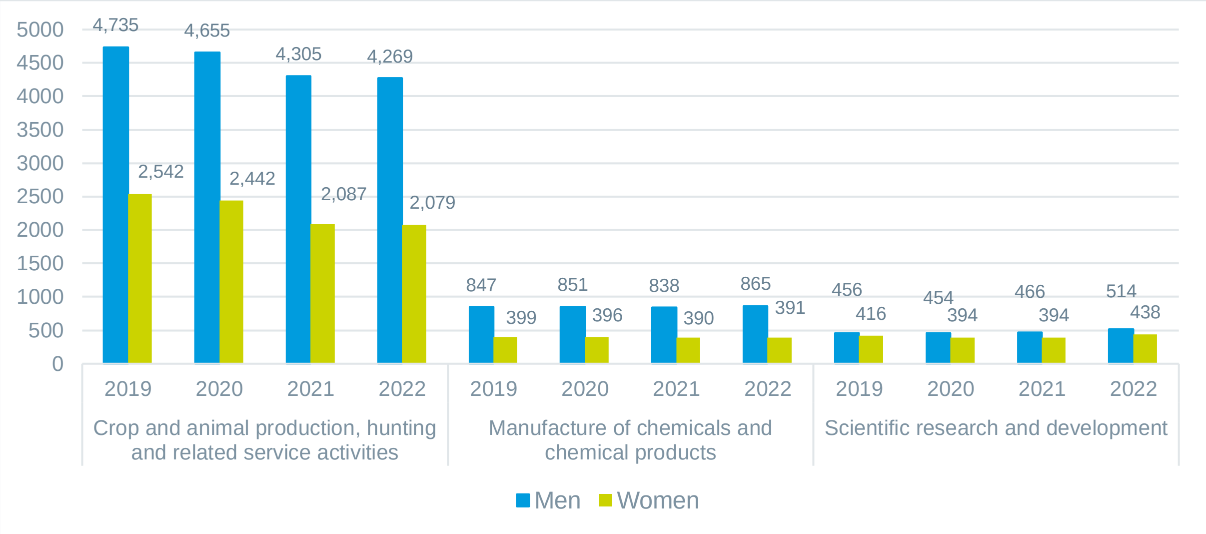
Evidence collected through desk research and interviews[180] shows that this market niche (as opposed to the agri-food sector in general) is less exposed to informality. One of the reasons for this is the strict regulation applied to both the production processes and the companies manufacturing the microbial and biochemical products. In addition, a factor influencing this is the specific technical knowledge needed for producing microbial and biochemical products, which requires more formal employment conditions.

With regard to employment indicators in this market niche, the available data is limited to data on a higher level of aggregation, as can be seen from Figure 7. Most workforce employed in the niche is in crop and animal production, hunting and related service activities (NACE sector A1). The gender gap is also the most prevalent within this sector, with male workers dominating. Meanwhile, the least unequal gender distribution is within the scientific research and development sector (NACE M72). However,

[170] European Commission (2021). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Empty on an Action Plan for the Development of Organic Production. COM(2021) 141 final/2, available here.
[171] Mordor Intelligence (2022). Europe Agricultural Microbials Market -Growth, Trends, COVID-19 Impact, And Forecasts (2022-2027). Available here.
[172] BASF (2021). Agricultural solutions. Available here.
[173] BASF (2022). Strong pipeline of BASF agricultural innovations will benefit food security, climate and environment. Available here.
[174] BASF (2021). Agricultural solutions. BASF. (2022). Strong pipeline of BASF agricultural innovations.
[175] Bayer (2022). Bayer highlights advancements of agriculture industry's most prolific R&D pipeline. Available here.
[176] Bayer (2021). Bayer grows sales and earnings significantly. Available here.
[177] Corteva (n.d.). Biologicals. Available here; AgNews (2022). Corteva Agriscience signs agreement to acquire biological leader Symborg. Available here.
[178] Corteva (2022). Corteva Agriscience signs agreement to acquire biological leader Symborg. Available here.
[179] BASF (2022). Organization. Available here.
[180] Interview with a representative from an international biocontrols organisation.

companies are actively addressing the gender gap by presenting various programmes and stipends to attract women to this market niche, currently dominated by male employees.[181] Some job postings also target female employees.[182]

Figure 7. The number of persons employed (in thousands) in NACE sectors A1, C20 and M72. EU-27



Source: Eurostat [LFSQ_EGAN22D].

In Table 3 below, we can see the number of companies based on economic activity and size relevant to the niche of biochemical and microbial products in the EU. It shows that the market, especially in the 'Manufacture of pesticides and other agrochemical products', tends to be more concentrated among larger producers, and very few smaller businesses in this sector exist in Europe. There is no detailed data available for the number of workers in 'Support activities for crop production' (A1.6.1) and 'Post-harvest crop activities' (A1.6.3).

Table 3 The number of companies based on economic activity and size (EU-27)

Economic activity (EU-27)	**Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms**		**Manufacture of pesticides and other agrochemical products**		**Scientific research and development**	
Size/Year	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Total	8 000	8 000	544	618	67 759	69 893
From 0 to 9 persons employed	5 568	5 471	335	403	61 800	64 085
From 10 to 19 persons employed	841	821	51	41	2 322	no data
From 20 to 49 persons employed	800	793	59	71	1 779	1 822
From 50 to 249 persons employed	857	854	76	78	no data	1 230
250 persons employed or more	339	341	23	25	277	282

Source: Eurostat [SBS_SC_SCA_R2]

Note: Data marked in red are marked as 'low reliability' in Eurostat's dataset. Cells where there are no data have been marked confidential by Eurostat. There was no data disaggregation for C20.1.5 M72.1.1, so we used higher-level aggregations, such as C20.1 and M72.

The biochemical and microbial products niche is, like other niches in the agri-food sector, affected by the digitalisation of the production of biochemical and microbial products. In the next section, we will

[181] BASF (2022). Women in BASF: Diversity & Development Opportunities. Available here; Bayer (2022). Levelling the Playing Field. Available here; Corteva (2022). Who we are: Inclusion and Diversity Equity. Available here; Koppert (2022). The importance of women in Agriculture. Available here; Corteva (n.d.). Women in Agriculture Say Barriers to Equality Persist, Removal Could Take Decades, Study Reveals. Available here.
[182] BASF (n.d.). Job Search. Available here.

discuss technological and market trends in the niche to understand where these trends are going in the short and medium term, and how they reflect on the biochemical and microbial products niche.

3.2 Main technological trends

Various technologies are becoming prominent in the biochemicals and microbials market niche, for both their production and application. Production primarily employs technologies for collecting, processing and analysing data, as well as advanced manufacturing tools and fermentation. Meanwhile, the application of biochemical and microbial products employs technologies such as drones and robotics, as presented in the chapter on digitalisation in agri-food.

- One of the most tested technologies in producing bioproducts is **precision fermentation.** During this process, the extracellular enzymes secreted by microorganisms are involved in the breakdown and/or transformation of complex substrates. As a result, it allows the creation of new products with improved properties. Such products are then used as insecticides for pest management and help increase the yields of certain bioactive compounds.[183]
- More recent trends, such as **Artificial Intelligence (AI), the Internet of Things (IoT)** and **Machine Learning (ML)** are, for example, used to detect outages, optimise machinery and processes for efficient manufacture and improve the quality of products.[184] They also help to develop optimal conditions to grow bacteria and other microorganisms that are the basis of organic PPPs, fertilisers, as well as analyse data at high speeds and return it to farmers in the form of insightful information. They can then use it to assist them in making crucial decisions relating to applying biochemical and microbial products in real-time.[185] Furthermore, **pattern recognition** methods[186] employed are especially important for recognition of different species of herbs, thus ensuring more precise application of biochemical and microbial products.
- **Computational methods,** meanwhile, are employed more often to determine which microbes are the most important in the synergistic ecosystem.[187] Furthermore, in addition to the foregoing technologies, scientists also see a potential for using technologies such as **3D printing** of bacteria for various bio-production purposes and protein modelling in the medium-term future.[188]

There are several examples of successful adoption of technologies mentioned in the production of biochemical and microbial products within the EU. For instance, bioinformatic tools are used in soil biodiversity. The French agri-tech start-up Mycophyto uses them to analyse the results of soil metagenomics studies to identify arbuscular mycorrhizal fungi (AMF) species, which are major components of microbial products.[189] The company uses AI-based prediction models, which integrate data identified as impacting the presence of species compared to climate, soil pedology and soil chemistry, and predict the presence of these species from GPS coordinates. They have already worked with winegrowers to maximise the life of the soil and to grow vine plants that are more resistant to drought and disease. Biome Makers is another company that integrates AI to help farmers better understand how their land's soil microbiome might impact growth for a given crop.[190] Their method (which entails DNA sequencing with AI and employs a global database of 10 million microorganisms and 35 000 soil samples) was tested by large olive oil producers in Portugal to obtain more information about microbial interactions within their soil. In this way, the oil producers devised their soil fertilisation strategy by preserving the microbial communities that mobilise the most nutrients.

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183 Omarini, A. B., Achimón, F., Brito, V. D., & Zygadlo, J. A. (2020). Fermentation as an Alternative Process for the Development of Bioinsecticides. *Fermentation*, 6(4). p. 120.
184 Bhardwaj, A., Kishore, S., & Pandey, D. K. (2022). Artificial Intelligence in Biological Sciences. *Life*, 12(9). p. 1430.
185 Bayer (2022). Using Data to Drive Decisions. Available here.
186 A data analysis method that uses machine learning algorithms to automatically recognise patterns and regularities in data.
187 Bengtsson-Palme, J. (2020). Microbial model communities: To understand complexity, harness the power of simplicity. *Computational and Structural Biotechnology Journal*, 18. p. 3987-4001.
188 Philp, J. (2020). Digitalisation in the bioeconomy: Convergence for the bio-based industries. In OECD, *The Digitalisation of Science, Technology and Innovation: Key Developments and Policies*. *OECD*. Available here. p. 143; also interview with an expert in chemical engineering.
189 De Rojas, C. (2022). Releasing the microbiome's potential to restore European soils. Available here.
190 Ibid.

Unlike the niche of digitalisation in agri-food, technologies in the niche of biochemical and microbial products have limited use, such that they support the production and application of biomicrobials. Therefore, some interviewees emphasised that the production of microbiological and biochemical products concerns primarily new and innovative scientific solutions rather than technologies for their application.[191] Nevertheless, all the technological trends presented are foreseen to be relevant in the short and medium term in order to make the manufacturing of biochemical and microbial products more efficient and products themselves more effective.

The development of new technologies in the niche is driving the demand for new occupations and skills. In this sense, applying machine learning to the development of biochemical and microbial products requires companies to find workers skilled in data analysis and programming, inter alia. We discuss which skills and occupational profiles are increasingly sought by companies in the niche –and in the context of current and future technological developments – in the section below.

3.3 Trends in occupational profiles and company skills needs

Although not primarily focused on technological innovation, as suggested above, the niche of biochemical and microbial products in the EU is certainly affected by the influx of new production methods and technologies in the market. Indeed, there is an increasing need for cross-disciplinary skills in the niche, such as agronomists with skills in computer programming, which affects the way in which workers are trained and hired in the niche. Below, we will discuss which skills demand trends are linked to which occupational profiles, and how they will develop in the short and medium term.

To identify the most prominent occupations within the biochemical and microbial products market niche, we explored ISCO groups 1 (managers), 2 (professionals), 3 (technicians and associate professionals) and 4 (clerical support workers). We then studied online job advertisements and career pages of various companies operating in the market niche of biochemical and microbial products for agriculture in the EU.[192] Analysing vacancies, we found that the greatest demand was for professionals (ISCO 2). Meanwhile, the lowest demand was registered for clerical support workers (ISCO 4). Such conclusions are supported by the nature of work in this market niche, which is mainly based on the creation and sale of biochemical and microbial products.

Managers

Among managers (ISCO 1), we find product managers (ESCO 1223.1), research and development managers (ESCO 1223.2), and production managers in agriculture, forestry and fisheries (ISCO 131) to be the most relevant occupations. Meanwhile, other important managerial occupations in this market niche include human resource managers (ESCO 1212.2) and category managers (ESCO 1221.3.2.1.1). All these vacancies within the ISCO 1 group usually require higher education (at least **ISCED 7**) in a relevant field, as well as previous management experience, knowledge of the market and language skills (usually the local language and English) alongside other role-specific expertise, for example, quality control processes and budgeting, proficiency with data analysis and visualisation software.

Professionals

Among professionals (ISCO 2), we observe such production-related occupations as chemists (ESCO 2113.1), biochemists (2131.4.2), biophysicists (2131.4.4), geneticists (2131.4.8), microbiologists (2131.4.10), agricultural scientists (2132.1), agronomists (2132.2), environmental programme coordinators (2133.6), soil scientists (2133.11), environmental engineers (2143.1), and biochemical engineers (2145.1.1). As in the case of managers, higher education (at least **ISCED 7**) is usually required in relevant fields. Additionally, previous working experience in a laboratory environment is key. Meanwhile, expertise in methods used and particular data management systems and statistical software packages (Minitab, R, etc.) is also important.

[191] Interview with an expert in chemical engineering.
[192] Some examples include: Corteva, multiple locations; CertisBio, multiple locations; BASF, Germany; Bayer; Koppert, multiple locations; LinkedIn, multiple postings, see also here.

Other prominent professional occupations which are not directly related to the manufacturing of biochemical and microbial products are accounting analysts (2411.1.1), financial auditors (2411.1.7), business analysts (2421.1), logistics analysts (2421.5), human resources officers (2423.3), training and staff development professionals (2424), public affairs consultants (2432.8), technical sales representatives in chemical products (2433.6.2), contract managers (2619.1), legal consultants (2619.7), and regulatory affairs managers (2619.12). Here, a higher level of education of at least **ISCED 6** is required alongside previous working experience, relevant technical knowledge, and business management software (for example, SAP).

Generally, roles within the ISCO 2 group (both related and production or support) also require a good command of the local language and English. We can see that professionals in this market niche need to be very familiar with engineering and digital skills such as programming and data science.[193] Emerging life science and digital skills will be in increasingly high demand, thus reflecting the growing importance of new technologies in this niche.[194]

Technicians and other occupational levels

Among technicians and associate professionals (ISCO 3), there are vacancies in this market niche for chemistry technicians (3111.1), chemical engineering technicians (3116.1), chemical processing plant controllers (3133.1), biochemistry technicians (3142.2.2), biology technicians (3142.2.3) and agricultural technicians (3142.1). Other occupations include commercial sales representatives (3322.1), import-export specialists in agricultural raw materials, seeds and animal feeds (3331.2.1.2), import-export specialists in chemical products (3331.2.1.4), supply chain assistants (3343.1.7) and legal assistants (3411.7). Although these usually do not necessarily require higher education (the levels **ISCED 3-6** are the most common among job advertisements analysed), they sometimes require previous work experience (or at least a common understanding of potential responsibilities) and other abilities such as mechanical aptitude, computer literacy, organisation and communication skills.

Among clerical support workers (ISCO 4), office clerks (4110.1), accounting and bookkeeping clerks (4311), payroll clerks (4313.1), machinery assembly coordinators (4322.1) and transport clerks are sought. Mostly, **ISCED 3-6** levels are required, together with some understanding of potential responsibilities, a good command of Microsoft Office software and communication skills.

Pay levels

Table 4 below illustrates annual salaries for different occupational profiles across sectors that are relevant to the biochemical and microbial products market niche in the EU. We used information from Glassdoor, a job portal, to compile the table. More information on methodology can be found in Annex I. Methodology. In most countries analysed, human resources officers and managers (in sales, R&D and HR) fall into the 10th decile, representing the highest income group in the EU-27, which stood at or above EUR 34 323 in 2021.[195] Overall, Germany and the Netherlands are the countries paying the most for the specialists identified within this market niche, with Greece and Italy paying the least. Surprisingly, such sector-specific roles as chemical engineers, chemists, biochemists and especially microbiologists fall into the 7th income decile or lower quite often (see values on the white background).

[193] Philp, J. (2020). Digitalisation in the bioeconomy. p.143.
[194] Chui, M., Evers, M., & Zheng, A. (2020). How the bio revolution could transform the competitive landscape. *McKinsey Quarterly.* p. 7.
[195] Eurostat (2022). ILC_DI01.

Table 4. Estimated total pay (annual) – average values (in EUR)

Occupation	BE	DE	EL	ES	FR	IT	NL	PL	SE
Human resources officer	no data	61 280	no data	no data	72 499	52 038	84 110	26 606	73 731
Sales manager	60 583	37 757	40 821	35 783	35 995	32 320	54 660	51 579	101 463
Human resources manager	47 347	30 089	33 977	29 002	31 370	30 116	81 437	54 496	73 426
R&D manager	36 024	47 736	19 232	no data	25 335	45 747	86 313	41 995	no data
Environmental engineer	21 330	27 513	9 001	8 755	16 696	204 573	22 290	17 682	28 036
Regulatory affairs manager	35 555	40 676	22 332	30 345	39 814	31 460	52 105	45 155	54 212
Lawyer	41 427	49 251	8 538	31 138	49 572	26 389	49 277	31 178	49 970
Contract manager	49 087	39 818	19 099	33 758	29 802	25 852	57 043	19 844	30 425
Accountant	31 615	34 773	19 309	24 280	31 344	22 937	44 667	21 387	42 314
Import-export specialist	16 012	26 729	7 801	21 199	24 342	16 994	21 739	105 148	26 894
Logistics analyst	26 626	38 047	no data	25 604	25 535	17 709	30 899	34 732	21 811
Business analyst	26 995	31 140	18 944	20 972	25 679	15 515	34 378	31 001	44 984
Commercial sales representative	14 401	46 296	no data	27 734	28 883	7 826	83 747	7 682	7 122
Chemical engineer	31 818	34 738	12 830	18 177	15 582	10 118	35 203	31 458	57 400
Legal consultant	16 558	31 140	19 582	no data	26 500	26 999	26 646	12 390	no data
Agronomist	14 032	31 685	7 285	24 689	22 321	25 164	31 494	21 469	no data
Chemist	15 796	31 274	7 626	13 961	no data	20 176	38 392	30 852	22 745
Biochemist	17 064	28 705	no data	9 353	9 763	no data	42 615	no data	21 505
Technical sales representative in chemical products	11 427	36 120	17 069	31 731	29 334	18 102	7 946	10 329	15 773
Legal assistant	23 685	33 233	9 115	13 207	24 810	no data	23 292	7 248	17 701
Microbiologist	21 085	13 203	9 320	21 905	24 966	10 965	29 115	no data	23 823
Office clerk	no data	18 226	6 760	17 999	no data	24 303	18 261	no data	
Supply chain assistant	10 511	22 128	7 672	no data	17 233	no data	19 658	no data	

Source: Glassdoor.

Note: Salary estimations are not filtered by industry and level of experience due to data availability. Glassdoor provides gross salary estimations, which is why we used the OECD's 'Average personal income tax and social security contribution rates on gross labour income'[196] for relevant countries to adjust and estimate net annual salaries. Salaries that belong to the 10th decile of Eurostat's 'Distribution of income' [ILC_DI01] table are in dark teal. Estimations in light teal fall into the 9th and 8th deciles, while the estimations in white fall into the 7th decile or lower. Values marked in red indicate lower levels of confidence. In such cases, a salary estimation on Glassdoor did not have a 'high confidence' or 'very high confidence' label, meaning that it was calculated based on a limited number of salaries.

General trends

The interviews confirmed that the most sought general occupations within the microbial and biochemical products market niche are professionals **(ISCO 2)** and technicians **(ISCO 3).** Some interviewees believed that, with the growth of this industry, advisory roles will become important to address a growing need for decision-making to use microbial and biochemical products.[197] In this context, the interviewees identified advisors with skills in agronomy and advisors with interdisciplinary knowledge, such as understanding environmental factors and their impact on other growth factors for crops. Meanwhile, all interviewees highlighted the demand for modellers to feed the real-time data into decision-making processes. Modellers should have knowledge in agronomy, combined with mathematical and computer

[196] OECD (2021). Average personal income tax and social security contribution rates on gross labour income. Available here.
[197] Interviews with an expert in chemical engineering and a representative of a European organisation in the field of food science and technology.

skills. In particular, the ability to feed the real-time data for population growth and decline into decision-making processes was identified as an important skill for modellers.

In general, **multi- and interdisciplinary skills** are becoming increasingly important in the niche. The interviewees emphasised that versatility is becoming especially important in the niche, meaning that microbiologists, for instance, will need to be familiar with different aspects of microbiology (i.e. toxicology, ecology, genetics, etc.), thus emphasising the transfer of skills.[198] In addition to qualifications in biology, chemistry, biochemistry and life sciences in general, some more specific skills relating to life sciences are in demand. These include, for example:[199]

- genome sequencing
- protein structure solutions
- quantum simulation
- precise genome manipulation
- targeted genetic therapies
- spatial multi-omics
- CRISPR-based diagnostics

Regarding technical and transversal skills, the research shows that technical knowledge is of the utmost importance within this market niche. However, the analysis of job advertisements and interviews indicated that social and intercultural skills and international experience are also highly appreciated.[200] This is due to the nature of the projects, which are usually multinational and involve people from various backgrounds.

In terms of qualifications, the interviewees could not agree on which level of qualification was needed for adequate skills in the niche. In general, the interviewees noted that those willing to work in this market niche are generally preferred to have higher levels of education. Most interviewees said that **higher education** in almost any field of life sciences (e.g. biology, chemistry or related) is suitable for sufficient skills. One group of interviewees stated that a master's degree is usually preferred. While master's degrees were emphasised for more technical fields such as microbiology and biotechnology, other interviewees stressed that higher levels of education need not be limited to specific profiles. Hence, they underlined the importance of **on-the-job learning** which is being offered in the niche. Furthermore, a different group of interviewees argued that **VET and higher education** graduates could achieve the same level of knowledge through different pathways, such as on-the-job education. In this sense, someone with a higher education background without vocational skills would need to learn those skills on the job, and vice versa.[201]

To address the need for specialists with various levels of experience, qualifications and skills, the higher education sector needs to attract school-leavers with a mathematical background. Therefore, graduates need to be trained for cross-cutting skills, such as skills in computation, programming and engineering in addition to their expertise in biology, chemistry, life sciences and related fields.[202] The interviewees confirmed that European universities seem to be addressing these labour market needs. There are bachelor's degrees in molecular and biophysical life sciences, life science and technology, which both integrate mathematics and programming into the courses.[203] Master's students can choose from an even greater variety and even more specialised programmes such as bio-inspired innovation, fabrication, bioinformatics and biocomplexity, environmental biology and chemical engineering.[204] The interviewees also agreed that the VET provision satisfied the needs for skills training in the niche. The secondary school programmes generally cover basic skills in sciences such as biology and chemistry. However, they emphasised that on-the-job education and continuous development (e.g. through professional seminars) are crucial in addressing emerging skills gaps after graduation.[205]

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198 Interview with a representative from an international biocontrols organisation.
199 Eisenstein, M. (2022). Seven technologies to watch in 2022. *Nature*, *601*(7894). p. 658-661.
200 Interviews with an expert in chemical engineering and a representative of a European organisation in the field of food science and technology.
201 Interview with a representative from an international biocontrols organisation.
202 Philp, J. (2020). Digitalisation in the bioeconomy: Convergence for the bio-based industries. *The Digitalisation of Science, Technology and Innovation*, 143.
203 See, for example, University of Utrecht, the Netherlands, Molecular and Biophysical Life Sciences. https://www.uu.nl/en; University of Groningen, the Netherlands, Life Science and Technology; TU Delft, the Netherlands, Life Science & Technology..
204 See, for example,University of Utrecht, the Netherlands, various programmes; University of Groningen, the Netherlands, Health and Life Sciences; Tu Delft, the Netherlands, various programmes.
205 Interviews with representatives from an international biocontrols organisation and an expert in chemical engineering.

Concerning the **non-formal training** in the sector, there are instances of learning opportunities provided by European or international organisations and private companies. For example, various organisations in this market niche organise seminars, workshops, trade fairs and industry conferences.[206] These events are usually open not only to employees of specific businesses but also to the general public. Although, according to some interviewees, such practices are generally considered complementary to formal education, they provide excellent opportunities for networking and exchanging knowledge.[207]

In-company training is another opportunity for gaining the niche knowledge required to perform specific work. For instance, Certis, one of the market leaders in the international and European agricultural microbial market, launched its own corporate university to train its employees. According to the company, in the last year, 77% of its global tech workforce upgraded their skills in data analytics, ops-tech and development, enterprise systems and project management. These tech courses were conducted online through Certis's e-LMS system established by Certis Corporate University (CCU), as well as in partnership with various global technology partners.[208] Bayer also has its 'Academy', which offers seminars and learning opportunities which consider global and local demands.[209] Many other companies also have their own learning practices and/or training centres. Learning-on-the-job was often mentioned during the interview programme as a very important source adding to the general knowledge gained in educational institutions.[210]

As we can see, the biochemical and microbial products niche is, much like the niche of digitalisation in agri-food, undergoing a change in terms of what kind of skills and occupations are in demand. Although the interviewees stressed that the educational opportunities already existing in the EU prepare graduates well for jobs in the niche, they underscored the need for continuous and professional development. In this context, the interviewees emphasised the need to develop transversal skills, in addition to learning how to work with new technologies relevant to the niche. One of the most prominent technologies in the niche is precision fermentation, which is an established technology, so it is expected to remain relevant in the short and medium term. New technologies that will become prominent in the short and medium term include AI and other computational methods (e.g. 3D printing of bacteria), pattern recognition technologies and IoT. Apart from the skills relating to operating new technologies in the sector, the findings of the study suggest the following skills to be increasingly important:

- quality control
- budgeting
- data analysis
- statistical software
- data management systems
- general digital literacy
- engineering
- communication and intercultural skills
- sales and marketing
- CRISPR-based diagnostics
- quantum simulation
- protein solutions
- genome sequencing
- microbiology
- agronomy
- mathematical skills

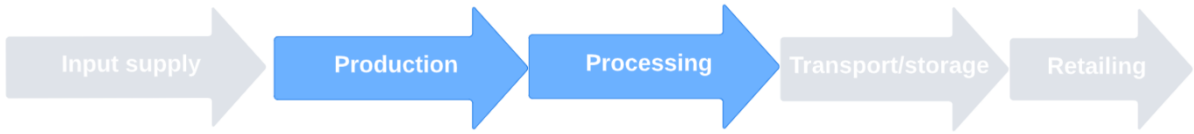
[206] See, for example, IBMA (2022). 8th Symposium: Working with Nature. Available here; Microbial Plant Protection Products Task Force. (2022). Available here; FEMS. (2022). Available here; Fertilizers Europe. (2022). Available here; AMFEP. (2022). Available here.
[207] Interviews with representatives from an international biocontrols organisation and European microbial plant protection products organisation.
[208] Certis Corporate University (n.d.). A Future Ready Workforce. Available here.
[209] Bayer (n.d.). Bayer Academy. Available here.
[210] Interviews with European microbial plant protection products organisation and expert in chemical engineering.

4. Organic and functional foods

Generally, companies which are active in the organic and functional foods market niche can operate at all levels of the agri-food value chain, including input supply, production, processing, transport/ storage and wholesale/ retail. These companies engage in producing inputs, such as organic seeds and biofertilisers, growing raw agricultural products, processing the raw products to manufacture food and beverages, and bringing the final products to sellers and consumers.

In this chapter, we primarily focus on the overview of the technological and market trends and skills needs of the companies active on the **production** and **processing** side of the agri-food value chain (see Figure 8 below).

Figure 8. Organic and functional foods market niche within the agri-food value chain



In the following sections, we will first provide an overview of the organic and functional foods market niche, presenting the main market and consumer trends. We will then discuss the main technological trends. Finally, we will reflect on the trends in occupational profiles and skills needs in the organic and functional foods market niche.

4.1 Overview of the market niche

At its essence, **organic food** production is supposed to respect natural life cycles. Organic regulations prohibit or restrict the use of certain practices in food production (e.g. the use of GMOs, ionising radiation, artificial fertilisers, herbicides and pesticides, hormones and antibiotics for animal health) and the number of food additives, and limit substantial changes in the food.[211] EU regulations on organic production exclude products from the fishing and hunting of wild animals but include the harvest of wild plants when certain natural habitat conditions are respected, as well as products from aquaculture.[212] Organic food production, therefore, falls under the following NACE sectors:

- A1.1.: Growing of non-perennial crops
- A1.2.: Growing of perennial crops
- A1.3.: Plant propagation
- A1.4.: Animal production
- A1.5.: Mixed farming
- A1.6.: Support activities to agriculture and post-harvest crop activities
- A3.2.: Aquaculture

Functional foods, also known as nutraceuticals, are highly nutritious foods or food supplements associated with health benefits beyond basic nutrition needs (such as protection against disease, prevention of nutrient deficiencies, or promotion of proper growth and development). This is due to their physiologically active food components (i.e. bioactive compounds or bioactive food components).[213]

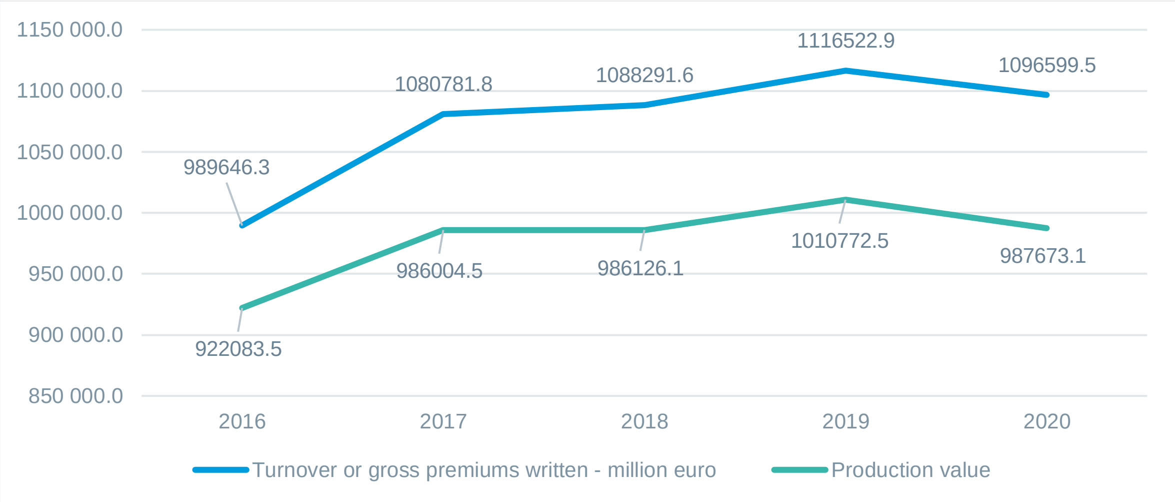
[211] European Court of Auditors (2018). Organic Food in the EU. Available here.
[212] European Commission (2022). Organic production and products. Available here.
[213] Litwin, N., Clifford, J., & Johnson, S. (2018). Functional foods for health. Hum. Nutr, 4, 18. Available here.

Functional foods can be further divided into three categories according to the nature of these components:

- natural food containing high levels of the functional ingredient. Examples include certain fruit, vegetables, nuts, seeds and grains (their production is covered by NACE sectors A1.1., A1.2., A1.4.);
- food to which functional ingredients were added or removed or changed. Some examples include foods fortified with vitamins, minerals, probiotics or fibres (their production is covered by the NACE sectors C10. 'Manufacture of food products' and C11. 'Manufacture of beverages');
- food supplements, such as vitamins, minerals, isolated or synthesised food ingredients, probiotics, fibre and amino acids. They are usually marketed in 'dose' form (e.g. pills, capsules or liquids in measured doses). Food supplements are regulated as foods in the EU, and their production is covered by NACE sector C10 (C10.8.9. Manufacture of other food products n.e.c.).

Organic and functional food production and processing are part of the wider agricultural and food processing industries, which are among the most important sectors in the EU. The agricultural sector employs around 8.7 million people on a full-time basis while also providing work for nearly 20 million people.[214] Agriculture alone contributed 1.3% of the EU's GDP in 2021,[215] creating an estimated gross value added of EUR 184.2 billion in 2021.[216] Moreover, farmland covers almost half (46.4%) of the total land area of the EU,[217] thus capturing the geographic extent of the industry. The food and beverages industry is the largest manufacturing sector per turnover and employment in the EU. In 2020, its turnover reached over EUR 1 billion (see Figure 9 below), constituting around 15% of total turnover in manufacturing.[218]

Figure 9. C10. Manufacture of food products and C11. Manufacture of beverages. Turnover and production value in EUR million, EU-27



Source: Own calculations based on Eurostat [SBS_NA_SCA_R2].

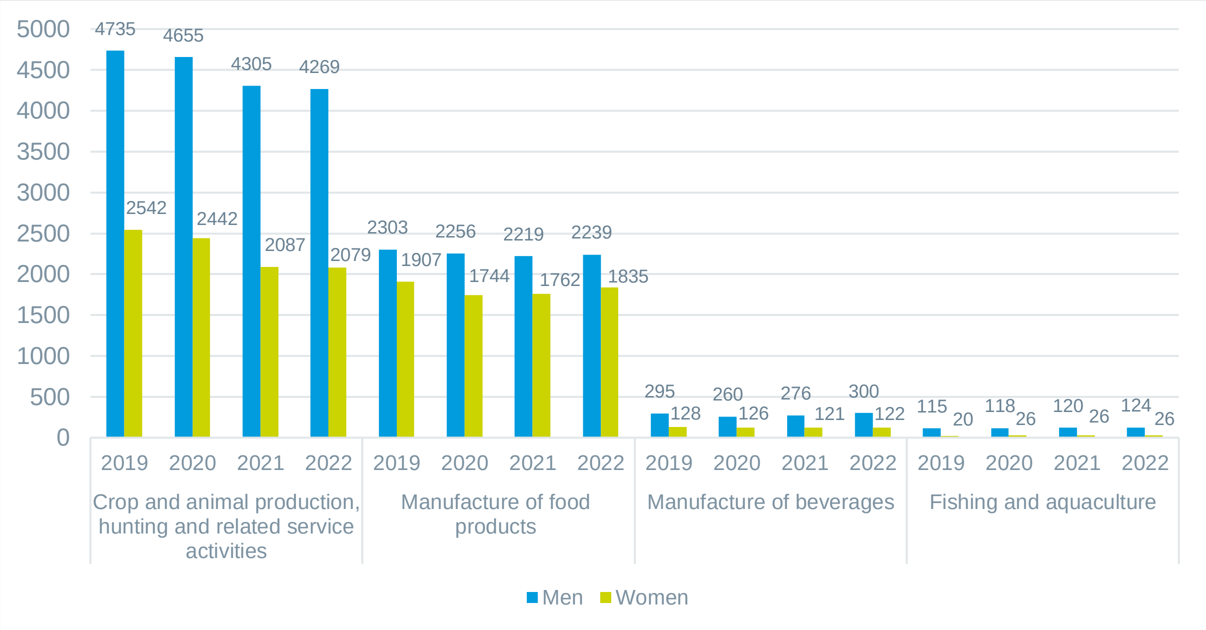
Note: C11 statistics are calculated as a total of values for each EU Member State (the EU-27 aggregate was not available). Data for Ireland are missing for 2016-2020; data for Finland are missing for 2018; data for Slovenia are missing for 2019 (in all cases marked as 'confidential').

Based on the Eurostat employment data, the total number of people employed in the agricultural production and food processing levels of the agri-food value chain[219] in the second quarter of 2022

[214] de Velde et al. ATI sectoral watch., p. 5. For more detailed statistics, see Eurostat. (2022). Farmers and the agricultural labour force: statistics. Available here.
[215] Eurostat (2022). Performance of the agricultural sector. Available here.
[216] Eurostat (2022). Performance of the agricultural sector.
[217] European Commission. (2022). Farms and farmland in the European Union: statistics. Available here.
[218] Based on Eurostat [SBS_NA_SCA_R2] and [TIN00149].
[219] Comprised of NACE sectors A1 – Crop and animal production, hunting and related service activities, A3 – Fishing and aquaculture, C10 – Manufacture of food products and C11 – Manufacture of beverages.

amounted to 11 135 100, which constitutes 6% of the total employment in the EU for that period.[220] More than half of them were employed in NACE sector A1 – Crop and animal production, hunting and related service activities (see Figure 10). Between 2019 and 2022, this sector experienced a steady decrease in the number of employees, with the biggest drop in 2021, while the other agri-food sectors remained more stable. A gender gap in employment is evident in all the agri-food sectors overviewed (A1, A3, C10 and C11), with male workers prevailing. While this gap is not as large in the food processing industry (C10 and C11), it is much more pronounced in agriculture (A1), with the number of female workers being half the number of male workers, and in fishing and aquaculture (A3), where male workers largely dominate.

Figure 10. The number of persons employed (in 1000) in NACE sectors A1, A3, C10 and C11. EU-27



Note: Values reported for 2022 are based on the data for the 1st and 2nd quarters of 2022. Data for women employed in 'Fishing and aquaculture' is limited; therefore, for 2019 the values from 2018 are reported, and for 2020-2022 the values from 2020 are reported.

Source: Calculations based on Eurostat [LFSQ_EGAN22D].

At the same time, a considerable amount of employment might not be captured by statistics, as the agricultural sector is traditionally associated with high levels of informality.[221] The exact size of informal economy in agriculture is difficult to measure due to the breadth of subsistence farming, family work and undeclared employment, seasonal work, and use of an irregular immigrant workforce. Moreover, farmers sell products in local markets without documenting these activities.[222] Recent research suggests that in the EU-15 Member States the level of informality in agriculture was between 12.7% and 27.8% over the past two decades (1996-2019) and did not decrease for the same period in contrast to the total levels of informal employment for the same countries.[223] According to some estimations, the highest numbers of unregistered agricultural workers in the EU are found in Greece (94%), Cyprus (85%) and Poland (56%).[224]

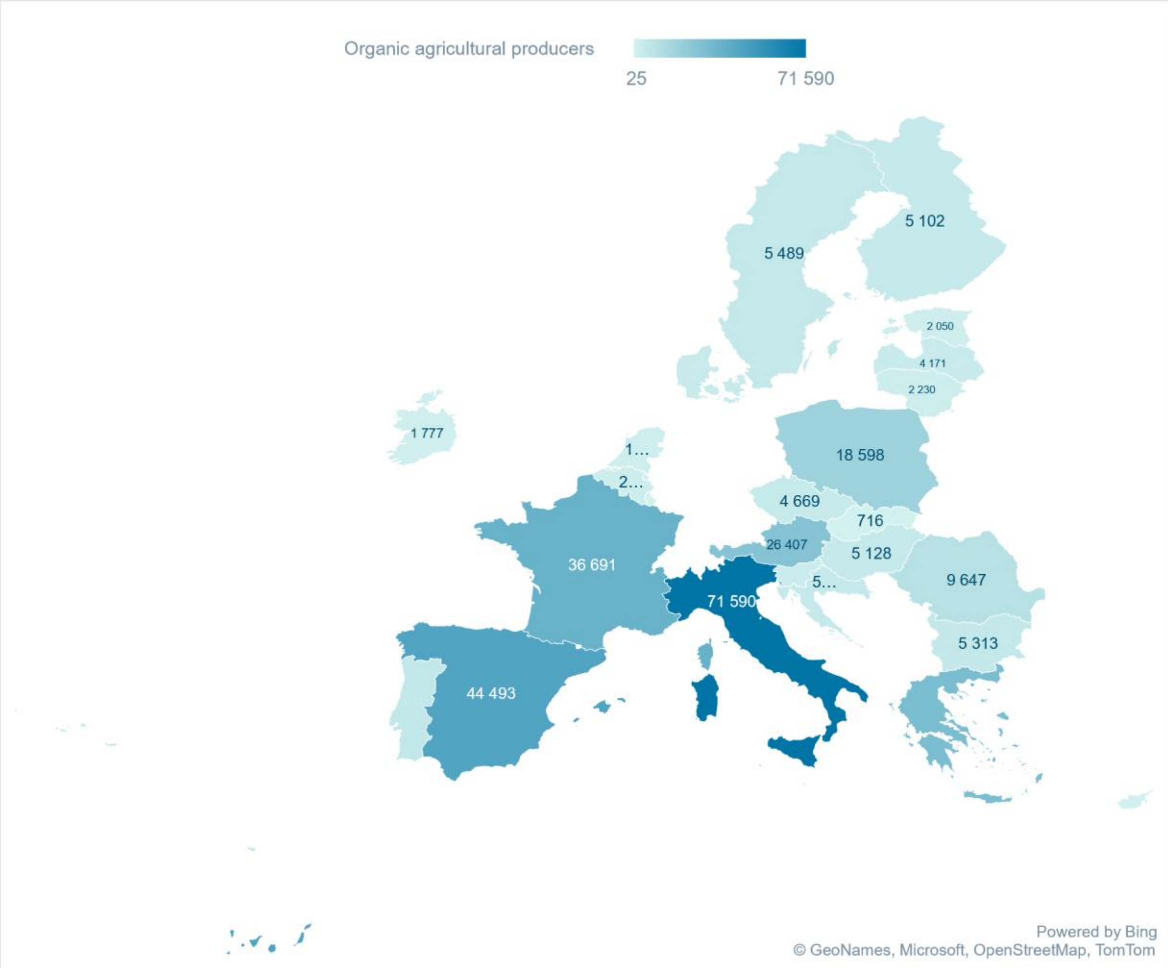
It is difficult to estimate the number of employees working in organic and functional foods production. While on the level of raw agricultural production the issue of high informality remains relevant for organic and functional foods, similar to conventional foods, it can be expected to be lower on the processing

[220] Calculations based on Eurostat [LFSI_EMP_Q] and Eurostat [LFSQ_EGAN22D].
[221] Schneider, F., Morkunas, M. & Quendler, E. (2022). An estimation of the informal economy in the agricultural sector in the EU-15 from 1996 to 2019. Agribusiness. p. 26.
[222] Ibid.
[223] Ibid.
[224] Williams, Colin C. & Horodnic, Adrian. (2018). Tackling undeclared work in the agricultural sector. European Platform Undeclared Work. Available here. p. 15.

level of the agri-food value chain. Manufacturing is less prone to informality; therefore, informality is expected to be less pronounced in companies that process organic and functional foods.

In the EU, the Member States with the highest number of organic agricultural producers are Italy, Spain, France, Greece (29 896), Austria and Poland (see Figure 11 below).

*Figure 11. Registered organic agricultural producers in the EU, 2020**

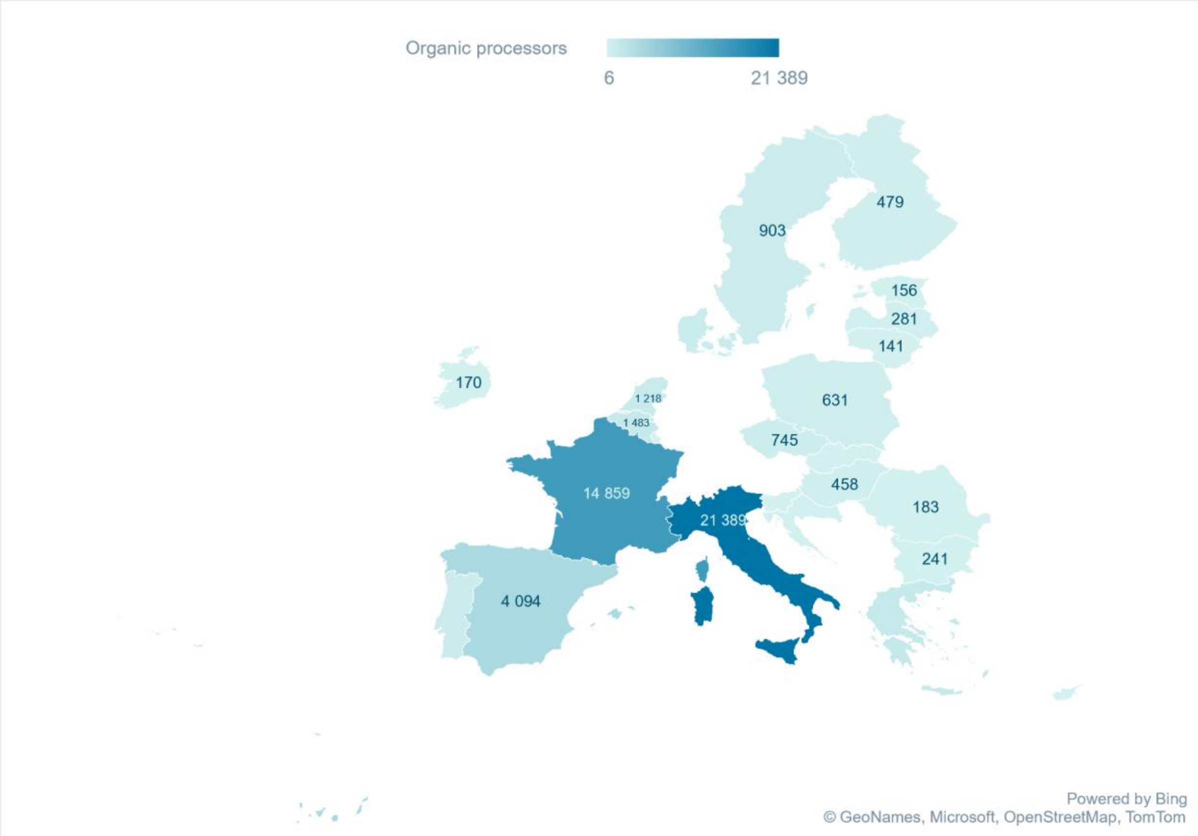


Source: Based on Eurostat (2022). Organic operators by status of the registration process.

*Note: Data is not available for Germany. Due to data availability issues, the data presented for Belgium, Croatia and Latvia is for 2019; the data for France is for 2017.

Unlike organic agricultural producers, organic processors are much less numerous and tend to be concentrated in a few Member States. The biggest number of organic processors in 2020 was in Italy (21 389) and France (14 859), followed by Spain (see Figure 12 below).

Figure 12. The number of processors of organic food in the EU, 2020



Source: Based on Eurostat (2022). Processors of organic products by NACE Rev. 2 activity (C).
Note: Data is not available for Austria and Germany.

A comparison of the demographic structure of organic and conventional farm management demonstrates that managers of organic farms tend to be younger (see Figure 13). Potentially, this can lead to higher technology uptake on such farms, as the older age of farmers was identified as one of the obstacles (see the section on digitalisation in agri-food). At the same time, as organic farms tend to be smaller, they face difficulties in finding financial resources to introduce more technologically advanced solutions due to subsidies being based on farm size.[225]

[225] Interview with a representative of a European organic association.

Figure 13. Age and sex of farm managers of holdings with only or some organic area and non-organic area, EU-27, 2016

Source: Eurostat (2016). Farm structure survey.

Market trends

Given that this niche, other than those discussed above, produces for the consumer (rather than businesses), it is largely driven by the trends in consumer tastes. Therefore, we will overview the most important market trends further.

In recent years, due to the growing awareness of nutrition, healthier lifestyles and environmental responsibility, consumers' demand is shifting towards healthier food products and more sustainable production practices. This drives the development of both **functional** and **organic** food, which belong to fast-growing segments of the European food market.[226] Ageing populations, increasing obesity rates, rising healthcare costs, and changing consumer preferences are expected to further contribute to the growth of both the functional and organic food markets globally in the future.[227]

Due to these developments, there is a growing demand for foods that can be broadly defined as healthy. It includes **naturally healthy foods**, such as spring water, 100% juice and nut snacks,[228] **gluten-free** products,[229] **lactose-free** and **low-carb** foods,[230] healthy food for children,[231] as well as **'clean label'** foods. [232] Clean label foods are the foods that are labelled as 'free of 'chemical additives, having easy-to-understand ingredient lists and being produced by use of traditional techniques with limited

[226] FiBL (2022). Exceptional growth of the European organic market 2020
– Organic market reaches 52 billion euros and organic farmland 17 million hectares in 2020. Available here.
[227] Meier, C. D., Siorak, N., Bonsch Buri, S., & Cornuz, C. (2015). Sustainable Supply Chains and Environmental and Ethical Initiatives in Restaurants in P. Sloan, W. Legrand, & C. Hindley (Eds.), The Routledge Handbook of Sustainable Food and Gastronomy. London: Routledge; PWC (2021). Vitamins & Dietary Supplements Market trends – Overview. Available here.
[228] Ciampi Stančová, K., & Cavicchi, A. (2019). Smart Specialisation and the Agri-food System. In *Smart Specialisation and the Agri-food System* (pp. 43-57). Palgrave Pivot, Cham. p. 10-11.
[229] These products provide a new source of differentiation in retail and restaurants: gluten-free versions of pasta and bread perform well in comparison with dropping sales of regular versions of these products, see Ciampi Stančová, K., & Cavicchi, A. (2019). Smart Specialisation and the Agri-food System. In *Smart Specialisation and the Agri-food System* (pp. 43-57). Palgrave Pivot, Cham. p. 10-11.
[230] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.) (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p.82.
[231] Interview with a researcher in food technology in a leading European research institution.
[232] Interview with a researcher in food technology in a leading European research institution; Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.) (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p.82; Ciampi Stančová, K., & Cavicchi, A. (2019). Smart Specialisation and the Agri-food System. In *Smart Specialisation and the Agri-food System* (pp. 43-57). Palgrave Pivot, Cham. p. 10-11.

processing.'[233] They are also marketed as 'free from' and 'no added'. Moreover, there is a growing demand for '**superfoods'**, which are raw foods naturally rich in nutrients and **fortified functional foods**, such as energy-boosting products and food with the addition of probiotics.[234]

The global **functional food and beverages** market amounted to USD 258.8 billion (around EUR 227 billion[235]), experiencing a notable 11% growth in 2020.[236] For the 2021-2028 period, a CAGR of 9.5% is expected for this market segment globally.[237] Companies are developing new food and beverage products for quick consumption such as functional confectionaries for children, nutrition bars, and drinks enriched with functional ingredients.[238] Probiotic products such as probiotic yoghurts are becoming more popular among consumers due to the growing awareness of digestive health.[239]

Sustainability and responsibility, including a growing awareness of animal welfare and environmental issues, are contributing to the broader adoption of **vegetarian and vegan diets** and the rise in demand for **plant-based alternatives** to animal products. [240] This shift in consumer demand is reflected in the appearance of start-ups and projects that develop these novel products.[241] These include meat and dairy alternatives from fungi, soy, wheat, peas, lupin, lentils and other sources, as well as plant-based egg white alternatives.[242] One novel protein source that is currently being researched and developed is insects. Research projects devoted to insect-based foods are ongoing in the EU, such as the ValuSect project supported by the INTERREG North-West Europe programme.[243] However, consumers' acceptance of such products is yet to mature. According to ValuSect, around 30% of EU consumers are willing to eat insect-based food. [244]

Sustainability trends are also reflected in the developing niche of **natural food for pets**. As the pet food industry experiences a trend of 'pet humanisation', it mirrors the human food market developments, with plant-based and sustainable alternatives becoming more popular. [245] Producers market their products as healthy, cruelty-free and environmentally friendly.[246]

The trends of vegetarianism and veganism, together with ageing populations and increasing healthcare costs, are among the drivers of the steady growth of the **food supplements** segment of the functional foods market in Europe, with the biggest markets being Italy and Germany.[247] Between 2014 and 2018 vitamins and food supplements sales in Europe increased with a 2.8% CAGR. The low growth rate could be explained by the European debt crisis effect on consumers.[248] Recently, it has been accelerated by the COVID-19 pandemic, with increased demand fuelled by consumers' desire to boost their immunity and strengthen their overall health.[249] According to the Euromonitor International Health and Nutrition Survey, in 2021, 42% of global respondents claimed that they consumed vitamins and supplements to boost their immune system.[250] At the same time, 50% of consumers claimed that they got vitamins from

[233] Edwards, A. (2013). Natural & clean label trends. *Ingredion Incorporated: Westchester, IL, USA*.
[234] Ciampi Stančová, K., & Cavicchi, A. (2019). Smart Specialisation and the Agri-food System. In *Smart Specialisation and the Agri-food System* (pp. 43-57). Palgrave Pivot, Cham. p. 10-11.
[235] Based on the 2020 average exchange rate of 1 USD = 0,877 USD. See here.
[236] Fortune Business Insights (2021). Functional Foods Market Report. Available here.
[237] Ibid.
[238] Ibid.
[239] Fortune Business Insights (2021). Functional Foods Market Report. Available here; PWC (2021). Vitamins & Dietary Supplements Market trends – Overview. Available here.
[240] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. P.82; PWC (2021). Vitamins & Dietary Supplements Market trends – Overview. Available here; interview with a researcher in food technology in a leading European research institution.
[241] The job portal search demonstrated that a considerable share of vacancies for agri-food professionals is posted by companies that develop such products.
[242] See the Finnish start-up Onego Bio. VTT (2022). Finnihs startup Onego Bio raises EUR 10 million in seed funding. Available here.
[243] Interreg North-West Europe (n.d.). ValuSect - Valuable inSects. Available here.
[244] Ibid.
[245] Gray, A. (2021), Sustainable eating: the future for pet food? *Veterinary Record*, 188: p. 454-455. Available here.
[246] See, for instance, the Five Letter Foods company website. Available here.
[247] PWC (2021). Vitamins & Dietary Supplements Market trends – Overview, p.10. Available here
[248] PWC (2021). Vitamins & Dietary Supplements Market trends – Overview, p.10. Available here.
[249] Fortune Business Insights (2021). Dietary Supplements in Europe Market Report. Available here; PWC (2021). Vitamins & Dietary Supplements Market trends – Overview, p.14. Available here.
[250] Euromonitor International (2021). Changing Attitudes in Health and Nutrition: Rise of Immunity-Boosting Strategies. Available here.

food rather than supplements;[251] therefore, the organic and natural/fortified functional foods market is also expected to benefit from the consumers' demand for products to strengthen immunity and health. Market challenges that can limit the growth include the tightening regulatory environment, the threat of counterfeit dietary supplements increasingly entering the market and consumer distrust due to the use of deceptive advertising and communication strategies.[252]

The abovementioned trends, such as environmental awareness, including increased awareness of the negative impact of pesticides on the environment, and the preference for healthier products, are also contributing to the steady growth of the **organic food sector**.[253] According to the 2020 Eurobarometer Survey on EU agriculture and the CAP, most of the surveyed consumers in the EU agreed that organic products were more likely to comply with rules on pesticides, fertilisers and antibiotics (82%); are more environmentally friendly (81%); and were produced with more respect to animal welfare (80%). Moreover, the organic logo is increasingly recognised by consumers – in 2020, 56% of surveyed citizens recognised it, compared to 27% in 2017.[254]

The global **organic food and drink** sales amounted to more than EUR 120 billion in 2020.[255] The largest markets were the United States (EUR 49.5 billion) with 41% of the global market, Germany (EUR 15 billion) and France (EUR 12.7 billion). The EU contributed to 37% of the global market (EUR 44.8 billion).[256] The COVID-19 pandemic has impacted the growing demand for healthy nutrition, positively impacting the sales of organic and functional food. According to a 2021 Euromonitor International Survey, consumers are prioritising **organic**, **natural and high-protein** ingredients to support their immune systems.[257] As consumers associate **organic foods** with good health, nutrition and wellness, the organic food market growth is likely to continue.

The organic action plan, developed by the EU to achieve the goal of the European Green Deal of at least 25% of the EU's agricultural land under organic farming and a significant increase in organic aquaculture by 2030, is further incentivising producers to turn to organic food production.[258] To promote the growth of the organic sector, the EC plans to devote 30% of research and innovation funding for agriculture, forestry and rural areas to topics relevant to the organic sector.[259] However, according to an interviewed representative of a European organic association, reaching this ambitious goal might be hindered by the flexibility that Member States have in creating national guidelines, as this can lead to difficulties with alignment with the overall EU objectives.

4.2 Main technological trends

The consumer trends are also an important factor driving the technological changes that affect how organic and functional foods are produced and marketed. For instance, the consumers' demand for healthier products with higher nutritional value is leading to the increased need for milder processing technologies that allow more nutrients to be preserved. A growing vegetarianism trend is leading to the need to develop alternative sources of protein and new functional food products, including food supplements. Sellers of organic products have started employing digital technologies such as blockchain to ensure traceability, allowing consumers to scan the QR-code of a particular product to check whether it was organically produced.[260]

One of the main technological trends in food processing is the development and adoption of **non-thermal** food processing technologies (e.g. high-pressure processing, pulsed electric fields), as

[251] Euromonitor International (2021). Changing Attitudes in Health and Nutrition: Rise of Immunity-Boosting Strategies. Available here.
[252] PWC (2021). Vitamins & Dietary Supplements Market trends – Overview. Available here.
[253] Ciampi Stančová, K., & Cavicchi, A. (2019). Smart Specialisation and the Agri-food System. In *Smart Specialisation and the Agri-food System* (pp. 43-57). Palgrave Pivot, Cham. P. 10-11; interview with a representative of a European organic association.
[254] European Commission. (2022). Organic action plan. Available here.
[255] FiBL & IFOAM – Organics International. The World of Organic Agriculture: Statistics & Emerging Trends 2022. Available here.
[256] Ibid.
[257] Euromonitor International (2021). Changing Attitudes in Health and Nutrition: Rise of Immunity-Boosting Strategies. Available here.
[258] European Commission (2022). Organic Action Plan. Available here.
[259] Ibid.
[260] Interview with a representative of a European organic association.

well as **novel thermal** technologies (e.g. ohmic heating, microwave). These innovations generally aim to reduce the negative effects of conventional thermal technologies. In particular, they aim to **save energy and water**, reduce **toxic waste**, improve the **organoleptic** qualities of products (such as flavour, texture and smell) and increase their **nutritional** value, which makes these technologies highly relevant for the production and processing of functional and organic food. Another trend is the use of nano/micro technologies, such as microencapsulation of ingredients.[261]

The adoption of such novel technologies is driven by the rising consumer demand for healthier foods with the same nutritional value as unprocessed foods (the growing demand for natural juices, for instance), as mentioned above. It is further incentivised by some policy developments, such as national initiatives within the framework of the EU Salt Reduction Framework, which support the adoption of novel preservation and microencapsulation techniques to replace salt as a food preservative.[262] According to a survey of food professionals in Europe in 2015, the main technologies which were applied at that time, and which were expected to be applied in the following 5 years were **microwave**, **high-pressure processing (HPP)** and **pulsed electric fields (PEF)**. Among the technologies that were expected to lead in 2015-2025, cold plasma and PEF were named as the most important.[263]

- **High-pressure processing (HPP).** HPP is the most used novel technology in the food industry.[264] It was also the most mentioned novel processing technology by the interviewees. HPP is used to preserve foods without additives and heating by applying pressures to inactivate bacteria at ambient temperatures.[265] Compared with conventional thermal processes, this technology improves flavour and colour of the product, as it preserves the pigments, vitamins and flavour substances better. It also prolongs the shelf life of products. However, HPP can affect the protein structure, which limits its application to meat and fish products, as it may decrease the quality characteristics of these products.[266] While this technology has been around for a long time, its large-scale usage started only around 20 years ago.[267] It is mainly applied in the processing of vegetables, fruit, seafood and meat.[268]

- **Pulsed electric field (PEF).** The main principle of this technology is the application of very short durations of a pulsed electric field to inactivate the cells of microorganisms. Like HPP, it better preserves the organoleptic and nutritional qualities of products. While the main goal of PEF application is pasteurisation, it also extends products' shelf life.[269] It was first patented around 30 years ago and entered large-scale industrial processes around 15 years ago. Despite efforts to incorporate this technology into the food processing industry, its commercialisation has been limited so far.[270]

- **Supercritical CO_2**: a green non-thermal technology with a wide range of application in the food processing industry, including decaffeination, sterilisation and extraction of bioactive compounds. Similar to the abovementioned technologies, it allows the nutritional value and organoleptic properties.[271]

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[261] European Commission (2015). Business Innovation Observatory. Sustainable, Safe and Nutritious Food: Food processing technologies. Available here.
[262] Ibid.
[263] Jermann, C., Koutchma, T., Margas, E., Leadley, C., & Ros-Polski, V. (2015). Mapping trends in novel and emerging food processing technologies around the world. Innovative Food Science & Emerging Technologies. p. 14-27.
[264] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 37; Jermann, C., Koutchma, T., Margas, E., Leadley, C., & Ros-Polski, V. (2015). Mapping trends in novel and emerging food processing technologies around the world. Innovative Food Science & Emerging Technologies. p. 14-27.
[265] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 24.
[266] Ibid.
[267] Ibid.
[268] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 37.
[269] Raso, S. Condón and I. Álvarez (2014). Non-thermal processing: Pulsed Electric Field, pp. 966-973 in Carl A. Batt, Mary Lou Tortorello (2014), Encyclopedia of Food Microbiology (Second Edition). Academic Press.
[270] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 24.
[271] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 28.

- **Cold plasma.** This non-thermal processing technology consists of the application of energetic reactive gases such as air, oxygen, nitrogen and helium to inactivate microbes in food products, without the use of antimicrobial chemical agents.[272]
- **Microwave.** Microwave is a novel heating technology, which allows the nutritional value of a product to be preserved. In the process of pasteurisation and sterilisation, microwave heating destroys pathogens faster and more efficiently and contributes to better organoleptic properties. It is also used for baking, blanching and cooking.[273]
- **Encapsulation** entraps a functionally active ingredient (e.g. aromatic compounds, colourants, probiotics and peptides) in a capsule of inert material.[274] This technology is used to prevent damage to functional ingredients by the harsh conditions of food processing, as well as to control the time and place of release of the active materials, and is often applied to nutraceuticals and probiotics.[275] While this technology has been used in the pharmaceutical sector, its use in the food processing industry in the US has been limited by the strict rules for generally recognised as safe (GRAS) encapsulation technologies and agents.[276]
- **Edible coating technology** offers a more sustainable way to extend the shelf life of food products, such as fruit and vegetables. The products are covered with natural materials such as polysaccharide, protein and lipid material by spraying, dripping, dipping, layering and novel methods such as vacuum impregnation technology. Additionally, vitamins and minerals can be added to edible coating to increase products' nutritional value.[277]
- **Precision fermentation.** This novel technology relies on microbial hosts to produce functional ingredients and is also used for alternative protein production. It allows for better purity of ingredients and lower levels of their incorporation.[278]
- **Extrusion** was named by several interviewees as a technology that will become more relevant in the future, especially for the production of plant-based meat alternatives.[279] Promising extrusion methods that can be used for producing novel foods are extrusion cooking, hot-melt extrusion, reactive extrusion and extrusion-based 3D printing.[280]
- Other novel processing technologies include ultrasound, ohmic heating, infrared (IR) heating, radio frequency (RF) heating and irradiation, and ionising radiation (not suitable for organic production), among others.

As mentioned before, conventional food processing technologies lack sustainability: they use more energy, can lead to problems with toxic waste and perform worse in the preservation of nutrients.[281] Many of the **innovative** solutions offer greener and more efficient alternatives, thus having the potential to contribute to the achievement of the goals of the European Green Deal and the F2F Strategy, in particular. The shift towards greener production is also reflected in the emerging efforts to valorise **food waste**. Some of the foregoing novel thermal and non-thermal processes allow for environmentally friendly food waste valorisation without the use of chemicals, such as toxic organic solvents. Innovative

[272] Niemira, B. A. (2012). Cold plasma decontamination of foods. *Annual review of food science and technology*, 3. pp. 125-142.
[273] Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions:Reconnecting Agri-Food, Technology and Society. Springer Cham. p. 31.
[274] Timilsena, Y., Haque, M. and Adhikari, B. (2020) Encapsulation in the Food Industry: A Brief Historical Overview to Recent Developments. *Food and Nutrition Sciences*, 11. p. 481-508.
[275] Reque, P. M., & Brandelli, A. (2021). Encapsulation of probiotics and nutraceuticals: Applications in functional food industry. *Trends in Food Science & Technology*, 114. p. 1-10.
[276] Cassani et al. (2020) and Kwak (2014) cited in Reque, P. M., & Brandelli, A. (2021). Encapsulation of probiotics and nutraceuticals: Applications in functional food industry. *Trends in Food Science & Technology*, 114. pp. 1-10.
[277] Oduro, K. O. A. (2021). Edible Coating. In *Postharvest Technology-Recent Advances, New Perspectives and Applications*. IntechOpen; Radziejewska-Kubzdela, E., Biegańska-Marecik, R., & Kidoń, M. (2014). Applicability of vacuum impregnation to modify physico-chemical, sensory and nutritive characteristics of plant origin products—a review. *International journal of molecular sciences*, *15*(9). p. 16577-16610.
[278] Specht, L. (n.d.). The science of fermentation. *Good Food Institute (GFI)*. Available here.
[279] Interview with a researcher in food technology in a leading European research institution; interview with a representative of a European Digital Innovation Hub that has agri-food related projects.
[280] Lazou, A. E. (2022). Food extrusion: An advanced process for innovation and novel product development. *Critical Reviews in Food Science and Nutrition*. p. 1-29.
[281] Granato, D., Barba, F. J., Bursać Kovačević, D., Lorenzo, J. M., Cruz, A. G., & Putnik, P. (2020). Functional foods: Product development, technological trends, efficacy testing, and safety. *Annual review of food science and technology*, *11*, 93-118.

producers use technologies such as microwave, ultrasound, PEF and HPP to extract phytochemicals from fruit and vegetable waste, for instance.[282]

The wide adoption of innovative technologies, however, faces difficulties.[283] While conventional methods can be more affordable but time-consuming, innovative technologies are faster but have lower investment yields.[284] Some of the technologies that are still considered 'novel' have been around for several decades but have not yet gained widespread acceptance by producers due to the costs of investments and availability of technologies.[285]

The EU **regulatory framework** can further slow some technological developments down. The Novel Foods Regulation was named by some interviewees as a limitation for the development of novel foods in the EU. Smaller companies face difficulties in finding the resources for evaluations and assessments required by the regulation.[286] Due to the strict regulations, some developers of novel food products are moving their production to other parts of the world.[287]

One example of a technology whose application and development in Europe are slowed down by the regulatory environment is CRISPR (Clustered Regularly Interspaced Short Palindromic Repeat). This is a gene-editing technology that has been used to modify the genes of animals and plants, and can be applied to enrich the food with nutrients, extend shelf life and improve organoleptic properties.[288] In the EU, products modified with CRISPR are subject to the GMO Directive.[289] Such products must undergo safety assessments and be labelled as genetically modified.[290] While this makes it unsuitable for organic production, it can be a highly relevant technology for functional food production. Due to the regulatory framework in the EU, which lowered interest in funding for GMO agricultural products, its development in Europe has been slow, and most patent activity is happening in the USA.[291]

Moreover, the current EU organic regulations are incompatible with a growing trend in the EU agri-food sector –Controlled Environment Agriculture (CEA), commonly referred to as **vertical farming**. Vertical farming is a high-tech sector that allows the obtention of reliable yields while significantly reducing the use of energy and water and reliance on chemicals such as pesticides and fertilisers. It has the potential for the fully automated production of crops and vegetables, allowing a reduction in labour costs. Such produce is grown locally and can be used in urban settings, thus reducing transport costs and emissions. As one interviewed representative of a vertical farming association stated, vertical farming 'ticks all the boxes' of the F2F Strategy. Moreover, there is a potential for increasing the nutritional value of some foods grown under CEA, compared to foods grown conventionally, for instance, by increasing light intensities to increase phytochemical accumulation, making it relevant to satisfy the demand for nutritionally dense products.[292]

In vertical farming, produce is mainly grown in water (hydroponics) or air (aeroponics), using mineral solutions to provide nutrients instead of soil. The EU regulations allow organic products to be grown only in soil, which makes it impossible to merge the potential or vertical and organic farming. While in the USA and some other countries vertical producers can be certified as organic, producers in the EU are limited in their abilities to reach consumers that value sustainability and foods grown without the use of pesticides.[293]

[282] As argued in Khajehei et al. (2019). Novel Food Technologies and Their Acceptance in Piatti, C., Graeff-Hönniger, S., Khajehei, F. (2019). Food Tech Transitions: Reconnecting Agri-food, Technology and Society. *Springer.* p. 16.
[283] Ibid.
[284] Ibid.
[285] Interview with a researcher in food processing in a leading European research institution; Piatti, C., Graeff-Hönninger, S. & Khajehei, F. (Eds.). (2019) Food Tech Transitions: Reconnecting Agri-Food, Technology and Society. Springer Cham.
[286] European Commission (2015). Business Innovation Observatory. Sustainable, Safe and Nutritious Food: Food processing technologies, p.11. Available here.
[287] Interview with a representative of one of the European Digital Innovation Hubs.
[288] Kumar, D., Yadav, A., Ahmad, R., Dwivedi, U. N., & Yadav, K. (2022). CRISPR-Based Genome Editing for Nutrient Enrichment in Crops: A Promising Approach Toward Global Food Security. *Frontiers in Genetics*, 1650.
[289] European Commission (2021). Commission Staff Working Document: Study on the status of new genomic techniques under Union law and in light of the Court of Justice ruling in Case C-528/16.
[290] Meyer, A. & Dastgheib-Vinarov, S. (n.d.). The Future of Food? CRISPR-Edited Agriculture. FDLI. Available here.
[291] Ibid.
[292] Mentioned by an interviewee from a European food science association. More information can also be found here: Gómez, C. et al. (2019). Controlled environment food production for urban agriculture. HortScience, 54(9), 1448-1458.
[293] Politico (2021). Vertical farming's sky-high ambitions cut short by EU organic rules. Available here.

Digital technologies are increasingly important for agri-food producers and processors, and the specifics of organic production make these technologies especially relevant for organic farmers. Due to limited opportunities for relying on pesticides or mineral fertilisers, organic producers depend much more on information about the crop or animal health.[294] Precision agriculture technologies can therefore become key for the growth of the organic sector. For more details on these technologies, please see the section Digitalisation in agri-food above.

4.3 Trends in occupational profiles and company skills needs

Based on the desk research of job search portals, we identified skills sought for occupations relevant for companies that produce or process organic/functional foods in the EU (see Annex I for details on the methodology). In the following sections we will first overview skills needs found in job portal searches and then present future trends in skills demand based on the insights from the interviews.

Managers

Among **managers (ISCO 1)**, **R&D managers** (ESCO 1223.2) usually require higher education (**ISCED 6-8**) in fields relating to agri-food (e.g. soil science, digital agriculture or others, depending on the company's needs).[295] Technical skills expected from employees include crop/soil/pest modelling, smart farming technology,[296] knowledge of functional ingredients,[297] integrated pest management,[298] innovation and project management,[299] competition analysis and sourcing of raw materials. Knowledge of English and MS Office is also required.[300] **Manufacturing managers** (ESCO 1321.2) usually need higher education (**ISCED 6**) in lean management and production management.[301] Among technical skills, companies prioritise continuous improvement, production and industrial project management,[302] knowledge of manufacturing and quality standards and relevant food production technologies.[303] With regard to transversal skills, employers highlight communication and negotiation skills, strong agility, responsibility, the ability to make decisions in uncertain environments,[304] and proficiency in English.[305]

Professionals

Among **professionals (ISCO 2)**, we explored vacancies for **science and engineering professionals** (ISCO 24). In companies active on the organic or functional food **agricultural production** level of the agri-food value chain, we found a demand for soil scientists (ESCO 2133.11), agronomists (ESCO 2132.2) and agricultural engineers (ESCO 2144.1.2). These specialists require **higher education** in agricultural sciences, with a specialisation suitable for a particular vacancy, such as agronomy[306] or agricultural engineering.[307] **Generally required skills** for such occupations include

[294] Interview with a representative of a government agency in Germany that manages a fund for financing R&D projects for the development and application of digital solutions in agriculture.
[295] Gelagri (organic frozen vegetables and fruit), France and Spain. R&D manager; Agrifirm (agricultural cooperative), Netherlands. R&D manager arable.
[296] Agrifirm (agricultural cooperative), Netherlands. R&D manager arable.
[297] Gelagri (organic frozen vegetables and fruit), France and Spain. R&D manager.
[298] Agrifirm (agricultural cooperative), Netherlands. R&D manager arable.
[299] Gelagri (organic frozen vegetables and fruit), France and Spain. R&D manager; Agrifirm (agricultural cooperative), Netherlands. R&D manager arable.
[300] Gelagri (organic frozen vegetables and fruit), France and Spain. R&D manager.
[301] HappyVore, (organic vegan meat producer), France. Continuous improvement and production engineer.
[302] HappyVore, (organic vegan meat producer), France. Continuous improvement and production engineer.
[303] La Vie (vegan meat producer), France. Co-manufacturing manager; HappyVore, (organic vegan meat producer), France. Continuous improvement and production engineer.
[304] La Vie (vegan meat producer), France. Co-manufacturing manager.
[305] La Vie (vegan meat producer), France. Co-manufacturing manager.
[306] Agricultural service company, Italy. Agritechnician/Agronomist; Nuts cultivation company, Spain, Agronomist engineer; VILMORIN ITALIA (seed producer), Italy. Agronomist; Agrifirm (agricultural cooperative), Netherlands. Soil specialist – regenerative farming.
[307] Dried fruit production company, Spain, https://g.co/kgs/4bzPh1

management of projects, staff and machinery,[308] knowledge of English[309] and MS Office skills.[310] More specific demands for different job positions include knowledge of plant nutrition and crop protection,[311] skills in crop planning,[312] designing of fertilisation plans, scheduling irrigation and fertigation, carrying out phytosanitary monitoring and control, supplying fertilisers and auxiliary material,[313] knowledge of regenerative farming practices, soil modelling,[314] data handling and using specialised computer programs such as AutoCAD and GIS,[315] as well as knowledge of policy frameworks such as the Common Agricultural Policy (CAP) and the Rural Development Programme (RDP).[316]

Organic/functional food companies active on the **processing** level of the agri-food value chain seek **engineering professionals** such as process engineers (ESCO 2141.10), production engineers (ESCO 2141.4.2) and food technologists (ESCO 2145.1.4), as well as **life sciences professionals** including food biotechnologists (ESCO 2131.5) and biochemists (ESCO 2131.4.2). For these professionals, employers usually seek candidates with higher education (**ISCED 6-7** or **8** for few positions) in agriculture engineering, processing technology,[317] biotechnology engineering, mechanical engineering, food science,[318] biochemistry and chemical engineering.[319] Commonly demanded **technical skills** are laboratory skills for designing and conducting experiments.[320] **Transversal skills** include the ability to work in (multidisciplinary) teams,[321] adaptability and flexibility, resilience, problem-solving, creative/innovative thinking,[322] communication skills,[323] project management,[324] leadership skills,[325] multi-tasking, planning and organisational skills, attention to detail,[326] and knowledge of English.[327] **Specialised knowledge** and skills for food (bio)technologists and biochemists include, depending on the company's activities, new product development, food safety certifications,[328] food chemistry and food processing,[329] and, more specifically, reaction flavour chemistry and making new textured material, design and development of bioprocesses,[330] optimisation of fermentation parameters, and preparation of samples for analysis with techniques such as High Performance Liquid Chromatography (HPLC), Ultraviolet–visible spectroscopy (UV-Vis) and Gas chromatography–mass spectrometry (GC-MS).[331]

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308 Dried fruit production company, Spain, https://g.co/kgs/4bzPh1; Nuts cultivation company, Spain, Agronomist engineer; Agrifirm (agricultural cooperative), Netherlands. Soil specialist – regenerative farming.
309 Agricultural service company, Italy. Agritechnician/Agronomist; VILMORIN ITALIA (seed producer), Italy. Agronomist; Agrifirm (agricultural cooperative), Netherlands. Soil specialist – regenerative farming.
310 Agricultural service company, Italy. Agritechnician/Agronomist; Dried fruit production company, Spain, https://g.co/kgs/4bzPh1
311 Dried fruit production company, Spain, https://g.co/kgs/4bzPh1
312 VILMORIN ITALIA (seed producer), Italy. Agronomist.
313 Dried fruit production company, Spain, https://g.co/kgs/4bzPh1
314 Agrifirm (agricultural cooperative), Netherlands. Soil specialist – regenerative farming.
315 Company specialised in dried fruit production, Spain, https://g.co/kgs/4bzPh1; Agrifirm (agricultural cooperative), Netherlands. Soil specialist – regenerative farming.
316 Agricultural service company, Italy. Agritechnician/Agronomist.
317 Syngenta (producer of seeds, organic), Netherlands. Process engineer.
318 GEA Group, New Food (production of plant-based meat), Germany. Process engineer; Bosque Foods (vegan meat producer), Germany, Food Technologist; Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist.
319 Mushlabs (food products from fungi), Germany. R&D intern.
320 Syngenta (producer of seeds, organic), Netherlands. Process engineer; Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist; Bosque Foods (vegan meat producer), Germany, Food Technologist.
321 Syngenta (producer of seeds, organic), Netherlands. Process engineer; GEA Group, New Food (production of plant-based meat), Germany. Process engineer; Bosque Foods (vegan meat producer), Germany, Food Technologist.
322 GEA Group, New Food (production of plant-based meat), Germany. Process engineer; Bosque Foods (vegan meat producer), Germany, Food Technologist.
323 Bosque Foods (vegan meat producer), Germany, Food Technologist.
324 Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist; Syngenta (producer of seeds, organic), Netherlands. Process engineer.
325 Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist.
326 Bosque Foods (vegan meat producer), Germany, Food Technologist.
327 Mushlabs (food products from fungi), Germany. R&D intern; Bosque Foods (vegan meat producer), Germany, Food Technologist; Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist; Syngenta (producer of seeds, organic), Netherlands. Process engineer; GEA Group, New Food (production of plant-based meat), Germany. Process engineer.
328 Bosque Foods (vegan meat producer), Germany, Food Technologist.
329 Onego Bio (producing animal-free white egg without chickens), Finland. Lead Food Scientist.
330 Bosque Foods (vegan meat producer), Germany, Food Technologist.
331 Mushlabs (food products from fungi), Germany. R&D intern.

Technicians and other occupational levels

Among **technicians and associate professionals (ISCO 3)**, we overviewed job postings for agricultural technicians (ESCO 3142.1) and industrial maintenance technicians (ESCO 3114.1.7). For these occupations, employers usually seek vocational education (**ISCED 4-5**) in related fields.[332] For agricultural technicians, training in agricultural engineering is necessary.[333] The **technical skills** in demand include the qualitative and quantitative monitoring of harvests, monitoring of agronomic trials, and knowledge of cultivation techniques, agricultural machinery and computer tools.[334] Among **transversal skills**, leadership skills are desired.[335]

For industrial maintenance technicians, employers require training in Industrial maintenance, electrotechnics, electromechanics, or electrical engineering.[336] **Technical skills** include automation and industrial IT,[337] in particular knowledge of computerised maintenance management systems (CMMS),[338] mechanical[339] and electrical engineering skills,[340] as well as knowledge of pneumatic and hydraulic technologies.[341] **Transversal skills** which employers seek include analytical and synthesis skills.[342]

With the new developments in the market niche, adopting automation, the spread of vertical farming and novel products development, the demand for 'traditional farming' workers will decrease in the future. By contrast, there will be a higher demand for **laboratory assistants** and **chemical technicians,** as well as new profiles such as **hydroponics technician** (discussed in the section on digitalisation in agriculture and food processing). Some interviewees highlighted this trend and emphasised that farmers will become more like laboratory technicians, in particular farmers working with CEA.[343]

The reviewed job postings for **lower occupational levels (ISCO 8 and 9)** in agri-food, such as food production operators (ESCO 8160.34), agricultural labourers (ESCO 9211) and horticulture workers (ESCO 9214.2) usually do not have specific education requirements, but relevant industrial/agricultural/storekeeping training is sometimes mentioned as desirable. In some cases, basic digital skills are needed (for instance, one job posting for seasonal corn collection workers requires making computer records[344]). For some job postings workers also need basic farm/industrial maintenance skills,[345] knowledge of hygiene practices,[346] and English language skills.[347]

Pay levels

Competitive **salaries** are key to attracting new skilled employees, as also identified by the interviewees. However, the agri-food sector is experiencing difficulties in attracting skilled workers due to the low salaries offered and high competition with other sectors, as well as the lower attractiveness of rural areas for the younger generation.[348] To understand the levels of salaries in the niche, we estimated the average salaries for occupational profiles across sectors relevant to organic and functional food production and processing, which we present below in Table 5. We relied on a Glassdoor salary estimations model to obtain the data. However, due to the lack of salary information specific to a certain

[332] HappyVore (organic vegan meat producer), France, Maintenance technician; Bioviver (pasteurised and sterilised organic fruit and vegetables), France, Industrial Maintenance Technician; Jean et Lisette, France, Industrial Maintenance Technician; Eureden (agricultural cooperative), France, Potato Specialist Technician.
[333] Eureden (agricultural cooperative), France. Potato Specialist Technician.
[334] Eureden (agricultural cooperative), France. Potato Specialist Technician.
[335] Eureden (agricultural cooperative), France. Potato Specialist Technician.
[336] HappyVore (organic vegan meat producer), France, Maintenance technician; Bioviver (pasteurised and sterilised organic fruit and vegetables), France, Industrial Maintenance Technician; Jean et Lisette, France, Industrial Maintenance Technician.
[337] HappyVore (organic vegan meat producer), France, Maintenance technician.
[338] Bioviver (pasteurised and sterilised organic fruit and vegetables), France, Industrial Maintenance Technician; Jean et Lisette, France, Industrial Maintenance Technician.
[339] HappyVore (organic vegan meat producer), France, Maintenance technician; Bioviver (pasteurised and sterilised organic fruit and vegetables), France, Industrial Maintenance Technician.
[340] HappyVore (organic vegan meat producer), France, Maintenance technician.
[341] Jean et Lisette, France, Industrial Maintenance Technician.
[342] HappyVore (organic vegan meat producer), France, Maintenance technician; Bioviver (pasteurised and sterilised organic fruit and vegetables), France, Industrial Maintenance Technician.
[343] Interview with a representative of a European association that deals with food science and technology.
[344] Eureden (agricultural cooperative), France. Seasonal corn collection worker.
[345] Infarm (vertical farming), Denmark. Urban Farmer; Yooji (organic baby food), France. Food processing operator.
[346] Yooji (organic baby food), France. Food processing operator.
[347] Infarm (vertical farming), Denmark. Urban Farmer.
[348] Interview with a representative of a European organic association.

industry, salaries are presented for all industries. The table does not present information on the low-skilled and unskilled agricultural workforce, as there is no available data on Glassdoor for these occupations.

Table 5. Estimated total pay (annual) – values, net (adjusted) (in EUR)

Occupation	BE	DE	EL	ES	FR	IT	NL	PL	SE
R&D manager	36 024	39 974	no data	no data	25 335	45 747	86 313	no data	no data
Manufactu-ring manager	no data	55 601	38 618	37 088	31 429	35 048	56 620	no data	26 554
Production engineer	35 516	35 378	25 872	22 589	30 816	23 714	41 460	25 115	32 448
Process engineer	28 252	36 339	15 306	23 608	25 735	20 565	42 531	28 145	45 604
Laboratory technician	21 137	22 398	no data	18 024	17 259	14 175	16 526	33 204	51 406
Food technologist	19 974	10 251	6 836	20 031	16 184	24 175	46 169	19 337	45 102
Agronomist	14 032	31 685	7 285	24 689	22 321	25 164	31 494	21 387	no data

Source: Glassdoor.

Note: Salary estimations are not filtered by industry and level of experience due to data availability. Glassdoor provides gross salary estimations, which is why we used the OECD's 'Average personal income tax and social security contribution rates on gross labour income'[349] for relevant countries to adjust and estimate net annual salaries. Salaries that belong to the 10th decile of Eurostat's 'Distribution of income' [ILC_DI01] table are in dark teal. Estimations in light teal fall into the 9th and 8th deciles, while the estimations in white fall into the 7th decile or lower. Values marked in red indicate lower levels of confidence. In such cases, a salary estimation on Glassdoor did not have a 'high confidence' or 'very high confidence' label, meaning that it was calculated based on a limited number of salaries.

The data shows that R&D and manufacturing managers are among the highest-paid occupations, where, for most countries, the average salary falls into the 10th decile, which in 2021 was at or above EUR 34 323.[350] The salaries of production and process engineers are more varied across countries, with the highest salaries found in Belgium, Germany, the Netherlands and Sweden. Laboratory technicians, food technologists and agronomists mainly fall into the 7th income decile or lower. In line with the views shared by interviewees, this indicates that many jobs that are relevant for the niche might not be appealing to candidates due to the lower salaries offered.

General trends

As the digitalisation of the agri-food production is growing, **digital skills** are becoming increasingly in demand for all occupational levels, including lower-level occupations. The interviewees stated skills such as robotics, automation, data management, digital security, general computer skills and e-commerce as being especially relevant for the niche.

Teams which work in agri-food companies are becoming increasingly **multidisciplinary**, bringing together people with backgrounds in ICT, social sciences, life sciences and others. This makes 'social' **transversal skills** such as group facilitation, moderation, communication, teamwork, networking, and flexibility/adaptability especially important for the future, as shared by our interviewees.

As demonstrated in the previous sections, there is a growing demand for novel products, such as, for instance, alternatives to animal proteins and functional products. As innovative companies emerge and grow, the demand for specialists with **skills relating to new food product development** will increase. The interviewees stated innovation and creativity, food research and development, chemical processing and food manufacture, and quality assurance as skills relevant for the future. Given that the regulatory environment for the novel food products and organic food is evolving, the knowledge of **food legislation** is also expected to gain in relevance in the coming years.

To market these products, companies will need to better understand the consumer demand, health and wellbeing, as well as possess **marketing** and **export/internationalisation** skills, according to interviewees. Marketing skills will become especially important in the organic and functional foods niche

[349] OECD (2021). Average personal income tax and social security contribution rates on gross labour income. Available here.
[350] Eurostat. ILC_DI01.

as a result of several developments. As novel food products (such as insect-based food or plant-based meat) are being developed, the way these goods are marketed will become one of the crucial elements in shaping their acceptance by consumers. Marketing skills will be important in creating trust in new products, as well as retaining trust in already established products, such as organic food and food supplements.

Finally, as the environmental awareness of companies and consumers grows and the EU continues fostering green transition, knowledge relating to **sustainable production, carbon footprint and animal welfare** will become progressively important.[351]

Both **vocational and higher education** skills will remain in demand according to interviewees, as these are complementary. One interviewee shared that, at farm level, vocational skills are more relevant, while at supply chain level, higher education is more suitable. Some interviewees mentioned that as production becomes more technologically advanced, there is **less need for low-skilled and unskilled workers**, and more need for skills at the university and VET level.

To meet the demand for these skills, education and training providers must adapt to the new developments. The interviewed experts from the EU-level and national organisations which operate in the organic and functional food niche shared a view that the **capacity of the education and training providers** to meet the skills demand is **sufficient** in the EU. To illustrate, there are several specialised programmes across the EU which train specialists in organic agriculture, mostly at **ISCED 7** level. For instance, there is a joint MSc programme 'EUR-Organic', which is offered by five renowned European universities in France, Germany, Austria, Poland and Denmark.[352] Another MSc programme is 'Agroecology: organic agriculture', offered by Wageningen University in the Netherlands and ISARA university in France.[353]

While **higher education** providers offer targeted programmes on organic production, **VET programmes** are usually broader in scope and do not specialise in organic farming or functional food. For this niche, the **non-formal and formal continuous vocational education and training** offer is more pronounced. For instance, the Sociedad Española de Agricultura Ecológica (SEAE) in Spain offers training in organic production at several levels (continuing education, formal vocational training, and university), including in-company training.[354] Another example is Erasmus+ project Startup.Bio, which aims to support and facilitate transition to organic farming by offering online training and virtual incubation for young farmers.[355]

Such training and on-the-job learning can help address the lack of practical knowledge, which was named by the interviewees as one of the main gaps in skills supply. According to some interviewees, non-formal training offered by various organisations, as well as conferences and online courses are important for addressing the gaps. Some of the interviewed organisations are themselves engaged in these activities: some train farmers to use digital tools, while others organise conferences and networking events for food science professionals. Other challenges that some interviewees highlighted are old curricula and the lack of adequate training in the use of novel technologies for teachers. This is hindering the development of new skills that are becoming relevant for the niche.[356]

All in all, the most common **skills** required for the overviewed occupational profiles include knowledge of English and MS Office skills. Then, specialised knowledge and education in specific areas relating to companies' activities is usually required. Vacancies for managers (ISCO 1) and professionals (ISCO 2) typically demand higher education and managerial skills. This confirms the conclusion that the niche is undergoing a shift relating to the adoption of new technologies and a shift in the traditional role of the farmer, where farmers will increasingly have to be equipped with broader technical knowledge. There is a capacity of formal and non-formal training providers to match the evolving labour market requirements in the short and medium term for the niche, but there are gaps in this regard, in particular relating to

[351] Confirmed by the interviews.
[352] University of Hohenheim (UHOH), Germany, University of Natural Resources and Life Sciences (BOKU), Austria, Warsaw University of Life Sciences (SGGW), Poland, Aarhus University (AU), Denmark, Institut supérieur d'agriculture et d'agroalimentaire Rhône-Alpes (ISARA-Lyon), France. More information is available here.
[353] More information is available here.
[354] See here.
[355] See here.
[356] As emphasised by an interviewee from a German research institute for technology.

equipping workers with practical skills such as using digital tools or connecting with professionals from the niche. In addition, given that the skills needed in the niche are increasingly university-level or VET skills, salaries will play a significant role in making the niche attractive to workers.

ANNEX

Annex I. Methodology

This report combines insights gathered from desk research and interviews with relevant EU stakeholders for each niche. For the **desk research**, we focused mainly on primary sources (e.g. EU reports, regulations and strategies). Where necessary, we included secondary sources, such as academic journal articles, as well as 'grey literature' such as reports from market intelligence companies. We also used statistical classifications (ISCO/ESCO and ISCED) to guide the analysis.

We conducted eight **interviews** for the digitalisation in the agri-food niche, three for the biochemical and microbial niche, and three for the organic and functional foods niche. Hence, we conducted 14 interviews in total. We used desk research to identify the interview participants. The stakeholder groups represented by the interviewees were various business associations, research institutes and centres, digital innovation hubs (DIH), businesses and individual academic researchers. Please see the interview questionnaires in

Annex II. Interview questionnaires.

Job portals search

To search for job postings, we focused on the most prominent job search portals, including LinkedIn and Glassdoor, as well as Welcome to the Jungle and Indeed.com. On these portals, we filtered for jobs based in the EU. Then, if a certain occupation was found in one country, we searched for similar postings, filtering by countries where most vacancies were previously found, to gain a more complete understanding of that occupational profile. We focused on countries such as France, Germany, the Netherlands, Italy and Spain.

To generate queries, we used niche-specific keywords, as well as keywords for certain occupations. The table below presents a non-exhaustive list of the keywords used.

Table 6. Keywords for job search

Niche	Keywords
Digitalisation in agriculture and food processing	digital marketing jobs; R&D manager; programming jobs; ICT specialist; robot technician; robotics agriculture; digital agronomy; cloud programmer; cloud engineer; digital agriculture; smart agriculture
Biochemical and microbial products for agri-food	pest control; microbial agriculture; biochemical production; pesticide production; R&D scientist; fermentation specialist; fermentation technician; human resources officer; sales manager; human resources manager; R&D manager; environmental engineer; regulatory affairs manager; lawyer; contract manager; accountant; import-export specialist; logistics analyst; business analyst; commercial sales representative; chemical engineer; legal consultant; agronomist; chemist; biochemist; technical sales representative in chemical products; legal assistant; microbiologist; office clerk; supply chain assistant
Organic and functional foods	organic agriculture; organic food; functional food; novel food; R&D manager; food production manager; process manager; food scientist; soil scientist; agricultural worker; agronomist; agricultural technologist; laboratory technician; food technologist; food supplements job

Additionally, we looked through job postings on the websites of large companies active in the niches in the EU. For the digitalisation in agri-food niche, we looked through postings in companies such as John Deere, Syngenta, Sencrop, KWS Group and Kubota Holdings Europe. For the niche of biochemical and microbial products, we looked at companies such as Bayer, BASF SF, Corteva, Koppert and CertisBio.

While the search aimed to be as comprehensive as possible, it is not exhaustive. At the same time, it does allow an insight into the trends in occupational and skills demand for all three niches that we discussed in the chapters above.

Average salaries

To identify average salary levels, we analysed Glassdoor salary data for nine EU Member States: Belgium, France, Germany, Greece, Italy, the Netherlands, Poland, Spain and Sweden. The choice of countries is justified by the fact that France, Germany, Italy, the Netherlands and Spain, apart from being some of the biggest markets for the niches in the EU, also had most vacancies found during the job portal search (see the section below). However, we expanded the number of Member States that we covered to achieve a more varied geographical distribution. Therefore, we added countries such as Sweden, Greece, Poland and Belgium to the search.

To reflect the most relevant salaries, we searched for salaries for these occupations, which we found during the job portals search. We relied on a Glassdoor salary estimations model to obtain these data.[357] Due to the lack of industry-specific data, salaries are reported for all industries (i.e. not specific to

[357] See here.

agri-food or the three market niches). As Glassdoor provides gross salary estimations, we used the OECD's 'Average personal income tax and social security contribution rates on gross labour income'[358] for relevant countries to adjust and estimate net annual salaries. We then mapped these salaries to the EU income deciles.

[358] OECD (2021). Average personal income tax and social security contribution rates on gross labour income. Available here.

Annex II. Interview questionnaires

Digitalisation in agriculture and food processing

Overview

1. Please describe your organisation and its role in the agri-food sector.
2. What potential do you see in digitalising the agri-food sector?
3. How does your organisation support SMEs that develop technologies for the agri-food sector? (Identify some specific projects or initiatives in this regard)
4. What are the most relevant EU and national-level policy initiatives in facilitating digitalisation in the agri-food sector?
    - What are the gaps in this regard?

Market trends and technological developments

5. What are the current market trends in digitalising agri-food?
    - What are the main drivers of these trends?
    - What are the main markets for these trends in the EU?
6. What potential is there for developing digital technologies for the agri-food sector?
    - How do you support SMEs that develop new technologies for the agri-food sector?
7. What are the main technological trends in the agri-food sector?
8. What are the main challenges to the uptake of new technologies in the sector?
9. How do consumers respond to innovative technologies in agri-food production? (e.g. are consumers interested in innovative technologies or are they more likely to buy groceries produced by innovative technologies)?
10. Are current uncertainties (e.g. Russian war against Ukraine, inflation, pandemic) affecting the adoption of cutting-edge digital technologies in the agrifood sector?

Labour market trends

11. What are the average salaries in relation to digitalisation of the agri-food sector? (by ISCO/ESCO group)?
    - For managers in marketing, ICT service managers, manufacturing and supply and distribution managers? (ISCO 1)
    - Professionals, such as science and engineering or ICT professionals? (ISCO 2)
    - For IT technicians, science and engineering technicians, and business services agents? (ISCO 3)
    - For manufacturing labourers, machine operators, and assemblers? (ISCO 4-8)
12. What is the overall gender distribution of workers in the sector? We can start with managers and go down to other staff.

Skills demand

13. What are the most demanded occupations for the agri-food sector in general? Here, consider different ESCO groups: ICT specialists and data scientists, managers, agricultural workers, IoT systems and application developers, science and engineering professionals, as well as sales and marketing managers.
    - What are the occupations not covered here that may be in high demand in the short-term and the medium-term years?

14. What are the most demanded occupations for developing technologies for the agri-foods sector?
    - Which of these occupations do you expect to become relevant in the short-term? Which in the medium-term?
15. What positions are the most difficult to fill in companies?
16. How does your organisation monitor skills demand?
    - Do you liaise with SMEs in the sector to understand their skills needs and gaps? Can you name some examples?
17. What are the most demanded skills in the agri-food sector in general? (Skills can be both technical and non-technical)
18. What are the skills needed for developers of technologies for the agri-food sector?
    - How about managers who sell and market these technologies?
    - What are the skills needed for other professionals working with technologies in the agri-food sector?
19. Do you cooperate with businesses developing technological solutions for agri-food to address their skills and human resources needs? With which?

Skills supply

20. What kind of formal education is provided to developers of digital technologies for the agri-food sector in the EU?
21. Do you think that the skills needs for the digitalisation of agri-food are best addressed by higher education or VET?
    - What is currently missing in VET programmes to address the skills needs?
    - How can these gaps be filled?
22. Do you cooperate with education providers and training providers to help businesses address their skills needs? With which?
23. How does your organisation support non-formal training for people to develop such skills?
    - Which type of organisations have you worked with that provide such training?
    - What can be said about the quality, accessibility, and frequency of such non-formal training?
    - What are the skills covered the most by this type of education? The least?
    - Are there any advanced digital skills which are not covered by non-formal education at all but will have a high priority in the near future?

Biochemical and microbial products for agri-food

Background information

1. Please briefly introduce the organisation and its activities.

Overview

2. What are your views towards biochemical and microbial production and its potential within the agri-food sector? Do you observe any growth trends (in sales, volume of production, investments) in relation to this market niche?
3. What would you say are the most common biochemical/ microbial products used in the agri-food sector? How do you think it will develop?

4. Are you aware of any EU and/ or national-level policy initiatives promoting the production and application of biochemical and microbial products in the agri-food sector? If yes, what are they? Do you find them effective and why?
5. What is the role of your organisation, if any, in supporting the biochemical and microbial uptake in the agri-food sector?

Employment indicators

6. What is the average salary of those working in the field of biochemical and microbial products? Consider the following:
    - managers (ISCO group 1);
    - professionals (ISCO group 2), for example, science and engineering professionals, business administration professionals;
    - technicians and associate professionals (ISCO group 3);
    - other groups of occupations, such as clerical support workers, service and sales workers, and skilled agricultural workers (ISCO groups 4-6).
7. What is the gender and age distribution of those working in this market niche? Consider the abovementioned groups.

Main technological trends

8. What technologies do you see to be the most prominent in the production of biochemicals and microbials?
9. What technologies do you think will become important in the future production of biochemicals and microbials?

Skills demand

10. What are the most demanded occupations in the agri-food sector overall and in the biochemical and microbial products market niche particularly? Consider the following:
    - managers (ISCO group 1);
    - professionals (ISCO group 2), for example, science and engineering professionals, business administration professionals;
    - technicians and associate professionals (ISCO group 3);
    - other groups of occupations, such as clerical support workers, service and sales workers, and skilled agricultural workers (ISCO groups 4-6).
11. Which positions do you find to be the hardest to fill?
12. What are the most demanded skills (both technical and non-technical) and qualifications (by ISCED) in the agri-food sector overall in this particular market niche? Consider the following:
    - managers (ISCO group 1);
    - professionals (ISCO group 2), for example, science and engineering professionals, business administration professionals;
    - technicians and associate professionals (ISCO group 3);
    - other groups of occupations, such as clerical support workers, service and sales workers, and skilled agricultural workers (ISCO groups 4-6).
13. What is the role of your organisation, if any, in helping businesses meet their skills demands?
14. How do you think the technological trends discussed above will change the skills demanded in the agri-food sector and in the biochemical and microbial products market niche?
15. Among these skills, which skills do you expect to become relevant in the short-term future? Which in the medium-term future?
16. What is the role of your organisation, if any, in addressing future developments discussed?

Skills supply

17. How well do the educational institutions (both vocational education and training (VET) and higher education) address current skills needs? What are the gaps observed? Consider the quality, accessibility, and frequency.
18. Are you aware of any particular educational institutions that businesses operating in the biochemical and microbial market niche cooperate with? Could you name any educational programmes whose graduates are targeted by businesses operating in this niche?
19. What are the non-formal training practices, if any, observed within this market niche? Consider the quality, accessibility, and frequency.
20. Which forms of education and/ or training do you think will be the most relevant in addressing future developments?

Organic and functional foods

Overview

1. Please briefly describe your organisation and its role.
2. What potential do you see in the agri-food sector and the sub-sectors related to organic food/functional food/ food supplements production?
3. What are the most relevant EU and national-level policy initiatives that influence the organic/functional foods sector in the EU?
   - What are the gaps in this regard? (e.g. different national or EU policies may be slowing down or preventing the implementation of certain technologies, such as vertical farming for organic production, etc).
4. Does your organisation support innovative SMEs in the agri-food sector/ value chain and organic food/functional food/ food supplements production? If yes, how?

Market trends and technological developments

5. What market trends do you observe in the (organic food/functional food/ food supplements) sector? What are the drivers of these trends?
6. (For instance, growing demand for organic and highly nutritious products, growing demand for products that are gluten-free, plant-based, etc.)
7. What innovative technologies are used in (organic food/functional food/ food supplements) production/processing? (For instance, novel non-thermal food processing technologies, gene-editing, encapsulation, etc.).
8. Among these technologies, which technologies do you think will become more important in the future (in the short-term and medium-term)?
9. What are the main obstacles for development and application of these new technologies in the EU?

Employment indicators

10. What is your estimation of the **average salary** of those working in the field of (organic food/functional food/ food supplements production)? Consider the following:
    - managers (ISCO group 1)?
    - professionals (ISCO group 2)?
    - other groups of occupations such as technicians, skilled agricultural workers, machine operators, etc.?
11. What is your estimation of the **gender distribution** of workers in the sector? Consider managers and other staff.

Skills demand

State of play

12. What are the most demanded **occupations** in the agri-food sector in general and in relation to the (organic food/functional food/ food supplements) in particular?

Consider the following:

- managers (ISCO group 1);
- professionals (ISCO group 2), for example, science and engineering professionals, business administration professionals;
- technicians and associate professionals (ISCO group 3);
- other groups of occupations, such as clerical support workers, service and sales workers, and skilled agricultural workers (ISCO groups 4-6).

13. What positions do you think are the most difficult to fill in companies?
14. What are the most demanded **skills** (technical and non-technical) in the agri-food sector in general and in the (organic food/functional food/ food supplements) production?
15. Do you **cooperate with businesses** in helping them meet their **skills and human resources demands**? With which businesses do you cooperate?
16. Does your institution cooperate with **education and training providers (**higher education, VET? How (for instance, curricula development, internship placements, etc.)? With which?

Trends

17. What **skills** will be needed in the agri-food sector and in relation to organic food/functional food/ food supplements production **in the future**?
18. Among these skills, which skills do you expect to become relevant in the **short-term**? Which in the **medium-term**?
19. Is your institution preparing for such future developments? How?

Skills supply

20. How well do the educational institutions (both vocational education and training (VET) and higher education) address current skills needs? What are the gaps observed? Consider the quality, accessibility, and frequency. What is missing?
21. Do you think that the skills that are demanded by companies are better addressed by higher education or by vocational education and training? What is missing from VET to meet skills needs?
22. What are the non-formal training practices, if any, observed within this market niche? Consider the quality, accessibility, and frequency.
23. How can your institution and intermediary bodies such as chambers of commerce, SME agencies, SME development centres, Innovation hubs, business associations, sector skills committees and others in the EU contribute to the supply and development of relevant skills for the agri-food sector and companies active in the agri-food sector in general and production of organic and functional foods in particular?

ACRONYMS

Amazon Web Services (AWS)

Artificial Intelligence (AI)

Certis Corporate University (CCU)

Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR)

Common Agricultural Policy (CAP)

Compound Annual Growth Rate (CAGR)

Computer-aided design (CAD)

Computerised Maintenance Management Systems (CMMS)

Continuing Vocational Education Training (CVET)

Controlled Environment Agriculture (CEA)

Digital Innovation Hubs (DIH)

European Commission (EC)

European Parliament (EP)

European Union (EU)

European Credit System for VET (ECVET)

Farm to Fork Strategy (F2F)

Fertilising Products Regulation (FPR)

Gas Chromatography-mass Spectrometry (GC-MS)

General Industrial Classification of Economic Activities within the European Communities (NACE)

Geographic Information System (GIS)

Generally Recognised as Safe (GRAS)

Global Positioning System (GPS)

Global Navigation Satellite System (GNSS)

Greenhouse Gas Emissions (GHG)

European Joint Research Centre (JRC)

European Skills, Competences, Qualifications and Occupations (ESCO)

High-Performance Liquid Chromatography (HPLC)

High-pressure Processing (HPP)

Infrared (IR)

Initial Vocational Education and Training (IVET)

International Standard Classification of Education (ISCED)

International Standard Classification of Occupations (ISCO)

Internet of Things (IoT)

Machine Learning (ML)

Plant Protection Products (PPPs)

Precision Agriculture (PA)

Pulsed Electric Field (PEF)

Radio Frequency (RF)

Remotely Piloted Aircraft Systems (RPAS)

Rural Development Program (RDP)

Small and Medium Sized Enterprises (SMEs)

Smart Agriculture (SA)

Smart Farming (SF)

Venture Capital (VC)

Vocational Education and Training (VET)

Ultraviolet-Visible Spectroscopy (UV-Vis)

Unmanned Aerial Systems (UAS)

Unmanned Aerial Vehicles (UAV)

Western Balkans (WB)

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The list of interviewees

	Interviewee Organisation	Affiliation
1	FarmTech Society	Secretary-General
2	FESTO Didactic	Department Manager for New Ventures
3	German Centre for Artificial Intelligence (DFKI)	Senior Researcher for research and business development in the agrifood sector
4	ICT Agri-Food	Coordinator
5	Innovation Technology Cluster Murska Sobota (ITC)	Senior Expert
6	New Agriculture New Generation (GenerationAg)	Chief Executive Officer
7	Institute of Agricultural and Food Economics in Warsaw	Assistant Professor (Academic Researcher)
8	Smart Farm CoLAB (SFCOLAB)	Executive Secretary
9	International Biocontrol Manufacturers Organisation (IBMA)	Director
10	Lackner Ventures & Consulting	General Manager
11	Microbial Plant Protection Products Task Force	Scientific Advisor
12	The European Federation of Food Science and Technology (EFFoST)	R&D Manager
13	Innovative Food System, Production Systems Unit, Natural Resources Institute Finland (LUKE)	Senior Scientist
14	Research Institute for Organic Agriculture (FiBL Europe)	Leader of the Department of Food System Sciences