EU CAP Network Seminar ‘Robotics and artificial intelligence in farming and forestry’

Final report

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Summary

The integration of robotics and artificial intelligence (AI) is becoming increasingly essential for addressing challenges in agriculture and forestry, such as labour shortages, environmental sustainability, and climate change. The European Union's Common Agricultural Policy (CAP) [1] emphasises the adoption of innovative technologies to boost productivity and sustainability across these sectors. In livestock farming, automation has been widely adopted, particularly through the use of automated milking systems (AMS). In contrast, arable farming has been slower to integrate robotics, despite the availability of technologies like drones, autonomous tractors and ground robots for tasks such as weeding, fertilising, and seeding. High investment costs and integration difficulties remain major barriers to widespread adoption.

Woody crops and forestry are even further behind in robotics and AI adoption. While precision agriculture technologies are gradually making their way into orchard and vineyard management, such as automated pruning, harvesting, and disease detection, these applications remain highly specialised and expensive. Forestry lags significantly due to the complexity of operating robotic systems in highly unstructured environments. Although some advancements in autonomous harvesting, tree planting and remote sensing are emerging, adoption is limited by rugged terrain, unpredictable environmental conditions and the need for significant infrastructure adaptation.

The EU CAP Network seminar on robotics and AI, held in Utrecht, Netherlands, on 19-20 February 2025 brought together 169 participants. These included farmers, foresters, researchers, advisors and representatives from Managing Authorities, National CAP Networks, farmers' and foresters' organisations, as well as EU-funded and innovation brokers. Participants explored the potential of robotics and AI to support sustainable and competitive agriculture and forestry.

Key takeaways included:

- Technology demonstrations (autonomous farming, AI-driven analytics and robotic harvesting).
- Field visits showcasing AI and robotics in livestock, fruit cultivation, horticulture and forestry.
- Poster session highlighting 26 projects on soil monitoring, pest detection, harvesting and retrofitting machinery.

Key challenges and opportunities identified:

1. **Technology accessibility** – Robotics must be affordable, user-friendly and adaptable (e.g. Robotics-as-a-Service (RaaS)).
2. **Agroecology and technology** – Robotics should work with nature, not reshape farming landscapes.
3. **Data ownership and interoperability** – Farmers must own and control their data, with 5G and open standards improving accessibility.
4. **Innovation gap** – Fast-track research-to-market to overcome the technology transfer 'death valley'.
5. **Regulation and investment** – Policies should promote adoption while ensuring EU competitiveness and sustainability.
6. **Early warning systems** – Investments needed in regional pest and disease monitoring.
7. **Capacity building** – Focus on farmer training rather than excessive communication events.

Some recommendations from the seminar highlighted robotics and AI as being transformational tools for agriculture and forestry, enhancing efficiency, sustainability and profitability. Their success depends on:

- **Farmer-centric innovation** – Solutions must be practical and co-developed with farmers to ensure effective adoption.
- **Accessible and adaptable technology** – AI and robotics need to be cost-effective, interoperable, and easily integrated into existing agricultural practices.
- **Supportive policies and funding** – Investment in innovation adoption is critical to accelerating implementation and generating tangible impact.
- **Bridging the innovation gap** –Faster validation and deployment mechanisms are needed to turn research and innovation results into operational tools.
- **More focused and strategic events** – Reducing fragmentation of events that compete for stakeholders' attention and fostering synergies across projects and networks.

These insights align with the EU's Vision for Agriculture and Food [2] and the **competitiveness compass for the EU** [3] both of which call for a resilient, sustainable and digitally empowered agri-food sector. The findings from this seminar offer practical input through the identification of **sixteen practice-based research needs**, which are summarised in this document. By addressing the challenges identified and capitalising on emerging opportunities, **Europe is well-positioned to lead in sustainable, high-tech agriculture and forestry**, where innovation drives both productivity and environmental stewardship.

1 European Commission (2025, April 10), Common agricultural policy overview (CAP): https://agriculture.ec.europa.eu/cap-overview_en.

2 European Commission (2025), Vision for Agriculture and Food. Agriculture and rural development, available at: https://agriculture.ec.europa.eu/overview-vision-agriculture-food/vision-agriculture-and-food_en.

3 European Commission (2023), A competitiveness compass for the EU, available at https://commission.europa.eu/topics/eu-competitiveness/competitiveness-compass_en.

1. Introduction

Agriculture and forestry are facing growing challenges, including the need to increase productivity, address labour shortages and meet rising sustainability demands. Precision and smart agriculture have emerged as effective responses, leveraging robotics, artificial intelligence (AI) and advanced sensors to support data-driven decision-making. These technologies ensure that inputs, such as water, fertilisers and pesticides, are applied exactly where, when and in the amount needed. By delivering the right action at the right place, time and quantity, this targeted strategy enhances efficiency, reduces waste and supports the transition to sustainable, resilient bio-based economies (see Annex 1 for further detail).

Robotics and AI are transforming how land and resources are managed. By automating key tasks, such as watering, fertilising, harvesting or monitoring, these technologies improve productivity while minimising waste and environmental impact. The integration of sensors, data analysis tools and autonomous machinery enables more precise and efficient farming and forestry operations.

Building on these foundations, robotics and AI play a critical role in automating labour-intensive and repetitive field operations. Robotic systems can perform tasks ranging from planting and pruning to monitoring forest health and executing targeted interventions, many of which are difficult, time-consuming or hazardous for humans. AI provides the intelligence behind these systems, analysing data from satellites, sensor networks and historical records to predict outcomes, optimise resource use and identify issues before they escalate. Together, robotic automation and intelligent decision-making form the backbone of precision agriculture and forestry, supporting not only higher productivity and profitability but also long-term environmental sustainability.

2. Key challenges in agriculture and forestry driving AI and robotics development

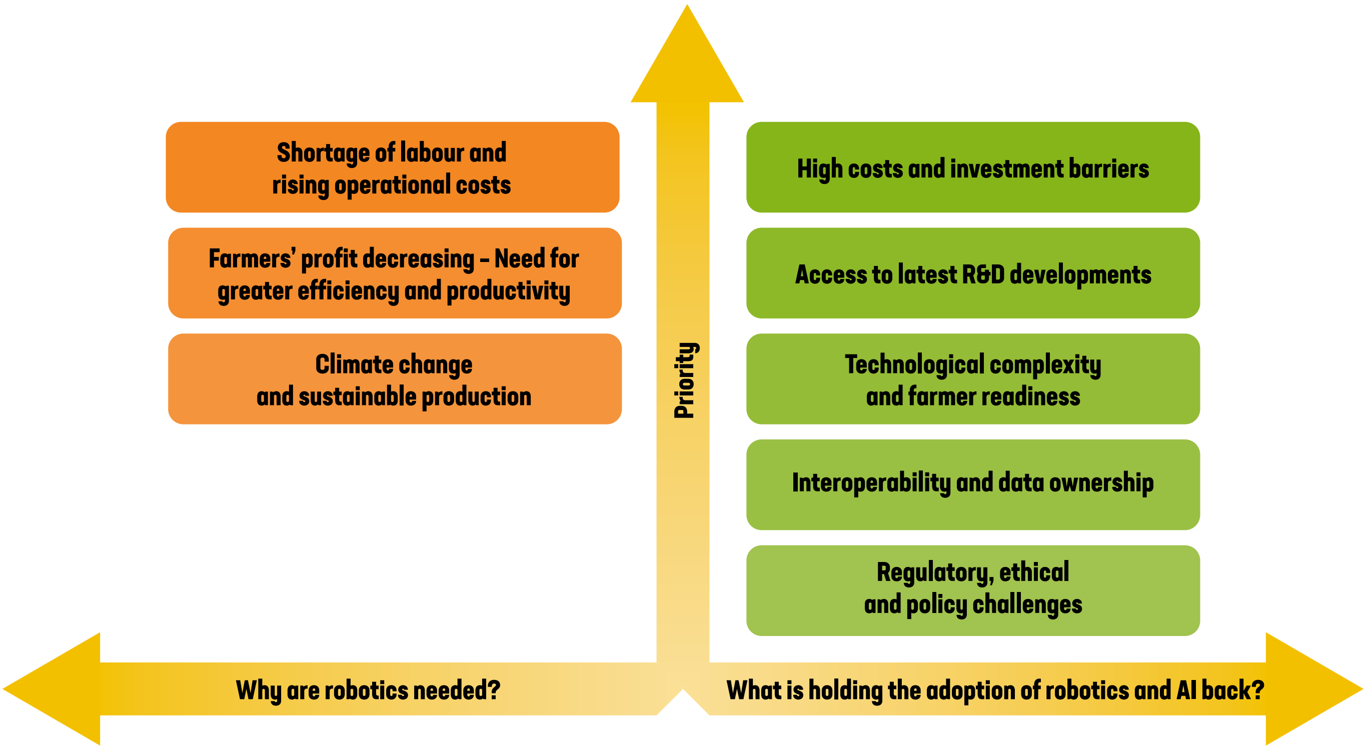
Figure 1. Word cloud generated from participants' responses to the reflection question 'What challenges could Robotics and AI address in agriculture and forestry?'. The visualisation highlights key themes such as efficiency, labour shortages and sustainability

Source: EU CAP Network

As part of the seminar discussion, participants reflected on the question '*What challenges could robotics and AI address in agriculture and forestry?*'. Their responses were captured in a word cloud (Fig. 1) and summarised into a visual overview (Fig. 2), highlighting the main challenge areas where these technologies are expected to make a significant impact. These can be grouped into three broad categories.

- **Societal challenges**
  - Addressing rural labour shortages through automation.
  - Enhancing worker safety in hazardous farming and forestry tasks.
  - Improving food security through AI-driven yield prediction and supply chain optimisation.
  - Overcoming trust and acceptance barriers to AI adoption among farmers and forestry professionals.
  - Supporting digital education and skills development for AI-enabled farming.
- **Environmental challenges**
  - Promoting sustainable resource management (e.g. reducing water, pesticide and fertiliser usage).
  - Preserving soil health and biodiversity through AI-driven monitoring.
  - Lowering carbon footprint by optimising machinery fuel use.
  - Applying precision farming to minimise waste and maximise crop yields.
  - Strengthening resilience to climate through predictive tools (e.g. AI-driven weather forecasting and risk prediction).
  - Preventing deforestation through automated surveillance.
- **Economic challenges**
  - Lowering production costs through AI-driven efficiency improvements.
  - Increasing profitability for farmers by reducing input waste.
  - Providing financial models (leasing AI solutions to small farms).
  - Supporting AI-driven predictive maintenance to reduce equipment downtime.
  - Enhancing supply chain management for greater market access.

Figure 2. A visual representation of the key challenges associated with the integration of robotics and AI in agriculture and forestry, viewed from two distinct perspectives



Source: EU CAP Network

Agriculture and forestry are undergoing profound transformations driven by increasing economic, environmental and social pressures. Robotics and AI are emerging as essential tools to help address these challenges, but their development and adoption are shaped by key factors that are reshaping the industry.

One of the most pressing issues is the **labour shortage and rising operational costs**. Across Europe, farms and forestry operations are struggling to find skilled workers, as younger generations move away from traditional rural professions. This is particularly evident in sectors that require manual, repetitive and physically demanding tasks, such as fruit harvesting, livestock management and forestry thinning. The labour crisis is compounded by increasing wages and unpredictable seasonal workforce availability [4], making automation not just an option but a necessity for ensuring the continuity of food and raw material production. Autonomous robots, AI-driven machinery and robotic harvesters have begun to fill these gaps, reducing dependency on human labour while improving efficiency.

At the same time, **climate change and environmental sustainability** are accelerating the need for AI and robotics in farming and forestry. Extreme weather conditions, soil degradation and biodiversity loss are challenging conventional agricultural practices, forcing farmers and foresters to adopt smarter, more precise and resource-efficient technologies. AI and robotics offer innovative solutions, from monitoring and predicting droughts to optimising water use and reducing chemical inputs through targeted interventions. In forestry, remote sensing and autonomous drones are helping monitor ecosystems, detect early signs of stress and support conservation efforts.

The demand for **greater efficiency and productivity** is another driving force behind the integration of robotics and AI. With global food demand expected to rise significantly in the coming decades, agricultural productivity must increase without further expanding farmland or depleting natural resources. AI helps optimise farm inputs, improving crop yields and reducing waste, while robotics is revolutionising mechanised operations, from precision planting and automated harvesting to livestock feeding and soil analysis. However, the challenge lies in making these technologies accessible and affordable for small and medium-sized farms, which represent the backbone of European agriculture. According to the European Commission, the average farm income in the EU increased between 2007 and 2018, reaching €35,300 per farm and €22,500 per annual working unit in 2018. However, significant differences can be observed across the EU and based on types of farming, sex, age and level of training of farm holders and managers [5,6], which could be better balanced with accessible robotics and AI technology.

4 Our World in Data (2021), Employment in agriculture, available at: https://ourworldindata.org/employment-in-agriculture.
5 Eurostat (2022), Farmers and the agricultural labour force – statistics, available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Farmers_and_the_agricultural_labour_force_-_statistics.
6 European Commission (2021), *Farm income increased over last decade, with important differences between EU countries*, available at: https://agriculture.ec.europa.eu/media/news/farm-income-increased-over-last-decade-important-differences-between-eu-countries-2021-07-09_en.

3. Barriers to AI and robotics adoption

Despite the growing potential of AI and robotics in agriculture and forestry, several barriers continue to hinder widespread adoption. While these technologies promise increased efficiency, sustainability and productivity, their integration into daily operations remains a challenge due to economic, technical, regulatory and social constraints. These barriers were identified by seminar participants during the World Café session (Fig. 3)

Figure 3. World Café session where participants collaboratively explored the challenges, opportunities and potential solutions for the adoption of AI and robotics across Europe

Source: EU CAP Network

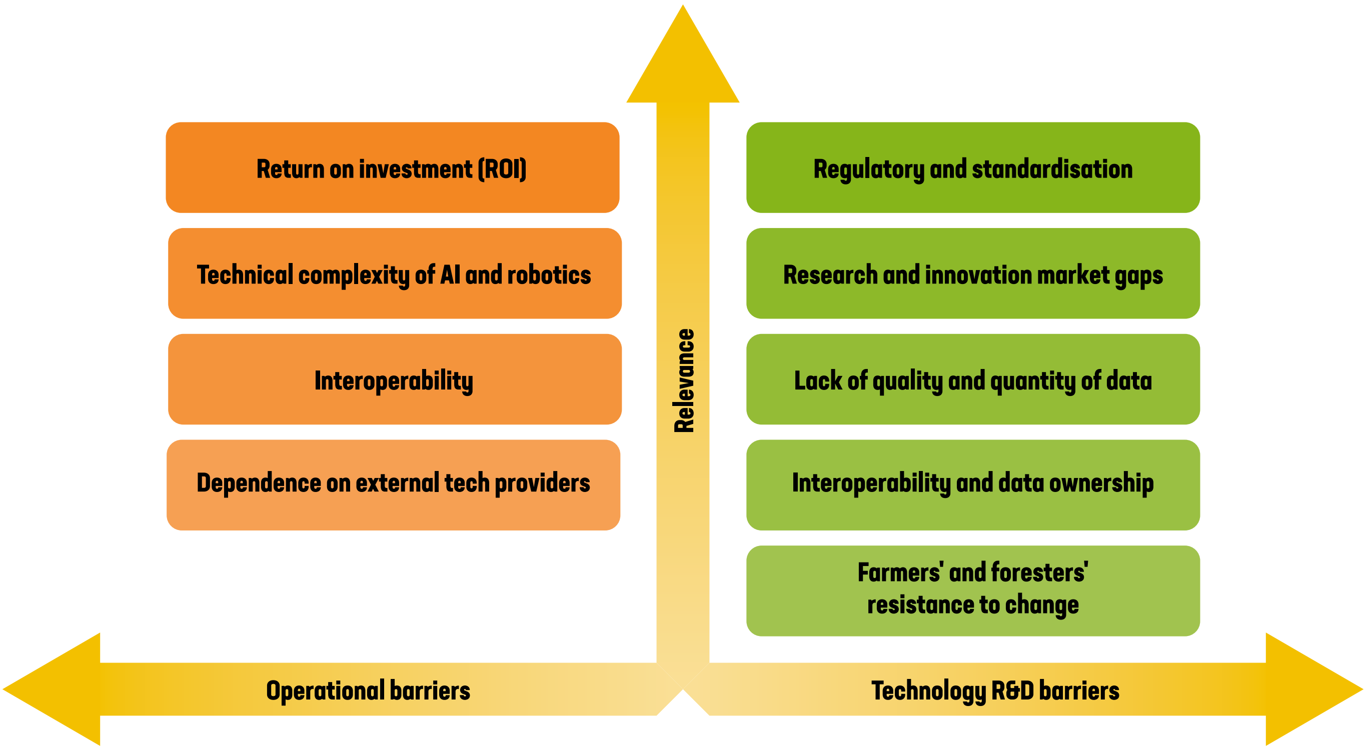
One of the most significant obstacles is the high cost of AI-driven robotics, as well as uncertainty regarding the **return on investment (ROI)**. Small or medium-sized farms, in particular, face difficulties in justifying the initial capital expenditure required for automation. Although these technologies offer long-term benefits such as reduced labour costs and optimised resource usage, the financial burden remains a deterrent. Additionally, ROI is not always immediate or predictable, as factors such as market fluctuations, weather conditions and regulatory requirements can impact profitability. This uncertainty slows the decision-making process for potential adopters, limiting the speed at which these technologies are adopted.

Another major barrier is the **technical complexity of AI and robotics** and **the limited digital capacity among end-users**. Many farmers and foresters are not trained in data analytics, AI model interpretation or robotic machinery maintenance, making it challenging for them to integrate these systems into their operations. Unlike traditional farming equipment, AI-based solutions require continuous updates, calibration and sometimes even software programming, which can be overwhelming for users unfamiliar with digital tools. The absence of adequate training programmes and technical support further exacerbates this issue, creating a gap between technological innovation and its practical application in the real world.

The effectiveness of AI in agriculture relies heavily on high-quality **data availability and interoperability**. However, data sources are often fragmented, siloed or incompatible across different systems. A lack of standardisation in data collection, storage and exchange protocols makes it difficult for farmers to integrate multiple AI tools or connect their robotic machinery with other farm management software. Without seamless interoperability, the benefits of AI and robotics are significantly reduced, limiting their capacity to enhance decision-making and operational efficiency.

Regulatory and standardisation challenges also hinder adoption. While the EU has established strict policies regarding safety, environmental impact and data governance, navigating these regulations can be complex and time-consuming for businesses developing robotics and AI-driven solutions. Complex legislation regarding autonomous vehicles in agricultural settings, AI decision-making in food production and ethical concerns related to worker displacement further complicates the landscape. Standardisation efforts are still lagging behind technological advancements, making it difficult for developers to design solutions that comply with multiple legal frameworks across different European countries.

Figure 4. Main barriers for robotics and AI adoption



Source: EU CAP Network

Lastly, **farmers' and foresters' resistance to change** remains a critical barrier. Agriculture and forestry sectors contain deeply rooted traditions and the shift to data-driven decision-making and automated systems can be met with scepticism. Some farmers fear losing control over their operations, while others worry about becoming overly reliant on technology. Additionally, concerns over cybersecurity, data privacy and **dependence on external tech providers** contribute to hesitation. Without clear demonstrations of real-world benefits, trust in AI and robotics remains a challenge, slowing the rate of adoption.

Overcoming these barriers requires a multi-faceted approach, including financial incentives, training programmes, improved interoperability and clear regulatory frameworks. Most importantly, AI and robotics must be designed with user accessibility in mind, ensuring that farmers and foresters can easily and confidently integrate these technologies into their work. By addressing these challenges, the agricultural and forestry sectors can fully unlock the potential of AI and robotics to drive sustainability, resilience and economic viability.

Summary of main barriers for adoption identified (Fig. 4):

- **High costs and investment barriers** – Robotics solutions remain expensive, making them less accessible to small- and medium-sized farms.
- **Technological complexity and farmer readiness** – Many farmers and foresters lack the necessary digital skills and technical expertise to integrate AI-based solutions effectively.
- **Interoperability and data ownership** – AI-driven agriculture requires seamless integration across different farming systems, yet standardisation and data-sharing policies remain underdeveloped.
- **Regulatory and policy challenges** – Robotics in farming must comply with EU safety regulations[7].
- **Trust and cultural resistance** – Scepticism and fear of over-reliance on technology slow down uptake.

The seminar emphasised that AI and robotics must be technologically advanced but also **accessible, adaptable and aligned with the needs of farmers and foresters**.

7 *Regulation (EU) 2023/1230 of the European Parliament and of the Council of 14 June 2023 on machinery and repealing Directive 2006/42/EC of the European Parliament and of the Council and Council Directive 73/361/EEC,* Official Journal of the European Union, L 202, pp. 1-84: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1230.

4. Emerging opportunities for AI and robotics in agriculture and forestry

As AI and robotics continue to evolve, new opportunities are emerging that can revolutionise the way agriculture and forestry operate, making them more efficient, resilient and sustainable. Innovations in computing power, business models and cross-sector integrations are paving the way for a more data-driven and automated future, ensuring that the sector can meet growing demands while addressing environmental challenges.

One of the most promising areas for robotics development is **edge computing, cloud-based AI and digital twin technology**. While traditionally AI applications in agriculture rely on centralised data processing, edge computing is shifting intelligence closer to the field, enabling real-time decision-making without the need for continuous internet access. This is particularly beneficial in remote forestry areas or large-scale farms with limited connectivity. AI-driven digital twins are also becoming more prevalent, allowing farmers and foresters to create virtual replicas of their land, crops and forests to simulate different conditions and optimise management strategies before taking real-world action. By combining sensor networks, AI-driven analytics and cloud-based computing, these advancements are making precision agriculture and forestry management more responsive, cost-effective and scalable.

Beyond technological improvements, AI is playing a transformative role in regenerative and climate-smart agriculture. With the increasing pressure to reduce emissions, restore soil health and adapt to climate change, AI is being used to monitor soil carbon levels, predict water requirements and optimise crop rotations **to enhance biodiversity**. Automated systems can now detect disease outbreaks, **prevent soil degradation** and improve **livestock well-being,** all while reducing the **environmental footprint of farming**. AI-powered drones and robotics are being deployed to manage weeds without herbicides, perform targeted fertilisation based on real-time soil conditions, and enable carbon sequestration strategies through optimised forest growth and logging practices. These innovations are making it possible to align **productivity with sustainability**, ensuring that AI-driven agriculture not only increases yields but also supports ecosystem resilience and biodiversity conservation.

New business models are also emerging to expand access to AI and robotics, particularly through **Robotics-as-a-Service (RaaS)**. Instead of requiring farmers and foresters to make large upfront investments in autonomous machinery, RaaS models allow them to pay for robotic services on demand, making advanced automation more accessible to small- and medium-sized farms. This approach not only lowers the financial barriers to entry but also ensures that farmers can benefit from continuous AI updates, maintenance support and technological upgrades without the burden of full ownership. The success of RaaS in automated weed control, drone-based crop monitoring and precision harvesting suggests that this model could be a game-changer in making high-tech farming solutions affordable and scalable.

Finally, the integration of **AI with the internet of things (IoT), blockchain and autonomous systems** is opening up new possibilities for improving efficiency across agricultural and forestry supply chains. **IoT sensors** enable real-time monitoring of soil conditions, climate variables and livestock health, supplying AI models with valuable data to support more accurate predictive analytics and informed decision-making.

At the same time, **blockchain technology aims to enhance** traceability and transparency in the value chain. It could potentially allow farmers and foresters to securely track produce from farm to table, manage carbon credits and implement fair pricing mechanisms through smart contracts. However, the real benefits of blockchain will only be realised when farmers are actively involved in the process, have control over their data and are empowered to influence how these systems are designed and governed.

When combined with autonomous vehicles and robotic systems, these technologies form the foundation of a connected, intelligent ecosystem. In this system, AI can coordinate and optimise farm and forestry operations with minimal human intervention, reducing waste, improving labour efficiency and supporting more sustainable practices. The opportunities presented by AI and robotics in agriculture and forestry are not just about technological sophistication; they are about creating practical, scalable and sustainable solutions. With continued innovation, more inclusive business models and increased connectivity, AI and robotics will play a defining role in shaping the future of food production and forest management, making them smarter, greener and more resilient to global challenges.

New opportunities are emerging to overcome key barriers in adopting AI and robotics in agriculture and forestry. These span innovative business models, enabling infrastructures and evolving production strategies, all aimed at making advanced technologies more accessible, affordable and scalable.

- **RaaS** – This service-based model allows small- and medium-sized farms to access robotics without significant upfront investment, instead paying based on usage or outcomes, thus lowering entry barriers.
- **AI-powered precision farming** – Intelligent systems are increasingly used to fine-tune irrigation, fertilisation and pest or disease management, improving resource use, productivity and sustainability.
- **Testing and Experimentation Facilities (TEFs)** – TEFs provide essential support for startups and small- and medium-sized enterprises (SMEs), offering real-world environments where AI and robotic solutions can be safely tested, validated and refined before market launch.
- **Early adopters as catalysts** – Farmers and foresters already implementing these technologies serve as important references and role models, demonstrating practical benefits and encouraging wider adoption through peer learning.
- **Mass production and economies of scale** – As market demand grows, the mass manufacturing of robotics and AI solutions helps drive down unit costs, making them more economically viable for broader segments of the sector.
- **New production models using original equipment manufacturer (OEM) components** – Leveraging OEM parts from mass consumer electronics, such as sensors, processors and camera modules, enables the development of high-performance robotic systems at significantly lower costs. This approach accelerates prototyping, reduces complexity and taps into existing supply chains, making innovation more agile and cost-efficient.

5. EU funding and support mechanisms

The adoption of AI and robotics in agriculture and forestry requires significant financial investment, not only for the **development of new technologies** but also for **ensuring accessibility, deployment and widespread adoption**. While the potential for AI-driven automation to improve efficiency, sustainability and profitability is well recognised, the high initial costs and technological complexity often present barriers for farmers, foresters and agribusinesses. To overcome these challenges, a diverse range of funding and support mechanisms has been established across Europe, leveraging EU programmes, private investments, regional initiatives and industry collaborations.

At the EU level, Horizon Europe, the **EU's flagship research and innovation programme**, provides substantial financial support for AI, robotics and digitalisation in agriculture and forestry. It funds multi-actor projects that bring together researchers, technology developers, farmers and policymakers to co-create scalable, practical solutions. Complementing this, the EIP-AGRI (European Innovation Partnership for Agricultural Productivity and Sustainability) fosters collaboration through **Operational Groups (OGs).** These grassroots innovation projects enable farmers and foresters to test AI-driven applications in real-world conditions and share results across regions.

Additionally, the Digital Europe Programme is actively investing in the **TEFs and Digital Innovation Hubs (DIHs),** which are tools that help SMEs develop, test and deploy AI-driven agricultural technologies. TEFs offer controlled environments where robotics and AI solutions can be validated before large-scale adoption, reducing risk for investors and accelerating the market entry of innovative technologies. DIHs serve as 'one-stop shops', offering farmers and agri-tech developers training, funding guidance and technical support to ease the transition toward digital and automated farming. These hubs are especially important in ensuring that cutting-edge research is translated into real-world applications, fostering digital transformation at both local and regional levels.

Beyond public funding**, private investments and venture capital** are playing an increasing role in scaling innovation. Investors are showing a growing interest in agri-tech startups that focus on automated harvesting, drone-based crop monitoring, AI-powered pest control and robotic livestock management. Companies specialising in RaaS are also attracting venture capital, as subscription-based models make automation more accessible to farmers without the burden of large upfront costs. Additionally, impact investors and sustainability-focused funds are increasingly supporting AI solutions that promote climate resilience, carbon sequestration and resource efficiency, recognising the long-term economic and environmental benefits of smart farming and precision forestry.

At a national and regional level, **governments are introducing grants, subsidies and tax incentives** to encourage the adoption of AI and robotics in agriculture. Some Member States offer direct financial assistance to farmers who invest in precision farming tools, autonomous machinery and data-driven decision-making systems. Others are focusing on **regional innovation hubs,** ensuring that even smaller agricultural communities have access to digital training, AI-powered advisory services and funding opportunities.

Finally, **industry collaborations and public-private partnerships** are emerging as powerful drivers of innovation in this space. Large agricultural equipment manufacturers are partnering with AI startups, universities and government agencies to co-develop robotics solutions tailored to farmers' and foresters' needs. These partnerships not only accelerate the commercialisation of AI-driven tools but also create pathways for knowledge exchange and technical support, ensuring that these innovations are accessible and practical for end users.

The combination of EU grants, venture capital, national subsidies, and collaborative initiatives is laying the financial foundation for the digital transformation of agriculture and forestry. By leveraging these support mechanisms, stakeholders can accelerate the adoption of AI and robotics, ensuring that the future of farming is more productive, sustainable, and technologically advanced. To ensure sustained impact, efforts must now focus **on bridging the innovation gap, enabling technologies to move from research to full-scale adoption**, and ensuring that AI and robotics deliver real value in the field – where they are most needed.

6. Research needs from practice

Figure 5. Interactive breakout sessions on AI and robotics in agriculture and forestry

Source: EU CAP Network

The seminar's interactive sessions and project showcases (Fig 5), revealed important research needs emerging from farmers, foresters and innovators working on the ground. These reflect the practical challenges of integrating AI and robotics into agriculture and forestry, highlighting priority areas for future research and innovation investments. The main research needs from practice can be summarised in 16 topics:

1. **Affordable forest planting innovations for labour-constrained operations.** Wildfires and deforestation remain critical threats to environmental sustainability, particularly in the context of climate change and biodiversity loss. While some solutions have been developed to ease the manual burden of forest planting, including mechanised attachments for existing forestry equipment, these approaches are often limited in scalability, adaptability to terrain and full automation. Further research is needed to develop advanced robotic systems specifically designed for automated tree planting, particularly in complex or degraded environments. This includes the creation of novel standalone planting robots and/or the automation of existing machinery through the integration of AI, robotics and precision control technologies. Advancing these technologies would not only reduce labour demands but also increase the efficiency, precision and consistency of reforestation and afforestation efforts, key components of the EU's climate resilience and ecosystem restoration goals.

2. **Sustainable and affordable biomass recovery for forest residue management.** Unmanaged forest biomass, including branches, undergrowth and logging residues, stores large amounts of energy and significantly increases the risk of severe wildfires, especially during increasingly hot and dry summers. At the same time, this biomass represents an untapped resource for bio-based products, such as bioenergy and biochar. Current methods for biomass recovery are labour-intensive, costly and poorly suited for complex forest environments. Research is needed to develop robotic and autonomous systems capable of efficiently identifying, cutting and collecting biomass while minimising ecological disruption. These systems should integrate AI-based perception, terrain navigation and precision tools, and be adaptable as standalone robots or attachments for existing machinery. Such innovations could help reduce wildfire risks while supporting the circular bioeconomy, turning forest residues into valuable products and promoting sustainable, climate-resilient forest management.

3. **Efficient and affordable tree pruning solutions to reduce labour and boost sustainability.** Pruning is a labour-intensive and repetitive task that plays a critical role in maintaining tree health, productivity and crop quality, particularly in fruit orchards, vineyards and woody perennial plantations. However, the availability of skilled labour is declining and the high costs associated with manual pruning are increasingly limiting the competitiveness and sustainability of these systems. Although some semi-automated tools and robotic prototypes for pruning exist, current solutions are often crop-specific, lack adaptability to different canopy architectures and require high levels of operator supervision. In many cases, these systems are also limited by inadequate perception technologies, energy constraints and integration challenges with existing farm operations. Further research is needed to develop robust, flexible and fully autonomous robotic pruning systems capable of operating in diverse environments and across different tree species.

4. **Smart soft fruit harvesting solutions for cost-effective and sustainable production**. Soft fruit harvesting remains one of the most labour-intensive and delicate operations in horticulture. Berries and other soft fruits are easily damaged during picking, requiring careful handling, precise timing and

experienced labour. However, labour shortages, rising costs and increasing demand for consistent quality are pushing the sector to seek more efficient and scalable solutions. While some robotic harvesters for soft fruit have emerged, current systems are still limited in terms of picking speed, accuracy and adaptability to different crop types, fruit sizes and plant structures. In addition, many solutions require highly controlled environments or significant changes to orchard layouts, which limits their adoption in traditional farming contexts. Further research is needed to develop advanced robotic harvesting systems capable of gently and efficiently harvesting soft fruits in open-field or protected cropping systems.

5. **Regionally/nationally adapted pest control with AI and IoT for sustainable crop protection.** Pest outbreaks remain a major threat to crops and forests, often spreading rapidly across regions and causing significant economic and ecological damage. Current monitoring approaches are fragmented, reactive and heavily reliant on manual reporting, which limits early detection and coordinated responses. There is a clear need for AI- and IoT-enabled pest management systems that operate at regional and national scales, combining real-time sensor networks, satellite imagery and predictive analytics. These systems should provide early warning alerts, support data-driven interventions and enable coordinated action across farms and territories. Developing such infrastructure would improve pest and disease control, reduce pesticide use and strengthen the resilience of agricultural and forestry systems, particularly under increasing climate pressures.

6. **On-demand fruit harvesting for better taste, less waste and more profit**. Consumer demand is increasingly shifting toward better-tasting, high-quality fruits that are harvested at peak ripeness. However, conventional harvesting practices are often driven by logistics and labour availability rather than optimal fruit maturity, leading to compromises in taste, texture and nutritional value. To meet these expectations, there is a growing need for on-demand harvesting technologies that allow fruits to be picked at the precise moment of ideal ripeness, based on real-time quality indicators rather than fixed schedules. While some progress has been made in remote sensing and digital maturity indices, current technologies lack integration with harvesting systems that can act on this data autonomously or semi-autonomously. Research is needed to develop intelligent, AI-driven harvesting solutions that combine real-time sensing (e.g. spectral imaging, tactile sensors and gas detection) with autonomous or robotic picking mechanisms, capable of making fine-scale harvest decisions within a single orchard or plot.

7. **Affordable robotics designed for small farms to reduce labour and boost efficiency.** Small-scale farms are essential to Europe's agricultural diversity and food security, yet they face disproportionate challenges in accessing and adopting robotic technologies. Most existing solutions are designed for large-scale operations, making them financially and operationally inaccessible for smaller holdings. To enable equitable adoption, two complementary research and innovation pathways should be pursued: a) Instead of high upfront investment, **RaaS models for small farms** offer robotics through flexible, pay-per-use or subscription-based services. Research is needed to develop lightweight, modular robots optimised for shared use, including task-specific solutions for weeding, monitoring and harvesting. Additionally, work should focus on logistics, fleet management and business models that make RaaS viable in rural contexts. These services would lower economic barriers, provide regular technical support and reduce the perceived risk of adopting advanced technologies; and, b) **Reducing manufacturing costs** through dual-use and mass consumer components. This parallel strategy involves lowering the production costs of robotic systems by leveraging dual-use technologies and off-the-shelf components from mass consumer markets, such as sensors, processors, cameras and mobility modules developed initially for drones, smartphones or gaming. Research should focus on designing robust, adaptable robotic platforms that integrate these components without compromising agricultural performance or safety. This approach would significantly reduce unit costs, accelerate prototyping, and support open innovation ecosystems for small-farm use of robotics. Together, these approaches can help deliver accessible, scalable and affordable robotic solutions that support digital inclusion, labour efficiency and environmental resilience across Europe's small farm sector

8. **Upgrading existing equipment with smart tech for cost-efficient input use.** Many farms across Europe, especially small- and medium-sized holdings, rely on conventional machinery that lacks digital capabilities. Replacing this equipment with high-tech alternatives is often cost-prohibitive; yet, improving the precision of water, pesticide and fertiliser use is essential for both economic efficiency and environmental sustainability. There is a clear need for cost-effective retrofitting solutions that combine IoT sensors, AI-driven analytics and control systems to upgrade existing machinery for precision agriculture applications. These solutions should enable real-time monitoring and adaptive application of inputs, based on soil conditions, crop health and weather data. Research should also explore interoperability with standard farming equipment, modular designs for easy installation and low-power, wireless communication systems suited for field conditions. These innovations would extend the lifespan and functionality of current machinery, reduce input waste and make precision agriculture accessible to a broader range of farmers.

9. **Smarter AI that learns from local conditions to support farming needs.** AI models in agriculture often face limitations when applied across different regions, climates, soil types and crop systems, as most are trained on narrow datasets that do not reflect the diversity of real-world farming environments. This reduces their effectiveness and slows adoption, particularly among small and medium-sized farms operating in less-studied or variable conditions. To address this, research is needed to develop more adaptable and context-aware machine learning models that can dynamically adjust to regional conditions and farming practices. These models should be capable of learning from heterogeneous datasets to support decision-making in diverse agroecosystems. Two complementary approaches can help accelerate this adaptability: a) **leveraging high-quality operational data** from larger farms and research networks. With proper incentives, privacy safeguards and data-sharing frameworks, anonymised data from precision farming systems can be used to train robust AI models that reflect real-

world variability across crops, practices and environmental conditions; and, b) **utilising simulation environments and digital twin technology.** Digital twin technology for fields, crops and farm operations can generate synthetic yet realistic data under a wide range of scenarios. These tools can support the development and testing of AI models in conditions where real-world data is scarce or difficult to collect. By combining real and simulated datasets, researchers can build AI systems that are more generali**s**able, scalable and locally relevant. This would result in more accurate, trusted and farmer-friendly tools that enhance productivity, reduce risks and improve resource efficiency in various agricultural systems.

10. **Farmer-controlled, secure, and connected data systems that work together.** As AI technologies become increasingly embedded in agricultural operations, data ownership, privacy and control remain major concerns, particularly among small- and medium-sized farmers. Farmers need assurance that the data generated by AI-driven machines, sensors and digital tools remains under their control and is used transparently and ethically. While substantial investments have already been made in data spaces, cloud platforms and decision support systems (DSS), the next critical research focus should be on developing secure, interoperable connectors that allow these systems to communicate with one another, enabling AI applications to reuse and exchange information without duplicating infrastructure. Emphasis should be placed on building modular, standards-based interfaces that integrate with existing DSS tools and farm management systems, thereby increasing adoption without requiring a full system replacement.

11. **Simpler AI tools and digital support to empower farmers in everyday decisions.** The successful adoption of AI and robotics in agriculture and forestry is not only a matter of technology availability; it also depends heavily on the digital literacy, confidence and usability experienced by end-users, particularly farmers and foresters who may lack technical expertise. Many current AI tools are overly complex, with dense dashboards, technical language and overwhelming data presentation. This makes them difficult for non-specialists to understand, trust and apply, especially under day-to-day operational pressures. There is a strong need for research into human-centred interface design that simplifies interaction with AI systems. Solutions should prioritise intuitive navigation, clear visual cues, voice-guided interactions and contextual data presentation, enabling users to quickly grasp key insights while accessing more detailed information only when needed. This is especially important for low-literacy users, older professionals and small-scale operators.

12. **Reliable, low-cost connectivity for farmers and foresters in remote areas.** Stable and reliable connectivity is a foundational requirement for modern digital agriculture, enabling real-time data exchange, cloud-based AI services and the remote operation and supervision of robotic systems. However, many rural and forested areas across Europe continue to face infrastructure gaps, including limited internet access, unstable mobile networks and bandwidth constraints, which significantly limit the deployment and safe operation of AI and robotic technologies. To bridge this gap, research is needed into communication solutions that are resilient, cost-effective and adapted to the realities of remote agricultural and forestry environments. This includes exploring low-bandwidth and satellite-based communication systems, long-range IoT networks (e.g. LoRaWAN) and decentralised models, such as edge computing, which reduce dependencies on continuous high-speed connections by processing data locally. In addition, hybrid connectivity models that combine terrestrial, satellite and mesh networks should be investigated to ensure consistent service across variable terrains.

13. **Flexible, low-maintenance monitoring with mobile robots instead of complex sensors.** While data-driven agriculture and forestry increasingly rely on real-time monitoring of environmental and crop conditions, installing and maintaining large quantities of fixed IoT sensors remains costly and labour-intensive. Sensor networks often require frequent calibration, power supply management and repairs, making them unsustainable for many farming and forestry operations, especially in remote or harsh environments. To address this, research is needed to develop mobile, cost-effective robotic platforms that can perform on-demand monitoring tasks across fields and forest plots, such as lightweight ground robots or drones. These robotic systems should be capable of carrying multi-sensor payloads, navigating autonomously, and collecting diverse types of data (e.g. soil moisture, canopy status and pest indicators) without the need for dense, fixed sensor networks.

14. **Getting cutting-edge technologies into farmers' hands earlier and more easily.** Despite significant investment in agricultural research and innovation across Europe, many farmers, particularly small and medium-sized producers, struggle to access, test and benefit from the latest technological developments. A persistent gap exists between laboratory results and practical adoption in the field, limiting the impact of promising AI, robotics and digital tools. Research is needed to develop new models that bring R&D directly onto farms, allowing farmers to become early adopters and co-developers of innovation. This includes the creation and support of ongoing, real-world validation projects, where researchers can test and fine-tune technologies in live production environments, gathering high-quality data for model training and performance benchmarking, while continuously improving system robustness and adaptability. These 'on-farm innovation labs' enable AI and robotic systems to evolve under real-world constraints (e.g. weather, soil, variability and user interaction), helping researchers better understand practical challenges and user needs.

15. **Strategic consolidation of communication and engagement efforts to better serve farmers and foresters.** Despite significant R&D investment in agricultural and forestry across Europe, many communication and dissemination activities remain fragmented, repetitive and disconnected from practitioners' needs. As a result, valuable project budgets are often consumed by parallel communication efforts, including events, webinars, newsletters and campaigns, that compete for the limited time and attention of farmers and foresters, without delivering meaningful value or coordinated knowledge. This has led to a saturation of low-impact outreach that risks alienating the very stakeholders

that innovation projects aim to support. Many practitioners report confusion and fatigue as they struggle to distinguish between overlapping initiatives and extract actionable information from generic messages. This issue is particularly acute in areas such as AI and robotics, where adoption depends on clear, trustworthy and relevant information tailored to on-the-ground contexts. Research is needed to develop more strategic, consolidated communication and engagement models, focusing on: **multi-project communication platforms and events** that bundle messages and results around shared themes (e.g. pruning, weeding and precision irrigation) instead of individual projects; **collaborative communication planning across consortia,** ensuring that efforts are complementary, aligned with practitioner calendars, and accessible through preferred local channels; **farmer- and forester-centred formats**, such as regional demo days, thematic knowledge weeks or sector-specific innovation roadshows, where solutions are shown, compared and discussed in ways that inform real decision-making; and **evaluation frameworks** to assess the actual utility and reach of communication activities, avoiding box-ticking and promoting real engagement. By addressing these issues, research can help maximise the return on public investment, reduce wasted resources and ensure that farmers and foresters receive coherent, timely and actionable insights, rather than communication overload.

16. **Agroecology-aligned robotics to support nature-positive farming systems.** As agriculture embraces robotics and AI, there is a growing concern that many technological solutions are being developed to fit industrial or uniform production models, often requiring changes to landscapes, planting patterns and input regimes that conflict with agroecological principles. If not carefully aligned with ecological practices, these technologies risk reshaping farming systems in ways that undermine biodiversity, soil health and long-term sustainability. There is a pressing need for research into agroecology-compatible robotic systems, which are tools that work with nature by enhancing, not replacing, ecological functions, such as soil regeneration, crop diversity, pollination, natural pest control and mixed cropping systems. This involves designing robotics that are adaptable to complex, heterogeneous environments, capable of operating in non-linear, poly-cultural fields and supporting minimal soil disturbance and low-input systems. Key research areas include: **development of lightweight, low-impact** robotic platforms suited for diversified and small-scale plots; **AI and sensing systems** that can detect and respond to biological signals (e.g. plant stress, beneficial insects and soil moisture) in real time; **integration with regenerative practices**, such as cover cropping, rotational grazing and agroforestry; and **participatory design** with agroecological farmers, ensuring tools address their realities rather than impose external models. This research will help ensure that robotics and agroecology are not seen as competing paradigms, but as complementary forces driving the future of sustainable farming. By embedding ecological intelligence into machines, technology can support resilient, climate-smart and biodiversity-friendly agricultural systems, while meeting production needs.

7. Strategies to increase impact and adoption in the EU

While AI and robotics hold transformative potential for agriculture and forestry, their impact remains limited by **fragmented initiatives, funding gaps across the innovation cycle and regulatory barriers**. For these technologies to become widely adopted and truly impactful, a strategic, long-term approach is required, one that moves beyond isolated pilot projects and toward a more cohesive, scalable innovation ecosystem.

One of the critical challenges is the innovation gap, where many promising AI and robotics solutions fail to transition from early-stage research (TRL 1-4) to fully commercialised products. Many initiatives receive funding for R&D but struggle to secure long-term investment for prototyping, testing, regulatory approval and market entry. To bridge this gap, a **'funnel model' of funding** should be adopted, which supports a broad set of early-stage innovations, then progressively concentrates resources on the most viable and scalable ones. This approach would accelerate market readiness while ensuring that investments lead to real-world deployment.

To foster a more supportive regulatory environment for AI and robotics in agriculture, policymakers must simplify and streamline approval processes for autonomous machinery and AI-driven decision-support tools. While regulations on automated vehicles, data protection and environmental impact assessments are vital for ensuring safety and safeguarding end-users, they can also impose significant costs and procedural hurdles that delay market entry and hinder adoption. A more harmonised and simplified regulatory framework, coupled with targeted support for EU start-ups and SMEs, is urgently needed. This framework should also enable innovations to be tested, certified and deployed consistently across Member States, reducing administrative burdens and providing both technology developers and farmers with the clarity and confidence to invest and innovate.

Moreover, legislation should actively promote sustainability, support the development of resilient European technologies and encourage the growth of EU companies. Special attention should be given to reducing certification costs for AI and robotic systems, particularly for European manufacturers, to ensure that these technologies are accessible, safe and trustworthy for farmers. Lowering these barriers would not only help accelerate adoption but also foster a competitive EU technology ecosystem aligned with strategic autonomy and environmental goals.

The establishment of **TEFs** and **regulatory sandboxes** can play a crucial role in this context by providing controlled environments where new technologies can be validated under real agricultural and forestry conditions, while still ensuring compliance with EU safety, ethical and environmental standards. These structures would help de-risk innovation and create pathways for faster, safer and more cost-effective deployment of AI and robotics across Europe.

Training and capacity-building are crucial for the adoption of AI and robotics, particularly among small and medium-sized farms, which often lack the necessary technical knowledge or confidence to implement automation. In this context, programmes that leverage the experience of early adopters can play a transformative role. Peer-to-peer learning, on-farm demonstrations led by pioneer users and farmer-led innovation networks can offer practical, trusted insights into how AI and robotics can be successfully implemented in real conditions. These initiatives are often more relatable and accessible than top-down training models, accelerating adoption through hands-on exposure and shared experience.

While **DIHs** and formal training centres continue to offer valuable support, a greater focus on farmer-driven knowledge exchange and community-based demonstration projects is essential to building long-term capacity and trust in new technologies. Additionally, integrating AI and robotics into agricultural education curricula will ensure that the next generation of farmers enters the sector already equipped with the digital and automation skills needed for the future of farming.

Real-world validation is crucial for building trust and ensuring that technologies meet the actual needs of users. Living labs, on-farm trials and multi-actor innovation networks, where farmers, researchers and tech companies collaborate to co-develop and test AI-driven solutions, should be scaled up and given long-term support. EU instruments, such as EIP-AGRI OGs and Horizon Europe-funded projects, already support these kinds of collaborations, but more structured, long-term funding is needed to ensure that these innovations progress beyond the pilot stage and into mainstream practice.

Finally, **financial incentives and new business models** must be scaled up to lower adoption costs and make automation accessible to smaller farms. Many AI and robotics solutions remain prohibitively expensive, making them inaccessible to all but the largest agribusinesses. Expanding subsidy programmes, tax incentives and low-interest financing options for farmers investing in precision farming and robotic systems could significantly increase adoption rates. Additionally**, scaling up RaaS models** would lower financial barriers and enable broader participation in the digital transition.

By aligning regulatory reforms, structured innovation funding, hands-on training and financial support, the EU can accelerate widespread adoption of AI and robotics in agriculture and forestry. These strategies will ensure that Europe not only leads in agricultural innovation but also creates a resilient, technology-driven food and forestry system that benefits both producers and the environment.

8. Conclusions

The seminar highlighted the growing role of AI and robotics in transforming agriculture and forestry. Participants explored cutting-edge technologies, emerging business models and practical examples of applications, from precision farming and automated harvesting to livestock monitoring and forestry robots. Despite this progress, challenges still hinder widespread adoption, such as high costs, regulatory complexity, limited technical expertise and fragmented innovation pathways.

The seminar underscored the importance of strategic funding, collaborative innovation and enabling policies to ensure AI and robotics deliver tangible benefits for farmers, foresters and the wider agri-food system. These findings contribute directly to the EU's Vision for Agriculture and Food, which promotes sustainability, resilience and a digitally empowered rural economy.

A key takeaway was the need for structured funding mechanisms that support AI and robotics across the entire innovation cycle, from early-stage research to fully deployed products. Current funding approaches often fragment resources across multiple small initiatives, limiting the scaling up of promising solutions. **A more coherent 'funnel' funding model that supports many early ideas but concentrates investments on the most viable and impactful ones** can bridge the innovation gap and accelerate real-world adoption.

For researchers and technology developers, the seminar emphasised the need for user-centric, interoperable and cost-effective AI and robotics solutions. Farmers must be co-creators, not just adopters. Solutions need to integrate seamlessly into existing agricultural and forestry workflows and offer real operational value. TEFs and DIHs were identified as key enablers in this process, offering spaces for validating AI and robotics under real-world conditions while providing structured support for end-users**. However, their impact remains limited at this stage and requires more substantial support and visibility.**

Regulatory reform was identified as a key lever for progress. Current rules on autonomous machines, data use and certification often slow down deployment. Harmonising EU-wide guidelines for autonomous farming vehicles, AI decision-making tools and robotics safety would provide a clearer pathway for innovation, while regulatory sandboxes could allow controlled experimentation with new AI applications before full-scale deployment. **Targeted support is needed to alleviate the cost of certification, enabling companies to accelerate compliance and market entry.**

Collaboration across sectors emerged as a powerful driver of impact. Case studies presented at the seminar showcased successful partnerships between agri-tech startups, large manufacturers, research institutions and farmer cooperatives. **Expanding public-private partnerships, cross-industry innovation platforms, EIP-AGRI OGs and other multi-actor projects would foster knowledge exchange and accelerate technology transfer**. Additionally, business models, such as RaaS, were highlighted as a viable approach to lowering financial barriers, enabling farmers to access automation solutions without large upfront investments.

For farmers and foresters, capacity building, digital literacy and trust are key. AI and robotics become meaningful only when accompanied by tailored training, advisory services and local demonstrations. The expansion of on-farm living labs, peer-learning networks and advisory services was widely acknowledged as a way to **bridge the knowledge gap and ensure that digital tools** are adapted to real-world farming and forestry needs.

Looking ahead, future initiatives should focus on deepening end-user engagement and improving coordination across EU and national programmes. **More integrated communication and dissemination strategies** would maximise synergies, reduce stakeholder fatigue and confusion, and broaden the impact of public investments, ensuring that innovation reaches the field faster and more effectively.

By aligning innovation, policy, funding, communication and education, the EU can turn AI and robotics into core tools of a sustainable, competitive and resilient agri-food system. The outcomes of this seminar can guide the future CAP and help deliver on the Vision of EU Agriculture and Food.

Annexes

1. Precision agriculture
2. Seminar objectives and organisation
3. The current implementation of AI and robotics in agriculture and forestry
4. Ongoing R&D projects: focus on seminar participants' contributions

Download all annexes from the seminar webpage.

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