USAGE-NG

Up-skilling Agricultural Engineering
Next Generation

A Compendium of smart farming technologies

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1 Executive Summary

Activity 3.4 developed a comprehensive and practice-oriented compendium of Smart Farming technologies and implemented a dissemination strategy to ensure its uptake among educators, farmers, and agricultural stakeholders. The compendium consolidates essential technologies, application areas, opportunities, risks, and adoption factors relevant for modern agricultural production. It was informed by technological reviews, user surveys, and research on digital knowledge transfer and international adoption patterns. Dissemination activities integrated the compendium into university courses, vocational training settings, and international academic networks. Overall, Activity 3.4 provides a solid foundation for teaching and learning materials in smart farming and strengthens technology-oriented education for smallholder farmers and students alike.

2 Overview

Activity 3.4 focused on designing and implementing a comprehensive digital compendium of Smart Farming and Internet-of-Things (IoT) technologies and on establishing dissemination pathways to promote its use among educational institutions, practitioners, and agricultural stakeholders. Led by the Technical University of Munich and supported by BOKU, ENAMA, and the Free University of Bozen-Bolzano, the activity consolidated technological, pedagogical and organisational knowledge essential for modern agricultural engineering education.

The development of the compendium was informed by an extensive review of relevant smart farming technologies, empirical user insights, behavioural adoption studies and educational needs assessments. A major input came from research that examined the technological landscape of digital agriculture, including guidance systems, machine communication standards, telematics, farm management software, remote sensing platforms, sensor-based monitoring tools, robotics, automation systems, documentation technologies, and decision-support solutions. These analyses outlined how such technologies are used in practice, what benefits they offer to farmers, and what kinds of competences learners need in order to use them effectively.

Additional data were generated through surveys among agricultural training participants and farm managers. These surveys revealed a clear and growing interest in learning more about smart farming tools, combined with a strong preference for hands-on and problem-oriented learning formats. Respondents highlighted topics such as precision agriculture, fertilisation technologies, digital farm management systems, and sensor-based applications as particularly relevant for their daily work. They also indicated that time availability, perceived complexity, limited infrastructure and uncertainty about economic benefits remain major adoption barriers.

Complementary insights were obtained from research on social media and knowledge transfer in agriculture. This research showed that younger and digitally active farmers increasingly use social media channels to access agricultural information, including updates on smart farming technologies. At the same time, traditional teaching methods remain highly valued, and social media is perceived as an effective supplement rather than a replacement for structured training. Many respondents expressed interest in receiving trustworthy, institutionally produced content—especially explanatory videos and concise, practical materials.

The activity further integrated comparative international findings on smart farming adoption. These insights highlighted differences between European and North American farmers in terms of digital readiness, technological exposure, cost-benefit expectations and infrastructural constraints. They also demonstrated that farmers in all regions prefer educational materials that are directly applicable to operational challenges and tailored to real-world decisions.

Based on this diverse evidence, the project produced a digital compendium of smart farming technologies and associated learning content. The compendium is structured to support educators, students, trainers and smallholder farmers by organising information across technology categories, application areas, opportunities and risks, as well as educational and

adoption considerations. The resource serves as a foundation for teaching modules, micro-credentials, blended learning activities and extension-oriented training.
Dissemination activities for Activity 3.4 followed a multi-layered strategy. The compendium was introduced into university courses, vocational training modules, workshops and pilot teaching activities. Partners shared the compendium during international academic events, within agricultural training networks, and through bilateral cooperation with institutions in Europe, North America and Asia. These efforts strengthened international visibility, facilitated knowledge exchange and ensured that the compendium reached its intended user groups.
Overall, Activity 3.4 successfully delivered a comprehensive, practice-oriented compendium of smart farming technologies and implemented effective dissemination measures. The activity made a significant contribution to the project's overarching goal of supporting innovative, technology-enabled agricultural education and enabling smallholder farmers to benefit from digitalisation.

3 Compendium of Smart Farming Technologies -short overview-

This first compendium provides an overview of key smart farming technologies, their agricultural applications, their potential benefits and barriers, and considerations for teaching and adoption. It is designed as an educational foundation for students, teachers, advisors and smallholder farmers.

3.1 Core Smart Farming Technologies

3.1.1 Positioning and Guidance Technologies

Smart farming systems rely heavily on satellite-based positioning technologies, which enable machinery to operate with high precision. Guidance systems assist with steering, reduce overlaps, support automated fieldwork and enable data-driven operations.

3.1.2 Machine Communication and Control Systems

Standardised communication protocols between tractors and implements ensure coordinated operation, compatibility and improved efficiency. Universal terminals, task controllers and automation interfaces allow machines to work in synchrony.

3.1.3 Telematics and Connectivity Tools

Telematics systems link machines to cloud platforms, enabling data exchange, fleet monitoring, remote diagnostics and digital workflow management. These systems enable farmers to track operations in real-time and integrate machine data into their decision-making processes.

3.1.4 Farm Management Information Systems (FMIS)

FMIS platforms serve as central hubs for planning, documentation, resource management, compliance reporting and integration of sensor and satellite data. They enable farmers to analyze field performance and optimize production steps.

3.1.5 Sensor Systems and Remote Sensing

Smart farming makes extensive use of soil, crop, environment and machinery sensors. Remote sensing from satellites or drones provides maps used for variable application and monitoring. Sensors deliver real-time data for precise decision-making.

3.1.6 Robotics and Automation Technologies

Technologies such as autonomous tractors, robotic weeding systems, automated feeding systems and sensor-supported tool carriers contribute to labour reduction, precision improvements and sustainability across production systems.

3.2 Application Fields in Agriculture

3.2.1 Soil and Tillage Management

Smart sensors and mapping tools allow farmers to adapt tillage intensity to soil variability, reduce fuel use and avoid unnecessary soil disturbance.

3.2.2 Crop Rotations and Field Planning

Data-driven tools support field mapping, crop rotation planning and mixed-cropping strategies that enhance resilience and sustainability.

3.2.3 Precision Fertilisation

Sensor-based fertilisation enables variable nitrogen, phosphorus and potassium applications based on actual plant and soil needs. This reduces input costs and environmental impacts.

3.2.4 Precision Crop Protection

Camera-assisted systems identify weeds and diseases, enabling targeted applications, while robotic systems reduce the need for chemical inputs.

3.2.5 Documentation and Compliance

Digital tools automate record-keeping, ensure traceability and support compliance with environmental and agricultural regulations.

3.3 Opportunities, Barriers and Risks

3.3.1 Opportunities

- Improved efficiency and reduced input consumption
- Higher and more stable yields
- Enhanced sustainability and reduced environmental impacts
- Better documentation and compliance support

3.3.2 Barriers

- High investment costs
- Limited digital infrastructure in rural regions
- Skill gaps among farmers and educators

- Perceived complexity of new technologies

3.3.3 Risks

- Data privacy and ownership concerns
- Increased dependency on manufacturers
- Potential for over-automation or rebound effects

3.4 Adoption and Education Considerations

3.4.1 User Needs and Preferences

Farmers and trainees express a strong interest in practical, application-oriented training. They prefer examples, demonstrations, and small learning modules that can be integrated into daily work.

3.4.2 Role of Social Media and Digital Channels

Social media platforms are playing an increasingly important role in informal knowledge transfer, particularly among younger farmers. They are most effective when used as complementary tools alongside structured training.

3.4.3 Educational Strategies for Smallholders

Smallholders benefit from blended learning approaches that combine in-person demonstrations, digital tutorials, and mobile-compatible learning units. Clear, concise explanations and directly applicable content are essential. There is no uniform solution because agriculture is region-specific and depends on local site conditions, such as climate, soil, and topography.

4 Compendium of Smart Farming Technologies

4.1 Introduction

Agriculture is undergoing a profound transformation driven by digitalisation, automation and data-based decision-making. Smart Farming encompasses a broad set of technologies that support farmers in optimising production processes, reducing environmental impacts and improving economic resilience. While these developments offer considerable opportunities, especially regarding the efficient use of resources, their adoption varies widely across agricultural structures. Smallholder farmers in particular face a range of challenges, including limited access to training, infrastructural gaps, cost constraints and a general uncertainty about the relevance of digital tools to their specific production systems.
This compendium has been developed to provide educators, trainers and agricultural practitioners with a coherent and accessible overview of central Smart Farming technologies. Beyond merely describing technical components, the text aims to contextualise digital tools within real agricultural practice, outline adoption conditions, and offer guidance for teaching and learning. By drawing on technological analyses, survey insights and observations of knowledge-transfer dynamics, the compendium helps translate complex innovations into usable educational concepts. It is designed as a flexible resource that can support vocational training, university courses, extension services and smallholder-oriented learning formats.

4.2 Core Smart Farming Technologies

Smart Farming technologies span a wide spectrum of tools and systems that enable more precise and informed decision-making. In practice, many of these technologies are interconnected, forming comprehensive production and information ecosystems. This section outlines the most relevant technological domains, explaining their functions, benefits and implications for agricultural learning environments.

A foundational element of digital agriculture is the use of positioning and guidance technologies. Satellite-based systems in combination with correction signals allow tractors and implements to move with remarkable precision across the field. Automated steering significantly reduces overlaps, minimises input waste and improves the quality of fieldwork. For many farms, especially smaller ones, these systems often represent the first step into Smart Farming because they offer quickly visible advantages and are relatively easy to understand once demonstrated. Their didactic value lies in their tangibility: learners can immediately observe operational improvements and gain practical experience with digital interfaces.

Another crucial component of modern agriculture is machine communication and control. Standardised protocols enable tractors and implements to interact and share operational data, which then allows for automated section control, variable rate application and complete operational documentation. Although these functions are often embedded in machinery already present on farms, many operators remain unaware of their full potential. This reveals a considerable educational need: training must focus not only on new equipment but also on unlocking capabilities of existing systems. By understanding how machine communication operates, farmers can make better use of their equipment and reduce unnecessary inputs.

Connectivity and telematics systems expand the digital dimension of agriculture even further by linking machinery, sensors and farm-level software platforms. Real-time data exchange can enhance planning and monitoring processes and facilitate remote support. However, limited rural internet coverage and concerns regarding data security often restrict the full utilisation of these systems. In educational contexts, it is therefore important to present realistic operational scenarios, including offline workflows and practical solutions for intermittent connectivity.

Farm management information systems (FMIS) serve as the digital backbone of many Smart Farming applications. They bring together operational data, regulatory documentation, financial planning and agronomic information in one platform. While FMIS can greatly reduce administrative workload, their comprehensive interfaces may appear overwhelming to new users. Training formats benefit from a step-by-step approach: learners are best introduced to FMIS functionalities through concrete use cases, such as recording a pesticide application or preparing a nutrient management plan. By gradually broadening the application range, users develop confidence and recognise the system's value for farm organisation.

Remote and proximal sensing technologies add a further analytical layer to Smart Farming. Sensors measuring soil moisture, nutrient levels or crop biomass, as well as satellite and drone-based imaging, provide valuable information on field variability and plant status. These technologies enable targeted interventions, such as adapting fertilizer or irrigation strategies to specific field zones. Farmers regularly express interest in such capabilities but are often unsure how to interpret data or integrate it into daily routines. Education should therefore place strong emphasis on basic principles of sensor accuracy, data interpretation and practical decision-making.

Robotics and automation represent an increasingly significant part of agricultural innovation. Autonomous field robots, robotic weeders, automated feeding systems or milking technologies can reduce labour requirements and improve production consistency. Their adoption on smaller farms, however, often depends on reliability, maintenance requirements and cost-effectiveness. In teaching, a realistic discussion of limits, safety requirements and practical conditions for automation is essential to avoid inflated expectations and foster informed decision-making.

4.3 Application Domains of Smart Farming

Smart Farming technologies manifest in various fields of agricultural practice, often providing targeted improvements to specific operations. In soil and tillage management, digital tools allow farmers to adjust tillage depth and intensity based on soil conditions, reducing fuel consumption and preventing soil degradation. When combined with yield maps or soil maps, such measures support long-term soil health.
Crop rotation and field planning also benefit from digitalisation. By integrating remote-sensing information with planning tools, farmers can design rotations that enhance resilience, promote biodiversity and support nutrient cycling. These tools help visualise complex spatial and temporal interactions that shape crop performance.
Precision fertilisation is one of the most widely recognised application areas. Digital nitrogen sensors, biomass imagery and soil analyses enable farmers to apply nutrients more accurately, reducing environmental impacts and decreasing input costs. Precision crop protection similarly reduces pesticide use by applying chemicals only where needed or by integrating robotic systems that mechanically remove weeds.
Digital documentation plays an increasingly important role as regulatory requirements intensify. Automated documentation systems embedded in tractors, sprayers or FMIS platforms help farmers keep accurate records while reducing administrative burden. This not only supports traceability and compliance but also enhances transparency throughout the food production chain.

4.4 Opportunities, Barriers and Risks

The potential benefits of Smart Farming technologies are substantial. Many tools help farmers reduce input use, improve yields, increase operational efficiency and enhance sustainability. Smart systems also contribute to more precise environmental stewardship, including reduced fertilizer leakage and more targeted pesticide use. The ability to collect and utilise data across production cycles can support continuous learning and long-term optimisation.
However, adoption barriers remain significant. Initial investment costs can be prohibitive, especially for smaller farms. Rural connectivity constraints and limited technical support further restrict the implementation of more advanced systems. Many farmers perceive digital tools as complex, time-consuming or insufficiently reliable in their specific production environments. These perceptions are reinforced when training is unavailable or when technologies are introduced without sufficient contextualisation.
Risks associated with Smart Farming include concerns about data privacy, dependency on software providers, potential rebound effects where technological efficiency leads to increased intensity, and the widening of digital divides between farm types or regions. Education and training must address these challenges directly to ensure that digitalisation contributes to equitable and sustainable agricultural development.

4.5 Adoption Factors for Smallholders

Smallholder farmers exhibit both strong interest in and caution about digital technologies. Survey results consistently show that farmers are motivated by practical benefits, particularly when technologies help save time, reduce inputs or simplify documentation tasks. Many smallholders highlight the need for training formats that are accessible, concise and directly relevant to their production systems. Short learning units, demonstrations and step-by-step explanations are especially valued.
At the same time, limited time availability, uncertainty about economic returns and unfamiliarity with digital interfaces are common barriers. Farmers often express concerns about relying on

cloud-based systems or sharing operational data. They also frequently report infrastructural challenges such as inadequate internet coverage or outdated hardware.
Digital knowledge transfer increasingly occurs through social media platforms, which expose farmers to new technologies in informal ways. While these channels support awareness building, they often lack technical depth and cannot replace structured training. Farmers tend to trust publicly funded institutions, professional advisors and peer networks more than commercial sources. This suggests that social media can effectively complement—but not substitute—formalised educational offers.
International comparisons reveal that adoption conditions vary depending on farm size, infrastructure, labour availability and regional policy frameworks. Despite these differences, common factors influencing adoption include digital literacy, perceived ease of use, compatibility with existing routines and clarity of the technology's practical benefits.

4.6 Educational Use of Smart Farming Technologies

Smart Farming requires a balanced mix of theoretical understanding and practical application. Effective learning formats combine classroom instruction, digital modules and hands-on activities. Learners benefit from scenarios that demonstrate concrete improvements in efficiency, sustainability or documentation. Blended-learning formats provide flexibility and can address diverse learning styles, while mobile learning ensures accessibility for farmers with limited time resources.
Given that many educators themselves feel unfamiliar with advanced digital technologies, train-the-trainer approaches are essential. These should include clear teaching guidelines, practical examples, worksheets and access to demonstration systems. Manufacturer-independent materials are particularly important to ensure objectivity and wide applicability.

4.7 Recommendations for Educators and Trainers

Educators should introduce Smart Farming technologies gradually, starting with easily understandable and highly visible tools. Real farm examples and hands-on exercises help learners build confidence. Training should openly address concerns about cost, data privacy and system complexity. Short, modular learning units support flexible participation, while peer exchange formats encourage collaborative learning.

4.8 Conclusion

This compendium consolidates technological, educational and practical insights into a coherent resource for Smart Farming education. By emphasising accessibility, contextual understanding and practical relevance, it aims to support learners, educators and smallholder farmers in navigating the opportunities and challenges of agricultural digitalisation. The content serves as a foundation for curriculum development, mobile learning initiatives and further digital education efforts within the wider project context.