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Title:	**Understanding Polish Farmers' Perceptions of Smart Farming: Data Use, Technology Adoption, and Sustainability Challenges**
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Table of contents

Table of figures

Abstract

This study investigates Polish farmers' perceptions of smart farming technologies, focusing on data use, technology adoption, and sustainability challenges. Utilising qualitative research and semi-structured interviews with 31 Polish farmers, the thesis explores the nuanced factors influencing technology adoption decisions within Poland's unique agricultural context. It sheds light on farmers' awareness and implementation of data-driven technologies, their alignment with sustainable agricultural practices, and the perceived benefits and risks of agricultural data initiatives. The research contributes to a deeper understanding of technology adoption in agriculture, particularly in under-researched regions, and provides actionable insights for stakeholders aiming to foster sustainable agricultural development in Poland.

1. Introduction

The agriculture sector faces unprecedented challenges in the 21st century. In the face of a growing population, projected to reach 9.7 billion by 2050 (United Nations, n.d.), the sector has to increase productivity (to meet the growing demand) while simultaneously reducing its environmental footprint. A combination of these two factors leads to sustainable agriculture being seen as an imperative rather than merely an option. This is true particularly in the European Union, where the importance of reaching set climate goals, in policies like the European Green Deal, has a very high priority. In Poland, agricultural land constitutes approximately 56% of the country's total area – 18.6 million hectares (Wsi, n.d.), representing an enormous opportunity for the implementation of new sustainable technologies with significant environmental impact. However, shifting Poland's agriculture toward sustainability and efficiency requires innovative, data-driven approaches. Consider the following example – a Polish grain farm in the Mazowieckie region. In spite of having access to modern machinery, the farm has not shifted to data-driven decision making, and most of the decisions are made with traditional methods (Matyka, 2020). Without soil moisture sensors or yield mapping, the farmer applies the same rate of fertilisers and pesticides across fields with varying needs for those. This not only impacts the profitability of each farm but also creates unnecessary environmental pollution through greenhouse gas emissions and chemical runoffs. Similar scenarios play out across thousands of farms in Poland.

Research has established that the adoption of digital technologies can significantly contribute to sustainable agriculture. For example, precision farming techniques can reduce input use by 20-30% while maintaining or even increasing yields (Balafoutis, 2017). Precision farming, for example, uses tools like soil sensors and satellite imagery to tailor resource use to specific field conditions. Data-sharing initiatives enable better supply chain transparency and resource optimisation across farms, as well as increase accessibility to new technologies. Studies from various European contexts demonstrate that farmers who adopted smart technologies often report improvements in decision-making capabilities and environmental outcomes (Kernecker, 2020). Agricultural Data Ecosystems are defined as networks of stakeholders sharing data to optimise agricultural efficiency through interconnected platforms and systems. Smart Services in this context refer to digital services that respond to data gathered and evaluated using networked and intelligent systems (Beverungen, 2017). Sustainable agriculture encompasses farming practices that protect the environment, expand natural resources, and optimise non-renewable resource use (Velten, 2015). However, significant knowledge gaps exist regarding how these concepts translate to the specific context of Polish agriculture. While extensive research has examined technology adoption in Western European countries by for instance, Long et al. (Long, 2015) and Kernecker et al. (Kernecker, 2020), Polish farmers' perceptions and experiences remain under-researched. This gap is particularly concerning given Poland's significant agricultural sector and its unique post-communist transition context.

This study aims to address this gap through qualitative research with Polish farmers, inspecting their experiences and perceptions with data-driven agricultural technologies. This research applies a conceptual framework that links well-developed agricultural data ecosystems to positive farmer perceptions, which in turn facilitate technology adoption and ultimately contribute to improved sustainability outcomes. Using semi-structured interviews with a sample of 31 Polish farmers representing diverse farm types, sizes, and regions in Poland, this study will provide rich insights into farmers' perceptions. This approach enables exploration of the nuanced factors influencing technology adoption decisions within the specific Polish context.

This research aims to contribute academically by extending theories related to technology adoption in the agricultural context by examining their applicability in the specific context of Polish agriculture and providing further insights into farmers' perceptions and experiences with smart technologies. It also addresses a geographical gap in literature by focusing on an important, yet under-researched, part of the European Union. Practical contributions this research provides are mainly insights into effective implementation strategies for innovative technologies in Poland for the agricultural sector, by identifying specific barriers that need to be addressed to further advance the technological shift.

The main research question guiding this study is:

What are Polish farmers' perceptions, experiences, and engagement with smart service technologies that aim to support sustainable farming?

Additionally, the following sub-questions will be considered:

1. What are the perceived benefits and risks of agricultural data initiatives for advancing sustainability goals among Polish farmers?

2. To what extent are Polish farmers aware of and implementing data-driven technologies, and how do these technologies align with sustainable agricultural practices?

3. What are the main barriers to adopting smart service technologies that support sustainability outcomes in Polish agriculture?

The thesis is structured as follows: Chapter 2 presents a comprehensive literature review covering agricultural data ecosystems, smart services in agriculture, farmer perception and technology adoption theories, and the Polish agricultural context. Chapter 3 details the research methodology, outlining the interview questions and methods of their analysis. Chapter 4 presents the findings from the qualitative interviews. Chapter 5 discusses these findings about existing literature and theoretical frameworks. Finally, Chapter 6 provides conclusions and recommendations for stakeholders and future research.

2. Literature review and conceptual framework

The following literature review is organised into four main sections: 2.1 Agricultural Data Ecosystems, 2.2 Smart Services in Agriculture, 2.3 Technology Adoption in Agriculture and 2.4 Agriculture in the Polish context. Each section is further divided into subsections to enhance clarity and ease of navigation.

2.1. Agriculture Data Ecosystems

Exploring the intricate world of agriculture data ecosystems, this part delves into their fundamental elements, encompassing the vast array of data sources, advanced collection methods, and robust processing infrastructures that underpin them. It further provides an overview of the European Union's landscape in this domain, discussing both progress and challenges, and specifically highlights the Agri Data Space initiative as a crucial step towards fostering data-driven agriculture.

2.1.1. Key components of the agricultural data ecosystems

As mentioned in the introduction, Agricultural Data Ecosystems can be defined as networks of stakeholders sharing data to optimise agricultural efficiency through interconnected platforms and systems. This concept represents the evolution of agricultural information management from isolated systems to interconnected networks of farmers, their data, technology, and other stakeholders. In the 1980s and 1990s, farm information systems were primarily record-keeping and simple operation planning (S. Fountas, 2015). Later, farm management information systems (FMIS) emerged, which integrated various on-farm data sources, but remained largely disconnected from external sources of information (Kaloxylos, 2012). Salami and Ahmadi in their paper describe FMIS as: "collecting, processing, storing and disseminating of data in the form of information needed to carry out the operational functions of the farm" (Payman Salami, 2010). The next step in the evolution of agricultural data ecosystems was enabled by the Internet revolution. It gained momentum with the proliferation of internet connectivity, cloud computing, and IoT technologies. In 2016 paper by Verdouw et al. authors noted that this shift will lead to a fundamental change in perspectives – viewing agricultural information as a part of a broader network of interconnected data sources and users, rather than a farm-specific resource (Verdouw, 2016). Modern agricultural data ecosystems go beyond the individual farm level, encompassing multiple stakeholders across the agriculture-food value chain. As Sundmaeker et al. realised, these ecosystems allow data flow between previously disconnected actors – such as farmers, processors (service providers), retailers, consumers, and policymakers – creating opportunities for innovative applications (H. Sundmaeker, 2016). The agricultural data ecosystem also incorporates the idea of value co-creation in some way. It is important to consider this perspective as it allows us to recognise that agricultural data has significantly more value if utilised in a network, rather than in isolation. This is in line with what Wysel et al. suggested in their 2021 paper: “Creating value from data requires a community of stakeholders, a facilitatory system, and data on, and for, the community.” (Wysel, 2021) Diverse data sources that collectively provide a comprehensive view of farming operations are a fundamental part of agricultural data ecosystems. Wolfert et al. in their 2017 article say that: “Data collected from the field or the farm include information on planting, spraying, materials, yields, in-season imagery, soil types, weather, and other practices.” (Wolfert, 2017). According to the authors, there are three classifications of agricultural data generation: process-mediated data is a result of the business processes that record and monitor events of interest. That could be purchasing, utilising or selling resources. Machine-generated data is generated by smart machines and sensors which measure and save farming processes. For example, sensory data about the levels of water in the soil. Authors also note that nowadays there is a rapid increase in the amount of this type of data due to the Internet of Things trend. Lastly, human-sourced data is a record of human experiences, for example, photos or videos. However, there are more types of data relevant for the agriculture decision-making process, for example, Mourtzinis et al. in their article underline the importance of weather data in the decision-making process. This includes measurements of precipitation, temperature, humidity, solar radiation, and wind speed collected from on-farm weather stations or external meteorological services. Weiss et al., in their 2020 paper, highlight the importance of remote sensing data, showing how satellite imagery provides multispectral and radar data that can be processed to generate vegetation indices, detect crop stress, and monitor land use changes across large areas (M. Weiss, 2020). This data source offers the advantage of consistent monitoring over time without requiring ground-based equipment installation. Market data, including commodity prices, input costs, and consumer preferences, connects agricultural production to broader economic systems. These can help farmers make informed decisions, for example, which crop to select or investment priorities.

A variety of data-collecting technologies that have advanced significantly in recent years are used in the gathering of agricultural data. By distributing networks of interconnected sensors across farm landscapes, IoT (Internet of Things) devices offer a revolutionary technique for gathering agricultural data. Tzounis et al. in 2017 explain how these can monitor soil moisture, humidity, temperature, plant and animal condition, enabling rapid response to changing conditions (Tzounis, 2017). Increasing reliability and declining cost of these sensors have accelerated their adoption. Balafoutis et al. in a 2017 paper presented examples of combines with yield

monitors, tractors with fuel consumption trackers, and sprayers with application rate controllers - all generate valuable operational data (Balafoutis, 2017). Unmanned aerial vehicles (UAVs) or drones have become a common way of collecting data in agricultural landscape. Hunt and Daughtry, in their 2017 paper, explain how drones
equipped with various sensors can capture high-resolution imagery on demand, monitor crop conditions, and apply treatments in specific locations (E. Raymond Hunt Jr., 2017). According to Fritz et al. (Steffen Fritz, 2019), application of satellite data for agriculture has recently expanded with improved temporal and spatial high-resolution imagery available in programs like MODIS, Landsat or Sentinel. Traditional manual data collection persists in many agricultural contexts, especially in regions where technological adoption is limited; however even these manual methods increasingly interface with digital systems through data entry portals, creating hybrid approaches that maintain human observation while enabling digital integration.

Data processing infrastructure in the context of agriculture data ecosystems consists of several interconnected components. A central component to agricultural data management is cloud computing, enabling scalable storage and processing power without requiring advanced internal IT infrastructure. Kamilaris et al. in 2017 (Kamilaris, 2017) explain how cloud platforms utilization is necessary for the agriculture sector to enable the aggregation of data from multiple sources and provide enough computational power to analyse the data. Recently, edge computing (processing data closer to its source) gained relevance. According to Zamora-Izquierdo et al. (Miguel A. Zamora-Izquierdo, 2019), edge computing enables real-time decision making in cases where it is highly significant to react quickly, for example, livestock monitoring. Agriculture data, as mentioned previously, is very diverse; hence there is a need for databases accommodating different types of data flexibly. Pavon-Pulido et al. (Pavón-Pulido, 1038–1068) show an example of how Google public cloud offering can be utilised for the task of storing agriculture-related data. Analytics tools process raw agricultural data into actionable insights through statistical analysis, machine learning algorithms, and artificial intelligence applications. Van Evert et al. (van Evert, 2017) document an example of how some of these tools can identify patterns in crop performance, predict disease outbreaks or optimise input use, based on real-time and historical data. Data visualisation tools are crucial for making complex agricultural data understandable and useful for decision-making. Gutiérrez et al. (Francisco Gutiérrez, 2019) highlight why it is important to visualise data and how interac
tive dashboards, map-based interfaces, and mobile applications can present information in ways that align with farmers' decision processes and practical needs. Infrastructure challenges persist in many agricultural regions, particularly related to rural connectivity. As noted by

Salemink et al. (Salemink, 2017), limited broadband access in rural areas can constrain real-time data transmission and cloud service utilisation, leading to decreased efficiency of farms. Agricultural data ecosystem provides numerous applications and services that aim to translate collected data into practical value for the farmers, improving productivity and environmental outputs. Farm Management Information Systems (FMIS) serve as comprehensive platforms for managing agricultural data and supporting decision making process. Fountas et al. (S. Fountas, 2015) trace the evolution of these systems from basic record-keeping tools to integrated platforms. Decision support tools are specialised applications that solve specific management issues, and can be categorised based on their purpose, including input optimisation (fertilizer calculators, irrigation schedulers), timing recommendations (planting windows, harvest timing), and risk assessment (pest pressure estimates, frost warnings). Predictive analytics applications leverage historical data and modelling techniques to forecast agricultural outcomes. Basso et al. (Wiseman, 2019) show an example of an application that predict disease outbreaks, yield potential, and market trends. This enables a more proactive, rather than reactive, management mode. Balafoutis et al. (Balafoutis, 2017) report tools that generate variable rate application maps for seeds, fertilisers, and crop protection products, optimizing input use based on field variability and crop needs. Certification and compliance tools help farmers navigate regulatory requirements and voluntary standards. Agricultural data ecosystems involve diverse stakeholders with varying interests, capabilities, and concerns. Farmers and agricultural producers occupy a central position as both data generators and end-users. Wiseman et al. (Wiseman, 2019) indicate that farmers' perspectives on privacy, data ownership and value creation highly influence their willingness to participate in the agricultural data ecosystem. Farmers' participation often hinges on recognising clear benefits that outweigh the costs and uncertainties associated with sharing data. Smart service providers have a high interest in the project and are also highly influential stakeholders as they develop and promote agriculture technologies and rely on farmer adoption for success. This research is also highly relevant for policymakers.

2.1.2. Current state in the EU

The European Union has established several policy initiatives that promote the development of agricultural data ecosystems. The Digital Europe Programme (2021-2027) dedicates 8.1 billion euro to accelerate digital transformation, including the agriculture sector (European Comission, n.d.). This complements the Common Agricultural Policy (CAP) reform, which explicitly promotes precision and digital farming techniques (Euroean Comission). The European Green Deal (European Comission, n.d.) and included in it Farm to Fork strategy have further underlined importance and relevance of data-driven practices in agriculture, by for example setting targets for reducing pesticide use by 50% and fertilizers by 20% by 2030 – goals which successful completion rely on precision agriculture technologies (European Comission, 2020). In 2020, the European Commission released the European Data Strategy (European Comission, 2020), which specifically identified agriculture as a strategic sector for data spaces development, which led to establishment of the Agricultural Data Space Initiative (Agri Data Space, n.d.).

Adoption of digital agriculture amongst EU states exhibits significant geographical disparities. Western and Northern European countries (Netherlands, Denmark, Germany) demonstrate higher adoption rates of digital technologies (Maloku, 2020) (Bellon-Maurel et al., 2023). Meanwhile, Southern and Eastern European countries exhibit lower rates of adoption (according to the WEF report, Eastern countries' climate-smart practice adoption rate is 22%, and 45% in Western countries (World Economic Forum, Deloitte, NTT Data, 2022)). Economic development patterns have been contributing to these disparities, but they are also influenced by farm structure. Regions dominated by large-scale farming operations (e.g., eastern Germany, parts of France) show higher technology adoption rates compared to regions characterised by smaller farms (e.g., southern Poland, Greece). The digital divide is also caused by disparity in ICT adoption between rural and near-urban areas (A.P. Barnes, 2019).

Digital infrastructure that supports agricultural data ecosystems varies across the EU. How ever, rural broadband coverage, which is essential for real-time data transmission between farm and cloud, reached around 92.2% by 2023; however, reliability and quality of the connection remain problems in some areas (OMDIA, Point Topic, 2024). To improve this, the European Union, through the European Network for Rural Development, commits funds and efforts to making the internet connection in rural areas better (European Commission, n.d.). Cloud infrastructure development has advanced significantly, with many major providers setting up agriculture-related services. It remains true also for edge computing, which is behind in development relatively to cloud computing; however, more and more companies start offering such services (eucloudedgeiot, n.d.). The European Union aims to address these gaps by establishing cloud federations, which facilitate the development of cloud-to-edge infrastructure (European Comission, 2024).

Many diverse sources invest in agricultural data initiatives across the EU, both public and private. The European Union established numerous programs aiming to support digital transformation in the agriculture sector. Many instances have been mentioned previously in this work, but other than those, for example European Investment Bank announced at the end of 2024 that they will invest 3 billion euros in farmers and the bioeconomy (European Investment Bank, 2024). When it comes to private funding, it has been mainly concentrated on Western European agriculture technology hubs, particularly in the Netherlands, France and Germany. For instance, AgFunder dedicated 5.1 billion euros in 2022 towards agrifoodtech investment in Europe (Ag Funder, 2023). Nevertheless, Eastern European countries, including Poland, have seen growing investor interest.

Different stakeholder groups show varying degrees of participation in agricultural data ecosystems. Large-scale farmers and agricultural enterprises have the highest levels of engagement, often participating in more than one data-sharing initiative. Small and medium-sized family farms adopt basic digital technologies more and more often, but remain hesitant about sharing data beyond their immediate service providers.

2.1.3. European Data Initiatives – Agri Data Space example

The Agri Data Space initiative emerged from the mentioned before European Strategy for Data launched in 2020. The Farm and Fork strategy advocated for a common European agricultural data space; hence, the initiative was established. The Agri Data Space initiative aims to create a Common European Agricultural Data Space (CEADS), which would: "facilitate data sharing, processing, and analysis in a secured, trusted, transparent and responsible manner" (Agri Data Space, n.d.). Development accelerated in 2021 when the European Commission released a conceptual framework document. The initiative entered its operational phase in 2022 with €10 million allocated from the Digital Europe Programme. Core objectives of the initiative are to: facilitate transparent and secure data exchange between different agricultural stakeholders while respecting data ownership rights; enable interoperability between different data platforms, formats, and systems through common standards and protocols; support innovation in agriculture sector by making high-quality data easily available for developing new applications and services, especially for precision farming and assessing sustainability; reduce administrative burdens for farmers by enabling once-only data provision for multiple regulatory reporting requirements. By achieving all those objectives, the initiative contributes to the European Green Deal objectives by providing the data infrastructure needed for sustainable agricultural practices (Agri Data Space , 2024).

Agri Data Space's governance network operates on multiple levels to ensure equal representation of stakeholders and simultaneously maintain alignment with broader EU data governance principles. The steering committee is responsible for providing oversight, and it is composed of the Directorate-General for Agriculture and Rural Development, the Directorate-General for Communications Networks, Content and Technology, and the Joint Research Centre, to ensure

alignment with broader agricultural and digital policy objectives. The operational layer is made of the Coordination Board with representatives from EU states, farmer organisations (e.g. Copa Cogea), research institutions, agricultural technology providers (e.g. CEMA), and data service providers. The objective of this body is to develop operational rules and also monitor the implementation process. So-called Working Groups manage technical governance, each group focus on a specific aspect such as architecture, data standards, and use cases. These groups bring together technical experts from relevant stakeholder organisations, e.g. AIOTI WG06.
(Alliance for Internet of Things Innovation, 2017). The governance model includes the principles established in the Code of Conduct on Agricultural Data Sharing by Contractual Agreement, developed by COPA-COGECA and other industry stakeholders (EU Code of Conduct Group, 2018).

Agri Data Space's technical architecture uses a shared model, aligning with the design principles of the European data spaces. Rather than creating a centralised repository, a network of interconnected data sources and services are established, which communicate through standardised interfaces. Main technical components of the initiative include: a common reference architecture based on the International Data Spaces (IDS) Reference Architecture Model; connectors and gateways that enable already active agricultural data platforms to join the data space while maintaining independent; a metadata registry that maintains information about available datasets, their characteristics, and access conditions, facilitating data discovery and integration; access and identity management services that verify and authenticate users, as well as enforce data usage policies, building on the EU's electronic identification systems (eIDAS); semantic interoperability components, including common ontologies and vocabularies for agricultural data, built on existing standards such as ADAPT, AgroVOC, and ISOBUS.

Agri Data Space is currently in its early deployment phase, which started in January 2025, meaning that it is currently focusing on testing through concrete use cases and expanding to the sector. It operates as a decentralised network, federating existing data initiatives, and emphasizes farmer interests. There are 5 milestones set for the future, regarding Agri Data Space – one every 6 months, with the first one in the middle of 2025. When the first phase – preparatory stage is done, producing shared governance and tech building block, the implementation stage will begin. After 6 months, the first report on Common European Agriculture Data Space is expected to be published, and work towards setting all onboarding guidelines will begin. Milestone 4 is expected to produce the first Minimum Viable Product of the CEADS. Then the operational stage will begin in which CEADS services will be established more broadly, the Network Administrative Organisation will be operational and govern, Business Compatibility

Grid will be harmonised, and the technical infrastructure fine-tuned. The last stage is called the scaling stage and will be about developing new use cases and bringing more participants into the ecosystem (AgriDataSpace, 2024).

2.2. Smart Services in Agriculture

This section defines smart services in agriculture, outlining their conceptual framework and diverse typologies. It further details the technical requirements and infrastructure needed for their implementation, as well as the significant environmental, economic, and social benefits they offer to the agricultural sector.

2.2.1. Definition and conceptual framework

Traditionally, the agriculture sector was based purely on product-oriented approaches. However, since smart services have been enabled by technologies supporting IoT, approaches shifted to data-driven, more informed decision making. In broad definition, smart services are: “a combination of physical and digital services that are based on the data of a physical product” (Mittag, 2018). In the agricultural context, these services utilize data collected from different sources such as machinery, satellite imagery, sensors and weather stations to provide real-time recommendations and insights, and automated solutions to improve farm operations.

Porter and Heppelman in their 2014 article (Michael E Porter, 2015) describe “smart, connected products” as those having 3 fundamental elements: physical components (for example electrical parts), smart components (for example sensors) and connectivity components (for example ports or networks allowing for data communication). This stay true also for each smart product (which is a part of a service) in agriculture context. In it’s core, each smart service in agriculture follows this process flow: some type of data related to farm operations is collected, sent to service provider to be analyzed, and finally service provider sends back some sort of actionable insight or recommendation.

Wolfert et al. in 2014 expand these concepts into a broader definition of Smart Farming – “the use of smart, data-rich ICT-services and applications, in combination with advanced hardware (in tractors, greenhouses, etc.)” (S. Wolfert, 2014). In another paper in 2017 it is explained that Smart Farming scope is broader than just Precision Agriculture – it is also “basing management tasks not only on location but also on data, enhanced by context- and situation awareness, triggered by real-time events” (Schüritz, 2019). Authors conceptualized Smart Farming as event and data management cycle, which allowed by cloud computing, continuously collect and monitors data, analyse it and plan based on the analysis.

A significant aspect of the smart service conceptualization in agriculture is its emphasis on value co-creation. Schüritz et al. in 2019 in their article explain why for data-driven services co-creation is so valuable (especially from the service provider perspective) (Schüritz, 2019). It is no different in the smart service in agriculture, through interactions between farmers and service providers, where farmers knowledge and contextual understanding combined with the technical skills to analyse the data and produce quality insights, generate recommendations and solutions tailored to specific needs of the farmer. This co-creative element distinguishes smart services from traditional approaches to adoption of agricultural technology, putting farmers as active participants rather than passive recipients of technological solutions. Understanding smart services not only from a technological standpoint but also as a co-creative process helps explain how farmers' perceptions shape their willingness to adopt these tools—an essential component of the conceptual framework underpinning this study.

2.2.2. Typology of smart services

Smart services in agriculture can be categorized in multiple ways, reflecting their diverse functions, technical characteristics, or value propositions. In Ray PP et al. authors list possible applications of smart services in agriculture. Irrigation management system aim to integrate real-time weather data, moisture sensors, remote control (of for example water flow by controlling pipe activation) and other cost saving measures to optimize water usage in agriculture (Ray, 2017). Pest and dieses control nowadays often takes form of a network of sensors that monitor pests and diseases, allowing farmers to reduce pesticide use and apply targeted treatments. Cattle movement monitoring is real-time tracking and monitoring of grazing cattle for improved livestock management. Dairy monitoring provide behaviour detection, health analysis, and predictive insights for dairy farming. Water quality monitoring measures real-time water quality parameters like pH, temperature, and turbidity. Greenhouse condition monitoring allow remote monitoring and autonomous control of greenhouse environments (Lakhiar, 2018). Soil monitoring facilitate remote soil condition monitoring, enhancing agricultural productivity (Pal, 2024). Precision agriculture by UAV (unmanned aerial vehicles) - AI systems enable precision farming by providing real-time weather data, land mapping, and analytics. Agricultural supply chain management - IoT enhances supply chain efficiency in agriculture by enabling real-time tracking and management of agriculture related products (Alshehri, 2023).

2.2.3. Technical requirements and infrastructure

The agricultural smart services require a robust technical backbone to enable data collection, processing, and communication in diverse agricultural environments. Sensor networks are in the heart of the smart services in agriculture, monitoring critical environment and operational parameters. These sensors measure soil moisture, temperature, humidity, nutrient levels, and other relevant agronomic indicators and the selection of these sensors needs to consider accuracy, reliability, and energy efficiency, especially in remote or harsh environments (Akyildiz, 2002). Advanced sensor technologies, such as wireless sensor networks (WSNs) and 6LoWPAN for low-power data flow, are fundamental to ensuring uninterrupted and consistent data gathering. Huge volumes of data produced from sensor networks need a robust data management solution. Nowadays, cloud computing platforms are widely accepted in storing, processing, and analyzing agricultural data, enabling integration of big data analytics and machine learning algorithms for predictive insights and decision-making support (al., 2017). The infrastructure needs to be scalable, assume growing need for computational capabilities and storing data with advanced security protocols, ensuring data privacy and integrity (Rodrigo Roman, 2013). Another significant factor for the infrastructure is energy efficiency and sustainability. Many sensor devices and communication nodes rely on battery power or renewable energy sources, such as solar panels, necessitating the design of systems that optimize energy consumption (Tifenn Rault, 2014).

2.2.4. Environmental benefits

Precision agriculture utilizes advanced technologies, that is sensors, data analytics, and automation to improve sustainability in agriculture by optimizing resource use and minimizing environmental impact. Primary environmental advantage of precision agriculture is its ability to optimize resources, for example reducing water usage – sensor based irrigation systems allow for optimized water distribution by delivering precise amounts based on real-time soil moisture data, significantly reducing over-irrigation and conserving water resources. Smith et al. 2017 study shows that such systems can reduce water consumption by around 30% compared to the methods applied traditionally (Palumbo M, 2021). Similarly, targeted application of fertilizers, based on the soil nutrient analysis, reduces the overall use of fertilizers by applying only the exactly necessary amount. Furthermore, excessive application of fertilizers can cause environmental damage in soil, this risk is mitigated when precision agriculture is used to distribute fertilizers (Hedley, 2014). Precision agriculture technologies also facilitate spot-treatment of pesticides, reducing total chemical inputs and limiting their environmental footprint. Furthermore, real-time monitoring of soil condition enables acting proactively, rather than reactively, against soil degradation, preserving structure and fertility over time.

Precision agriculture significantly contributes to reduction of the climate impact of farming operations. Optimize machinery operations, enabled by GPS-guided systems, lower greenhouse gas emissions by reducing unnecessary passes over fields and fuel use. Efficient supply chains, driven by data analytics, further decrease the carbon footprint by streamlining transportation and logistics. Furthermore, data-driven soil management approach enhance carbon sequestration by fostering healthier soils with increased organic matter content. Research suggest that wide-spread implementation of such practices can increase carbon sequestration by 1.2-3.1 billion tons of carbon globally, therefore improve environmental state of the planet (Lal, 2011). Precision agriculture supports biodiversity by enabling targeted practices that minimize ecological disruption. Precise field mapping help farmers identify sensitive areas within or adjacent to farms, making it possible to not disturb natural ecosystems. Reduced pesticide usage, achieved through for instance drone sprayers, protects non-target organisms such as pollinators and other beneficial for farm insects, for example research highlights that precision application methods can significantly lower pesticide exposure to unintended species (Aktar MW, 2009).

2.2.5. Economic benefits

Precision agriculture delivers significant economic advantages by reducing costs, enhancing yields, improving market competitiveness, and mitigating risks. Precision agriculture decreases operational expenses by optimizing resource use and streamlining farm management. By monitoring and optimizing seed, pesticides and fertilizers application, guided by technologies like variable rate application, farmers can substantially lower the overall cost compared to traditional methods. According to some studies nitrogen fertilizer use can be decreased by 31.26kg per hectare with crop yield decrease (R. Bongiovanni, 2004). Remote control and task automation allow for cutting labour cost by reducing need for manual field checks and repetitive tasks, allowing farmers to manage larger areas with fewer workers. Technologies like predictive maintenance, enabled by equipment sensors, lowers repair costs by identifying issues before the machines break down and need to be replaced. Additionally, energy costs are minimized through optimized machinery use.

Precision agriculture increases crop yield by optimizing production process and reducing waste. Techniques such as precise irrigation and nutrient delivery improve crop productivity by tailoring conditions to specific needs, ensuring plants receive exact amounts needed. Similarly, health monitoring and precise feeding methods improve performance of livestock by adjusted diets and early illness detection, that leads to increased output per animal. Crop losses from pests, diseases, and adverse weather are reduced through real-time monitoring and early intervention, with tools like drones and satellite imagery providing actionable insights. In recent years, researchers propose many different models detecting need for an early intervention, reducing losses significantly (Yun, 2024). Better harvest quality is achieved through optimal timing and handling practices, informed by data on crop maturity and weather forecasts, leading to higher crop outputs (F, 2024).

Adopting precision agriculture unlock new revenue streams and market opportunities. Documented sustainable practices, such as reduced chemical use and efficient resource management, enable farmers to command premium prices from environmentally conscious consumers and retailers. Studies show, that consumers are willing to pay more for food produced in sustainable fashion (Shanshan Li, 2021). Due to digitalization of processes in agriculture, farmers have enhanced tracing capabilities, which helps to meets growing consumer and regulatory demands for transparency, particularly in markets like the European Union. Furthermore, access to different sustainability related certifications (for instance Rainforest Alliance certificate) is easier, since data generated by precision tools can serve as a verifiable data on compliance with the requirements.

2.2.6. Social benefits

Precision agriculture not only enhances productivity and sustainability but also delivers significant social benefits by reducing workloads, fostering knowledge development, and improving quality of life for farmers and rural populations. Smart services in agriculture reduce the physical and occupational burdens on farmers, automated robotic systems, like for example autonomous tractors, reduce the need for physical labour (Getahun, 2024). Farmers can shift responsibility of performing repetitive and time consuming tasks like planting or harvesting to automated solutions. Exposure to hazardous conditions and substances, such as pesticides, is minimized through precise application technologies (e.g., drones or spot sprayers), reducing health risks for workers. Furthermore, farmers can oversee the operations from distance, due to remote monitoring, even on their mobile phones. It offers more flexible working hours and reducing the need for constant field presence. The implementation of precision agriculture speeds up the education and skill development within farming communities. Data-informed insights from devices such as soil sensors and yield monitors offer farmers practical information, enhancing their comprehension of crop and land dynamics. Digital tools maintain and improve agricultural knowledge by recording different approaches and results, establishing a knowledge repository available for future farmers. Precision agriculture improves the quality of life for farmers by decreasing stress and enhancing working conditions. Automated monitoring and alert systems, like those that keep track of livestock health or irrigation requirements, lessen the burden of ongoing manual supervision, alerting farmers only when intervention is necessary (Getahun, 2024). Time saving technologies liberate hours that were once devoted to repetitive tasks, encouraging a healthier work-life balance.

This change also boosts job satisfaction, as farmers participate in more strategic, less tedious tasks, such as analysing data or organizing operations.

2.3. Farmer perceptions and technology adoption

This section delves into farmer perceptions and technology adoption within agriculture. It explores various theoretical frameworks that explain this process, along with the key factors that influence farmers' decisions to embrace new technologies.

2.3.1. Theoretical frameworks for technology adoption in agriculture

To understand why and how farmers adopt new, emerging technologies depend on many factors. There are several well established frameworks, which have been developed and designed to explain technology adoption process and can also be applied to the agriculture context. The Technology Acceptance Model (TAM), developed by Davis et al. in 1989 (Fred D. Davis, 1989), has been accepted and applied in agriculture-related research (Mel Vincent Ampo, 2024). Davis and his colleagues identified two core factors that contribute to the decisions about technology adoption: perceived usefulness and perceived ease of use. Later, in 2000 TAM model was extended by Venkatesh and Davis (Venkatesh V. &., 2000), and used in, for instance, research about farmers' perceptions and attitudes toward precision agriculture technologies (Anne Mims Adrian, 2005). Diffusion of Innovation theory, developed by Rogers, provides a different perspective on technology adoption, dividing farmers into different groups (innovators, early adopters, early majority, late majority, and laggards) based on their willingness to adopt new technologies (Rogers, 1983). Sunding and Zilberman, in their work in 2001, applied this theory to the agricultural context, underlying how innovations spread through farm communities over time. Another relevant theory is the Unified Theory of Acceptance and Use of Technology (UTAUT) developed by Venkatesh et al. in 2003, which model estimates perceived likelihood of adopting a technology depends directly on four variables – performance expectancy, effort expectancy, social conditions and facilitating conditions (Venkatesh V. &., 2003). Variables such as age, gender, experience and voluntariness of use moderate the strength of prediction of the model. Developed by Ajzen in 1991 Theory of Planned Behavior (Ajzen, 1991) has also been applied to agricultural technology adoption research by for instance Borges et al. in their 2014 paper which explored farmers' intentions to adopt improved natural grassland management in Brazil (João Augusto Rossi Borges, 2014). Rezaei-Moghaddam and Salehi used this theory in their 2010 research to examine factors that influence adoption of precision agriculture among farmers from Iran, highlighting the role of attitudes, subjective norms, and perceived behavioural control (Rezaei-Moghaddam, 2010). A more agriculture-specific framework was described by Klerkx et al. in 2010 paper emphasizing the interactions between different actors in the agricultural sector (Laurens Klerkx, 2010).

2.3.2. Factors influencing technology adoption

The adoption of agricultural technologies is influenced by a set of complex interconnected factors. Feder et al. in 1985 paper identified one of the earliest framework attempting to understand technology adoption in agriculture (Feder, 1985). Authors stated that features like uncertainty and risk aversion, access to information and economic factors (profitability, costs, credit availability, and farm size) are crucial for technology adoption. In 2016 Long et al. classified barriers to the adoption of innovative technologies for climate-smart agriculture (CSA) based on supply-side barriers, i.e. those which technology providers face, hindering their ability to distribute their technology, and demand-side barriers, i.e. those of potential users (Thomas B. Long, 2016). Supply-side barriers authors identified are: difficulty in substantiating product value and demonstrating effectiveness, limited understanding of, and access to, funding or investment, a restrictive or unsupportive regulatory environment, products being too costly, and obstacles in reaching and connecting with potential customers. On the demand-side, barriers are: low awareness of CSA, high costs and long ROI periods, issues related to regulations and policies, difficulty in training and reaching farmers, and lack of proof regarding the effectiveness of technologies. In 2013 Pierpaoli et al. conducted a systematic review of agriculture adoption studies, the paper underscores the complexity of technology adoption in agriculture, emphasizing that it's rarely a straightforward or immediate process (Emanuele Pierpaoli, 2013). Authors identified several significant factors for adoption of precision agriculture tools, including: farm size - larger farms often show a greater intention to adopt precision agriculture technologies, likely due to economies of scale, farmer's confidence with technologies - a farmer's technological skills, economic considerations – cost reduction and positive benefit/cost balance are crucial. Authors also indicated that total income, land tenure, farmer education, access to information, and location are highly significant variables. As Aubert et al. observed in 2012, decision-making process regarding adoption of new technologies is often cumulative effect of multiple influences that vary according to local contexts, socioeconomic conditions, and the specific technology being considered (Benoit A. Aubert, 2012).Bolodeoku et al. in their 2022 paper define perceived usefulness as: "an individual's perception of how technologies or a particular technology are set to improve the individuals' tasks or roles in terms of efficiency and effectiveness" (Precious Bolanle Bolodeoku, 2022). Adrian et al. in 2005 found that perceived usefulness is an important factor for technology adoption, as it has significant impact on the perception of net benefit among farmers in the southern United States (Anne

Mims Adrian, 2005). Similarly, Reichardt et al. demonstrated that farmers in Germany who perceived benefits from precision agriculture technologies, such as input cost reduction and yield improvements, were significantly more likely to adopt them (Reichardt, 2009). Furthermore, authors identified that perceived usefulness is more significant than perceived usability, and underlined positive relationship between image of precision farming and its perceived usefulness. Aubert et al. also found that perceived usefulness is a mediating variable in adoption intents, for example in access to information (Benoit A. Aubert, 2012). Tey and Brindal in 2012 paper state that since farms are led as business and aim to be profitable, any technology adaption has to perceived as net beneficial and profitable from farmer's perspective (Tey, 2012). Farmers are more likely to adopt technologies that they perceive as advantageous, easy to use, and compatible with their existing farming practices.

Perceived ease of use refers to farmers' expectations about the effort required to implement, operate, and maintain new technologies. Davis in 1989 defined it as "the degree to which a person believes that using a particular system would be free of effort" (Fred D. Davis, 1989). This factor has proven relevant and significant also in agricultural context. In a study by Caffaro and Cavallo in 2019, authors investigated factors affecting the use of Smart Farming Technologies (SFTs) in Italian farmers from the Piedmont region (Federica Caffaro, 2019). They found that ease of use significantly influenced Italian farmers' adoption of precision agriculture technologies, especially among older farmers and those with less formal education. Likewise, Kernecker et al. in 2020 study established that perceived complexity and operational difficulties were crucial barriers to adoption of smart farming technology (Kernecker, 2020). Aubert et al. in 2012 demonstrated that adoption rates of farm management information systems was reduced by complicated user interfaces and the need for specialized technical knowledge (Benoit A. Aubert, 2012). Study conducted by Rose et al. in 2016 observed that technologies that do not require much effort and little changes to existing farming practices have higher adoption rates (David C. Rose, 2016).

Social influence plays a significant role in agricultural technology adoption through peer effects and community norms. Rogers in his 2003 paper emphasized the significance of social learning and observability in his diffusion of innovations theory. In many cases, farmers rely on trusted neighbours and other members of community when it comes to making decisions about technology adaptation, as shown by Maertens and Barrett study of social network effects on adoption in 2013 (Maertens, 2013). Furthermore, Läpple and Kelley in 2013 study found that farmers are more likely to adopt technologies that had been successfully implemented by respected peers in their community (Doris Läpple, 2013). Genius et al. in 2014 identified that farmer to farmer communication and extension services are strongly associated with technology adaptation and diffusion, through social learning processes (Genius, 2014). The relevance of these social aspects highlights the need for technology promotion strategies that utilize already present social networks and opinion leaders within farming communities.

Data security concerns have become significantly more important factor in the context of agricultural technologies adoption, particularly in the modern world of digital and data intensive technologies. Wiseman et al. in 2019 research established that farmers’ concerns about data ownership, privacy, and potential misuse of farm data were significant barriers to adoption of precision agriculture technologies in Australia (Leanne Wiseman, 2019). Similarly, Regan in 2019 examined Irish farmers perceptions about risks associated with smart farming. Study found that worries about third-party access to their data and lack of clarity regarding data usage policies were key barriers to digital agriculture adoption (Regan, 2019). Study conducted by Jakku et al. in 2019 highlighted that transparency and clear data governance frameworks are essential for building farmers' trust in digital agricultural platforms (Emma Jakku, 2019). Furthermore, in their study in France, Carolan stated that farmers were more willing to adopt technologies from companies or organizations that they already established trust with (Carolan, 2020).

Farm characteristics have important influence on technology adoption decisions, creating diverse adoption patterns across different agricultural settings. Often larger farmers can implement technologies and benefit from them due to economies of scale. Lowenberg-DeBoer and Erickson findings are in line with that statement, as in their research farm size consistently predicted precision agriculture adoption, with larger operations better able to absorb fixed implementation costs and realize economies of scale (Lowenberg-DeBoer, 2019). Similarly, Tey and Brindal (2012) identified land tenure as an important factor, with land owners more likely to invest in long-term technological improvements than tenant farmers (Tey, 2012). Type of farm is also relevant, when considering adoption patterns, Castle et al. findings in 2016 demonstrated that type of farm and production systems affect technology relevance and compatibility, highlighting that specialized farms often adopt technologies tailored to their specific requirements earlier than diversified operations farms (M. H. Castle, 2016). Regional and location factors also influence technology adoption, as Daberkow and McBride demonstrated in their 2003 paper (Daberkow, 2003). They also further confirmed that farm size is also a significant factor in this context.

2.4. Agriculture in Polish context

The agricultural landscape in Poland is characterized by significant fragmentation, with an average farm size of 11 hectares (U.S. DoA, 2024), significantly smaller than the EU average of 17.4 hectares. 1.3 million Polish farms account for 14.4%
of total EU farmland (eurostat, 2022). The state of high fragmentation largely stems from post-communist transition processes and historical land reforms that resulted in the redistribution of previously collectivized farms (Ingham, 1998). According to Polish National Statistics Office, the agricultural sector employs approximately 8.4% of the Polish workforce (Gus, 2024), and is responsible for around 2.2% of national GDP, showing that it continuously have socioeconomic importance despite gradual decline in relative economic significance. Poland is a leading producer of several agricultural goods within the European Union market. In particular, it is the largest producer of apples, the third largest producer of cereals, and maintains significant in dairy, pork, and poultry sectors (Gus, 2024). Poland presents regional diverseness, with larger and more modernized farms located in the western part of Poland, while smaller and more traditional, very often family enterprises, in the eastern Poland. Farm size is ranging from an average 4 ha in the South to 23 ha in the North of Poland. This spatial differentiation has important implications for technological adoption patterns and development strategies, and stems from historical implications of Polish territory being split and governed by different countries (Ewa Kiryluk-Dryjska, 2020). Worrying trend emerges among farm operators, with a significant percentage of farmers approaching retirement age. This shift is accelerated by rural to urban migration patterns, typical for younger generations, creating labour shortages in agricultural regions (Foundation for the Development of Polish Agriculture, 2020). This demographic pressure even further advances the need for technological adaptation to counter labour constraints. Furthermore, small farms are becoming increasingly non-profitable, which leads to many owners selling their farmland, even though hesitancy to sell land remains high in Poland (Borzutzky, 2024).

The digital transformation of Polish agriculture presents a complex landscape of adoption. Research conducted Borusiewicz et al. in 2016 on a sample from two Polish regions showed, that only 8% and 14% of farmers used specialist computer in their farms (Borusiewicz, 2016). Furthermore, authors noted, that main source of information for the questioned farmers were the internet, television and professional agricultural press. The rural-urban digital divide remains a significant barrier to digitalization in Poland, according to the Polish Office of Electronic Communications urban internet penetration is high (Communications, UKE Office of Electronic, 2021), however rural areas experience some limitations, especially in regard to high-speed connections, which are essential for agriculture smart technology applications. The infrastructure gap is particularly problematic in the south-eastern part of Poland. Financial constraints significantly impact digitalization efforts, small farms often struggle with highly limited investment capacity (Soliwoda, 2020), and this barrier is advanced even further by uncertainty about return on investment.

Polish agricultural policy operates within the dual framework of national strategies and Euro pean Union programs. The Strategy for Sustainable Rural Development, Agriculture and Fish eries 2030 (Strategia zrównoważonego rozwoju wsi, rolnictwa i rybactwa 2030) put agricultural modernization and digitalization as one of the strategic priorities (Wsi, n.d.). However, small and medium farms struggle to access required support for technology investments and implementation. Developed by the EU Common Agricultural Policy (CAP) provides a significant policy and funding framework. Since joining European Union, Poland received substantial funds allowing for modernisation of different sectors, including agriculture. Emerging programs like CAP further extend this possibility for member states like Poland, while targeting focus of investments on farm modernization and digital transformation. Kiryluk-Dryjska analysed farmers from which regions tend to apply for additional funding (Ewa Kiryluk-Dryjska, 2020). Regions with better developed agricultural structures tend to benefit more from rural development programs, deepening the already existing gap between them and underdeveloped regions. Advisory and educational services play an important role in technology adoption. Staniszewski, in his 2014 paper, notes that Agricultural Advisory Centres (ODRs) have increasingly incorporated digital training into their programs; however, considering the size of Poland and the number of potential beneficiaries, the number of ODRs and their resources remain inadequate (Staniszewski, 2014). The limited capacity of advisory services supporting digital transformation poses a significant constraint on nationwide adoption of smart technologies.

2.5. Conceptual model and research gap

The conceptual model that drives this study proposes a connection between a well-developed data ecosystem and positive farmer perception of new technology, which in turn increases adoption of smart services that improve the commonality of sustainable practices in agriculture. The model is supported by existing literature, which highlights the influence of technology perception on implementation, the link between smart service adoption and improved sustainability, and the known digital divide between urban and rural areas. While prior research has established these general relationships, there remains a significant gap in understanding how

Polish farmers specifically perceive and engage with data-sharing initiatives and data-driven services.

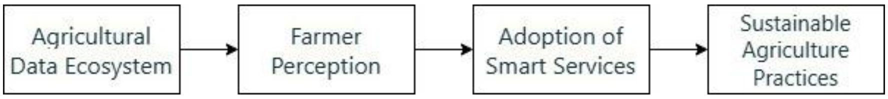

Figure 1 - Conceptual model

This study addresses this gap by qualitative interviews with Polish farmers to gain insights into their awareness, perceived benefits and risks, and the adoption barriers they face. By focusing on the Polish context, this research aims to provide a deeper understanding of how agricultural data initiatives are perceived and applied at the farm level across different EU member states, offering insights for shaping more effective policies and implementation strategies across European Union.

3. Methodology

This section covers the methodology employed to investigate Polish farmers' perceptions of smart farming technologies, data use, and associated risks and benefits. It details the qualitative research design, including the systematic literature review, participant selection, and the semi-structured interview approach used for data collection. Furthermore, it explains the hybrid coding and data analysis techniques applied to interpret the rich, nuanced data gathered, ensuring a comprehensive understanding of the research phenomenon.

3.1. Research design

This study adopt a qualitative research design to deeply investigate the perceptions of Polish farmers about smart farming technologies, data use and associated with them risks and benefits. This approach was chosen as it is better suited for the goal of understanding complex phenomena that are not fully understood yet, especially when context is specific like in this case – of Polish farmers. A qualitative research design is justified by the nature of the research questions, which aim to delve into the "why" and "how" behind farmers' experiences, attitudes, and decision-making processes, rather than simply measuring frequencies or correlations. By utilizing semi-structured interviews as a data collection method, this design allows for in-depth investigation of farmers' opinions, and lived experiences, providing rich, nuanced data that quantitative methods might not be able to capture.

3.2. Literature review

A systematic literature review was conducted as a crucial preparatory stage of this study. The main purpose of the literature review was to establish a extensive theoretical foundation for understanding Polish farmers' perceptions of data-driven technologies in agriculture. It guided the identification of key concepts, prevailing research trends, and existing gaps in the academic discourse, and by that means helped refine the research questions and the design of semi-structured interview. The search of literature was performed across well-known academic search engines, including Google Scholar, Scopus and Web of Science, to ensure wide coverage of relevant and appropriate peer-reviewed publications. The strategy applied a combination of keywords related to the main themes of the research, key search terms included: "smart farming, precision agriculture, digital agriculture, technology adoption, agricultural technology, IoT in agriculture, big data in agriculture, agricultural data sharing, sustainable agriculture, farmers' perceptions on technology, agricultural innovation, European agriculture, Polish agriculture, agriculture smart services, Polish agriculture policy, European agriculture policy". Furthermore, significant portion of the literature included in the literature review was found by exploring reference list in the articles found by keyword search. Another useful source of finding relevant literature was grok.com large language model, which enables feature of "deep search", which essentially performs a comprehensive search through websites for information specified in a prompt (the beforementioned list of key search terms was utilized in this approach too). The search was mainly focused on years 2000 to 2025 to capture both recent research advancements and foundational works. After compiling final list of relevant literature, some exclusion criteria were applied, namely: non peer-reviewed papers and duplicate articles were excluded from the list. The next step was initial screening of titles and abstracts to remove some of the articles that were not sufficiently relevant. Finally, the full-text review was performed and final list of literature was completed. From the selected articles, relevant information was systematically extracted. This included the study's aim, methodology and key findings related to this thesis research questions. After that, extracted data was synthesized thematically, categorizing findings according to the main theoretical constructs.

3.3. Semi-structured interviews

The data collection for this was collected by conducting semi-structured interviews with Polish farmers. The qualitative approach was chosen to extensively examine farmers' attitudes, experiences and perceptions regarding data-driven technologies, which would be harder to capture using quantitative methods.

3.3.1. Participants

The sample of the study includes 31 Polish farmers. Participants of the study were selected in a manner to represent a diverse farm types, regions and farm sizes. The aim of having a diverse sample is to be able to capture a broad spectrum of experiences and perspectives within the Polish agricultural context, strengthening the transferability of the findings. Initial contact with farmers who were interviewed was established in several ways: through the internet forums (for instance on social media), attending farmer markets, personal network of contacts, and snowballing through initial contacts.

3.3.2. Interview protocol

The interview protocol emerged based on the insights derived from the literature review, ensuring that it addressed research questions and main themes of the study. The questionnaire was designed to be flexible and allow for follow-ups and exploration of topics that emerged during the conversation, while maintaining consistency at its core across all interviews. The questionnaire was structured into five thematic sections guiding the conversation:

I. Introduction and background – this initial part of the conversation aimed at learning about farmers' backgrounds, they were asked about farm type, size, location, duration of farming, family farming history, and typical daily/weekly activities

II. Agricultural data ecosystems – this section focused on farmers' awareness and perceptions related to agricultural data, and their current practices. Questions covered types of data collected (e.g., yield, input usage, weather), collection methods (manual, sensors, software), current use of digital tools for data management, experiences with software, thoughts on data sharing, and perceived value of data-driven insights for efficiency and sustainability

III. Smart services in agriculture – this theme focused on farmers' usage of and familiarity smart services in their agriculture operations. It explored general knowledge of "smart farming," the use of particular smart service technologies (such as automated systems and precision agriculture tools), their experiences (both positive and negative), the reasons behind their consideration or rejection of alternative technologies, the specific farm needs that smart services can address, and their expectations for implementation support and training

IV. Technology adoption – this core section of the interviews delved into the factors which influence farmers' decisions-making process regarding adoption of new technologies. Questions covered general willingness and openness to adopt new technologies, main sources of information about new technologies and possibilities, and the biggest obstacles in new technologies adoption.

V. Polish context – the last section aimed to understand information specific to the Polish agricultural environment. Questions covered general challenges faced by farmers in Poland (e.g., economic, climate, labour, regulatory), how farm size/structure affects technology investment, awareness and participation in government/EU support programs, quality of internet access, and views on the future of agriculture in Poland regarding technology's role.

3.3.3. Interview process

All interviews were conducted in Polish. Before each interview started, participants received information regarding the purpose of the study, confidentiality status and data usage, such that informed consent was acquired. Most of the interviews were conducted in person, in different locations – local markets and farms, some of the conversation were conducted online, as some of the interviewees were located far from my location and it helped to make the data collection feasible in a relatively short timeframe. Each interview lasted around 20 minutes and was audio-recorded with farmers' permissions. The audio recordings were subsequently transcribed verbatim to ensure accuracy and facilitate detailed qualitative analysis and later translated to

English language. Careful confidentiality was maintained, by making the participants names and farm details anonymised during transcription.

3.4. Coding the interviews

The coding scheme for the interviews data was developed using a hybrid (inductive and deductive). This method was applied due to its ability to systematically categorize and later analyse interview transcripts, enabling both the emergence of new information from the data and the usage of pre-defined areas of inquiry related to the research questions. The coding process involved several steps in the following order:

I. Familiarization and initial deductive coding – after the interviews transcripts were completed, the idea was to first read through all the interviews again and gain a general overview of a whole sample. The initial list of codes was developed to capture which parts of interview are corresponding to which themes of the study (see Appendix 1).

II. Inductive code development and sub-categorization - within these broad deductive categories, a more inductive approach was then employed. Each transcript was again separately and carefully read through, identifying specific phrases, sentences, or paragraphs that captured key ideas, opinions, and experiences. Following the assignment of the codes, these segments were categorized into sub-codes that represented recurrent themes and nuances in the farmers' answers. For instance, under the code "Internet Access", sub-codes such as "Poor and Limiting", "Reliable and Sufficient", and "Reliable but Limited for Tech" were developed directly based on the farmers' descriptions.

III. Codes refinement - All codes and sub-codes were refined, merged, or split as analysis progressed to ensure, distinctiveness, clarity and full coverage of the data. Each code and sub-code was clearly defined to maintain consistency throughout the coding process.

This hybrid coding approach, combining both inductive and deductive elements and incorporating quantification, allowed for a rigorous and structured analysis. It ensured that the findings were deeply rooted in the qualitative narratives while also providing a descriptive understanding of the commonality of various themes across the participant group, thereby enhancing the trustworthiness and transparency of the analysis for addressing the research questions.

3.5. Data analysis

The data analysis in this study involved a hybrid approach of combining qualitative interpretations with descriptive quantification of the coded interview data. It was implemented to capture in-depth understanding of farmers' understanding of problems in question, while at the same time supply the analysis with insights into the prevalence of specific sub-categories.

After the coding procedure (see section 3.4) and the systematic quantification of sub-code occurrences, the analysis concentrated on the thorough interpretation of the coded segments. Each code was carefully examined to uncover meanings behind farmers' remarks, perspectives and experiences. To build a thorough grasp of each theme area, this required identifying patterns, contradictions, and unique insights both inside and across the narratives. To provide the rich 'why' and 'how' behind the numerical count, the analysis, for instance, examined how the sub-code INTERNET_ACCESS: Poor and Limiting manifested for individual farmers, what specific impacts it had on their operations, and how it influenced their decisions to adopt technology.

Additionally, the number of occurrences for each sub-code was used to provide a descriptive overview of the data. These descriptive counts emphasized the prominence and prevalence of particular concerns and viewpoints among the farmers. It is important to highlight that these descriptive statistics are not meant for inferential statistical analysis; instead, they aim to substantiate and provide context to the qualitative results by showing the relative significance of various perspectives and experiences.

3.6. Ethical considerations

When conducting research involving human subjects it is especially important to adhere to ethical principles to ensure their well-being, rights, and privacy are protected. This research was planned and carried out following recognized ethical standards for studies involving humans, highlighting informed consent, confidentiality, anonymity, and secure handling of data. Before taking part in the semi-structured interviews, all potential participants were given extensive details regarding the study. This process of obtaining informed consent included explaining verbally the study's purpose, objectives, nature of their participation and how their data will be used. Participants were provided with contact information in case any of the farmers wanted to withdraw from the study at any point. All participants had an opportunity to ask any questions regarding the study, and only after participants understood all information about the study, the interviews were initiated.

Strict measures were enforced to protect the confidentiality of participant details and guarantee the anonymity of their responses in the thesis and any future publications. These actions encompassed: anonymization of the data – any information that is personally identifiable has been removed from interview transcripts and any research notes during the transcription and coding process, and participants were assigned identification codes (e.g. Farmer 1, Farmer 2 etc.). Secure data handling and storage – throughout the whole study, the data has been stored on a safe physical storage and the access to it has been limited only to people knowing the password to the storage. Moreover, secure digital storage has also been implemented to prevent any incident that may have occurred and cause the loss of the data. In this case access to the raw data was also restricted. Data will be retained only for the period necessary for the completion and examination of the thesis, after which it will be securely deleted or destroyed.

4. Results

This analysis examines the perceptions, experiences, and engagement of Polish farmers with smart service technologies that support sustainable farming practices. The analysis is performed on 31 coded interviews with Polish farmers across diverse farm types, sizes, and regions. The findings reveal a complicated landscape where positive attitudes toward technology adoption collide with structural barriers. The analysis answers the central research question of the thesis: *What are Polish farmers' perceptions, experiences, and engagement with smart service technologies that aim to support sustainable farming?*

4.1. Polish farmers' perceptions of agricultural data initiatives for sustainability

When investigating the perceived benefits and risks of agricultural data initiatives for improving economic and sustainability goals, Polish farmers show a nuanced understanding that balances optimism with pragmatic concerns. The majority of farmers (24 out of 31) see the high potential for technology-sustainability connections, indicating that the link between digital technologies and environmental outcomes is well-established in farmers' minds. This finding challenges assumptions that farmers might show scepticism regarding technology's environmental benefits.

The perceived benefits of data-driven technologies are multi-sided and closely align with farmers' operational priorities. Most frequently farmers identify efficiency and yield improvement as key benefits, with 18 farmers recognizing data's high value for optimization and efficiency purposes. Furthermore, 11 farmers highlight the importance of data for health and monitoring applications, especially relevant for livestock operations. The significance of precision resource management, mentioned by 21 farmers as a primary technology need, demonstrates that farmers understand how data-driven approaches can decrease input waste while maintaining production levels. This aligns with their recognition that environmental challenges (19 occurrences) and economic pressures (26 occurrences) are concerns that technology might help address.

However, farmers' perspective on technology's potential is interfered by significant concerns about their data privacy and security. Despite keeping generally positive attitudes toward data sharing (26 farmers express positive views), privacy and security concerns turn out as the most frequently cited risk, mentioned by 17 farmers. This apparent contradiction reveals the complexity of farmers' relationship with data technologies. They acknowledge the collective benefits of sharing data for improving their agricultural efficiency while simultaneously worrying about losing control over their information. Only 2 farmers express directly negative or distrustful attitudes toward data sharing practices, suggesting that concerns about privacy rise from uncertainty about data governance rather than farmers' fundamental opposition to sharing their data.

The relatively low occurrence of other perceived risks is also informative. Only 6 farmers expressed worries about competitive harm or misuse from data sharing, and just 2 farmers cite complexity or practicality as major concerns. This suggests that farmers' perceptions about risk are focused and specific rather than generally pessimistic. They are not opposing the technology itself but rather concerned about the frameworks and institutions that would govern data use. Moreover, six farmers express no concerns at all, indicating that for some, the benefits clearly outweigh potential risks and concerns about them.

4.2. Technology awareness and implementation among polish farmers

The second research sub-question asks to what extent Polish farmers are aware of and implementing data-driven technologies, and how these technologies align with sustainable agricultural practices. The findings indicate a significant gap between awareness and implementation that lead to important implications for technology adoption strategies.

Polish farmers exhibit high levels of technology awareness, with 24 farmers showing general awareness of smart farming concepts and 9 farmers displaying specific knowledge of particular technologies. Only 7 farmers indicated limited awareness, suggesting that information distribution about agricultural technologies has been relatively successful. This high awareness level is supported by farmers' diverse information-seeking behaviours, with agricultural press (21 farmers), peers and other farmers (18 farmers), and internet sources (13 farmers) serving as main information channels. Additionally, the fact that farmers actively seek information from multiple sources show genuine interest in staying informed about developments in technology. However, this awareness does not convert into broad implementation of technologies. The data reveals an evident implementation gap, with 17 farmers categorized as non-implementers facing barriers, while only 16 farmers have implemented some type of smart technology across all categories (GPS-based, sensor-based, yield monitoring, and other smart technologies combined). This represents an implementation rate of approximately 50%, despite awareness levels approaching 80%. The gap becomes even more highlighted when inspecting current data collection methods, where manual methods dominate (for 28 farmers, it is still one of the methods of data collection) compared to automated systems (11 farmers), even though 23 farmers use basic software and spreadsheets.

The connection between current technology use and sustainable farming practices is reflected in the data collection priorities and technological requirements identified by farmers. Farmers are already collecting data most relevant to sustainability outcomes, with resource inputs and yield production data each tracked by 24 farmers, and environmental and weather data monitored by 21 farmers. Existing data collection behaviours create a foundation for more sophisticated sustainability monitoring through smart technologies. The emphasis on precision resource management as a technology need (21 farmers) directly supports sustainable farming objectives by enabling more efficient use of resources like fertilizers, pesticides, and water.

The sustainability connection becomes more straightforward when looking into farmers' future outlook. Twenty farmers consider technology essential for the future of agriculture, and nine specifically focus on sustainability as a key driver. This forward-looking perspective, combined with farmers' recognition of environmental and climate challenges (19 farmers) at the regional level, suggests that technology adoption in the future may increasingly be motivated by sustainability objectives rather than purely economic considerations.

Implementation patterns present in the data show that farmers are selective in their technology adoption, mainly focusing on well-known and proven technologies that offer clear operational benefits. GPS-based technologies (6 farmers) and sensor-based systems (10 farmers) represent the most common implementations, reflecting farmers' preference for technologies that enhance precision and monitoring capabilities. Importantly, the high number of farmers (17) facing implementation barriers indicate the willingness to adopt technologies, but is constrained by external factors.

4.3. Barriers to smart service technology adoption in Polish agriculture

The third research sub-question addresses the barriers stopping adoption of smart service technologies that support sustainability outcomes. The analysis reveals that barriers are not uniformly distributed but rather concentrated in specific areas that create systemic challenges for technology adoption.

Economic constraints emerge as the most significant barrier, affecting 29 out of 31 farmers. This nearly universal presence of economic barriers inherently shapes the technology adoption landscape in Polish agriculture. Dominating cost-driven decision criteria, appearing in nearly every interview, leads to conclusion that economic considerations override all other factors in farmers' technology evaluation processes. This economic focus is emphasized even further by the 13 farmers who communicate affordability concerns about future technology adoption, indicating that economic barriers are not just current obstacles but expected future challenges too. The nature of these economic constraints is multifaceted. Financial constraints at the structural level affect 14 farmers, while scale limitations impact 22 farmers, representing 71% of the sample. This high number of scale limitations is particularly significant given that 22 farmers operate generational farms, suggesting that traditional family farming structures may be associated with limited technology adoption capacity. This indicates that generational farms often operate at scales that make large technology investments economically challenging.

Technical and operational challenges constitute the second major barrier category, affecting 23 farmers. These challenges differ from economic constraints, since they rather relate to the practical aspects of implementing and managing new technologies. The attention on practical training as a support requirement (19 farmers) and reliable technical support (12 farmers) suggests that farmers acknowledge their need for additional capabilities to adopt smart technologies successfully. Unlike economic barriers, technical challenges appear to be resolvable through creation of appropriate support systems and training programs.

Farm-specific and contextual barriers affect 11 farmers, representing a smaller but significant group facing unique challenges related to their specific farming situations. These barriers are often associated with the mismatch between available technologies and particular farm characteristics or regional conditions. The relatively lower occurrence of these barriers show that technology solutions are increasingly more adaptable to diverse farming contexts, nevertheless customization is still important for some operations.

The barrier analysis reveals important patterns when examined alongside adoption attitudes. The majority of farmers (16) express moderate willingness to adopt new technologies, while only 8 farmers are reluctant or unwilling. This 2:1 ratio of willing to reluctant farmers suggests that barriers, rather than attitudes, are the primary constraint on technology adoption. The fact that even willing farmers face significant barriers (particularly economic ones) indicates that addressing these structural constraints could unlock substantial adoption potential.

Regional challenges provide further context for understanding adoption barriers. Economic challenges dominate at the regional level (26 farmers), creating an environment where individual farm economic constraints are reinforced by broader economic pressures. Environmental and climate challenges (19 farmers) and regulatory pressures (15 farmers) add complexity to farmers' decision-making environment, potentially making technology adoption both more necessary and more difficult to achieve.

The support requirements identified by farmers provide a roadmap for addressing implementation barriers. Beyond the practical training and technical support already mentioned, farmers express need for access to trials and advisory services (4 farmers), simplicity and usability improvements (5 farmers), and specialized support (6 farmers). Only 3 farmers indicate they need no support, suggesting that most farmers recognize the importance of external assistance in overcoming adoption barriers.

4.4. Synthesis: understanding Polish farmers' technology adoption landscape

The analysis reveals that Polish farmers' engagement with smart service technologies for sustainable farming is characterized by informed optimism constrained by structural barriers. Farmers demonstrate sophisticated understanding of technology's potential benefits, particularly for sustainability outcomes, while maintaining realistic concerns about implementation challenges. The primary obstacles to adoption are not attitudinal or knowledge-based but rather structural and economic.

The data collection practices of Polish farmers provide a strong foundation for smart technology adoption. Most farmers already collect relevant data through manual methods, indicating that the conceptual leap to automated data collection systems is smaller than might be expected. However, the persistence of manual methods (28 farmers) despite the availability of digital alternatives suggests that the transition requires more than just technological solutions.

The sustainability connection is well-established in farmers' minds, with the vast majority recognizing technology's high potential for environmental benefits. This creates a favourable context for promoting smart technologies as tools for achieving sustainability goals. However, the economic constraints that affect nearly all farmers mean that sustainability benefits alone are insufficient to drive adoption; technologies must also demonstrate clear economic value.

The finding that farmers maintain positive attitudes toward data sharing while expressing privacy concerns suggests that successful technology adoption will require trusted institutional frameworks rather than simply better technologies. The agricultural data ecosystem approach advocated in the research framework appears aligned with farmers' needs for collaborative yet secure data sharing arrangements.

Looking forward, farmers' recognition that technology will be essential for agriculture's future, combined with their specific technology expectations and sustainability focus, indicates readiness for a technological transition. However, realizing this potential will require addressing the economic and structural barriers that currently prevent willing farmers from implementing available technologies. The high level of technology awareness among farmers suggests that information and education efforts have been successful, but the implementation gap indicates that the next phase of technology adoption support must focus on overcoming practical and economic obstacles rather than building awareness.

5. Discussion

This chapter presents a comprehensive discussion of the findings from the qualitative research conducted with Polish farmers, as detailed in Chapter 4. It aims to highlight patterns within these findings, situate them within the extant literature reviewed in Chapter 2, and formulate implications for both theory and practice. Furthermore, this chapter acknowledges the limitations of the study and proposes directions for future research.

5.1. Research questions and main findings

This study was guided by the main research question:

What are Polish farmers' perceptions, experiences, and engagement with smart service technologies that aim to support sustainable farming?

To address this, the following sub-questions were considered:

1. What are the perceived benefits and risks of agricultural data initiatives for advancing sustainability goals among Polish farmers?

2. To what extent are Polish farmers aware of and implementing data-driven technologies, and how do these technologies align with sustainable agricultural practices?

3. What are the main barriers to adopting smart service technologies that support sustainability outcomes in Polish agriculture?

The main findings from the qualitative interviews, as presented in Chapter 4, are summarized below:

Finding 1: Perceived Benefits of Smart Farming Technologies. Polish farmers recognize the potential of smart farming technologies to enhance efficiency, optimize resource use, and improve environmental outcomes. Specifically, they highlighted benefits related to precision farming techniques, such as reduced input costs (fertilizers, pesticides) and increased yields through tailored resource application. There is also an understanding that data-driven decision-making can lead to better overall farm management.

Finding 2: Awareness and Implementation of Data-Driven Technologies. While there is a general awareness of smart farming technologies, the actual implementation varies significantly among Polish farmers. Many are still in the early stages of adoption, often using traditional methods alongside nascent digital tools. The adoption of advanced technologies like soil moisture sensors, yield mapping, and satellite imagery is not widespread, though there is an increasing interest.

Finding 3: Barriers to Adoption of Smart Service Technologies. Several significant barriers hinder the widespread adoption of smart service technologies in Polish agriculture. These include: lack of financial resources for initial investment, insufficient digital infrastructure (e.g., limited broadband access in rural areas), lack of technical knowledge and training, concerns about data privacy and ownership, and a general scepticism towards new technologies stemming from traditional farming practices.

Finding 4: Alignment with Sustainable Agricultural Practices. Farmers generally perceive smart farming technologies as tools that can contribute to sustainable agriculture by enabling more precise resource management, reducing waste, and minimizing environmental impact. However, the direct link between technology adoption and tangible sustainability outcomes is not always explicitly recognized or prioritized by all farmers, often overshadowed by immediate economic concerns.

5.2. Discussion of main findings

5.2.1. Perceived benefits and alignment with existing literature

Polish farmers' recognition of the benefits of smart farming technologies, particularly in terms of efficiency and resource optimization, aligns with existing literature on precision agriculture. Studies by Balafoutis (2017) and Kernecker (2020) in other European contexts similarly emphasize the potential for reduced input use and improved decision-making through digital technologies. The finding that farmers see these technologies as contributing to sustainable agriculture, even if the direct link is not always prioritized, resonates with the broader discourse on sustainable agriculture, which views technology as a key enabler (Velten, 2015). This study's contribution lies in confirming these perceptions within the specific, under-researched context of Polish agriculture, demonstrating that the fundamental understanding of technology's utility for efficiency and sustainability is present, despite varying levels of adoption.

5.2.2. Awareness, implementation, and the digital divide

The varying levels of awareness and implementation among Polish farmers, with many still relying on traditional methods, highlight a significant digital divide. This finding is consistent with observations by Salemink et al. (2017), who point to limited broadband access in rural areas as a constraint on real-time data transmission and cloud service utilization, which are crucial for advanced smart farming. While there's an increasing interest in new technologies, the slow pace of widespread adoption suggests that awareness alone is insufficient. This study contributes by underscoring the persistence of traditional practices and the nascent stage of digital transformation in Polish agriculture, emphasizing the need for targeted interventions that bridge the gap between awareness and actual implementation.

5.2.3. Barriers to adoption: financial, infrastructural, and knowledge gaps

The identified barriers—financial constraints, insufficient digital infrastructure, lack of technical knowledge, and concerns about data privacy and ownership—are consistent with challenges reported in technology adoption literature across various agricultural contexts. For instance, the financial barrier is a common impediment to technology adoption in agriculture globally. The infrastructural limitations, particularly rural connectivity, echo the concerns raised by Salemink et al. (2017). Concerns about data privacy and ownership, as highlighted by Wiseman et al. (2019), are critical factors influencing farmers' willingness to participate in agricultural data ecosystems. This study's unique contribution is in detailing how these universal barriers manifest within the specific post-communist transition context of Polish agriculture, where historical factors and current economic realities may exacerbate these challenges. The scepticism towards new technologies also points to a cultural barrier that needs to be addressed.

5.3. Implications for theory and practice

This section explores the broader implications of our findings, highlighting both their contributions to existing academic theories and their practical relevance for various stakeholders. We'll first delve into how this study enhances our understanding of technology adoption in agriculture, particularly within the Polish context. Following this, we'll outline concrete recommendations for policymakers, government agencies, and smart service providers, aiming to foster more effective and sustainable smart farming practices.

5.3.1. Theoretical implications

This study extends existing theories of technology adoption by providing empirical evidence from a previously under-researched geographical context—Polish agriculture. It confirms that factors such as perceived benefits, infrastructure availability, financial capacity, and trust (related to data privacy) are critical determinants of technology adoption, even in diverse socio-economic settings. The findings also contribute to the understanding of agricultural data ecosystems by illustrating the challenges in fostering data sharing and collaboration when foundational elements like robust infrastructure and clear data governance policies are lacking. The study highlights the importance of considering the unique historical and cultural context when applying general technology adoption models.

5.3.2. Practical implications

For Policymakers and Government Agencies:

- Investment in Rural Digital Infrastructure: The most adaptable variable is digital infrastructure. Policymakers are recommended to prioritize significant investment in expanding high-speed internet access to rural agricultural areas. This is a foundational step for enabling the adoption of data-intensive smart farming technologies in those areas. Without this, other initiatives will have limited impact. They stand to benefit greatly from increased agricultural productivity, reduced environmental impact, and improved competitiveness of the Polish agricultural sector.

- Financial Incentives and Subsidies: To address financial barriers, government agencies should introduce targeted subsidies, grants, and low-interest loan programs dedicated specifically for smart farming technology adoption. These programs should be designed to be easily accessible to farmers of all scales, allowing also small scale farmers to leverage them. The conditions for success include clear application processes and adequate funding to make a visible difference in investment costs.
- Education and Training Programs: To overcome knowledge gaps and scepticism, comprehensive educational and training programs are crucial. These programs should focus on practical skills for using smart farming technologies, demonstrating their benefits, and addressing concerns about data management. Partnerships with agricultural universities and other related organizations can enable effective implementation. The benefit is a more skilled and tech-savvy farming community, resulting in more efficient and sustainable practices.
- Data Governance and Trust Frameworks: To alleviate concerns about data privacy and ownership, policymakers must establish clear legal frameworks and guidelines for agricultural data governance. This includes defining data ownership, usage rights, and security protocols. Building trust through transparent policies will encourage farmers to participate in data-sharing initiatives, which are vital for the development of robust agricultural data ecosystems. Polish lawmakers should actively engage in crafting EU legislation on data governance to ensure effective representation and influence.

For Smart Service Providers and Technology Developers:

- User-Friendly and Affordable Solutions: It is recommended to develop smart farming technologies that are intuitive, easy to use and implement, and affordable, especially for small and medium-sized farms. Focus on solutions that demonstrate clear and immediate return on investment, and be able to communicate it. This will lead to lowering entry barrier and increase adoption rates.
- Localized Support and Demonstrations: Provide localized technical support and organize practical demonstrations of smart farming technologies in action. This will help overcome scepticism and build confidence among farmers who value hands-on learning and peer validation.

- Transparent Data Policies: Clearly communicate data privacy status and ownership policies to farmers, explain their rights and what obligations data holders have. Offer options for data control and ensure robust security measures. Building trust in data handling practices is crucial for successful adoption.

5.4. Limitations

This study, while providing valuable insights, has several limitations. Firstly, its qualitative nature, based on semi-structured interviews with a sample of 31 Polish farmers, limits the generalizability of the findings to the entire Polish agricultural sector. The sample, though diverse, may not fully represent the heterogeneity of farming practices and perceptions across all regions and farm types in Poland. Secondly, the study relies on self-reported perceptions and experiences, which may be biased by social desirability or incomplete recall. Furthermore, the study did not quantify the direct impact of technology adoption on specific sustainability metrics, focusing instead on perceptions. Finally, the study involved interviewing only farmers, if more stakeholders (e.g. legislators, service providers) were interviewed, the study would provide much more comprehensive overview of the data-driven technologies landscape in agriculture in Poland.

5.5. Suggestions for future research

This section describes recommendations regarding future research which emerged, based on the findings and limitations of this study. Firstly, a quantitative study approach about technology adoption could be conducted (for instance a large-scale quantitative survey) to examine and assess the rates of smart farming technology adoption across a more representative sample of Polish farmers. This would enable statistical analysis of factors influencing adoption of these technologies, and confirm generalizability of findings. Future research could also focus on quantifying the actual economic and environment impacts of smart farming technologies in Poland. This would for example involve collecting empirical data on metrics like input reduction, yield increases, greenhouse gas emissions, and other sustainability indicators. In-depth case studies of Polish farms that have successfully integrated smart farming technologies could provide valuable insights into best practices, implementation strategies, and the long-term benefits. This would offer practical guidance for other farmers and highly informative for legislators and service providers. Future research can also examine role of agricultural cooperatives, farm associations and other collective entities in facilitating technology transfer, knowledge sharing, and collective investment in smart farming infrastructure in detail. This would provide more information regarding importance of existence of such organizations for smart service adoption. Future studies should also investigate and develop the most effective pedagogical approaches and content for training programs aimed at improving digital literacy and smart farming skills among Polish farmers. Lastly, comparative studies on perceptions between Polish agriculture and other post-communist or developing agricultural economies would be of great value, aiming to identify common challenges and successful strategies for technology adoption.

5.6. Conclusion

This study has provided critical insights into Polish farmers' perceptions, experiences, and engagement with smart service technologies for sustainable farming. It highlights a clear recognition of benefits, alongside significant barriers related to infrastructure, finance, and knowledge. By situating these findings within existing literature and offering practical implications for policymakers and technology providers, this research contributes to a more nuanced understanding of agricultural technology adoption in a unique European context. The suggested future research directions aim to build upon these insights, fostering a more sustainable and technologically advanced agricultural sector in Poland and beyond.

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8. Appendix

Appendix 1 – list of codes and sub-codes

ADOPTION_ATTITUDES: Highly Willing, Moderately Willing, Reluctant, Unwilling; ADOPTION_BARRIERS: Economic Constraints, Farm-Specific and Contextual Barriers, Technical and Operational Challenges; CURRENT_DATA_COLLECTION: Animal Health and Reproduction, Environmental and Weather, Financial and Market, No Data Collected, Resource Inputs, Yield and Production; CURRENT_DATA_COLLECTION_METHODS: External Services, Manual Methods, Sensors and Automated Systems, Software and Spreadsheets, Undecided; DATA_MANAGEMENT_TOOLS: Basic Software/Spreadsheets, Farm Management Software, No Software/Digital Tools, Specialized Digital Tools; DATA_SHARING: Advisory Services, Contractual/Processor Requirements, Cooperative/Community Sharing, No Data Sharing, Regulatory/Subsidy Requirements; DATA_SHARING_ATTITUDE: Negative/Distrustful, No Opinion, Positive, Sceptical/Neutral; DATA_VALUE: High Value – Health and Monitoring, High Value – Optimization and Efficiency, Low Value – Experience Preferred, Moderate/Conditional Value, Uncertain/No Opinion; DECISION_CRITERIA: Complexity-Driven, Cost-Driven, Knowledge/Experience-Driven, Reliability/Practicality-Driven, Unclear/Non-Responsive; FARM_CHARACTERISTIC: Farm Characteristic: Animal, Farm Characteristic: Crop, Farm Characteristic: Mixed; FARMING_BACKGROUND: Generational Farm, Long-Term Experience, Mid-to-Recent Experience, Self-Started Farm; FUTURE_OUTLOOK: Affordability Concerns, Policy/Market Challenges, Scepticism/Limited Role, Specific Technology Expectations, Sustainability Focus, Technology Essential; INFORMATION_SOURCES: Advisors, Agricultural Press, Associations/Networks, Conferences/Workshops, Fairs/Exhibitions, Internet, Peers/Other Farmers, Suppliers/Dealers; INTERNET_ACCESS: Poor and Limiting, Reliable and Sufficient, Reliable but Limited for Tech; PERCEIVED_BENEFITS: Benchmarking, Disease/Pest Monitoring, Efficiency/Yield Improvement, Knowledge Sharing/Planning, No Benefits Expressed; PERCEIVED_RISKS: Complexity/Practicality, Misuse/Competitive Harm, No Risks Expressed, Privacy/Security; POLICY_AWARENESS: Aware – Not Participated, Participated, Unaware – Not Participated; REGIONAL_CHALLENGES: Disease/Pest, Economic, Environmental/Climate, Labor, Regulatory; STRUCTURAL_FACTORS: Financial Constraints, No influence, Reliance on Subsidies/Grants, Scale Limitations, Specialization Needs; SUPPORT_REQUIREMENTS: Access to Trials/Advisory, None, Practical Training, Reliable Technical Support, Simplicity and Usability, Specialized Support; TECH_AWARENESS: Exploration/Consideration, General Awareness, Limited Awareness, Specific Technologies; TECH_EXPERIENCES: Negative Experiences, Neutral Experiences, Non-Use, Positive Experiences; TECH_IMPLEMENTATION: GPS-Based Technologies, Non-Implementation/Barriers, Other Smart Technologies, Sensor-Based Technologies, Yield Monitoring; TECH_NEEDS: Health Monitoring, Labor Reduction, Other Needs, Pest/Disease Prediction, Precision Resource Management; TECH_SUSTAINABILITY_CONNECTION: High Potential, Sceptical/Experience-Based, Uncertain/Unknown; UNIMPLEMENTED_TECH: Automation Technologies, Drone/Satellite Imagery, Monitoring Systems, No Technologies Considered, Precision Agriculture Technologies

Appendix 2 – interview questionnaire

I. Introduction and Background

Could you please tell me about your farm? (e.g., type of farm, size, location, main crops/livestock)
How long have you been farming, and has your farm been in your family for generations?
Could you describe your typical daily/weekly activities on the farm?

II. Agricultural Data Ecosystems

What types of data do you currently collect and use for your farm management? (e.g., yield data, input usage, weather records)"
How do you collect this data? (e.g., manually, sensors, software)
Are you currently using any software or digital tools to record, store, or analyse your farm data?
If yes, which ones? What are your experiences with them?
Have you ever shared your farm data with any external parties, such as advisors, cooperatives, or companies?"
What are your thoughts on the idea of sharing agricultural data within a network or platform to improve farming practices?
How valuable do you think data-driven insights could be for improving your farm's efficiency and sustainability?

III. Smart Services

Are you familiar with the concept of 'smart farming' or digital technologies in agriculture?
Which, if any, smart service technologies are you currently using on your farm?
(If applicable) Could you describe your experience with these technologies? What are the main benefits and challenges?
Have you considered using other smart service technologies but decided against it?
If yes, why? What are the main barriers?
What specific needs or challenges on your farm do you think could be addressed by smart service technologies?
What are your expectations regarding the support and training required for implementing smart service technologies?

IV. Technology Adoption

In general, how willing are you to adopt new technologies on your farm?
What factors influence your decision to try or not try a new technology?
What are the main sources of information you rely on when learning about new agricultural technologies?
What are the biggest obstacles or challenges you face when trying to implement new technologies?

V. Polish Context

What are the main challenges you face as a farmer in Poland today?
How does the size and structure of your farm (e.g., family farm, larger enterprise) affect your ability to invest in new technologies?
Are you aware of any government programs or EU policies that support the adoption of new technologies in agriculture?
Have you participated in any of these programs? What was your experience?
How would you describe the availability and quality of internet access in your area, and how does it affect your farm operations?
What are your views on the future of agriculture in Poland, particularly regarding the role of technology?

Official statement of original thesis

By signing this statement, I hereby acknowledge the submitted thesis (hereafter mentioned as “product”), titled:

Understanding Polish Farmers’ Perceptions of Smart Farming: Data Use, Technology Adoption, and Sustainability Challenges

to be produced independently by me, without external help.

Wherever I paraphrase or cite literally, a reference to the original source (journal, book, report, internet, etc.) is given.

By signing this statement, I explicitly declare that I am aware of the fraud sanctions as stated in the Education and Examination Regulations (EERs) of the SBE.

Place: Maastricht, Netherlands

Date: 19/06/2025

First and last name: Jakub Polakowski-Karol

Study programme: Business Intelligence and Smart Services

Course/skill: EMTH0009 – Master’s Thesis

ID number: i6249092

Signature: 

Statement on the use of Generative AI (GenAI) in the master thesis

I hereby certify that I adhered to the SBE guidelines on the use of GenAI tools such as ChatGPT in the master thesis. In the box below, I document how and for what purposes I used GenAI.

During the preparation of this work, I used GenAI for the following purposes:

• Search engine: [Chat GPT, Grok, Claude: I used these language models as search engines, sometime early this year they introduced "deep-search" mode, which works very well in search and identifying content on the internet related to the prompts, hence I leveraged that for my search of literature for literature review]

• Language assistant: [Chat GPT, Grok: I used these models to improve the structure, spelling and grammar of some sentences, always making sure no new content was added, just my content rephrased such that it is more correct and appropriate language]

• Translator: [Chat GPT: I conducted interviews in Polish language so for analysis I wanted to translate them to English for convenience, hence the initial translation was performed with the language model, but further corrections and checks were done manually by me]

After using any tool, I reviewed, quality-checked, and edited the content as needed and take full responsibility for the content of the thesis.

By signing this statement, I explicitly declare that I am aware of the fraud sanctions as stated in the Education and Examination Regulations (EERs) of the SBE.

Place: Maastricht

Date: 19/06/2025

First and last name: Jakub Polakowski-Karol

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Sustainable Development Goals (SDG) Statement

Name Jakub Polakowski-Karol

ID i6249092

Supervisor Amar Sidi

Date 19/06/2025

SDG Code(s): 12

Explanation: I believe my research for the thesis is linked to responsible consumption and production goal. The research aims at gaining insights regarding data sharing and data driven smart services, which foster sustainable agricultural practices. In consequence, utilizing such services leads to improved efficiency in food production In the face of growing needs of our society, I see it as particularly important issue to address.