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Unlocking the Potentials of IoT Adoption in Agriculture: Insights from Norwegian Farmers

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Abstract

This study delves into the adoption of Internet of Things (IoT) technology in the agriculture industry, which has the potential to revolutionize resource allocation and operational efficiency and meet the growing global demand for food and water. Despite its potential, the adoption of IoT technology in agriculture remains generally low. Hence, this research aims to explore the motivating factors influencing IoT adoption, assess the impacts of adoption on agriculturists, and identify the challenges that need to be addressed to promote future IoT adoption in the agricultural sector. Semi-structured interviews with Norwegian agriculturists who have adopted IoT technologies were conducted using an exploratory qualitative approach. Our findings reveal several key factors that influence IoT adoption, including the availability of technical support, governmental policies, and the intentions of agriculturists' children to carry on farming traditions. The adoption of IoT has led to improved decision-making, operational efficiency, and control for agriculturists, although they may not be fully aware of all the consequences associated with adoption. Additionally, the study highlights a lack of support and knowledge among industry stakeholders, which could hinder the diffusion of IoT adoption in agriculture. These findings contribute to our understanding of the complexities surrounding IoT adoption in agriculture and provide insights for policymakers, industry stakeholders, and agriculturists seeking to maximize the benefits of IoT technology. Addressing the challenges identified, such as enhancing technical support systems, developing supportive policies, and increasing awareness among agriculturists, can foster a conducive environment for greater IoT adoption in agriculture in Norway.

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1. Introduction

The global population is projected to reach 9.7 billion by 2050, resulting in a 50% increase in food demand, while climate change, resource scarcity, and the COVID-19 pandemic exacerbate global food security concerns (FAO et al.2020). Implementing the Internet of Things (IoT) in agriculture can address these challenges by promoting sustainable practices and ensuring food safety (Jayashankar et al., 2018). However, despite its potential benefits, IoT adoption rates in agriculture remain low, possibly due to skepticism, limited knowledge, and unreliable information (Elijah et al., 2018). The IoT infrastructure is usually a complex system integrating various devices with processing, communication, sensing, identification, and networking capabilities (Da Xu et al., 2014). The definition of IoT varies depending on various technologies. However, a commonly accepted definition is "*a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols, where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network*" (Da Xu et al., 2014, pp. 234-244). The IoT architecture is commonly divided into three layers: perception, network, and application layers (Tzounis et al., 2017).

Agriculture is a critical industry that supports over 2.8 billion people worldwide (FAO, 2021). To address the challenges faced by the industry, such as unpredictable weather, price volatility, and environmental changes, more resilient agricultural systems are needed (FAO, 2021; Kamilaris et al., 2016). Norwegian agriculture is influenced by the country's natural conditions and limited growable land, relying on family farming and governmental subsidies (Almaas, 2004). The Norwegian Climate Action Plan (2020) emphasizes the need for green technology, including IoT, to reduce greenhouse gas emissions without compromising food production. The literature highlights the need for more research on the monetary benefits of IoT adoption in agriculture (Elijah et al., 2018), especially in specific contexts such as Norway, where limited academic research is available. Furthermore, addressing the knowledge gap between sustainability and "green" information systems (IS) and information technology (IT) is essential (Anthony, 2016). Lastly, the rapid development of new technologies necessitates the continuous exploration and evaluation of the capabilities of agricultural IoT technologies (Khanna & Kaur, 2019). Hence, this research aims to address the following three main research questions:

- (1) What are the key motivating factors for the adoption of IoT technology among Norwegian Agriculturists?
- (2) How has the adoption of IoT technology affected Norwegian agriculturists and their farming operations?
- (3) What are the current challenges and areas of concern that can hurdle IoT technology adoption in agriculture?

The rest of the paper is organized as follows. A literature review is presented in section 2. Section 3 illustrates the methodology adopted in this research. The main findings of this research are presented in section 4. A discussion of the findings is presented in section 5, followed by a conclusion and recommendations for future research in section 6.

2. Literature Review

2.1. IoT Applications in Agriculture

The implementation of IoT technology is shifting the existing agriculture methods towards the concepts of *smart farming* and *precision agriculture*. IoT is the key to these concepts, as it ensures the continuous data flow between sensors and devices, making it possible to add value to the obtained data by automatic processing, analysis, and access (Villa-Henriksen et al., 2020). While definitions of precision agriculture in literature are somewhat inconsistent, the definition that is widely adopted is the use of a management strategy that incorporates temporal, spatial, and individual data, along with other relevant information, which can assist in making informed decisions regarding resource allocation, productivity, quality, profitability, and sustainability in agricultural production (ISPA, 2018). This strategy involves gathering, processing, and analyzing data to estimate variability, to improve resource use efficiency (ISPA, 2018). For example, rather than applying equal amounts of fertilizers on an entire agricultural field, precision agriculture methods will measure conditions by using different IoT technologies and adapt their fertilizing strategy accordingly (Schrijver et al., 2016). Smart farming is developing beyond the modern concept of precision agriculture. According to Villa-Henriksen et al. (2020), it also bases its management tasks on spatial data, such as in precision agriculture. However, it is enhanced with context awareness and activated by real-time events, improving the performance of previously precision agriculture solutions. It emphasizes information and communication technology, where IoT technologies provide massive volumes of data being captured, analyzed, and used for near real-time decision-making (Wolfert et al., 2017). IoT technology in agriculture empowers farmers with decision-making tools and automation technologies for better quality,

productivity, and sustainability (Elijah et al., 2018; Jayashankar et al., 2018). Access to real-time agricultural data through intelligent devices allows farmers to make informed decisions (Boursianis et al., 2022). IoT also aids in food supply chain traceability, creating value for farmers, retailers, processors, and consumers (Ferrag et al., 2020). With the emergence of 5G networks, deploying, monitoring, and managing IoT devices on farms will become more accessible (Tang et al., 2021).

IoT applications in agriculture are vast, including livestock monitoring, dairy monitoring, virtual fencing, crop farming, and water management & irrigation. Livestock Monitoring is an IoT-based solution that provides real-time tracking, activity monitoring, and health record management for livestock (Karthick et al., 2020). Dairy Monitoring is a milking robot that has played a significant role in dairy farming, increasing productivity, efficiency, and profitability (Kvam et al., 2022). Virtual fencing addresses challenges in livestock farming, such as large and remote grazing areas, by allowing location tracking and herding without physical barriers (Muminov et al., 2019). Crop Farming is an IoT technology that provides insights into soil analysis, fertilizers, pesticides, yield prediction, and irrigation (Tang et al., 2021). IoT devices also aid in disease and pest management, minimizing risks in crop production (Ayaz et al., 2019). Water Management & Irrigation are IoT technologies that optimize water usage, improve water quality and quantity, and minimize human intervention (Ayaz et al., 2019; Elijah et al., 2018). In Norway, IoT technology has been employed in diverse agricultural facades, including crop management, livestock monitoring, and precision farming (Kaur & Kaur, 2019). Despite the numerous benefits, IoT in agriculture faces challenges, such as security and privacy issues, cybersecurity threats, agroterrorism, and other vulnerabilities, which slow the adoption rate (Gupta et al., 2020; Tzounis et al., 2017).

2.2. *IoT Adoption in Agriculture*

The IoT technology has the potential to transform agricultural and farming methods globally. Increasing profitability, optimizing decision-making, and limiting risks that drive IoT adoption is perceived as motivating factors for adoption (Jayashankar et al., 2018). Previous research also suggests that a farmer's likelihood to embrace IoT technology is influenced by factors such as education, farm size, technical expertise, and age (Barnes et al., 2019). On the other hand, Knierim et al. (2018) argue that age and education do not always affect the likelihood of IoT adoption in agriculture. Technology adoption could also be influenced by social influence and marketing activities (Pillai & Sivathanu, 2020). However, substantial adoption barriers persist, such as high costs of adoption (Barnes et al., 2019; Villa-Henriksen et al., 2020). In addition, the perceived risk of data exploitation negatively affects IoT adoption in agriculture (Farooq et al., 2019). A considerable challenge is farmers' lack of awareness and understanding of IoT technologies (Ayaz et al., 2019; Pillai & Sivathanu, 2020). According to Farooq et al. (2019), the transition from traditional to IoT-based agriculture could also be stalled by uneducated or tech-illiterate farmers.

While the extant research demonstrates the potential of IoT technology to reshape agriculture and farming practices, however, addressing challenges like high costs, limited awareness and knowledge, and perceived data misuse risks is crucial for successful IoT adoption in agriculture.

3. **Theoretical Framework & Method**

3.1. *Theoretical framework*

Information systems literature presents several theories and models to investigate and understand technology adoption, users' acceptance, and their intention to practice and use the technology. These include, but are not limited to, the Technology Acceptance Model (Davis, 1985), the Theory of Planned Behavior (Ajzen, 1991), the Theory of Diffusion of Innovation (DOI) (Rogers, 2003), the Technological, Organizational, and Environmental framework (Tornatzky et al., 1990) and Determinants of Diffusion, Dissemination, and Implementation of Innovations (MDDDI) (Greenhalgh et al., 2004). This study adopts elements from the Diffusion of Innovation theory and the Model of Determinants of Diffusion, Dissemination, and Implementation of Innovations to explore and identify the factors influencing IoT adoption and post-adoption evaluation in agriculture. Rogers (2003) proposes four main elements in the diffusion of innovation: innovation, communication channels, time, and the social system. The theory also proposes five attributes affecting the rate of adoption and five adopter categories that classify members of a social system based on their innovativeness: Innovators, Early adopters, Early majority, Late majority, and Laggards. The MDDDI model, initially developed for health services, focuses on the entire adoption process and the factors that may influence this adoption process (Greenhalgh et al., 2004). It consists of nine components that incorporate factors and processes influencing the adoption of innovations. These components include the innovation, communication and

influence, the outer context, the adopter, system antecedents for innovation, system readiness, linkage, assimilation, and implementation process (Greenhalgh et al., 2004).

This research integrates the DOI Theory and the MDDDDII conceptual model elements to guide the study scope, the research questions, the development of the interview guide, and the structuring of the findings and discussion. The MDDDDII model adds additional features and dimensions compared to the DOI theory, such as technical support, the knowledge required, and risk (Greenhalgh et al., 2004). The MDDDDII has been widely used in IS research in general and IoT in agriculture studies in specific. For example, Pathak et al. (2019) found the MDDDDII model helpful in understanding and identifying factors affecting IoT adoption in agriculture, but highlighted the need for a more comprehensive and complementary approach. Hence, this research focuses on four components from MDDDDII: the adopter, the innovation, communication & influence, and the outer context while incorporating elements from the DOI theory.

3.2. Research design

To investigate the adoption of IoT by Norwegian farmers, this study employs an exploratory qualitative research approach. Exploratory qualitative research aims to uncover new insights, perspectives, and a deeper understanding of a phenomenon or topic (Oates, 2006). Qualitative interviews are helpful in exploratory research because they allow the researcher to delve deeply into topics, grasp the participants' viewpoints, and uncover new themes or ideas that may not have been considered earlier. Expanding on the exploratory qualitative design, this study follows the guidelines for data collection and analysis (Oates, 2006) to address the research questions.

A crucial aspect of qualitative research is determining the appropriate sample size for data saturation. Marshall et al. (2013, p. 11) state that data saturation is achieved "*when the researcher gathers data to the point of diminishing returns when nothing new is being added.*" This concept suggests that collecting additional data will no longer contribute to understanding the research topic or provide new insights. In this study, a critical reflection on the number of participants was conducted with data saturation in mind. After completing the sixth interview, it was observed that no new topics or perspectives emerged from the data, signifying that saturation had been reached.

3.2.1. Data Collection and Analysis

Initially, various Norwegian agriculture industry experts were contacted to understand the industry better. The information obtained from these experts served as a pilot study, guided the interview guide's development, and aided the authors in identifying agriculturists and farmers that have adopted IoT technologies. Hence, a snowball sampling technique (Oates, 2006) was used with the industry experts to identify and access agriculturists who have adopted IoT technologies within the Norwegian market. Data were collected through in-depth individual semi-structured interviews that span a period of four months. Semi-structured interviews were conducted based on an interview guide developed following Oates' (2006) guidelines and influenced by the MDDDDII and DOI theory, as stated earlier.

Participants in this study were selected based on the size of their farms (medium to big) and their active use of IoT technology in agricultural operations. The table below provides an overview of the informants and the conducted interviews.

Table 1. Participant group: Norwegian agriculturists.

Participants	Type of farming	Size	IoT Technology	Interview Time
Participant A	Dairy production	Medium/Large	Milking robot & Activity monitoring	1:45
Participant B	Dairy production	Large	Milking robot & Livestock monitoring	2:20
Participant C	Crop farming	Large	Irrigation & Crop monitoring systems	2:30
Participant D	Crop farming	Large	Storage & Crop monitoring systems	2:30
Participant E	Livestock	Medium/Large	Virtual Fence	2:15
Participant F	Livestock	Medium/Large	Virtual Fence & Activity monitoring	1:05

Rather than focusing on one specific agricultural industry or IoT application, this research examines IoT's broader landscape in agriculture. As a result, three diverse agricultural areas have been chosen for this study, each employing a different IoT technology and application. Namely, dairy production, crop farming, and livestock farming were chosen because they represent some of Norway's most critical agricultural areas (Kaur & Kaur, 2019). In addition, these three industry areas are typically and commonly acquired by early adopters of IoT technologies, and usually employ state-of-the-art agricultural IoT solutions. All interviews were digitally recorded and conducted in the Norwegian language. The interviews were later transcribed and then translated into English. The data collection process followed the General Data Protection Regulation (GDPR) guidelines, and signed consent was obtained from all the study participants before the actual interviews.

To perform the data analysis, the collected data was color-coded and then divided into five main categories based on the components of the MDDII (Greenhalgh et al., 2004), and the DOI theory (Rogers, 2003). The utilization of a color-coding technique (Knafl et al., 1988) was employed to reveal commonalities, contrasts, and trends within the collected data. This color-coding system enhanced the data visualization and detection of patterns throughout the data analysis phase. The analysis involved thematic analysis by identifying the data's themes, similarities, and differences, and aided in synthesizing the findings (Yin, 2015).

4. Findings

This section provides an overview of the results obtained from the interviews conducted with Norwegian agriculturists, and identifies similarities, differences, and concerns found in the data elucidated by the study participants. As mentioned, the findings are organized into five sections guided by the MDDII conceptual model and the DOI theory.

4.1. The Adopter

According to Rogers (2003), adopters are integrated into the local social system and act as opinion leaders, often influencing others in their network. Adopters are crucial for the diffusion process as they help to spread innovation among the broader population. Characteristics such as needs, motivation, values, and skills were identified in the extant literature as essential for exploring technology adoption among agriculturists (Greenhalgh et al., 2004). Our findings suggest that future farms' security (ownership), improved decision-making, increased control, and increased animal health were critical factors and motivators for investing in new technology (e.g., IoT) in Norway. The participants in this research emphasized the importance of several factors as being significant. Those factors include the suppliers' overall performance in the market, the suppliers' technical support services, reputation and trust, the ability to cooperate with clients, and the ability to provide testing and training on various IoT technologies to farmers, before the actual acquisitions take place, and to increase the farmers' awareness of the potential applications of those technologies.

Given the fact that the majority of the farms in Norway are usually family-owned, involving several generations in some cases (Almas, 2020), the future security of farm ownership was thus identified as a significant factor in influencing IoT technology adoption in Norway. For example, informant F elaborates on how the future security of the farm's ownership motivated and expedited their IoT investment and adoption, *"I believe we would not have made the investments that we have done if our daughters did not signal that they are interested in taking over the farm."* Similar assertions were provided by Participant A, *"If we did not have anyone to take over the farm, we would not have made the investments we have done so far."* Furthermore, participant A also elaborated that one of the main drivers of adopting IoT solutions was to *"prepare the farm for the next generation, as they will see it as a major benefit."*

4.2. The Innovation

This component presents the features of IoT technologies that influence the adoption among agriculturists and how they have experienced several aspects of the IoT adoption process regarding different features of the technologies.

The participants identified several factors that motivated them to invest in IoT technologies, including gaining more flexibility and time, improving decision-making, gaining more control, increasing animal health, and utilizing resources more effectively. In general, the study participants stated that the relative advantage of IoT technologies

was a significant motivating factor for adoption. The participants emphasized the importance of trust and cooperation with suppliers and the quality of technical support. They shared both positive and negative experiences with the support provided by their suppliers. The participants also highlighted the significance of the supplier's knowledge and the importance of pre-testing IoT technologies in Norway before actual adoptions. Participant B elaborated, "*We now depend on the robot. If there is a malfunction, we have no other way to milk our animals*". Hence, the participants discussed the importance of observing and trying IoT technologies before investing in them, specifically in harsh weather conditions. They also mentioned their experiences with being part of pilot studies and the benefits of investing in innovations in the startup phase. Participant B also emphasized the importance of trying IoT technologies along with training, stating, "*Watching a YouTube video where everything appears great is not sufficient enough; we have to be able to try it ourselves when considering investing.*"

4.3. Communication and Influence

Communication and influence are crucial for promoting the adoption of agricultural technologies. This involves using social networks, expert opinions, and marketing techniques to spread information about innovations (Pathak et al., 2019). Agriculturists rely heavily on their social networks for information about agricultural technologies. Four participants (Participants A, B, C & F) emphasized the importance of learning from other farmers who have already implemented these technologies. Participant A stated, "*When one is about to start such a process and spend so much money, one needs to gain knowledge from other agriculturists who have already implemented such technologies.*" Social media platforms like Facebook also play a significant role in sharing ideas and experiences among farmers. All participants believed that they had influenced other agriculturists to invest in IoT technologies, with one participant noting that they had convinced seven other farmers to adopt the technology.

Expert opinions from Norwegian advisory service providers are also a valuable source of information for agriculturists. However, some participants expressed concerns about the level of knowledge among advisors in the agriculture industry in Norway, especially regarding IoT technologies. Two participants preferred to seek advice from international experts who often have different perspectives and experiences with innovations. Participant D claimed that the reason is due to "*The [knowledge] level in Norway is not sufficient enough, particularly within our type of production.*" Agricultural events like conferences and seminars allow farmers to expand their social networks and gain new information. However, participants noted that the social aspect of these events is often more valuable than the content. Agricultural magazines were also mentioned as a source of information, with participants highlighting the importance of staying up to date with new technologies in the industry.

4.4. Outer Context

External factors such as incentives, funding, and the socio-political climate significantly impacted our participants' adoption of IoT technologies in agriculture. The participants in the study provided insights into these factors, expressing the importance of the various financial incentives and funding opportunities in Norway. Some participants expressed the importance of incentives; "*Incentives are important in order for us to make changes; we are not able to do it ourselves*" (Participant A). The findings also demonstrate that Innovation Norway¹ was identified as a significant source of financial support for IoT projects in Norway. Innovation Norway, a national development bank and state-owned enterprise, offers programs and services encouraging entrepreneurship in Norway. It is a subsidiary of the Norwegian Ministry of Trade, Industry, and Fisheries, and its main headquarters is in Oslo, with additional offices in each of the Norwegian counties and 30 other countries across the globe. While Innovation Norway was identified as a significant source of financial support, more funding capacity was deemed necessary by the participants. The participants also suggested that the government subsidize the prices of agricultural products to support the industry. As Participant D said, "*We get the same price for the lettuce as we did 20 years ago.*" The participants also considered and discussed the sociopolitical factors that may affect the agriculture industry in Norway. Uncertainty regarding

¹ <https://en.innovasjon Norge.no/>

governmental policies and directives was a concern for some, while others expressed frustration at decision-makers that lacked agriculture and farming domain knowledge or experience. One participant stated their thoughts about the future of their farm, saying, “*It depends on the politics. If it is not more predictable, I will no longer be interested in doing what I do* (Participant B). Sustainability was perceived as necessary, with customers driving change in sustainable practices. The Norwegian Climate Action Plan was met with mixed opinions, with some expressing concerns about its attainability and ability to achieve sustainability goals. Low incomes and concerns about the future of the industry were shared by some participants as significant hurdles for technology investments. The COVID-19 pandemic's positive effect on the increase of demand in the industry was also noted in our findings, but it also brought challenges, such as a reduced workforce and increased vulnerability.

Overall, the participants acknowledged the importance of IoT technologies for sustainable and efficient farming practices. However, external factors such as incentives, funding, and the socio-political climate play a crucial role in their adoption decisions and investment justification.

4.5. The Impact of Implementing IoT Technologies in Farming

IoT technologies have generally improved everyday life and farming operations for all our informants, which was deemed the most critical advantage for Norwegian adopters, with increased control and improved decision-making being the most-frequently-mentioned advantages. Other benefits include enhanced animal and crop health, improved product quality, efficiency, and reduced uncertainty were also identified as paramount drivers for adoption. The technology has also resulted in more sustainable practices and has made it easier for farmers to follow the required certifications and regulations imposed by the government.

Unexpected advantages, such as increased carbon storage and new technology use, have also been uncovered from the findings of this research. However, two participants also argued about the undesirable consequences of adopting IoT technologies, such as having less contact with their animals. Nonetheless, they stated that the benefits of the technology outweighed this negative aspect. Almost all participants experienced technical challenges after implementing IoT technologies, such as battery capacity and positioning errors. Only one participant (E) expressed concern about privacy and security challenges. Despite being familiar with the security and privacy domains, the participant stated that “*I have neither any worries nor any roles to play if such security challenges should occur*” (Participant E). In addition, one participant (C) experienced a security breach but did not consider it a significant issue or a barrier to the adoption of technology.

Adopting IoT technologies in farming has resulted in numerous advantages, with some challenges and technical difficulties that must be addressed. Table 2 presents a summary of this study's main findings, divided into three main themes corresponding to the study's research questions. These themes are further used in the following discussion section to answer the research questions.

Table 2. Summary of findings.

Factors influencing IoT adoption	Outcomes by using IoT technology	Challenges & Areas of concern
Knowing that someone is going to take over the farm	Increased control	Lack of information and knowledge by policy makers
Relative advantage: More control, replace human effort, better decision making, improved efficiency, increased flexibility and reduced uncertainty	Better decision-making	Lack of knowledge by different stakeholders in agriculture
Technical support	Reduced uncertainty	A great need for technology experts in Norway
Tech needs to be adapted to Norwegian climate and landscape	Improved efficiency	Privacy and security issues
Observability & Trialability	Improved production	A need for more subsidies and support
Expert opinions	Improved livestock and crop health	An industry which is characterized by uncertainty
Social networks	Less contact with animals compared to before (negative)	The economy in agriculture

5. Discussion

As presented in the literature review and the findings sections, various factors may influence IoT adoptions in Norway, and several benefits of adopting IoT technologies were identified and discussed. In addition, several challenges that can negatively affect the adoption of IoT technologies have been identified, which can explain the low adoption levels of IoT technologies among Norwegian agriculturists. The following section is divided into three main sections to answer the study's research questions. The three sections are 1) Motivating factors influencing IoT adoption in agriculture, 2) The impact of adopting IoT in agriculture, and 3) Challenges & areas of concern within the Norwegian context.

5.1. Motivating Factors Influencing IoT Adoption in Norwegian Agriculture

Adopter's characteristics, such as needs, motivation, values, and skills, are crucial in technology adoption (Greenhalgh et al., 2004). Previous studies found factors like farm size, education, technical skills, and farmer's age decisive in agricultural technology adoption (Barnes et al., 2019). This study, however, revealed that knowing that someone will take over the farming operations in the future is an essential determinant for IoT investment among Norwegian agriculturists, as IoT is perceived to aid in securing the farm's future.

The findings also suggest that gaining more control and improving decision-making were among the primary motivations for adopting IoT technology in Norway, diverging from the focus on economic aspects in previous research (Knierim et al., 2018). This implies that for Norwegian farmers, making farming operations less time-consuming and gaining more control is more critical than increasing profits and reducing costs. Furthermore, *"replacing human effort"* (i.e., automation) emerged as a new factor among Norwegian farmers of relative advantage. This need for automation was fueled by challenges in finding workers, hiring, and the Covid-19 pandemic's impact on foreign experts and the labor movement to Norway, due to the imposed border restrictions and closures in Norway at the time.

Trustworthy suppliers with good service agreements, accessibility, and technical support have also been identified as influencing factors in IoT adoption among Norwegian agriculturists. While some participants preferred Norwegian technologies. However, most informants prioritized the technology's attributes, well-tested devices, and locally based service personnel, regardless of the technology's country of origin. In addition, the ability to observe the IoT technologies and being part of pilot studies (trialability) have been viewed as crucial factors that will enable farmers to assess the technology's suitability for their operations, better identify the required resources and process changes, which would lead to an increased rate of future successful IoT adoptions. Hence, this corresponds with the existing literature that argues that the *trialability* of the technology by farmers is vital for reducing risks of failures and increasing the likelihood of IoT adoption in Norway (Knierim et al., 2018).

However, most IoT suppliers do not offer trials and potential client involvement opportunities, posing an adoption barrier in Norway, as technology demonstrations, pilot studies, and user engagement are valuable strategies for IoT diffusion and enterprise-wide adoption (Haddara & Elragal, 2013; Rogers, 2003).

The findings also suggest that the agriculture community is a social system critical to the adoption process, with agriculturist-to-agriculturist exchanges forming the core of the technology diffusion among the farmers in Norway. Based on trialability, observability, and relative advantage, interpersonal communication among agriculturists was deemed an influencer on farmers' attitudes toward technology adoption, corresponding to earlier studies within the same domain (e.g., (Barnes et al., 2019)). In addition, our findings suggest that expert opinions, particularly from advisory service providers, are considered essential information sources for Norwegian farmers, which corresponds to the DOI theory (Rogers, 2003). Some participants, classified as *innovators* in this study, seek validation from international experts when adopting more expensive and data-demanding technologies. Some of the participants claim to may have influenced other agriculturists to adopt IoT technologies in their farms, suggesting that they may be perceived as *opinion leaders* (Greenhalgh et al., 2004). This highlights the importance of *innovators* and *early adopters* in technology diffusion (Knierim et al., 2018; Pillai & Sivathanu, 2020). Agricultural events such as conferences and seminars are appreciated by agriculturists, primarily for networking purposes.

In addition, *external factors* significantly influence IoT adoption among Norwegian agriculturists (Greenhalgh et al., 2004). While participants are affected by governmental sustainability regulations and restrictions, they do not feel pressured by policymakers to invest in IoT for sustainability purposes (Ayaz et al., 2019; Jayashankar et al., 2018). The study participants also acknowledge the importance of *customer demands* as drivers of change and express willingness to adjust to government requirements. The informants deemed the increase in governmental financial support capacity, particularly from Innovation Norway, as a significant motivating factor that will increase the likelihood of adopting IoT technologies in Norway. However, some participants noted that they are not dependent on financial support for their decision to adopt IoT technologies but consider it a beneficial contribution.

5.2. The Impact of IoT Technology Adoption on Agriculture

In the case of IoT technology adoption in agriculture, prior studies have emphasized the role of economic factors, such as *profitability* and *cost-effectiveness*, in driving IoT adoption in agriculture and farming (Jayashankar et al., 2018). Rogers (2003) identified *relative advantage* as a crucial determinant of an innovation's adoption rate, with cost-effectiveness or effectiveness being key factors that can increase an innovation's adoption rate (Greenhalgh et al., 2004; Rogers, 2003). However, the findings of this research suggest that the informants did not view profitability as the primary driver for adopting IoT technologies (in Norway), and were uncertain whether IoT implementation increased profits, indicating a low emphasis on the economic factors and drivers. These findings suggest that non-economic factors may be equally important or even more critical than economic factors regarding IoT adoption in agriculture within the Norwegian context.

Despite the uncertainty regarding economic outcomes, the informants in this study acknowledged the significant value that IoT technologies provide in other areas, such as improving decision-making, enhancing efficiency, increasing control, and enabling farm sustainability and future transfer of ownership. These findings align with prior research on the benefits of IoT technology in agriculture (Elijah et al., 2018). However, this research revealed that only two participants believed that IoT technologies led to more sustainable agricultural processes, while others had not considered this. This finding is somewhat surprising, given that adopting IoT technology is widely believed to be crucial in promoting and contributing to sustainable agriculture practices and operations (Ayaz et al., 2019).

While economic factors may have a role in IoT adoption in agriculture, other factors such as improved decision-making, enhanced efficiency, increased control, and future transfer of ownership may be equally or even more critical factors in driving IoT adoption in the agricultural sector in Norway. These findings highlight the need for further research on the factors that influence IoT adoption in agriculture and the importance of addressing the challenges that hinder IoT technology adoption in agriculture, such as the lack of awareness and knowledge of IoT technologies among farmers (Knierim et al., 2018; Pillai & Sivathanu, 2020).

5.3. Challenges and Areas of Concern

Farooq et al. (2019) emphasized the importance of agriculturists' education and awareness in increasing technology adoption, particularly IoT adoption in agriculture. While this study did not particularly investigate the impact of participants'

level of formal education on IoT adoption, however, it revealed that formal education and the lucrative job opportunities in other industries might threaten and affect the willingness of agriculturists' children to take over the farms in the future. The uncertainty in the agriculture industry and the desire for higher incomes in other sectors can result in children not wanting to continue the family farming business. Thus, IoT adoption is perceived to be influenced by the future of the farm and external factors affecting the industry. On the other hand, having IoT-enabled farms have been perceived by most informants as a potential opportunity to transfer their farms to *modern* (smart) farms, which may attract future generations to take over the farms.

Security and privacy were also identified in the literature as significant challenges in IoT adoption in agriculture (Farooq et al., 2019). The study participants, however, did not express significant concern about security and privacy issues during or after their IoT adoptions. Some participants believe that the suppliers should be responsible for handling these issues and ensuring that their infrastructures follow state-of-the-art technologies and regulations regarding security and privacy.

Greenhalgh et al. (2004) suggested that adoption success is more likely when intended adopters receive sufficient training and support. Participants in this study reported dissatisfaction with suppliers and sellers who lacked knowledge about their specific farming operations. Our results also illustrate a need for more knowledgeable agricultural experts and advisory service providers in Norway. The study participants reported a lack of Norwegian experts and insufficient knowledge of current advisory services. The unpredictable nature of agriculture necessitates making informed decisions, and inadequate access to expertise can negatively impact IoT adoption and farming operations, which is in line with previous studies in Norway (e.g., (Knierim et al., 2018)). Thus, one of the agriculture industry's main challenges is the general lack of knowledge of farming processes and specifics among policymakers, suppliers, and other stakeholders. Knowledge sharing and cooperation between agriculturists and stakeholders are essential to overcome these challenges and ensure the agriculture industry's future.

6. Conclusion and Future Research

This study highlights the importance of examining multiple factors influencing IoT adoption in agriculture. The findings indicate that simplified and flexible daily life are among the primary drivers of IoT adoption and continued use among Norwegian farmers, as opposed to increased profitability, the predominant driver identified in earlier studies. This highlights the need for continued research into IoT adoption in agriculture, with a focus on national contexts to better understand the diverse contextual factors driving adoption. One of this study's key contributions is identifying previously unexplored factors influencing IoT adoption, such as farm security, technical support, and governmental policies. This research also highlights the challenges and factors that may hinder IoT adoption in agriculture, including insufficient knowledge and support among stakeholders in Norway. This also suggests the need for educational initiatives to enhance awareness and knowledge of IoT technologies among farmers and other stakeholders in the agricultural sector. Despite these challenges, agricultural IoT technologies offer significant benefits to farmers, including enhanced decision-making, increased control, and improved efficiency, ultimately making their lives easier, more predictable, and less time-consuming. This highlights the potential of IoT technologies to transform the agricultural sector and improve farmers' livelihoods.

There is a research gap in the extant literature on IoT adoption in agriculture within the Norwegian context. Future research could look at specific elements and components contributing to IoT adoption in agriculture to better understand the process and influencing factors. Future studies and explorations could include examining sociopolitical issues that may impact the technology adoption, and comparative research across various contexts, such as different nations or technical applications, may reveal interesting new factors.

Although it does not offer immediate solutions, this study highlights challenges that may explain IoT's general low adoption rates in the agriculture industry, which could be valuable information to stakeholders. Providing robust technical support and knowledgeable representatives and sellers is essential for suppliers. The results also indicate that agriculturists value the opportunity to try and observe IoT technologies. This aligns with the DOI's arguments (Rogers, 2003), that hands-on experience allows individuals to understand and explore how innovations working under specific conditions may lead to higher technology diffusions. Thus, agriculture technology (AgTech) companies and suppliers should enable agriculturists to observe, get involved, and try out IoT technologies on a limited basis before purchases. In addition, testing new IoT technologies in Norwegian conditions and making test results visible to agriculturists can reduce adoption uncertainty. The findings on adoption outcomes are essential for suppliers' and AgTech companies' marketing efforts. Rather than solely emphasizing profitability, improved decision-making, increased control, and enhanced quality of life should also be highlighted. However, it is crucial to consider that this study focuses on "innovators" and "early adopters" (Rogers, 2003), and perceptions might differ for other

agriculturists. Further research should explore how different IoT technologies influence profits, as profitability has been a critical adoption driver in previous literature.

The government and policymakers must also reduce the industry's uncertainty to ensure well-functioning Norwegian agriculture.

Overall, this study provides insights into the factors driving IoT adoption in agriculture and underscores the need for a more comprehensive approach to research in this area. The findings can assist non-adopters in understanding the impact of IoT technologies on their farming operations and help them avoid common pitfalls. The findings also have practical implications for farmers and policymakers, highlighting the need for increased support, potential client involvement in pilot projects, and awareness-building initiatives to promote and diffuse the adoption of IoT technologies in the agricultural sector.

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