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Up-skilling Agricultural Engineering
Next Generation

Smart and Sustainable Farming in Transition: Technologies and Learning Models for Climate Adaptation

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Contents

1 Executive Summary

This report presents a comprehensive desk study of state-of-the-art smart farming technologies that support climate change adaptation and sustainable agricultural transition, with a specific focus on small and medium-sized farms in Europe. It reviews key digital solutions—including IoT sensors, data analytics and AI, robotics, drones, and integrated farm management platforms—and assesses their practical applicability, maturity, and adoption potential for smallholder contexts. The analysis is embedded in current EU policy frameworks (CAP, European Green Deal, European Skills Agenda) and complemented by selected international examples. The report identifies critical skill and competence needs for farmers and advisors, highlights relevant European initiatives, and outlines key gaps and opportunities for education and training. Its findings provide an evidence-based foundation for the design of learner-centred, practice-oriented smart farming education within subsequent USAGE-NG work packages.

2 Overview

Climate change and evolving market pressures are driving an agrarian transition in Europe and beyond. Farmers face more frequent droughts, extreme weather, and environmental regulations, alongside generational shifts and economic challenges. In response, smart farming solutions – the integration of digital technologies like IoT sensors, artificial intelligence (AI), robotics, and data platforms – are emerging as key tools to make agriculture more resilient and sustainable. These technologies promise to **"***produce more with less***,"** helping farms adapt to climate impacts while meeting goals for reduced emissions and resource use. Crucially, this report focuses on small and medium-sized farms, which form the backbone of European agriculture (over 80% of EU farms are below 10 hectares). We explore how smart farming can be scaled down and tailored to these smaller operations in a practical, cost-effective way.
This report is intended for educators and curriculum developers in agricultural training and vocational programs. The aim is to provide a state-of-the-art desk study of current smart farming solutions for climate change adaptation, grounded in real-world projects and policy context. We emphasize how digital innovations can complement low-tech and traditional practices, rather than replace them, to achieve climate-smart and sustainable farming. The primary focus is on the European Union (EU) context – aligned with EU frameworks like the Common Agricultural Policy (CAP), the European Green Deal, and the European Skills Agenda – with a dedicated chapter on insights from the Global South (particularly Africa) to broaden the perspective.

Structure of the report: We begin by outlining key smart farming technologies and their technical features, then assess their applicability to small-scale farms, including maturity and adoption readiness. We examine the competencies farmers and farm advisors need to effectively use these tools, linking to EU's sustainability and digital competence frameworks (e.g. GreenComp). Next, we highlight notable EU initiatives (such as SmartAgriHubs, DESIRA, AGreen'Smart, Farmer 4.0, and others) that exemplify innovation in this space and discuss how these projects connect with educational goals and upskilling efforts. We then provide an international perspective with examples from Africa, where digital farming services are helping smallholders adapt to climate challenges. Finally, we discuss adoption potential in the next five years and the alignment of smart farming with EU policy priorities (CAP reform, Green Deal targets, and the Skills Agenda), before concluding with recommendations for educators and stakeholders. (Eurostat 2024; Hirt 2021; Sanyaolu und Sadowski 2024)

3 Smart Farming Technologies and Their Applications

Modern smart farming encompasses a suite of digital and data-driven technologies. Below we detail the major categories of solutions – IoT-based sensors, data analytics and AI, robotics and automation, drones and remote sensing, and farm management platforms – explaining how each works and how it contributes to climate adaptation and sustainable agriculture. We place special emphasis on how these technologies can be scaled to small farms or made accessible through shared services, given that high upfront costs and complexity often hinder adoption on family farms. Table 1 provides a comparative summary of these technologies, their benefits, and readiness for smallholder use. (Morrison 2024; Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025)

3.1 IoT Sensors and Smart Monitoring

The Internet of Things (IoT) in agriculture refers to networks of on-farm sensors and devices that collect data on environmental and crop conditions. These include soil moisture probes, weather stations, water level monitors, temperature and humidity sensors, and even camera-enabled pest traps. By deploying IoT sensors throughout fields, greenhouses, or barns, farmers can continuously track factors like soil moisture, microclimate, CO_2 levels, and pest activity. For example, a small vineyard might install soil moisture sensors and a rain gauge that automatically transmit data to the farmer's phone, indicating when and where irrigation is needed. Likewise, a livestock farmer could use connected thermometers and humidity sensors in barns to adjust ventilation and prevent heat stress in animals. (Kumar et al. 2024; LHP Europe 2022)

Technical description: IoT farm sensors are typically battery-powered or solar-powered devices with wireless connectivity (using protocols like LoRaWAN, NB-IoT, or simple GSM). They send readings at regular intervals to a gateway or cloud platform where data is aggregated and visualized. Many systems include alert functions – for instance, sending an SMS if soil moisture falls below a threshold or if frost is predicted overnight. Farmers can access real-time dashboards or receive recommendations based on the sensor data. (Kumar et al. 2024; Rafi et al. 2025)
Benefits for climate adaptation: By providing granular, real-time data, IoT sensors enable precision agriculture – applying water, fertilizers, and other inputs only when and where needed. This precision helps farms cope with climate variability by optimizing resource use and avoiding waste. For instance, precision irrigation systems use soil moisture and weather data to cut water usage by up to 20–50% while maintaining yields. Similarly, sensor-informed fertilization can reduce runoff and nitrous oxide emissions (a potent GHG), contributing to both climate adaptation and mitigation. More immediately, sensors offer early warning of extreme conditions (drought, frost, heatwaves) so that farmers can take protective actions. Overall, data-driven farm management reduces vulnerability by making production more controlled and efficient (Precision Agriculture | Discover the key services, thematic features and tools of Climate-ADAPT 2025; Farmonaut® 2024).
Applicability to small farms: IoT solutions can be surprisingly scale-neutral. Unlike large combines or machinery, a basic sensor kit can benefit a 2-hectare vegetable farm as much as a 200-hectare wheat operation. In fact, surveys show small-scale farmers readily adopt farm management and monitoring tools that are low-cost and user-friendly, since these have immediate benefits regardless of farm size. For example, a network of a few soil sensors (costing a few hundred euros) can save a small farmer money by optimizing irrigation scheduling and preventing crop stress. As one field engineering firm notes, bringing affordable connectivity and IoT tools to small farms allows them to collect a "vast array of metrics" – light, temperature, soil moisture, humidity, CO_2, pest counts – and then use that data to precisely adjust water, fertilizer, and pesticide application, reducing expenses and raising crop health. The key is affordability and simplicity: leveraging existing, proven sensor devices and easy deployment methods keeps it practical. Many smallholders already use basic weather apps; IoT takes this a step further by giving farm-specific data. (Kumar et al. 2024; Rafi et al. 2025; Hirt 2021; LHP Europe 2022)

State of development and readiness: IoT in agriculture is a relatively mature technology. Robust sensor products and farm-specific IoT platforms have been on the market for years. The cost of sensors continues to drop, and connectivity infrastructure is improving even in rural areas. That said, challenges remain in ensuring reliable internet coverage (rural broadband gaps) and in managing the data generated. Interoperability is also an issue – many devices work in silos with their own apps. The EU recognizes these challenges and is investing in solutions: a 2025 Horizon Europe call explicitly seeks "*digital tools tailored to small farms*" that use data (including next-gen tech like generative AI) to help manage inputs and resources sustainably. This reflects a push to bridge the digital divide so that monitoring and decision support systems reach farms of all sizes. In practice, IoT readiness for small farms is high if cost issues are addressed – e.g. through subsidies, cooperative purchases, or service models that provide sensors as a service. (Rafi et al. 2025; Horizon-europe.gouv.fr 2025)

3.2 Data Analytics and Artificial Intelligence

Behind the hardware on the farm, advanced data analytics and artificial intelligence play a growing role in smart farming. These tools turn raw data (from sensors, drones, machines, or satellites) into actionable insights. AI algorithms can detect patterns and make predictions that help farmers with decision-making. For example, machine learning models can analyse weather forecasts and soil data to recommend optimal planting dates, or scan images of crops to identify early signs of disease or pest infestation. Computer vision, a form of AI, is used in tasks like automated fruit counting or quality grading, and in robotics (such as a weeding robot distinguishing crops from weeds via camera). AI-driven decision support systems can also optimize supply chain logistics – for instance, predicting yields and adjusting market strategies accordingly. (Shahriar et al. 2025)

Technical description: Data analytics in agriculture often involves cloud-based platforms that aggregate multiple data streams – from IoT devices on the farm, remote sensing imagery, historical climate data, and even market prices. Using big data techniques, these platforms can provide farm-level recommendations (e.g., "Field X needs 20mm of irrigation within the next 2 days to avoid stress") or broader forecasts (e.g., pest outbreak risk maps). Artificial intelligence methods, particularly machine learning, improve these analyses by learning from large datasets. For instance, an AI model trained on thousands of plant images can diagnose crop diseases from a farmer's smartphone photo with impressive accuracy, effectively acting as a virtual agronomist. Another emerging application is generative AI, which could, for example, simulate crop growth under different scenarios or answer farmers' questions in natural language by drawing on vast knowledge bases. The EU's future vision even includes generative AI in farming tools, as noted in funding calls (Horizon-europe.gouv.fr 2025; Gupta und Kumar Pal 2025; Shahriar et al. 2025).

Benefits and role in climate adaptation: AI and analytics are essential for making sense of complexity. Climate change has introduced more uncertainty in farming – rains are less predictable, pest pressures shift, and historical patterns no longer hold. AI can crunch enormous amounts of data (including new climate projections) to support climate-smart decisions. For example, AI-powered climate advisory services can downscale seasonal forecasts to advise farmers on which crop varieties to plant for expected conditions, or whether to invest in drought mitigation this year. Predictive analytics can warn a farmer of likely disease outbreaks based on weather trends and sensor data (humidity, leaf wetness), allowing preventive measures. By optimizing inputs, AI also contributes to mitigation: the World Economic Forum estimated that widespread use of precision farming analytics could cut agriculture's greenhouse gas emissions by 5–10% by 2030. In sum, data-driven farming increases both productivity and resilience, forming a core pillar of climate-smart agriculture (Mizik 2021; Shahriar et al. 2025; Sanyaolu und Sadowski 2024).

Applicability to small farms: The power of AI can reach small farms largely through user-friendly applications and services rather than standalone high-tech systems on the farm. Many smallholders won't be running neural networks on their own computers, but they can use smartphone apps or advisory hotlines that are AI-enabled behind the scenes. Indeed, in regions with many small farms (like parts of Europe and most of Africa/Asia), a common approach is digital advisory services: farmers receive text messages or app notifications generated by AI that give site-specific advice (e.g., "there's a 70% chance of maize blight in your area next week; consider this fungicide"). These services aggregate data across thousands of farms, which both reduces cost per farmer and improves the AI's training data. One successful example is *Farmerline* in Ghana, which uses voice/SMS to deliver weather forecasts and agronomic tips to about 1 million small farmers. Another is the *PlantVillage Nuru app*, which allows farmers even in remote African villages to use an AI-based image recognition tool on a low-cost Android phone to diagnose plant diseases and get treatment advice (Bhalla 2021). These illustrate how even small-scale producers can benefit from cutting-edge AI through well-designed interfaces. In Europe, small farms are increasingly using Farm Management Information Systems (FMIS) that incorporate analytics – a farmer may input planting dates and get yield predictions or use a pest risk alert service that leverages AI on regional data. The main requirement is basic digital literacy and trust in the recommendations, which education and advisory systems need to foster. Surveys in Austria found that many small farmers are open to digital tools but want to be sure the benefit exceeds the cost. Clear, problem-solving advice powered by AI can demonstrate that benefit (e.g., showing time saved or crop losses averted). (Hirt 2021; Bhalla 2021)

State of development: AI applications in agriculture are rapidly evolving. Many startups and research projects are focusing on agri-algorithms – from drone-based crop analytics to machine learning for automated machinery. Some tools are market-ready (e.g., image-based diagnostic apps, yield prediction models integrated in software), while others are experimental (e.g., AI for complex tasks like picking delicate fruit). One challenge is interoperability and data sharing – as noted by experts, tech providers often don't develop reusable modules or open data standards, which hinders combining data sources and drives up costs for end-users (Morrison 2024; Gupta und Kumar Pal 2025).

Another challenge is reliability: models trained in one region may not directly transfer to another without local data (the "site-specific" nature of agriculture). Nevertheless, the trend is toward more accessible AI. Even generative AI chatbots for agriculture have emerged in pilot forms, which farmers could query for tailored advice (with the caveat that the knowledge base must be accurate and locally relevant). In the near term, we expect AI to be increasingly embedded in farm apps, machinery (smart tractors with vision systems), and public advisory services. The adoption potential in the next 5 years is high wherever digital infrastructure exists – small farms that use smartphones and have some connectivity can tap into these AI-driven services easily. Education efforts, therefore, should include building farmers' ability to interpret and trust data-driven recommendations. (Morrison 2024)

3.3 Robotics and Automation (Precision Machinery)

One of the most exciting frontiers in smart farming is the rise of robotics and automation. This includes self-driving tractors and sprayers, robotic arms for harvesting or pruning, and small autonomous field robots that can perform tasks like weeding or seeding with minimal human intervention. Drones for crop spraying or pollination can also be considered part of farm robotics. Collectively, these innovations are often termed Agriculture 4.0, drawing a parallel to Industry 4.0 automation. By taking over labour-intensive or precise tasks, robots can dramatically reduce the physical burden on farmers, address labour shortages, and apply inputs (fertilizer, pesticide, water) with pinpoint accuracy. As one European analysis noted, autonomous farm robots can reduce labour hours and input use (water, fertilizers, pesticides) while improving yields and farm margins. This makes them a powerful tool for both climate mitigation (through efficient input use) and adaptation (through alleviating labour constraints and optimizing timing of operations). (ECBF 2025)

Technical description: Agricultural robots range from large autonomous machines (e.g., a driverless tractor or combine) to swarms of small robots the size of a lawnmower. Many utilize

GPS navigation, LiDAR, and cameras to move through fields and perform tasks. For example, a robotic laser weeder like the prototype *Evabot* in Portugal uses cameras to identify weeds among crops and then zaps them with lasers – eliminating herbicide use. Other robots use mechanical tools: Naïo Technologies' robots, used in some European vegetable farms, mechanically hoe weeds or drill seeds with high precision. Drones equipped with multispectral cameras can autonomously survey fields and even spray in targeted spots. A key component of automation is the software that plans and coordinates operations (often called a robotic farm "operating system" or digital twin). For instance, the EU's recent *Robs4Crops* project combined smart implements, autonomous vehicles, and a planning software called a Farming Controller to coordinate robotic weeding/spraying in pilots across different countries. Robots can operate in structured environments (like orchards with set row spacing) or increasingly in more complex, unstructured fields using AI to adapt to conditions in real-time. (Robs4Crops 2024; GOFAR 2025)

Benefits for climate-smart farming: Robotics directly addresses one of the biggest issues in agriculture today – labour availability. In Europe, for each farmer under 35 there are nine over 55, and many farms struggle to find workers for planting or harvest seasons. By mechanizing tasks that were previously manual, robots ensure timely operations (e.g., planting within the optimal window, harvesting at peak ripeness) despite labour shortages or heatwaves that make manual work difficult. This improves resilience to climate impacts like compressed growing seasons or erratic weather – a robot can work longer hours or in tough conditions if needed. Automation also enables reduced tillage and controlled traffic farming, which help maintain soil structure and moisture (important under drought stress). From an environmental angle, many robotic systems aim to minimize chemical use: e.g., targeted weeders replace blanket herbicide spraying, and precision sprayers use machine vision to spray only diseased plants. This contributes to the Green Deal goals of cutting pesticide use and pollution. Additionally, some robots are electric or solar-powered, reducing on-farm fuel emissions. By improving efficiency (more output per input unit), automation can lower the greenhouse gas intensity of production. In summary, robotics can "*massively improve*" labour efficiency and reduce chemical inputs and waste, aligning with both adaptation (labour/productivity) and mitigation (resource use) objectives. (ECBF 2025; Horizon-europe.gouv.fr 2025)

Applicability to small-scale farms: Historically, advanced machinery primarily benefited large farms – smallholders couldn't justify a million-euro combine for a tiny plot. However, a paradigm shift is underway to make automation accessible to smaller farms through new models of use. Two key approaches are downscaling the technology (developing smaller, cheaper robots) and shared access models (like cooperatives or "robot-as-a-service"). On the technology side, Europe is seeing development of *lightweight, autonomous machines suited to smaller fields*, allowing regions with fragmented land (like Northern Portugal's mosaic of tiny plots) to "leapfrog" to high-tech solutions without going through heavy mechanization first. For instance, small battery-powered robots or retrofitted small tractors can navigate fields that big machines can't, and they cost far less than a full-sized combine. One cooperative leader in Portugal noted that "*autonomous machines could become key to making our small and medium farms profitable and preventing their abandonment, if there is real support and investment*". This highlights that small farmers *want* technology but need it to be affordable and adapted to their scale.

Enter the *cooperative and service model*: Instead of each farm buying a robot, a group of farmers can share one through a cooperative, or a service provider can offer robot work on-demand (similar to hiring a custom operator). This is often dubbed the "Uber for tractors" concept or more generally Machinery-as-a-Service. The famous example is *Hello Tractor* – a startup in Africa that equips tractors with GPS and connects owners with farmers needing tractor services via a mobile app. Through Hello Tractor, even a 1-acre farmer can hire a tractor for two hours to plough her field, dramatically reducing her labour from a month of hand-digging to an afternoon of supervised machine work. In Europe, advanced versions of this model are being tested for robots: the Robs4Crops project adopted a holistic Robot-as-a-Service (RaaS) model, enabling small and medium farms to use autonomous weeding/spraying robots without a substantial upfront investment. Farmers can effectively subscribe to a robotic service, paying per use or per hectare,

which the project found to be a promising avenue for uptake. Cooperatives are also eyeing this – in Portugal, an olive growers' cooperative with 2,800 members is considering shared ownership of robots or hiring models to make tech viable for smallholders.
Despite these developments, adoption among small farms is still in its infancy. Barriers include the high cost of many commercial robots, lack of local suppliers or maintenance services, and the need for farmers to trust and learn new systems. Indeed, farmers remain cautious about the "*high up-front investment*" for autonomous machines and worry about interoperability with their existing tools. Early experiences show that when those barriers are lowered, interest is strong. In pilot programs (e.g., robotic weeding trials in vineyards and vegetable farms), small farmers have been *optimistic* about the benefits but emphasize the need for refinement and local support. Key requirements to make robotics small-farm-friendly are user training, reliable support, and evidence of cost-benefit. Encouragingly, cost-benefit tools are emerging – Robs4Crops, for instance, developed an open-source cost analysis tool for farmers to compare the economics of robotic vs. conventional methods, highlighting cases where robots can save money or labour. (GOFAR 2025; Robs4Crops 2024; Bhalla 2021)

State of development: Agricultural robotics is a fast-growing market (projected around $100 billion globally by 2030) with many startups and research prototypes reaching maturity. In Europe, numerous field pilots are proving the concepts. Examples include the *LaserWeeder* in France, robotic milking systems (already common in medium-sized dairy farms), strawberry-picking robots being tested in the UK, and drone crop-spraying services in Spain. EU-funded projects like *Robs4Crops* (focused on developing a complete ecosystem for robotics adoption) and country initiatives like Italy's *AgroBot* programs are working through regulatory, safety, and interoperability issues. The consensus is that fully autonomous farms are not yet realistic in the very short term (farming is complex and seasonally variable, but many labour-intensive tasks can be partially or fully automated now or in the next few years. We are likely to see *hybrid models* first – e.g., a farmer supervises two weeding robots via smartphone, rather than personally weeding or spraying. Within five years, experts anticipate a greater commercial availability of small field robots and a growth in custom robotic service companies. Importantly, the EU policy environment is supportive: the new CAP encourages modernizing farms and has funds for innovation; the Green Deal's emphasis on reducing chemicals indirectly pushes demand for robotic alternatives (like mechanical weeding); and the EU's Recovery and Resilience Facility in some countries subsidizes precision equipment for farms. All these signals suggest the adoption curve for ag robotics could steepen, with small farms included through shared models. (ECBF 2025)

3.4 Drones and Remote Sensing

Remote sensing technology allows farmers to assess crop and soil conditions from above (or from afar), providing a larger-scale perspective that ground sensors or visual scouting might miss. The two main remote sensing tools in smart farming are drones (UAVs) and satellite imagery.
Drones equipped with cameras (visual, multispectral, or thermal) can fly over fields to capture high-resolution images. They can identify spatial variability in crop health via NDVI (vegetation index) maps, detect water stress, pest damage, or nutrient deficiencies, and even count plants or animals. Some advanced drones carry spraying equipment to do targeted pesticide or bio-control release on problem spots, which is far more precise than traditional blanket spraying. Drones can also be used in livestock farming – for example, to monitor cattle herds in large pastures or to check field conditions in remote parts of a farm.
Satellite remote sensing (like Europe's Copernicus Sentinel satellites) provides free imagery of farmland at frequent intervals (every 5 days for Sentinel-2 optical images at 10m resolution). While coarser in resolution than drones, satellites give regular, standardized data useful for monitoring crop growth, drought impacts, or flood damage. Earth observation data has become a valuable input for climate-smart farming, e.g., by feeding into drought early warning systems,

yield forecasting models, or insurance schemes. As the Farmtopia project coordinator noted, even "*the Earth Observation Copernicus infrastructure qualifies as hardware that offers data*" for agriculture – essentially treating satellite feeds as another sensor layer from the sky. (Morrison 2024)

Benefits for climate adaptation: Remote sensing enables macro and micro-level monitoring that can guide adaptive actions. On the macro scale, satellite data can identify emerging climate-related threats – such as the onset of drought stress across a region, or a locust outbreak front – allowing for large-scale response and resource allocation. On the farm scale, drones can help a farmer spot issue early: for instance, a drone map might reveal a section of a field that didn't germinate well due to dry soil, prompting the farmer to adjust irrigation or reseed if time allows. In irrigation management, thermal drone imagery can pinpoint leaks or inefficient watering areas in orchards. After extreme weather, drone surveys can quickly assess damage (for insurance or for the farmer's recovery planning). All these uses improve a farm's situational awareness under climate variability. Moreover, by quantifying variability, remote sensing encourages site-specific management – e.g., only replanting the damaged zone, or variable-rate application of fertilizer based on the drone's nutrient index map – which increases input efficiency and reduces waste. This precision not only adapts to climate stresses but also cuts emissions and runoff. Another adaptation angle is that remote sensing data accumulated over time builds a record that can guide longer-term shifts: a farmer might use multi-year NDVI trends (via satellite) to identify which parts of a field consistently suffer in drought and decide to shift those to a more drought-tolerant crop or fallow in dry years. Thus, remote sensing is a key enabler of climate-smart planning and real-time decision support on farms. (Zhang und Kovacs 2012)

Applicability to small farms: Drones have become quite accessible even to modest farms, thanks to decreasing costs and simpler user interfaces. A few years ago, only large agribusinesses might have their own drone or hire a specialized agronomist with one; today, even an individual vegetable farmer can buy a basic quadcopter with a good camera for under €1,000. Indeed, many extension services and farmer cooperatives now own drones that they use to provide services to members. Small vineyards, for example, have used drones to map vine health and detect disease early, saving entire crops by treating infections in time. One challenge for very small farms is expertise – operating the drone and interpreting the imagery requires some training. This is where third-party services come in: companies or agri-tech startups offer drone scouting as a service, delivering analysis to the farmer. In Africa, we've seen entrepreneurs offering drone crop-spraying to smallholders on a per-acre fee, which is safer (reducing farmers' exposure to chemicals) and often more thorough than manual spraying on larger plots.

Satellite data, on the other hand, is available to anyone with an internet connection at no cost. The barrier is turning raw satellite data into useful insight for a smallholder. Thankfully, a proliferation of platforms (some government-provided, some commercial) does this. For instance, the European Space Agency and EU have tools through the Climate-ADAPT and CAP networks that give farmers drought indices or crop vigor indices for their location. Some national paying agencies in the EU even use satellite data to assist farmers in proving compliance (through "area monitoring" in the CAP, which reduces the burden of on-farm inspections). For a small farmer, the benefit is indirect: they might receive an alert "plots 4 and 5 show signs of under-greening this week – check for problems." As digital literacy improves, more farmers are directly engaging with these tools, often via simple mobile apps. (van der Wal 2018)

State of development: The technology here is advanced and continually improving. Drones are becoming more autonomous (some can follow pre-programmed flight paths and automatically analyse images with AI on the device or cloud). Regulations in the EU for drone use are a consideration – small farm users must abide by rules on drone flight, but these are being standardized and generally permit agricultural drone operations with some basic training/certification. Satellite remote sensing is benefitting from higher frequency data (more satellites launched, like Planet's daily imagery or newer EU missions) and better resolution. We foresee that within 5 years, near-real-time remote sensing integration into farm management will be common. Insurance companies, governments, and big farm input suppliers are already leveraging these tools (e.g., offering insurance payouts triggered by satellite drought indices, or

advising fertilizer rates based on satellite biomass images). The key for small farms is to ensure open access and user-friendly interfaces, so they are not left behind. EU policy is supportive: the CAP's digital strategy encourages using Copernicus data for "smart agriculture," and research programs continue to fund on-farm remote sensing applications.
Finally, a trend worth noting is the merging of remote sensing data with ground data (IoT + drones + satellites together). When combined, a very powerful picture emerges – for example, satellites might flag an anomaly in a field's growth pattern, a drone can zoom in for a closer look at that spot, and ground sensors can confirm if it's a soil moisture issue. Data platforms increasingly aim to merge these for the user. This integration will benefit all farms, but particularly small ones that need cost-effective insights (satellite data covers the broad picture essentially for free, focusing the use of a paid drone service only where needed). In conclusion, remote sensing is a critical component of smart farming that extends a farmer's "eyes" and analytical capability, enabling proactive and adaptive management at both small and large scales. (European Commission 2025)

3.5 Farm Management Platforms and Data Integration

All the technologies above generate valuable data – the challenge is making that data actionable through effective management. *Farm Management Information Systems (FMIS)* and data integration platforms serve as the "brain" of a smart farm, bringing together sensor readings, AI analyses, and remote observations into a coherent interface for decision-making. An FMIS is typically a software (cloud-based or local) that allows a farmer to record all farm operations, monitor inputs and outputs, plan activities (planting schedules, harvest logistics), and receive recommendations. Many FMIS today incorporate modules for specific functions: for example, a nutrient management module that uses soil test data and yield goals to suggest fertilizer plans, or a compliance module that helps generate the reports needed for organic certification or subsidy payments. Data platforms in agriculture also refer to broader systems that allow sharing and aggregating data beyond a single farm. For instance, a regional data platform might gather anonymized data from hundreds of farms to generate benchmarking reports or to power AI advisory services that individual farms subscribe to. The EU has been investing in the concept of a "*Common European agriculture data space*" to facilitate interoperability – so that machinery data, satellite data, and farm records can talk to each other securely across different provider systems.

Benefits: A well-utilized FMIS can significantly enhance a farm's sustainability and climate resilience. It acts as a digital logbook and assistant, ensuring nothing falls through the cracks. Farmers can set up alerts (e.g., when a threshold of growing degree days is reached for pest emergence, or when a silo's temperature rises indicating possible spoilage). By analyzing past records, the system can help in adaptive management – for example, identifying which crop varieties performed best under the last drought year to inform future planting. FMIS also often include economic analysis, which is vital for small farms under financial pressure: they can see the cost-benefit of an action (like installing drip irrigation) and justify climate adaptation investments. On the environmental side, having integrated data allows holistic optimization: instead of treating irrigation, fertilization, and spraying as separate, the system finds synergies (e.g., scheduling irrigation right after fertilization to help nutrients absorb, but avoiding irrigation when a heavy rain is forecast to prevent runoff). This whole-system approach is at the core of smart agriculture, which aims to optimize the entire farm rather than just individual inputs (Mizik 2021).
Small farm considerations: For small and medium farms, the barrier to using FMIS used to be complexity and cost. Many early systems were designed for large commercial farms or required expensive licenses. The situation is improving with the advent of simplified mobile-based farm apps and even free or freemium platforms targeted at smallholders. For instance, there are apps where a farmer can easily enter daily activities (plowed 1 ha, planted 0.5 ha of barley, applied

5mm irrigation) and receive basic analytics. Extension services in Europe often recommend certain tools and may offer training. As noted in the SmartAgriHubs survey, small farms particularly appreciate digital tools for farm management and communication, since these scale well – using a planning app or a messaging group with fellow farmers has benefits regardless of farm size. In fact, in regions of small farms, farm management software was found to have higher adoption than advanced field machinery because it's affordable and immediately useful. The majority of respondents in one study had a positive or neutral attitude toward automation and digitization, essentially saying *"I'll adopt it if it clearly benefits me more than it costs"*. (SmartAgriHubs Consortium 2021, para. 4) Modern FMIS try to make that value obvious by saving time on record-keeping (some can even automatically log data from machinery or sensors, sparing the farmer manual entry) and by simplifying compliance with environmental measures (e.g., generating the reports needed to get CAP greening payments, etc.).

Another important aspect is knowledge sharing and advisory integration. Good platforms connect farmers to advice – some have built-in chat with agronomists, or community forums, or integration with government advisory bulletins. For a small farmer who might not have a dedicated advisor visiting regularly, this connection is invaluable. For example, a platform might notify the user: *"There's a blight warning in your county – click here for recommended actions"*. This ties into the concept of AKIS (Agricultural Knowledge and Innovation Systems) promoted by the CAP, where digital platforms are part of strengthening knowledge flows to farmers. (Hirt 2021)

State and challenges: While many FMIS and platforms exist, a major issue has been the lack of interoperability and the proliferation of proprietary systems. Farmers sometimes need to use one app for their tractor data, another for their drone imagery, and another for farm accounts – a fragmented experience that is a deterrent. The EU's digital agriculture strategy is tackling this by fostering standards and encouraging open APIs. Projects like *ATLAS* and *DEMETER* (H2020 projects) specifically worked on interoperability frameworks so that different agtech solutions can plug into a common data exchange. According to Farmtopia's coordinator, currently *"tech providers aren't developing reusable software modules,"* which hinders integration and keeps costs high. Overcoming this will greatly benefit small farms who need plug-and-play simplicity. (Morrison 2024)

Another challenge is data privacy and ownership – farmers can be wary of sharing data on platforms if they fear misuse. EU regulations like GDPR and upcoming rules on agricultural data aim to ensure farmers retain control over their data while still benefiting from collective insights. Educationally, farmers and advisors need to be informed about these issues so they can participate confidently in digital ecosystems.

Looking ahead five years, we expect more consolidation and professionalization of farm data platforms. They will likely incorporate advanced features like digital twins (virtual models of the farm that simulate scenarios) – indeed, Robs4Crops created an open-source digital twin for robotic operations, which could be extended to broader farm planning. We also foresee these platforms aligning with sustainability metrics: helping farms measure their carbon footprint, soil health, and biodiversity impact automatically from the data they already log. This is aligned with EU's push for green accounting in farming. (Robs4Crops 2024)

In summary, the FMIS or platform is what ties all other smart farming components together into a usable decision-support system. For small farms, it is often the entry point to digitalization (even a simple Excel sheet or a planning app is a start). Ensuring these tools are accessible, user-friendly, and integrated with both high-tech inputs and traditional knowledge will be crucial. The next section will delve into how such digital tools can complement and enhance low-tech practices, a particularly important consideration for educators bridging traditional farming wisdom with new technology.

Table 1. Overview of Key Smart Farming Technologies (and their relevance for small farms):

Technology	Purpose & Benefits	Small-Farm Applicability	Development & Adoption Status
IoT Sensors & Networks	Monitor field conditions (soil moisture, weather, pests) in real-time; enable precise input use (water, fertilizer) and early warnings. Benefits: resource efficiency, lower costs, better timing of operations (LHP Europe 2022).	High – Scale-neutral and modular. Even very small farms can deploy a few low-cost sensors (often via kits or local cooperatives). Yields immediate insights (e.g., when to irrigate) without needing large acreage[.	Mature technology, many products available. Costs decreasing and rural connectivity improving. Adoption growing, though dependent on internet access. EU projects focusing on tailoring IoT for small farms and ensuring interoperability (Horizon-europe.gouv.fr 2025).
Data Analytics & AI	Analyse data to provide decision support (e.g., yield forecasts, pest/disease detection via image recognition, climate risk alerts). AI can optimize input plans and predict issues for proactive management (Mizik 2021).	Medium-High – Usually accessed through user-friendly apps or advisory services rather than directly by the farmer. Small farms benefit via AI-powered recommendations (SMS alerts, smartphone apps) provided by extension services or companies. Requires basic digital literacy.	Rapidly evolving. Many AI tools in pilot or early use (e.g., disease diagnosis apps, chatbots). Increasing integration into farming software and public advisory. Key hurdle is data sharing and trust. Expected to see broad uptake within 5 years through integrated farm platforms and services.
Robotics & Automation	Automate physical tasks (weeding, planting, harvesting, milking) using autonomous machines or drones. Benefits: saves labour, can reduce chemical use (e.g. robotic weeding instead of herbicides), precision operations. (GOFAR 2025).	Medium – Direct ownership is often too costly for individual small farms, but accessible via cooperative ownership or contracting (RaaS). Smaller, lower-cost robots are being developed for small plots. Drones for spraying/scouting can be hired per job. Labor savings and productivity gains are very relevant to small farms with limited workforce. (GOFAR 2025; Robs4Crops 2024)	Emerging but with fast growth. Robotic milking well-established; field robots and drone services are in pilot-to-early commercial stage. Adoption low but rising in EU; many trials show optimism if costs can be managed. Within 5 years, likely moderate adoption via service models and as prices fall. Regulatory frameworks (for drones, autonomous

Technology	Purpose & Benefits	Small-Farm Applicability	Development & Adoption Status
			vehicles) evolving to accommodate growth. (GOFAR 2025)
Drones & Remote Sensing	Aerial imaging by drones or satellites to assess crop health, soil moisture, damage, etc. Benefits: whole-field overview, early problem detection, targeted intervention (drone spraying), data for insurance/climate analysis (Bhalla 2021).	Medium – Drones can be used on small farms through shared services or by owning simple models (community/extension often provides). Satellite data is freely available; small farms can access it via apps (though may need advisory support to interpret). Even a 1-ha farm can benefit from knowing variability and issues via remote images.	Drones: technology mature, cost decreasing; usage growing especially in high-value crops and by service providers. Satellite: very mature and increasingly high-resolution; being integrated into EU farm monitoring. Adoption by smallholders depends on access to processed info – trend is positive as more farmer-friendly tools emerge.
Farm Management & Data Platforms	Software platforms to record and analyse farm operations, integrate data from sensors/AI, and assist in planning & compliance. Benefits: holistic view of farm, better record-keeping, data-driven decisions for improved productivity and sustainability. (Mizik 2021)	High – Many small/medium farms already use basic digital record systems or apps (even spreadsheets). Modern FMIS are becoming simpler and cheaper (some tailored to small farms). Provides value regardless of scale (time savings, knowledge access). Key for enabling small farms to participate in "digital agriculture" fully.(Hirt 2021)	Numerous solutions available; however, interoperability and user-friendliness improving gradually. Adoption is moderate – higher for simpler tools (calendar apps, etc.) and lower for complex systems. Expected to rise as younger, digital-native farmers take over and as policy encourages e-management of farm data. Focus now on data standards and farmer data ownership rights.

Table 1: Key smart farming technologies and their relevance to small farms. Even modest family farms can leverage sensors, data, and drones with relative ease, while larger investments like field robots often require cooperative models to be viable. Overall, trends point to increasing accessibility of all these tools through cost declines, service-based delivery, and improved user-centric design. (Bhalla 2021; LHP Europe 2022)

4 Integrating Digital Tech with Traditional Farming Practices

A central message for educators and practitioners is that smart farming technologies should complement, not replace, low-tech and traditional practices. Resilience in agriculture often comes from blending new innovations with time-tested methods. Small farmers tend to rely on a wealth of indigenous knowledge and simple techniques (crop rotations, mixed cropping, seed saving, water harvesting, etc.) that have helped them weather variability for generations. Digital tools can enhance these practices by providing better information, coordination, and precision. This chapter explores some examples and principles of this integration:

- **Climate-Smart Agronomy:** Traditional agronomic practices like crop rotation, cover cropping, mulching, and agroforestry are cornerstones of sustainable farming. Digital technology can optimize the timing and monitoring of these practices. For instance, a farmer practicing rainfed mixed cropping can use local weather sensor data or SMS weather forecasts to decide when to plant each crop to maximize use of rainfall. A simple mobile app can remind and guide a farmer on rotational planting schedules or cover crop sowing dates based on climate data. In sub-Saharan Africa, where agroforestry (like interplanting trees with crops) is traditional, satellite data is now used to identify the best places to plant trees for windbreaks or shade, aligning with indigenous knowledge of the landscape. Farmer-led knowledge sharing has also gone digital: an example is *Digital Green*, a project where farmers film short videos of successful practices (e.g., composting techniques, mixed fodder systems) and share them via portable projectors in village groups. This low-tech/high-tech hybrid spreads traditional knowledge faster and wider, aided by digital distribution. It's a model of how ICT can amplify grassroots innovation without displacing it. (World Bank 2017)
- **Water Conservation:** Many traditional irrigation and water conservation methods exist (from drip lines made of clay pots to terrace systems on slopes). IoT sensors and predictive analytics can significantly enhance these. For example, consider a community-managed canal irrigation system – historically, farmers take turns based on fixed schedules. By introducing cheap moisture sensors and a simple scheduling app, the community can shift to need-based irrigation scheduling, which often follows traditional wisdom (like watering when certain plants wilt or when the soil feels a certain way) but now validated and timed by data. In India, some villages use a combination of rain gauges (a very old tool) and digital rain-feed data to manage their earthen check-dams and decide when to release water to fields. Thus, traditional water harvesting structures (ponds, tanks, bunds) become more effective when combined with digital monitoring of rainfall and soil moisture, ensuring every drop is used optimally under unpredictable climate patterns. (FAO 2013)
- **Indigenous Weather Knowledge Meets Modern Forecasting:** Smallholder communities worldwide have traditional indicators for weather (certain animal behaviours, plant flowering times, etc.). These are now being recorded and studied alongside meteorological forecasts in participatory climate services. Mobile phone networks enable quick dissemination of traditional advisories (for example, elders' predictions of rains) combined with scientific forecasts, delivered in local languages. In many African countries, "*blended*" advisories are given: a text might say the official forecast and then add a local proverb or insight aligning with it, making farmers more receptive and able to contextualize the information. Digital platforms like *MetMaasai* in Kenya respect and include pastoralists' own climate observations via SMS reporting, supplementing satellite data to guide grazing decisions. This approach builds trust in technology by validating it against known reference points, leading to better adoption of modern climate adaptation measures. (Radeny et al. 2019)

- **Low-Tech Precision Farming:** It sounds like an oxymoron, but even without expensive equipment, farmers can do a form of precision farming using basic tools plus digital guidance. For example, sticky traps for monitoring pests are a decades-old low-tech method; now farmers can simply take a photo of the trap with a smartphone and an AI service identifies and counts the pests, advising whether levels reach an action threshold. The trap itself is simple, but digital analysis adds precision to the traditional practice of visually checking pest traps. Similarly, soil testing used to require lab visits which many small farmers never did – now there are pocket soil test kits (chemical or sensor-based) whose results can be input to a phone app to get fertilizer recommendations. Farmers who long understood the value of manure and compost (a traditional soil health practice) can leverage these tools to apply just enough supplemental fertilizer, avoiding overuse and saving money. (Muromba et al. 2025)
- **Mechanization via Sharing:** Traditional small farming often relied on community labour sharing (e.g., everyone helps each other harvest). Modern tech-driven mechanization can mimic that ethic through sharing platforms. We discussed *Hello Tractor* in Africa, which essentially digitizes the age-old practice of borrowing a neighbour's ox or tractor in exchange for labour or payment. By formalizing it through an app and GPS tracking, it reduces the friction and ensures even those without direct neighbour connections can access machinery. The concept of cooperative machinery rings, common in parts of Europe (where groups of farmers jointly purchase equipment and schedule its use), is being turbocharged by digital scheduling tools. A cooperative can use an online calendar for its single robot weeder, ensuring every member gets a fair and timely slot – effectively a high-tech twist on communal resource use. This directly prevents the scenario of tech dividing farmers; instead, it fosters collective benefit, akin to traditional shared work but with a robot doing the heavy lifting. (Daum et al. 2021)
- **Cultural Heritage Crops and Tech:** In the face of climate change, many communities are reviving traditional crop varieties (landraces) that are more drought-tolerant or pest-resistant. Digital seed banks and farmer networks help in exchanging seeds and knowledge about these varieties. For instance, some EU projects have created online platforms where farmers can source heritage seeds and get advice on cultivation (often from veteran farmers). This exchange used to happen only at local markets or by word of mouth; now it's scaled up. IoT sensors can then help compare performance: farmers planting an heirloom wheat might log into a platform where dozens of others are also testing it under various conditions, with sensor data feeding a collective evaluation of how it performs under different rainfall or soil conditions. This marriage of agrobiodiversity conservation (a traditional value) with data analytics helps identify the best locally adapted varieties for climate resilience.

In all these examples, the guiding principle is **"***appropriate technology***"** – using the simplest tool that effectively addresses the problem and ensuring that high-tech interventions reinforce ecological and social strengths of traditional farming, not undermine them. Low-tech measures (like mulching for moisture retention) often provide the first line of defence in climate adaptation; high-tech measures (like automated drip irrigation) can build on that by fine-tuning and scaling the impact. Educators should impart that smart farming is not just about gadgets – it's about knowledge integration. A small farmer armed with a smartphone and local wisdom can be as "smart" as a large operation with the latest machinery, if not more, because of the intimate contextual understanding. (Mizik 2021)
From a pedagogical view, this integration means curriculum should cover both traditional agroecological practices and digital skills, highlighting case studies where they work in tandem. Vocational training modules might pair a lesson on, say, integrated pest management (IPM) with a session on using a pest scouting app. Students could learn how a pheromone trap works (low-tech IPM) and simultaneously how to upload trap data to a regional network that issues wider warnings (high-tech extension). Such holistic training ensures future farmers and advisors don't see technology as a silver bullet in isolation but as part of a larger system of sustainable farming.

5 The Role of SDGs and sustainability

Agriculture is central to many of the Sustainable Development Goals (SDGs), which are an international call to action. Adopted by the UN in 2015, the Sustainable Development Goals (SDGs) are a set of 17 global goals designed to tackle urgent issues like hunger, poverty, and environmental degradation. Since agriculture directly affects food security, economic growth, and environmental sustainability, it is essential to reaching these objectives.
To advance sustainable agriculture practices that are in line with the SDGs, cooperation between governments, corporations, non-governmental organizations, and local communities is crucial. Partnerships can offer the tools, information, and technology required to empower farmers and increase agricultural output in a sustainable manner.
Through the implementation of sustainable practices, agriculture can:

- Stop poverty and hunger.
- Encourage the planet to be healthier.
- Give communities more power and build inclusive economies.

Since what we sow today will determine the future of our planet, changing agriculture to become more resilient, inventive, and sustainable is the key to reaching the SDGs.
The UN Sustainable Development Goals (SDGs) — especially **SDG 2 (Zero Hunger)**, but also SDG 1 (No Poverty), SDG 6 (Clean Water), SDG 8 (Decent Work & Economic Growth), SDG 12 (Responsible Consumption & Production), SDG 13 (Climate Action) and SDG 15 (Life on Land) — are reshaping agriculture from a largely production-only sector into a multi-objective system balancing food security, environmental stewardship and rural livelihoods. The SDGs drive policy, funding and on-farm practice change (e.g., precision farming, climate-smart agriculture, carbon farming), and they are a major reason for investment in digital tools, training and cooperative business models for small/medium farms.
This transformation is visible in EU policy and in the ag tech / education projects reviewed through USAGE NG qualitative analysis proposing some considerations on the sustainable, digital, educational and socio-economic impacts on the SDGs development. We selected thematic relevant papers considering titles, abstracts and keywords. We selected relevant EU initiatives that are in synergy with USAGE NG to conduct the relevant linking with SDGs and to align USAGE NG with the **Times Higher Education (THE) Impact Rankings** indicators for **SDG 4 (Quality Education)** and **SDG 2 (Zero Hunger)**

Which SDGs matter most for agriculture — and how they impact the sector
SDG 2 — Zero Hunger (direct impact)
Targets on food security, nutrition and sustainable agriculture make governments prioritize resilient food systems, climate-smart crops and productivity-with-sustainability metrics. This drives investment in advisory services, seeds, irrigation and digital monitoring. SDGsWorld Food Programme
Your Smart Farming report frames smart tech (IoT, remote sensing, precision irrigation) as tools to deliver SDG-2 outcomes for small farms (increase yield reliability, reduce loss).
SDG 13 — Climate Action (adaptation & mitigation)
Agriculture must both adapt to climate impacts (droughts, pests, heat) and reduce GHGs (fertilizer N_2O, methane). Climate policy pushes measurable mitigation (carbon accounting, carbon farming schemes) and adaptation plans — which in turn require monitoring & verification (digital MRV). Smart tools and education are enablers. ScienceDirect
SDG 15 — Life on Land & biodiversity
Practices promoted by SDG15 (agroforestry, reduced pesticides, habitat conservation) mean farmers must change management — precision tech helps reduce pesticide/fertilizer use and map biodiversity outcomes. EU Farm to Fork & Biodiversity strategies explicitly link these targets to digital innovation.
SDG 1, 8, 10 — Poverty, decent work, inequality

Agricultural development strategies aligned to SDGs embed social objectives: maintain rural incomes, create decent agri-jobs, and reduce rural poverty. Education, micro-credentials and cooperative business models (RaaS, machinery rings) help smallholders benefit rather than be left behind. The USAGE NG project emphasises training, lifelong learning and entrepreneurship as part of SDG alignment.

SDG 6, 12 — Water & Responsible Consumption

Water efficiency targets and responsible production push precision irrigation and nutrient management (reducing runoff). Digital data platforms and FMIS are becoming core to compliance and best-practice monitoring.

USAGE-NG impacts **SDG 2 (Zero Hunger**) and **SDG 4 (Quality Education)** by:

It impacts **SDG 2 (Zero Hunger)** by:

- Advancing **sustainable agriculture education and research**, especially on food security and nutrition.
- Developing **innovative farming and food system practices** through academic partnerships and knowledge sharing.
- Encouraging **community engagement projects** that address local food challenges, improve productivity, and promote environmentally sustainable farming.

SDG 4 (Quality Education) by:

- Enhancing **internationalization of higher education** through mobility programs, research cooperation, and exchange of best practices.
- Supporting **capacity building** for educators and students, including digital skills, curriculum innovation, and inclusive learning environments.
- Promoting **lifelong learning opportunities** via collaborative projects and training aligned with sustainable development needs.

Times Higher Education (THE) Impact Ranking indicators → USAGE-NG contributions

THE indicator	**Metric Description**	**USAGE-NG Contribution / Evidence**
2.1 Research on hunger, nutrition, sustainable agriculture	**Academic research output on hunger, nutrition, food security**	**Produces research and course content on climate change adaptation, precision agriculture, sustainable farming, and food security, focusing on small-scale and resource-limited settings.**
2.2 Campus food waste and sustainable food practices	**Actions to minimize waste and promote sustainable production**	**Training promotes resource-efficient farming (optimized inputs, reduced energy use, precision irrigation, waste minimization) contributing to more sustainable agri-food systems.**
2.3 Proportion of graduates in agriculture and aquaculture	**Graduates in agriculture-related fields**	**Integrates new smart farming curriculum into BA, MA, and lifelong learning programs, increasing graduates with agriculture-related qualifications.**
2.4 Work with local, national, and global partners	**Partnerships addressing hunger**	**Collaborates with universities, industry, NGOs, and UN-CSAM; extends training to**

	and sustainable agriculture	**Africa and Asia to improve food security and poverty reduction.**
THE indicator	***Metric Description***	***USAGE-NG Contribution / Evidence***
4.1 Research on early years and lifelong learning education	***Research output in journals, projects, and reports related to lifelong learning***	***Development of research-led training modules on smart farming, sustainability, and digital agriculture targeting smallholder farmers, rural youth, and lifelong learners.***
4.2 Proportion of graduates with teaching qualifications	***Graduates with teaching or training qualifications***	***Project trains educators, trainers, and advisors in agriculture through micro-credentials, indirectly increasing the pool of teaching-qualified professionals in agricultural engineering.***
4.3 Lifelong learning measures	***Provision of adult education, continuing education, open learning***	***Creates EQF-aligned micro-credentials accessible via mobile learning platforms, shared free with partner HEIs and globally. Supports continuous skill development for rural and international learners.***
4.4 Commitment to inclusive education	***Policies and practices to ensure education access for all***	***Targets smallholder farmers, mountain communities, women, and remote learners; reduces barriers via mobile-based, modular, and multilingual delivery.***

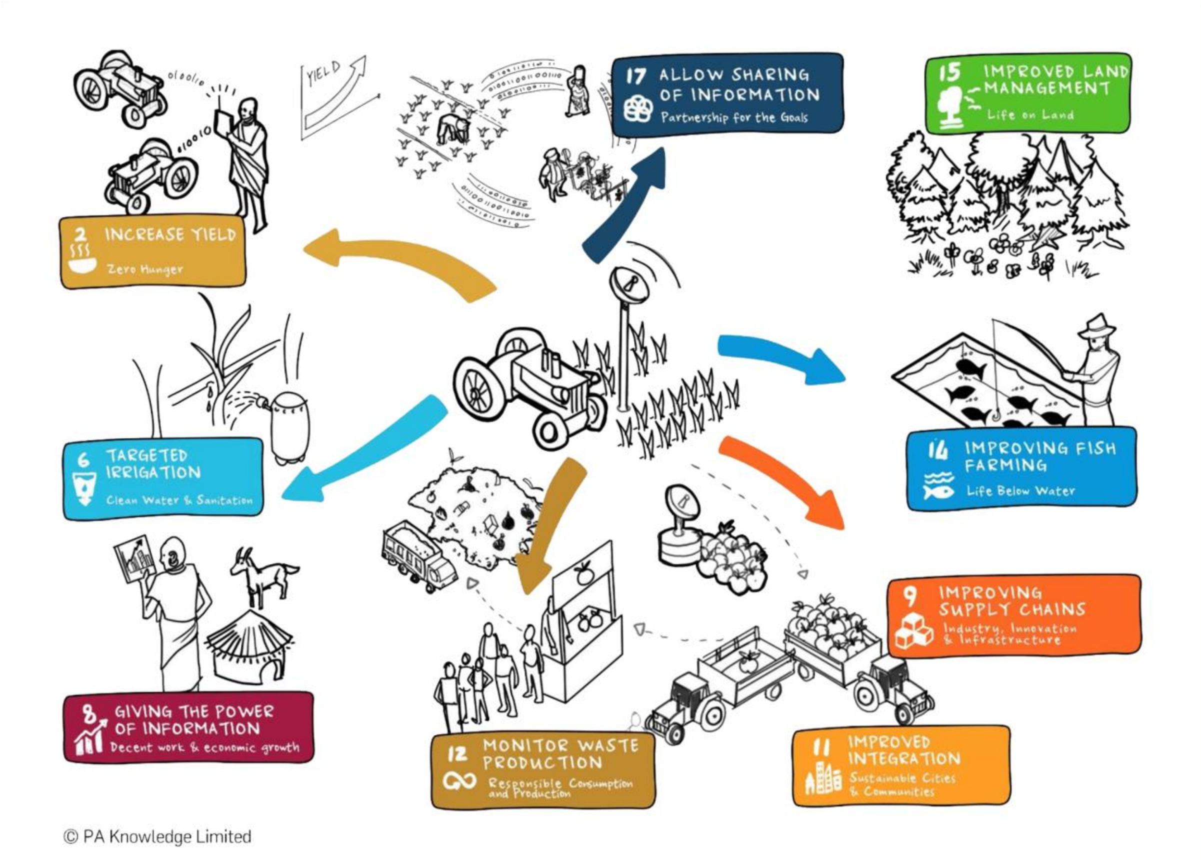
Mechanisms: *How* SDGs change practice and institutions in agriculture

- **Policy & funding signals** — SDG-driven policies (EU Green Deal, CAP measures, national climate plans) create incentives: grants, green payments, e-infrastructure funding (e.g., rural broadband) and conditional programs (organic, carbon payments). These accelerate digital uptake and sustainable practices.
- **Measurement & accountability** — SDG monitoring needs indicators and robust data. That pushes adoption of sensors, remote sensing and FMIS (farm data platforms) for MRV of emissions, soil carbon and input use.
- **Education & skills** — Achieving SDGs requires new competences (GreenComp, DigComp): data literacy, climate adaptation planning, agritech operation and entrepreneurship. Examples from many Erasmus+/Horizon projects that are building curricula, micro-credentials and living labs to upskill farmers and advisors (See the Matrix).
- **Business model innovation** — To include small farms, SDG goals push cooperative and service models (Robotics-as-a-Service, HelloTractor-type models, shared DIHs) that lower cost barriers and distribute benefits. Examples from FarmTOPIA, Robs4Crops and RaaS pilots.
- **Multi-stakeholder platforms** — SDG implementation encourages networks (DIHs, Living Labs, EIP-AGRI) that connect researchers, farmers, companies and policymakers

— improving co-design and adoption of relevant tech. The USAGE NG synergy matrix lists many such projects.

Evidence of impact (what the literature & projects show)

- Productivity + resource efficiency: Precision irrigation, nutrient management and AI advisory can maintain/raise yields while cutting water and fertilizer use (thus reducing emissions).
- Resilience: Use of seasonal forecasts, sensors and decision support reduces vulnerability to droughts, pests and extreme events — contributing directly to SDG-2 and SDG-13 adaptation objectives.
- Inclusion & livelihoods: Digital advisory (SMS/voice), cooperative machinery access and micro-credentials can improve smallholder adoption and income. The Farmerline / HelloTractor examples illustrate scale and social impact in Global South contexts that are instructive for Europe.
- Policy compliance & measurement: Satellite & sensor data increasingly used in area monitoring (CAP), insurance triggers and carbon schemes — enabling payments for sustainable outcomes.



The picture illustrates how digital agriculture tools directly support key SDGs like Zero Hunger (SDG 2), Clean Water (SDG 6), Decent Work & Economic Growth (SDG 8), Industry Innovation (SDG 9), and Responsible Production (SDG 12) by enhancing on-farm decision-making, resource efficiency, and data transparency

Where gaps and risks remain (so SDG aims are not automatically met)

- Digital divide & skills gap: Many small farmers lack connectivity, devices or the skills to use complex tools — risking uneven benefits. USAGE NG highlights the need for modular, mobile-friendly training and micro-credentials.
- Interoperability & data ownership: Fragmented proprietary systems and unclear data governance undermine trust and scaling. The USAGE NG analysis finds the interoperability as a major barrier and recommend open standards.
- Equity/rural employment impacts: Automation could displace labour if not paired with social measures and retraining. SDG alignment requires policies to protect decent rural work (SDG8).
- Monitoring & credible baselines: Carbon and biodiversity payments need robust baselines; measurement errors can distort incentives. Digital MRV helps but must be transparent and scientifically robust.

Practical recommendations (policy, education, practice) — linked to SDG action

- Scale education & micro-credentials: Fast-track modular training (EQF-aligned micro-credentials) in data literacy, climate adaptation and agritech operation — use Farm 4.0 / AGreen'Smart / USAGE NG outputs as templates.
- Fund shared access models: Prioritize RaaS, cooperatives and DIHs so small farms access robotics, drones and sensors without prohibitive capital outlay. Pilot public support for cooperative acquisition & local maintenance hubs.
- Invest in rural digital infrastructure & advisory: Broadband + strengthened AKIS (advisory systems) to translate tech into local practice — this closes the adoption loop required by SDGs.
- Adopt open standards & data governance: Mandate open APIs and farmer data-ownership safeguards for any subsidized system to avoid vendor lock-in and protect equity.
- Design inclusive MRV for payments: When deploying carbon or biodiversity payments, build digital MRV systems with verification steps, farmer training, and accessible interfaces.

6 European Initiatives and Case Studies in Smart Farming

The European Union has been a hotbed of innovation in digital and climate-smart agriculture, funding numerous projects and building networks to disseminate new solutions. These initiatives often serve as living laboratories and knowledge hubs that benefit small and large farms alike. For educators, they provide rich case studies and resources that can be incorporated into training programs. Below we highlight several notable EU and international initiatives, focusing on their goals, accomplishments, and how they align with small-farm needs and educational efforts. (A more detailed listing of relevant projects is provided in *Annex 1*.)

6.1 SmartAgriHubs (2018–2022) – Building a Digital Innovation Ecosystem

One flagship EU project was SmartAgriHubs, a €20 million Horizon 2020 initiative connecting over 160 partners across Europe. Its core objective was to create a network of Digital Innovation Hubs (DIHs) to accelerate the adoption of digital solutions in the agri-food sector. In practice, this meant linking tech developers, agricultural research, industry, and farmers through regional clusters. SmartAgriHubs supported 28 flagship innovation experiments across these clusters, demonstrating various digital innovations on real farms. For example, one experiment in France tested IoT and AI for precision viticulture, while another in Slovenia focused on smart dairy farming solutions. Each experiment was facilitated by a local DIH, which acted as a one-stop-shop offering both technological and business support to farmers and SMEs. (Cordis 2025)

Relevance to small farms and education: A key challenge SmartAgriHubs addressed was bridging the urban-rural and large-small farm digital divide. By extending the innovation ecosystem into every region, including those with predominantly smallholdings, it aimed to ensure inclusive access to new technologies. The project explicitly recognized structural differences: “large vs small family farms” in digital uptake and strove to tackle these disparities. For small farms, the local DIHs are particularly valuable. These hubs (often hosted by universities or farm advisory agencies) provide training, demonstrations, and even funding support for farmers to try out technologies. SmartAgriHubs also invested in improving the **“***innovation services***”** of these hubs – essentially training the trainers, so that advisors in rural areas are well-equipped to guide farmers on digital tools. (Cordis 2025; Beers 2024)

From an educational standpoint, SmartAgriHubs generated a wealth of open-access materials: case studies of the experiments, best practice guides, and a vibrant online community (the Synergy Portal). These resources can be used in vocational training to illustrate real-world implementations of smart farming. For instance, an instructor can present the case of a Bulgarian small-scale vegetable cooperative that, through SmartAgriHubs, adopted a low-cost sensor network and marketing app, leading to economic and environmental benefits – a concrete story that students can dissect. The project’s legacy is a sustained network of DIHs that continue to operate post-2022, many of which offer continuing education workshops and collaboration opportunities for agricultural colleges. In summary, SmartAgriHubs *“connected the dots”* of Europe’s agri-tech innovation, ensuring small farms were part of the digital transformation narrative. (Cordis 2025).

6.2 DESIRA (2019–2023) – Digitization Impact and Rural Resilience

DESIRA (Digitisation: Economic and Social Impacts in Rural Areas) was a Horizon 2020 research project taking a broader socio-technical look at digitalization. Rather than developing specific farm tools, DESIRA aimed to assess how digital trends affect agriculture, rural communities, and governance. It established a network of 20 Living Labs across Europe, each focused on a particular context – from digital tools for organic fruit production in Lake Constance, to smart villages in Greece, to precision farming adoption in Latvia (Desira 2025). In each Living Lab, local stakeholders (farmers, advisors, businesses, citizens) co-examined the past, present, and future impacts of digital innovations on their livelihoods (Desira 2025). The project also set up the Rural Digitalisation Forum, a Europe-wide community to discuss policy needs and share knowledge on rural digitization (Desira 2025).

Findings and relevance: One key contribution of DESIRA is a methodology to evaluate digital readiness and impact in rural areas – essentially providing tools for assessing what digital technologies are suitable in a given context and what their social implications might be. For example, in some regions the Living Labs found that a lack of broadband and digital skills was a bigger barrier than the availability of tech itself, highlighting the need for infrastructure investment and training (Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025). In others, they noted that certain technologies could actually increase inequalities (if only large farms afford them) unless accompanied by inclusive strategies – reinforcing the idea of cooperative or public support for digital adoption. (Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025)

For small farms, DESIRA's message was that technology must address real needs and fit local conditions, echoing what we saw with Farmtopia's approach. It's not enough to "push" tech; you need co-creation and mindset changes – a conclusion that matches many farmers' pragmatic stance of *"show me it benefits me and I'll use it"*. DESIRA also delved into skills and education: it produced policy briefs recommending updates to agricultural education curricula to include more digital literacy and data management, as well as support for lifelong learning so current farmers aren't left behind. It stressed that advisory services (AKIS) need to evolve, training advisors in digital tools so they can better support farmers. (Hirt 2021; Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025)

For educators, DESIRA offers a rich set of discussion material: its Digital Stories repository and scenario development exercises can be used in classes to discuss the future of farming communities under digital transformation. One could, for instance, use the DESIRA scenario of a "fully digital dairy farm in 2030" versus a "partially digital cooperative farm" to debate pros and cons with students. The DESIRA Policy Roadmap is another useful output, summarizing what policy changes (from EU to local level) are needed to ensure digitalization delivers social benefits. In essence, DESIRA brings a human-centric lens, reminding us that smart farming is not just about tech efficacy but about people – farmers, workers, consumers – and that education and participatory approaches are key to a successful agrarian transition. (Desira 2025)

6.3 FarmTOPIA (2023–2026) – Affordable Digital Solutions for Small Farms

A very pertinent ongoing project is *FarmTOPIA,* funded under Horizon Europe and explicitly aimed at **"***democratizing digital farming***"** for small and medium-sized farms. As noted earlier, small farms have low adoption rates due to high costs, uncertain benefits, lack of tailored solutions, and skill gaps. FarmTOPIA seeks to reverse this by co-creating cost-effective Agricultural Digital Solutions (ADS) hand-in-hand with farmers. It has 18 Sustainable Innovation Pilots across 15 countries, focusing on strategic crops/livestock where current digital offerings are inadequate. What sets FarmTOPIA apart is its emphasis on business models as much as technology – for example, it looks at cooperative ownership models (like the French CUMA machinery coops) to reduce costs, and developing reusable software modules to avoid each solution being built from scratch (Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025; Farmtopia 2023)

Key aspects: The project is pursuing a multi-actor approach: involving farmers, tech providers, advisors, and policymakers together in the pilot design. This ensures solutions solve *real* problems and are user-friendly. For instance, one pilot might develop a modular sensor kit for small dairy farms to monitor milk quality and cow health, with farmers co-designing the interface so it's easy to use and addresses their specific routines. Meanwhile, tech providers ensure it's built on open standards so it can plug into existing farm management apps. FarmTOPIA also explicitly works on training and mindset – it plans to reach 64,000 small farms with access and training in these ADS by project's end. This includes field days, demonstration events, and digital learning resources. (Morrison 2024)

Importantly, FarmTOPIA addresses the "*adoption conundrum*" head-on: they note that small farmers are wary mainly due to high cost and low digital literacy, and also that when low-cost options exist, they often have limited functionality. By engaging farmers in creation and by lowering costs through modular design and public infrastructure support, the project hopes to crack this conundrum. They are even examining issues like interoperability (complaining that current ADS lack it, which hinders uptake) and trust in data handling.

For educators and extensionists, FarmTOPIA's progress can provide very concrete examples of innovation diffusion. It shows how to implement the principle "*with farmers, not just for farmers*." Curriculum developers can use FarmTOPIA case studies to illustrate how participatory design works: e.g., describing a pilot where vegetable growers and programmers sat together to design a pest alert app, resulting in a tool that even older farmers found intuitive. It also underscores the importance of teaching not just technology operation, but business and cooperative skills – since new models like sharing machinery or data cooperatives require farmers who can organize collectively and understand contracts, cost-sharing, etc. FarmTOPIA's work with models like CUMA (a machinery-sharing cooperative with 225,000+ French farmers) is very relevant here.

In summary, FarmTOPIA is a cutting-edge example aligning perfectly with small-farm needs and agrarian transition. It's essentially implementing many recommendations that earlier sections of this report (and other projects like DESIRA) have identified: co-creation, cost reduction, training, and policy feedback. Its results, as they come out, should be watched closely by anyone updating agricultural education for the digital age. (Farmer 4.0 2021; Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025; Morrison 2024)

6.4 Farmer 4.0 (2018–2021) – Experiential Learning for Digital Skills

Farmer 4.0 was an Erasmus+ Strategic Partnership that took a directly educational angle, developing a new teaching model to facilitate the "*cultural transition*" of farmers and agricultural students toward the farm of the future. Recognizing that a major barrier to Agriculture 4.0 is not just technology but people's skills and mindsets, Farmer 4.0 created innovative training approaches. Notably, it combined experiential and immersive learning methods: using virtual reality (VR) simulations, hands-on prototyping through FabLabs, and inter-generational job shadowing between older and younger farmers. The idea was to expose learners to new technologies in a practical, engaging way and to break down resistance by building confidence and competence. (Farmer 4.0 2021)

Outputs and methods: The project developed VR training modules where, for example, a learner can virtually operate a piece of farm machinery or visualize a sensor network in a greenhouse, without the real-world risk or cost. This is especially useful for complex or dangerous operations (like learning to calibrate a drone sprayer virtually before doing it live). They also set up temporary FabLabs (fabrication laboratories) where students and farmers could tinker with building simple tech – such as assembling an Arduino-based weather station or modifying a small robot – fostering a maker mindset and demystifying the technology. Job shadowing involved pairing young agriculture students with innovative farms or tech companies, and conversely, tech students with traditional farms, to encourage knowledge exchange. This addresses cultural gaps: older farmers learn digital tricks from the youth, while young folks gain respect for traditional practices and pain points that tech needs to solve. According to project reports, participants found this two-way mentorship helped "make technology feel more human" and relevant. (Farmer 4.0 2021)

Relevance to vocational training: Farmer 4.0 directly feeds into curriculum design. It produced guidelines and curricula that other institutions can adopt, including a framework for e-learning acceptance in the agricultural sector (one study validated a Technology Acceptance Model extension specifically for Farmer 4.0's e-learning approach). In practice, a vocational school could integrate Farmer 4.0 modules by, say, using VR farm scenarios in class or establishing

partnerships for student internships at high-tech farms. One concrete example: in Italy, as part of Farmer 4.0, students used VR to simulate operating a precision planter and then went to a field to watch a real precision planter in action – the combination helped them quickly grasp and appreciate the technology's value. (Farmer 4.0 2021)
For small farmers already in the workforce, the project's approach of mobile FabLab workshops can be replicated by extension services. Imagine a rural training center hosting a "Digital Farm FabLab Week" where farmers come in to experiment with building a low-cost sensor or to play a tractor simulation game that teaches them about yield mapping. By making learning hands-on, fun, and peer-supported, Farmer 4.0 addressed the psychological barrier – it made digital farming "less scary" and more accessible, particularly to those who may not learn best via formal lectures.
In terms of synergy with EU strategic goals, Farmer 4.0 is aligned with the European Skills Agenda and the Osnabrück Declaration on VET, which call for innovative, inclusive, and lifelong learning approaches in the face of digital transitions. It exemplified how to implement these principles in the agricultural domain. (Farmer 4.0 2021)

6.5 AGreen'Smart (2020–2023) – Green & Smart Agriculture Education Network

Another Erasmus+ project, AGreen'Smart, created a transnational teaching network focused on the intersection of digital farming and climate-smart agriculture. It united universities and institutes from across Europe (France, Portugal, Finland, Norway, Greece, Sweden, etc.) to develop a joint curriculum and resources for "*smart and green agriculture*" . The project's philosophy was that future agricultural engineers and advisors must be trained to see technology (Smart) as a lever for sustainability goals (Green). This resonates strongly with EU policy: as they noted, the CAP post-2020 and Green Deal demand higher environmental ambition supported by digitalization, yet adoption of such tech by farmers remains low and its role in achieving green goals is *"still blurry"*. AGreen'Smart set out to clarify that by educating a new generation. (CITAB 2025)
Activities and deliverables: AGreen'Smart established a high-quality European teaching network that delivered courses to three cohorts of students during the project, effectively piloting a mini curriculum across institutions. The content was transdisciplinary: it covered digital technologies in crop and animal farming (precision ag, precision livestock), climate change adaptation and mitigation practices, agroecology, and socio-economic aspects of sustainability. Students gained transdisciplinary skills bridging agronomy, data science, and environmental science. Notably, the project produced a catalogue of open-access online courses to reach a broader audience (like farmers or alumni who want continuing education). Topics ranged from "IoT for Greenhouses" to "GHG accounting on farms" to "Robotics in Agroecology," each blending technical and sustainability perspectives. (CITAB 2025)
Another goal was to mainstream these topics into degree programs. AGreen'Smart partners worked on developing a full Master's program in "Smart and Green Agriculture," which would be sustained beyond the project, ensuring continuity and expansion of the approach. They also engaged stakeholders – public authorities and companies – to ensure the curriculum meets professional needs and to facilitate research internships and industry placements for students (CITAB 2025).
For educators everywhere, AGreen'Smart provides both materials and a model. The open courses and case studies can be directly used or adapted in other institutions. The network's structure (multiple universities co-teaching modules) might inspire new Erasmus+ collaborations or at least exchange of teaching practices. Pedagogically, AGreen'Smart emphasized problem-based learning: students often worked on real case studies, for example analysing how digital tech could improve sustainability on a particular farm, then presenting solutions that consider economic viability and social acceptance (not just tech for tech's sake). This kind of assignment could be replicated easily in any agricultural college course.

The project also highlights the **importance of continuing education**: one of its objectives was providing lifelong learning opportunities (for "a large public") in these domains. This aligns with the European Council's call for micro-credentials and upskilling pathways. Indeed, AGreen'Smart's outputs could be packaged as micro-credential modules (5 ECTS short courses on, say, Climate-Smart Farming with Drones) that vocational training centers can offer to farm advisors or even progressive farmers. (CITAB 2025)

In summary, AGreen'Smart brought together the green and digital threads of EU strategy into the curriculum – effectively operationalizing frameworks like **GreenComp** (sustainability competencies) alongside **DigComp** (digital competencies) in the context of agriculture. It underscores that tomorrow's farmers and farm advisors need a dual skillset: *digital savvy* and *sustainability literacy*. The project's legacy likely includes a generation of graduates with that combined mindset, as well as educational resources to cultivate those competencies more widely.

6.6 Other Notable Initiatives

Beyond these detailed examples, numerous other projects and programs deserve mention, each contributing in specific ways to smart farming and climate adaptation:

- **VISCA, MOSES, LIFE AgriAdapt** – EU projects focusing on climate services for vineyards, water-saving irrigation, and risk management on farms, respectively. They produced tools like tailored climate forecast apps for farmers (VISCA for viticulture) and methodologies for assessing farm vulnerability and adaptation options (AgriAdapt). These provide case studies on applying data to specific climate challenges (e.g., forecasting heatwaves to reschedule vineyard harvesting).
- **NEFERTITI (2018–2022)** – A network of demonstration farms and "innovation hubs" for exchanging practical knowledge on new farming practices, including digital tools. It facilitated peer learning visits where farmers could see technologies in action on real farms, helping demystify them. The network spanned topics from arable precision farming to organic farming innovations. Its approach of on-farm demos is key for small farms, which often trust seeing how a neighbour makes tech work more than any brochure.
- **EIT Food and SmartAgriHubs spin-offs** – Through the EIT (European Institute of Innovation & Technology), programs have supported agri-tech startups and testbeds. Many startups emerging in Europe target small farm issues – such as low-cost soil sensors (e.g., *Soilmentor*), farm management apps for specific niches (cheese production tracking, etc.), or new finance platforms (crowdfunding for farm adaptation projects). Encouraging entrepreneurship in this space ultimately gives farmers more solution options.
- **CAP AKIS and EU Farm Advisory** – Under the new CAP 2023–2027, each EU country must strengthen its Agricultural Knowledge and Innovation System (AKIS), integrating farm advisory, research, and education. There is funding for digital advisory tools and training of advisors. For example, some countries are creating "digital agriculture competence centers" for advisors. This policy framework means that in the coming years, small farmers should receive more coordinated support in adopting smart farming – advisors will be better equipped to guide them. It's important educators connect with these national AKIS plans to align curriculum with what advisors will need to know.
- **International programs (Global South)** – Organizations like the FAO, World Bank, and CGIAR run initiatives like Climate-Smart Agriculture (CSA) Country Programs, Digital Ag for Africa (e.g., the African Development Bank's TAAT program includes digital advisory components), and various bilateral projects. They often generate training manuals and case studies that can be used in courses to illustrate global perspectives. For instance, FAO's TECA platform shares simple tech practices (like solar drip irrigation designs, or wind-powered pumps) which can be paired with discussions on how modern sensors might improve those.

The mosaic of projects shows that smart farming is not a monolith – it's an evolving field with many players tackling different pieces of the puzzle. For educators, one challenge is staying updated, but the flip side is an abundance of real-world examples to enrich teaching. Annex 1 provides a summary table of selected initiatives, including these and the ones detailed above, to guide further exploration.

7 Skills and Competencies for the Digital-Green Transition in Farming

Advancing smart farming and climate adaptation on small and medium farms is as much a human challenge as a technical one. Farmers, farm managers, advisors, and even policymakers need new competencies to effectively implement and sustain these innovations. This chapter outlines the key skill sets required and relates them to established competence frameworks and educational priorities. It also considers the current gaps and how vocational training can address them, ensuring that the agricultural workforce is prepared for the twin transitions – digital and green – emphasized by EU strategies.

7.1 Competence Areas Overview

Building on analyses like the EU's GreenComp (European Sustainability Competence Framework) and DigComp (Digital Competence Framework), as well as sector-specific studies, we can group the competencies into several broad categories:

- **1. Sustainability & Climate Competences:** Understanding climate-smart agriculture practices, resource efficiency, and environmental stewardship. This includes knowledge of agroecology, regenerative practices, greenhouse gas mitigation strategies on farms, and climate risk management. It also involves systems thinking – seeing the farm as part of larger ecosystems and value chains – and the ability to implement practices that improve sustainability (e.g., nutrient management, biodiversity enhancement). *GreenComp* emphasizes embodying sustainability values and futures thinking; for farmers, this might translate to being able to plan farm changes with long-term climate scenarios in mind and valuing conservation goals alongside productivity (Mizik 2021).
- **2. Digital & Technical Competences:** Proficiency in using ICT tools, farm-specific software (FMIS, GIS mapping tools), and operating or at least interacting with digital hardware (sensors, drones, automation systems). It's not necessary that every farmer becomes a coder, but core skills like data literacy (being able to interpret graphs of sensor data or yield maps), basic troubleshooting of tech equipment, and understanding the principles of technologies at use (for example, knowing what an AI recommendation is based on, or how to recalibrate a sensor) are crucial. According to one survey, a barrier was that small farmers are "mostly not digitally literate enough to use the solutions and interpret the information". Thus, training needs to boost digital literacy specifically applied to farm contexts. Competences here also include information management (e.g., keeping digital records secure, understanding data privacy and ownership issues for farm data) and the ability to choose appropriate tech solutions (critical evaluation of tools). (Morrison 2024)
- **3. Agronomic and Domain-specific Competences:** These remain foundational – deep knowledge of crops, soils, livestock, pests, etc., because without it, digital tools cannot be applied wisely. What changes is the extension of this knowledge to integrate data analytics. For instance, a modern agronomic competence is knowing how to combine conventional field observations (like visual plant health assessment) with sensor readings and satellite indices to diagnose an issue. It's the ability to *blend traditional agronomy with evidence from digital sources*. This competence grows out of experience, but education can accelerate it by teaching with integrated approaches (like case studies where students use both manual and digital diagnostics). Domain knowledge also must expand to cover new

topics like precision farming techniques and data-driven decision frameworks (e.g., understanding what variable rate technology can do for seeding or fertilizing and what conditions make it effective).

- **4. Transversal Soft Skills:** Critical thinking, problem-solving, adaptability, and collaboration are extremely important. With fast-changing technology, farmers and advisors must be lifelong learners **–** able to continuously update their knowledge and adapt to new tools. Problem-solving is needed to troubleshoot technology and to make decisions when data is conflicting or uncertain. Communication skills are vital: whether it's a farmer explaining a technical problem to a support hotline, or an advisor convincing a skeptical farmer to try something new, clear communication (often across different knowledge backgrounds) makes a big difference. Leadership and initiative also come into play, especially for those who might champion digital innovation in their cooperatives or communities. In many rural areas, one or two "spark plug" individuals (often younger farmers or innovative advisors) lead the way – their ability to articulate the benefits and train peers in a new practice is crucial (essentially acting as peer educators). Therefore, teaching presentation, demonstration, and networking skills in agricultural training can pay off by empowering these local champions.
- **5. Entrepreneurship & Business Skills:** As we've seen, new business models (like RaaS, cooperatives, direct marketing using digital platforms) are part of the transition. Farmers need competences in basic economics (cost-benefit analysis of an investment in technology), in exploring new value streams (like using data to get sustainability certifications or carbon credits), and in navigating funding opportunities (grants for innovation, etc.). Risk management is another key skill – understanding and managing the risks associated with both climate and trying new technologies (which might fail or have bugs) and having strategies like phased adoption or insurance. The RBC Farmer 4.0 report from Canada (referenced in some literature) emphasized that tomorrow's farmers must be more data-focused and innovation-minded in running their farms. In the EU context, this aligns with fostering an entrepreneurial mindset where farmers see themselves not just as producers but as innovators and stewards with a business to evolve. (RBC Wealth Management 2019)

7.2 Competence Framework Alignment (GreenComp, etc.)

The European Sustainability Competence Framework (GreenComp) is structured around four interrelated areas: embodying sustainability values, embracing complexity in sustainability (systems thinking), envisioning sustainable futures, and acting for sustainability (agency). We can map farming competences to these: (BIANCHI et al. 2025)

- ***Embodying values:*** Farmers with this competence integrate sustainability into their decisions, e.g. willingly adopt practices that protect soil and biodiversity because they value those outcomes (even if initially inconvenient). Education can foster this through emphasizing concepts like land stewardship, or exposure to the long-term impacts of today's choices.
- ***Systems thinking:*** A farmer sees connections – how reducing tillage can improve soil moisture retention which buffers against drought and cuts irrigation needs or how adopting a solar pump not only cuts costs but aligns with climate goals. They consider the farm holistically, including social and supply chain aspects. Training exercises that involve mapping out all effects of a change (e.g., what happens if we introduce a robot weeder – impacts on labour, soil, neighbours, etc.) build this competence.
- ***Futures thinking (envisioning):*** Being able to plan for 5, 10, 20 years ahead under scenarios. For instance, envisioning what their farm might look like in a 2°C warmer world and what adaptations are needed. Or envisioning how emerging tech (like maybe gene-edited crops or new automation) might influence them and preparing proactively. Use of

scenario planning tools or even simple exercises like writing a "farm strategy 2030" help here.

- ***Acting for sustainability**:* This is about having the know-how and confidence to implement changes – essentially everything from trying an experimental plot for regenerative practices to participating in policy discussions (like being on a local water board as a farmer representative). We want farmers who not only have ideas but also the agency to put them into practice and advocate broadly. Micro-credentials or short courses that cover project management, grant writing for farm improvements, or leadership in cooperatives could strengthen this.

Meanwhile, the Digital Competence Framework (DigComp 2.2, updated in 2022) outlines competences like information and data literacy, communication and collaboration (digital), digital content creation, safety, and problem-solving. For farming, information and data literacy translates to being able to find and interpret digital farming information (like using an online pest database or reading sensor analytics) – which is essential in using any smart farming system. Digital communication might be as simple as participating in a WhatsApp group of local farmers to share tips, or as advanced as collaborating with researchers through an online platform (like DESIRA's forum or EIP-AGRI networking). Content creation could mean farm entrepreneurs building a digital presence (social media marketing of farm products or contributing data to open platforms). Safety encompasses both cybersecurity (keeping farm data and systems secure – imagine the importance as farms become IoT-heavy, even protection against hacking equipment) and personal safety (using drones or robots safely, understanding regulations). Problem-solving in DigComp is basically being able to troubleshoot or figure out new digital tools on one's own – an invaluable skill as tech continuously evolves. (Vuorikari, Riina Kluzer, Stefano Punie, Yves 2022)

7.3 Current Gaps and Educational Responses

From various studies, we know certain gaps:

- Traditional programs tend to focus heavily on farming systems knowledge (about half of training content) and less on information management and AI/robotics (which were present but not dominant). This indicates a need to boost the digital tech component in curricula. Notably, interactive and modern didactic methods like flipped classrooms or conversational learning were rare in current training, whereas they could be very effective for these topics. So there's room to innovate in teaching methods too. (European Union - DG Agri 2024; BIANCHI et al. 2025; Beers 2024)
- Many current farmers lack formal training opportunities post-school. The average age of farmers is high, and many haven't had exposure to digital training. So beyond integrating into formal education, extension and adult education must step up. That's where micro-credentials and short courses come in. The EU's promotion of micro-credentials (short, certified learning units) is ideal for this sector – for example, a 2-week online course on "Using Drones for Crop Monitoring" could give a mid-career farmer the exact skill needed without a full degree, and be recognized if done under a quality framework. (BIANCHI et al. 2025; European Union - DG Agri 2024; Beers 2024)
- A gap often cited is at the advisor level – advisors themselves need upskilling to serve as digital coaches. Without that, farmers won't get the support they need. Therefore, vocational excellence projects (like some running "training the trainer" programs) are vital and should be expanded. (Cordis 2025; Beers 2024)
- **Gender gap:** It's observed that women are underrepresented in usage of digital farming solutions (only about 25% of users in Africa, likely similar trends in other places). Encouraging women farmers to engage with smart farming (and ensuring solutions address their needs) is important. Part of that is making training inclusive – scheduling at times accessible for all, having women trainers or digital ambassadors, and highlighting how tech can reduce labour burdens often carried by women. (African Business 2019)

- **Soft skills gap:** Historically, ag education may not emphasize soft skills or entrepreneurship enough, focusing more on technical. But to navigate transitions, those skills are critical. EU policy (Osnabrück Declaration) calls for fostering these in VET. Activities like group projects, on-farm problem solving, interdisciplinary teamwork with IT students etc., in education can nurture communication, leadership, and innovation skills in a safe environment. (CEDEFOP 2020)

Educational responses to bridge gaps could include:

- Updating curricula to explicitly include modules on **Digital Agriculture** (covering basics of sensors, GIS, farm software, data analysis) and **Climate-Smart Agriculture** (covering adaptation practices, carbon farming, etc.), ideally integrated rather than siloed. (Mizik 2021)
- Implementing **practical digital skill training**: e.g., every student might learn to install and configure a simple sensor, fly a small drone (where legal), use an FMIS demo, and perform basic data analysis in Excel or specialized farm software. The confidence from having done it once in training will translate to easier adoption later. (Gupta und Kumar Pal 2025; Kumar et al. 2024)
- Strengthening **internships and exchanges**: e.g., placement at a tech-oriented farm or agri-tech company for students, and short exchange visits for current farmers to tech demonstration sites (leveraging programs like ERASMUS for young farmers or national farm exchange schemes). (Beers 2024; Cordis 2025)
- Encouraging **community learning and networking**: Educators can help students build networks (maybe through alumni groups focused on agtech, or connecting with local farmer tech clubs). The creation of communities of practice where farmers and advisors regularly share experiences is known to boost collective competence. (Beers 2024)
- Focusing on **holistic problem-based learning**: Presenting real farm case scenarios (like a small dairy wants to reduce emissions and improve profitability – what smart solutions and management changes could they implement?) forces learners to draw on sustainability knowledge, consider economics, and possibly propose a digital tool – thus combining multiple competences. (European Union - DG Agri 2024; BIANCHI et al. 2025)

The ultimate goal is to create a farmer and advisor population that is resilient and empowered – able to critically evaluate new technologies, adopt those that truly help their farm sustainability and productivity, and integrate them smoothly with their existing practices. The European Skills Agenda's target of training millions in digital and green skills will include tens of thousands in the agriculture sector. By aligning agricultural education and extension with these broader efforts, we can ensure small and medium farms have the human capacity to harness the smart farming revolution.
As a final note in this section, *Annex 2* provides a summary of key competencies and example specific skills within each category, as a reference for curriculum designers to ensure coverage of these critical areas.

8 Policy Alignment and Future Outlook

The push for smart farming solutions is happening in tandem with significant policy shifts in the EU. It's crucial to recognize how these technologies and practices align with – and can be leveraged to achieve – the goals of major policy frameworks such as the Common Agricultural Policy (CAP) 2023–2027, the European Green Deal (and Farm to Fork Strategy), and the European Skills Agenda. In this chapter, we briefly outline these policy drivers and discuss how they create both incentives and expectations for adopting digital, climate-smart farming on smaller farms. We also synthesize an outlook for adoption in the next five years, considering policy support, economic trends, and technological maturity.

8.1 Common Agricultural Policy (CAP) and Farm to Fork

The CAP has traditionally been a key shaper of farming practices through its subsidy and compliance rules. In the 2023–2027 CAP reform, there's a notable emphasis on sustainability and innovation. Three of the nine CAP specific objectives directly relate to climate and environment (climate change action, sustainable management of natural resources, biodiversity) and there is a cross-cutting objective on modernizing agriculture through knowledge and innovation (including digitalization). Member States' CAP Strategic Plans include measures to encourage precision farming, nutrient management, organic farming, and other sustainable practices, often with funding earmarked for farm modernization (e.g., grants for technology adoption, support for advisory services). (CITAB 2025)

For example, some countries provide capital grants or tax incentives for farmers who purchase precision ag equipment or decision support tools. There are also Eco-schemes within Pillar I that can indirectly promote smart farming – e.g., an eco-scheme paying for more precise fertilizer use could motivate farmers to use sensor-based systems to meet the requirements. Agri-environmental measures in Pillar II might fund training sessions on digital farming or subsidize advisory visits that include digital farm assessments.

Moreover, CAP places a strong focus on strengthening AKIS (Agricultural Knowledge and Innovation Systems). Each country must invest in farm advisory systems, innovation support services, and knowledge transfer, often highlighting digital skills. As noted, a healthy AKIS will mean advisors bringing smart farming knowledge to even the smallest farms. Projects like EIP-AGRI Operational Groups, funded under CAP, also often revolve around introducing a new technology or practice in a pilot region with farmers. These are opportunities for small farms to experiment with tech with financial and expert support.

The Farm to Fork Strategy, part of the Green Deal, sets concrete targets like reducing chemical pesticide use by 50%, reducing fertilizer losses by 50% (which roughly means 20% less fertilizer use), achieving 25% organic farming by 2030, and reducing antimicrobials in livestock by 50%. These ambitious targets cannot be met with business-as-usual; they implicitly rely on precision and innovation. For instance, how to reduce pesticides by half while keeping crop yields? Likely through integrated pest management bolstered by digital monitoring (so sprays are only done when and where needed, and alternatives like mechanical weeding or biocontrol are used). The Farm to Fork Strategy and the EU Biodiversity Strategy also call for better data and traceability in the food chain – something digital tech provides. To monitor reduction of inputs and environmental impact, robust farm data (possibly via sensors or automated reporting) will be essential. (European Commission 2020a)

Thus, policies are creating a permissive and encouraging environment for smart farming. They provide funding carrots and regulatory sticks that together push farms toward adopting these solutions. For a small farm, this might mean in the next grant application period, they find a measure that will co-fund a new zero-emission seeder or a farm weather station network. Or they find that participating in a carbon farming scheme (getting paid for soil carbon sequestration) is easier if they use a digital tool to quantify their practices. The convergence of sustainability goals and digital tools is clearly recognized in the political discourse. As an example, the European Commission's DG-AGRI has noted that "*digital transformation…is essential to meet environmental and climate goals*" and to maintain viability of small farms. (European Commission 2020a)

8.2 European Green Deal and Climate Policy

Beyond Farm to Fork, the broader European Green Deal aims for climate neutrality by 2050, with intermediate 2030 goals, and covers all sectors including agriculture. Agriculture is expected to reduce emissions (currently ~10% of EU GHG comes from agriculture) and increase carbon sinks (soil carbon, agroforestry). One can anticipate more initiatives like carbon farming incentives, where farmers get payments for carbon sequestration or emissions reductions (for instance, via the upcoming Carbon Farming Initiative). Smart farming can greatly aid this by measuring and verifying practices: remote sensing to estimate soil carbon changes, digital MRV (monitoring, reporting, verification) systems to track activities for carbon credits, and precision application to reduce nitrous oxide emissions from fertilizers. Already, some ag-tech companies offer platforms that help farmers generate carbon certificates by inputting their farm data and using models – a process that requires digital competency to participate in. (European Research Executive Agency 2025; Mizik 2021)

Another aspect is climate adaptation policy: the EU Climate Adaptation Strategy (2021) emphasizes making agriculture resilient. Climate-ADAPT (the knowledge platform) promotes adaptation options like precision agriculture and improved advisory services. At member state level, many have climate adaptation plans that involve investing in agricultural innovation (e.g., drought-resistant tech, early warning systems). So policy is aligning resources to drive adaptation, which often means technology adoption as a tool.

Financially, one must note the NextGenerationEU recovery fund (post-COVID) which had significant green and digital portions. Some countries allocated recovery funds to things like broadband expansion in rural areas, smart irrigation projects, or digital skill programs for rural youth. These one-time boosts can accelerate the enabling environment – for instance, widespread rural broadband by 2025 (targeted in some states) will remove a key barrier to IoT adoption.(van der Wal 2018)

8.3 European Skills Agenda and Education Policy

The European Skills Agenda (2020) sets targets for upskilling and reskilling Europeans, with special emphasis on digital skills (aiming to have 70% of adults with basic digital skills by 2025) and aligning training with the green transition. It encourages public-private partnerships on skills, more vocational education graduates, and a culture of lifelong learning. In agriculture, this means more support for farm apprenticeships, digital training workshops, and mobility for learners (Erasmus+ also now prioritizes green/digital projects heavily, as evidenced by projects like AGreen'Smart and Farmer 4.0 we discussed). The Osnabrück Declaration (2020) specifically targeted vocational education improvements: flexibility, inclusivity, modular learning (micro-credentials), and a focus on sustainability and digitalization. (European Commission 2020b; CEDEFOP 2020)

Concretely, we're seeing things like the launch of a Climate and Sustainability education initiative by the EU, and the "Education for Climate Coalition," which includes projects in farming communities. GreenComp itself (released by the JRC in 2022) is meant to guide educators in integrating sustainability competences across all fields – which agricultural education can be a pioneer in, given how tangible sustainability is in farming. There's also discussion on recognizing informally acquired skills (many farmers learn by doing or through non-formal means) – using mechanisms like proficiency badges or certificates that could be part of a future EU-wide micro-credential framework. (BIANCHI et al. 2025)

All this points to a policy environment that not only demands sustainable, digital farming but is also willing to invest in the people-side to make it happen.

8.4 Adoption Potential in the Next 5 Years

Taking into account the above policy drivers, technological trends, and the current state of small farms, what can we expect by 2030 in terms of adoption?

- **IoT and Sensors:** Likely a significant uptick. As connectivity improves (5G and LPWAN networks expanding in rural areas) and costs drop, more small farms will adopt basic sensor setups, especially for water management and microclimate monitoring. One can imagine that in some regions, water regulations or incentives might even require soil moisture sensors for farms above a certain size to optimize irrigation (some water-scarce areas already moving that direction). With user-friendly interfaces being developed, even farmers in their 60s might comfortably use a simple dashboard on their phone that shows tank levels or field humidity – akin to how many now use smartphones for weather. So expect IoT to become mainstream on medium farms and increasingly common on small ones, particularly for high-value crops or in cooperatives where cost is shared. (Kumar et al. 2024; Rafi et al. 2025; Getahun et al. 2024)

- **FMIS/Data platforms:** Within 5 years, having at least a basic digital record-keeping system might become almost a necessity for market access or compliance. Supermarkets and certifiers are pushing for more traceability (e.g., documentation of pesticide applications, animal welfare logs). Smart farming platforms help automate that, so adoption will be partly market-driven. We may see integrated farm data platforms offered by cooperatives or supply chains (for example, a dairy cooperative giving its farmers a herd management app that also feeds into quality traceability – win-win). So, adoption will broaden, though some smallest farms might still hold out with paper if not pressured. But new generation farmers will by default use digital tools as they take over. (Getahun et al. 2024; Kumar et al. 2024; Gupta und Kumar Pal 2025)
- **Robotics and Drones:** These will likely see more service-based presence. By 2030, it's plausible that in many European farming regions, there will be contractors who offer drone scouting or robot weeding as a service to multiple farms. Individual small farm ownership of field robots might still be limited (due to cost), but the cooperative model could have a few breakthroughs. If, for instance, a particular robot weeder or fruit picker proves its worth, a progressive cooperative might invest and that success could spur others. Market growth predictions are high, but realistic adoption in small farms might be moderate. However, certain subsectors (orchards, vineyards, high-value veggies) could be early adopters because labour issues are acute there and the economics favour automation sooner (some vineyards in France already use robotic mowers and by 2025 there will be more). Government policy can accelerate it too – e.g., France's recovery plan had grants for precision and robotic equipment. If extended, such subsidies reduce the payback time. (ECBF 2025; Robs4Crops 2024; GOFAR 2025)

One also expects incremental automation: tractors with auto-steering and section control (which many medium farms already use) might trickle down to smaller farms via second-hand equipment market or cheaper retrofit kits. So even if not full robots, partial automation (like smart sprayers that automatically shut off when overlapping) will increase. This aligns with environmental goals (less overlap = less excess chemical) and labour ease.

- **AI and Analytics Services:** Use of AI will probably be widespread but in a somewhat "invisible" way – embedded in many of the tools farmers use (FMIS, sensor platforms, market apps). So adoption in that sense will be high, though farmers might not label it as "I use AI" – they'll just use a tool that happens to have AI under the hood. One explicit area might be remote advisory/chatbots. Possibly within 5 years we might see farmers texting an AI advisor (trained on agronomic knowledge) for quick answers. Early versions exist now; by 2030 they could be quite refined. Adoption depends on trust and reliability – they won't replace human advisors but could fill in gaps. Given labour constraints in extension services, these could become common for basic queries. (Shahriar et al. 2025; Gupta und Kumar Pal 2025; Getahun et al. 2024)
- **Global South tech transfer:** Interestingly, some innovations from Africa/Asia might come to Europe's small farms. For instance, the idea of Hello Tractor-like services could inspire similar EU-wide platforms for machinery sharing. Or mobile payment and micro-insurance schemes tested in Kenya might find use in European contexts (imagine micro-insurance for a community-supported farm network). Collaboration and knowledge exchange is two-way. Already, Europe learns from smallholder innovation environments in developing countries about frugal innovation – doing more with less, which suits smaller EU farms too. So adoption doesn't only flow one way. (African Business 2019; Bhalla 2021)
- **Barriers and conditions:** Not everything will be rosy. Key conditions for achieving these adoptions: continued investments in training (so farmers know how to use and maintain

tech), strong advisory support, infrastructure (rural internet, electricity reliability, etc.), and addressing fragmentation (lots of different platforms that don't talk to each other could frustrate users – progress on data standardization is needed). Interoperability is being worked on; if successful, it will smooth adoption (no one wants to juggle 5 apps). The new EU Data Act and specific rules on ag data might clarify data-sharing obligations and rights, which can encourage more open ecosystems (Farmtopia's complaint about lack of reusable modules might be resolved by industry if pushed by policy or market demand. (Farmtopia 2023; Morrison 2024)

- **Economic viability:** If farm margins remain tight, technologies must prove either a cost-saving, a yield-boost, or a new income to be adopted. Many smart farming tools do show cost savings or yield increases, but often the profitability is context-dependent. As they get cheaper and more proven, we cross threshold where not using them may become the competitive disadvantage. Some interviewees have said in future, not using precision tech might be like not using tractors today – you *could* do without, but you'd likely fall behind. (Sanyaolu und Sadowski 2024; Getahun et al. 2024)
- **Generational change:** A wave of farm retirements is expected, with younger farmers (hopefully) stepping in either via succession or new entry. These younger people are generally more tech-comfortable, so they'll likely accelerate adoption naturally. However, in the EU many newcomers face capital constraints. One solution might be more cooperative models or group investments among young farmers – which tech can facilitate by linking them. (Hirt 2021; GOFAR 2025)

In conclusion, by the late 2020s, we can expect smart farming to move from pilot to commonplace in many aspects on European farms, including small and medium ones. There will still be diversity – some high-tech "lighthouse" farms using the full suite, some middle adopters using a few key tools, and some traditionalists (often constrained by finance or mindset) using minimal tech. The aim of education and policy is to shift the distribution towards more farms in the middle and leading edge, and fewer completely left behind. Given the climate urgency and structural changes, doing nothing is not really an option; small farms will either adapt (with support) or struggle. Fortunately, the synergy of EU policy support, technological advancement, and a generation more attuned to sustainability gives hope that the adoption curve will steepen in an inclusive way.

9 Conclusion

Smart farming solutions are no longer a futuristic concept but an evolving reality transforming how food is produced on farms of all scales. For Europe's small and medium-sized farms, these technologies – from simple soil sensors to sophisticated AI-driven platforms – offer a path to reconcile productivity with sustainability. They enable farmers to adapt proactively to climate change, whether by optimizing water use during droughts, shielding crops from extreme weather with better forecasts, or cutting emissions through precision input management. At the same time, smart tools can lighten drudgery and improve economic viability, helping small farms remain competitive and attractive for the next generation. As one cooperative leader put it, if supported well, autonomous and digital solutions could "*become key to making our small farms profitable and preventing them from being abandoned.*" (GOFAR 2025)

However, technology alone is not a silver bullet. The successful examples we've explored underscore a holistic approach: co-creation with farmers, integration with traditional knowledge, robust advisory support, and enabling policies. Projects like FarmTOPIA and DESIRA highlight that adoption only happens when innovations truly fit farmers' needs, when costs and benefits are transparent, and when farmers have the skills and confidence to use them. In other words, the agrarian transition is as much about human and social innovation as about gadgets. (Democratizing digital farming through smart solutions for small farms | EU CAP Network 2025)

For educators and curriculum developers, this means the mandate is clear: embed digital and sustainability competencies into agricultural training at all levels. Empower learners to be critical thinkers who can navigate a data-rich farming environment and make judicious decisions that favour long-term resilience. Foster an innovation mindset – today's farmers and advisors must be agile learners, experimenters, and even entrepreneurs. As we've detailed, aligning curricula with frameworks like GreenComp ensures that values of sustainability and systems thinking become second nature to new graduates. Incorporating hands-on digital tool experience and case studies from projects around Europe (and the Global South) grounds theoretical knowledge in practical reality. The Global South chapter underlined that in Africa and other regions, necessity and opportunity have driven rapid adoption of certain digital farming services (like mobile finance, remote advisory, equipment sharing), albeit with challenges of scale and inclusion (Bhalla 2021). European small farms can learn from these experiences – for example, the power of simple mobile solutions and the importance of design for low-literacy or resource-constrained users. In an interconnected world, innovation flows both ways. Partnerships (through Erasmus+, FAO networks, etc.) that link European farming educators with those in Africa, Asia, and Latin America can spur mutual learning and ensure that smart farming does not develop in a vacuum but is informed by diverse contexts. (Bhalla 2021)
Looking ahead to the next five years, we anticipate a considerable uptick in smart farming adoption on small and medium farms, driven by the confluence of policy incentives, generational change, and technology maturation. There may well be setbacks or slower uptake in some areas – for instance, if a promised technology underdelivers or if economic conditions make farmers risk-averse. It will be important to monitor and openly share both successes and failures. The role of EU and national programs in facilitating this (through innovation networks, open data portals, etc.) will remain crucial. By 2030, farming could look quite different: it might be routine for a family farmer to check a smartphone dashboard each morning for tailored advice, to let a small robot handle the weeding, to market products via digital platforms, and to receive payments not just for yields but for ecosystem services quantified by sensors and satellite data. Achieving that vision in an equitable way – where even the smallest farms and the most remote rural areas are included – is an ambitious undertaking, but one that the EU is strategically backing. (European Commission 2025)

In conclusion, smart farming is a key enabler on the journey to a climate-resilient, sustainable agrifood system, but it must be pursued smartly – with a focus on people, education, and appropriate application. Small farms form the fabric of European rural life; equipping them with the right tools and skills means they can continue to thrive and innovate through the challenges of climate change and economic pressure. For educators, this is a call to action to refresh and enrich programs, for policymakers a call to maintain supportive frameworks, and for farmers and advisors a call to engage with curiosity and openness. As the desk study has shown through myriad examples, when these pieces come together, the results are impressive: higher yields with fewer inputs, better incomes with lighter workloads, and farming communities that are both custodians of tradition and pioneers of the future.
With the foundations laid by current initiatives and a clear direction from strategic policies, the next decade can indeed usher in a smarter, greener, and more resilient agriculture, anchored by the ingenuity and adaptability of Europe's farmers.

10 Annex 1: Selected Initiatives and Projects in Smart Farming and Climate Adaptation

The following table provides a summary of key initiatives referenced in the report, along with their focus, timeframe, and relevance. These examples can serve as a resource for further exploration or incorporation into educational materials.

Initiative / Project	**Type & Duration**	**Focus and Outputs**	**Relevance to Small Farms & Education**
SmartAgriHubs (EU H2020)	Network of Digital Innovation Hubs (2018–2022)(Cordis 2025)	Created a Europe-wide ecosystem of 140+ Digital Innovation Hubs, ran 28 flagship innovation experiments demonstrating digital tech (IoT, AI, robotics) in farming. Developed one-stop-shop support in 9 regional clusters, connecting tech providers, researchers, and farmers (Cordis 2025).	Brought digital solutions to all European regions, including those dominated by small farms. DIHs offer local training and tech trials for farmers, lowering barriers to entry. Outputs (case studies, best practices) are valuable teaching tools to show real-world impact of digital farming. (Beers 2024)
DESIRA (EU H2020)	Research & Network (2019–2023)(Desira 2025)	Assessed socio-economic impacts of digitalization in 20 rural "Living Labs". Explored how tech (precision ag, rural broadband, e-services) affects rural communities and different farm types. Produced a Rural Digitization Forum, policy roadmap, and tools like the "Socio-cyberphysical framework" for analysing digital transformations.	Highlighted the need for inclusion and skills in digital roll-out Identified barriers specific to small farms (skills, infrastructure) and recommended strengthening advisory services. Educationally, provides case studies on digital adoption challenges and emphasizes participatory approaches (e.g., involving farmers in tech design).

Initiative / Project	Type & Duration	Focus and Outputs	Relevance to Small Farms & Education
FarmTOPIA (EU Horizon Europe)	Innovation Pilots (2023–2026)	Co-creating low-cost, farmer-driven digital solutions for small farms. Running 18 pilots across 15 countries in diverse sectors. Focus on modular, reusable tech and new business models (e.g., cooperative ownership, subscription services) to **"democratize"** digital farming. Aims to provide access/training to 64,000+ small farms, bridging digital divide.	Directly targets small farm needs – ensuring tech fits local problems and budgets. Will generate examples of successful adoption via co-design, which can be instructional for extension training. Emphasizes multi-actor engagement (farmers, advisors, IT developers) – a model for student projects or living lab exercises in curricula. Outcomes will likely include new open-source tools and cost-benefit data for small-scale deployment.
Farmer 4.0 (Erasmus+)	Education & Training (2019–2021)	Developed innovative teaching methods for Agriculture 4.0 skills. Combined VR simulations, FabLab maker activities, and farm job shadowing to facilitate mindset shift and skill acquisition among young farmers and ag students. Produced e-learning platform and guidelines for experiential learning in ag.	Helped modernize agricultural VET by introducing immersive and hands-on learning. Especially relevant for engaging youth and overcoming technophobia in older generations via inter-generational learning. Its modules and VR scenarios can be reused in other training contexts. Demonstrated how to teach not just the "how" of tech, but the "why," by placing learners in realistic farm-of-the-future situations.

Initiative / Project	Type & Duration	Focus and Outputs	Relevance to Small Farms & Education
AGreen'Smart (Erasmus+)	Academic Network & Curriculum (2020–2023)	Built a cross-border **teaching network** linking digital agriculture with climate-smart practices. Created transdisciplinary courses and an open online course catalogue on topics like precision farming, AI, climate adaptation, agroecology. Trained 3 cohorts of students and laid groundwork for a joint Master's in Smart & Green Agriculture (CITAB 2025).	Ensured future ag professionals are dual-skilled in sustainability and digital tech. Outputs (syllabi, course materials) can be leveraged by other institutions to update their programs. Involved industry and authorities to align skills with job market needs, which benefits graduates (including those entering advisory roles for small farms). Promotes lifelong learning by making some content available to the broader public (e.g., farmers, alumni) (CITAB 2025)
VISYFARM (Erasmus+)	Research & Education (2020–2023)	Studied viability of small farms run by young farmers under Green Deal and CAP reforms in Central/Eastern Europe. Analysed policy measures (e.g., young farmer supports, Farm-to-Fork targets) and on-ground realities in CZ, PL, SK, HU, LT. Produced a comprehensive publication with findings and recommendations for supporting these farms.	Although focused on socio-economic viability, it highlights importance of upskilling and innovation for small farms to meet Green Deal requirements. Provides case studies of young farmers implementing new practices. Educators can use these to discuss entrepreneurship and policy impact on farm management. Recommendations stress need for training in business

Initiative / Project	Type & Duration	Focus and Outputs	Relevance to Small Farms & Education
			planning, diversification, and innovation for the next generation of farmers.
Robs4Crops (EU H2020)	Pilot & Demonstration (2021–2024)(Robs4Crops 2024)	Pioneered an integrated robotic farming system (for spraying, weeding) with pilots in 4 countries. Emphasized a holistic Robot-as-a-Service model and open architecture. Developed a cost-benefit assessment tool and open-source "digital twin" and Farming Controller to ease adoption. Demonstrated retrofitting existing tractors into autonomous units in different contexts (vineyards, orchards, field crops)(Robs4Crops 2024).	Showcased how automation can be deployed on real farms, including addressing non-tech aspects like financing, insurance, and user training. The RaaS model is directly relevant to small/med farms – offering a blueprint to access robotics without heavy investment. Its open-source tools lower barriers for innovators/startups to further develop affordable robotics. Educationally, the project's outputs can enrich engineering or farm management courses (students can experiment with the digital twin, for example, or analyse the provided cost analyses to learn about evaluating innovation). (Robs4Crops 2024)
Hello Tractor ("Uber for Tractors")	Private/Development initiative (2014–ongoing) (Bhalla 2021)	Nigeria-based startup operating in 13 African countries, connecting small farmers with tractor services via a mobile app and IoT device on tractors. Over	Global South example of solving mechanization gap with digital tech. Illustrates a successful service model that could inspire similar approaches in

Initiative / Project	Type & Duration	Focus and Outputs	Relevance to Small Farms & Education
		500,000 farmers served, 55% of whom had never accessed mechanization before (Bhalla 2021). Farmers aggregate demand to rent tractors affordably; tractor owners optimize usage and track machines via GPS (Bhalla 2021).	Europe (e.g., app-based machinery rings). Emphasizes how low-tech (tractors) + high-tech (mobile app, GPS) yields social impact (labour saving, timeliness). Can be used in training to demonstrate innovation addressing smallholder needs and to spark discussion on adapting solutions across regions.
Farmerline (Ghana)	Social enterprise (2013–ongoing)	Provides voice and SMS agricultural advisory in local languages to small farmers (weather forecasts, agronomic tips, market prices, financial education). Reaches about 1 million farmers across West Africa. Also offers a digital marketplace connecting farmers to inputs and buyers.	Shows the power of **mobile communication** for farmer education and decision support. Relevant to European context for reaching remote or older farmers who may prefer voice messages over apps. Demonstrates inclusive design (catered to various literacy levels). In an educational setting, it exemplifies user-centered service design and could motivate development of analogous services for European farmers less reached by traditional extension.

Initiative / Project	Type & Duration	Focus and Outputs	Relevance to Small Farms & Education
ClimateSmart Agriculture (various)	FAO & World Bank programs (2010s–ongoing) (Mizik 2021)	Global framework and country projects to promote CSA, which integrates productivity, resilience, and mitigation. Projects often include technology components like climate-informed advisory, stress-tolerant crops, or resource-efficient practices. Many generate training materials and case studies (e.g., FAO's curricula on CSA).	Provides conceptual grounding for linking smart farming to climate goals. The triple-win approach of CSA aligns with EU Green Deal targets and smart tech enabling those wins. Educators can draw on CSA case studies (like water-saving irrigation schemes or digital climate advisory services) to illustrate big-picture impact. Also often highlights participatory approaches and the importance of local knowledge integration – reinforcing lessons from our report about blending tech with tradition. (Mizik 2021)

(Table: Overview of select initiatives. These illustrate a range of efforts from high-level networks to on-farm pilots and educational innovations. They collectively address technical, social, and educational dimensions of the agrarian digital transition.)

11 Annex 2: Key Competencies for Smart, Sustainable Farming

This annex summarizes the critical competencies (knowledge, skills, attitudes) that farmers, advisors, and agricultural students should develop to effectively implement smart farming solutions and drive agrarian transition in the context of climate change. The competencies are grouped into four categories with examples:

A. Sustainability & Climate Competences

- *Systems Thinking:* Ability to understand farm systems holistically, recognizing interactions between soil, water, crops, climate and how a change in one aspect (e.g., introducing a cover crop) affects others (soil moisture, pest pressure, etc.) (Mizik 2021).
- *Climate Adaptation Strategies:* Knowledge of climate risks (droughts, floods, new pests) and corresponding adaptive practices (drought-tolerant crop varieties, water harvesting, diversified cropping). Skill in creating and implementing a farm adaptation plan (e.g., adjusting planting calendars based on seasonal forecasts).

- *Mitigation & Environmental Impact:* Understanding of farming's environmental footprint (GHG emissions, nutrient runoff, biodiversity impacts). Ability to apply practices that reduce emissions (precision fertilization to cut N_2O, agroforestry for carbon sequestration) and to monitor/improve resource efficiency. Familiarity with tools for estimating carbon footprint or energy use on farm. (Getahun et al. 2024)
- *Sustainability Values & Compliance:* Strong ethos of stewardship for land and community. Commitment to meeting and exceeding environmental standards (e.g., comfortable with record-keeping for organic or eco-scheme compliance). Advocating for sustainable practices among peers (acting as a role model or "green champion").

B. Digital & Technical Competences

- *Data Literacy:* Ability to read, interpret, and derive insight from data – whether it's a simple rainfall chart, a yield map, or an AI-generated recommendation. Knowing basic statistics to make sense of variation and trends (for instance, comparing test plot yields).
- *ICT Proficiency:* Practical skill in using farm management software (entering data, generating reports), smartphone apps for farming, and common office tools (spreadsheets for budgeting or analyzing trial results). Capability to learn new applications quickly (since software evolves).
- *Equipment Operation & Troubleshooting:* If using sensors, drones, automation – ability to operate them safely (e.g., knowing drone flight rules, calibrating a sensor) and perform first-level troubleshooting (checking connections, restarting systems, etc.). Understanding of machine guidelines and maintenance needs (cleaning sensors, updating firmware).
- *Digital Communication & Collaboration:* Using digital channels to communicate – e.g., participating in online farmer forums, using messaging apps with supplier groups or advisor networks. Collaborating through digital means, such as contributing farm data to a collective platform or coordinating with machinery sharing via apps. Awareness of netiquette and effective online information sharing (possibly in multiple languages, given EU context).
- *Cybersecurity & Data Privacy:* Basic practices for digital safety – using strong passwords for farm software, being cautious with unknown emails/devices (preventing malware on farm PCs or machines), understanding rights over farm data (who owns sensor data uploaded to the cloud, etc.). This ensures confidence in adopting cloud-based and IoT solutions without falling victim to data misuse.

C. Agronomic & Management Competences

- *Core Agronomy/Livestock Knowledge:* A firm grounding in crop biology, soil health, integrated pest management, animal husbandry, etc. – as the foundation upon which tech is applied. (E.g., knowing pest life cycles and economic thresholds makes sensor pest alerts meaningful to interpret.)
- *Precision Farming Techniques:* Specific know-how on precision practices – e.g., how to create and use variable-rate application maps, how to conduct and utilize soil sampling geospatially, or how to use GPS in field operations. Also understanding limits of precision ag (like minimum field sizes or calibration needs) to apply appropriately.
- *Enterprise Management & Economics:* Skills in whole-farm planning – budgeting, cost-benefit analysis of innovations, marketing strategies (potentially using e-commerce or social media). Calculating ROI for a new tech investment (like an IoT system) and assessing financing options. Essentially combining agronomy with business acumen to maintain profitability during transitions.
- *Regulatory and Policy Literacy:* Being up-to-date with relevant policies (CAP schemes, environmental regulations, data laws). Knowing how to take advantage of funding opportunities for innovation (writing a simple grant or application for a tech subsidy).

Understanding and navigating certification or compliance requirements digitally (like using an app to keep spray records for an audit). (Horizon-europe.gouv.fr 2025)

D. Transversal Soft Skills

- *Critical Thinking & Problem Solving:* Questioning assumptions and hype around new tech – ability to critically evaluate if a solution is suitable for one's context (does this solve my problem? what evidence?). Troubleshooting issues when they arise – e.g., if yields didn't improve after using a tool, analyzing whether it was tool fault or implementation gap. (Morrison 2024)
- *Adaptability & Continuous Learning:* Willingness and ability to continuously learn new methods or technologies. This might mean attending workshops, seeking information online, or experimenting on a small scale before scaling up (and learning from failures). As climate and tech evolve, this agility is key.
- *Communication & Leadership:* Effectively communicating with diverse stakeholders – explaining needs to a tech developer, or explaining a new practice to farm workers. For advisors, translating complex digital concepts into farmer-friendly language. Leadership could involve spearheading a group innovation (like forming a machinery ring, or leading a demo event) – requiring persuasion, organization, and teamwork skills.
- *Collaboration & Networking:* Competence in working with others: e.g., participating in cooperative groups, innovation networks, or multi-actor project teams (like those in EIP-AGRI). Knowing how to share knowledge generously and also learn from peers – building a professional network that can support problem-solving. An example is an advisor collaborating with IT experts to develop a local app, or farmers in a region forming a WhatsApp group to collectively negotiate with a tech provider for a discount.
- *Entrepreneurship & Initiative:* Especially for younger farmers or those diversifying, the ability to spot opportunities (like a niche market or a gap in services), take calculated risks, and mobilize resources (financial, human) to pursue innovation. This includes resilience – being prepared that not every experiment works, but treating it as a learning step.

Each of these competences contributes to creating **"Farmer 4.0"** – a term used to describe a farmer who is strategic, data-savvy, and systems-oriented. Likewise, advisors or educators with these competences can effectively guide and train others. Embedding these into educational programs (through dedicated modules, practical exercises, and assessments that test these skills) will prepare the workforce to harness smart farming technologies to their full potential and steer the agrarian transition in a positive direction. (RBC Wealth Management 2019)

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