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Factors Influencing the Adoption of Artificial Intelligence in Smart Agriculture

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Abstract

The agricultural sector faces mounting pressure to increase food production sustainably in the face of climate change and population growth. To achieve "Zero Hunger" of Sustainable Development Goal 2, the integration of Artificial Intelligence (AI) technologies into agriculture, known as Smart Agriculture, holds immense potential to enhance productivity, optimize resource utilization, and address the growing global food demand. AI offers significant potential to revolutionize farming practices by optimizing resource use, improving crop yield, and enhancing decision-making. However, the widespread adoption of AI in smart agriculture remains limited compared to other industries. Through the lens of the Technology Organisation Environment (TOE) framework, this qualitative study aims to identify and analyse the key factors that influence the adoption of AI in Smart Agriculture. Through in-depth interviews with farmers, agricultural experts, policymakers, and technology providers, the study examines the factors that facilitate or hinder the adoption of AI-based solutions. The results identify both encouraging and discouraging factors categorized into economic, socio-psychological, contextual, technological, organisational factors and environmental aspects. The research findings provide insights into the complex interplay of these factors and offer recommendations to support the widespread adoption of AI in the agricultural sector. By addressing the identified barriers and leveraging the driving forces, this study contributes to the understanding of the dynamics surrounding the integration of AI in Smart Agriculture, ultimately paving the way for more efficient and sustainable food production systems.

Keywords
Artificial Intelligence (AI), smart agriculture, smart farming, Zero Hunger, Sustainable Development Goal 2 (SDG2).

1. Introduction
The global population is projected to reach nearly 10 billion by 2050, placing unprecedented demands on the agricultural sector to meet the growing food requirements therefore necessitating a significant increase in food

production (United Nations 2019). Conventional agricultural practices have reached their limits in terms of productivity and resource efficiency, prompting the need for technological advancements that can revolutionize the industry. One of the primary global challenges confronting the agricultural industry is the issue of food insecurity, which is intricately connected to the second Sustainable Development Goal (SDG 2) known as "Zero Hunger" (United Nations 2022). As reported by the Food and Agriculture Organization (FAO), an estimated 691 to 753 million individuals globally will experience food insecurity by the year 2023, primarily due to the impacts of El Nino-induced drought (FAO 2023). At the same time, climate change poses a growing threat to agricultural productivity (Georgopoulos et al. 2023). To address these challenges, the agricultural sector must embrace innovative technologies like Artificial Intelligence (AI). Artificial Intelligence (AI) has emerged as a transformative technology with the potential to address the challenges faced by the agricultural sector (Annappa et al. 2023).

AI encompasses a range of machine-learning techniques that can analyze vast datasets, identify patterns, and make data-driven predictions (Yaiprasert and Hidayanto 2024). Smart Agriculture, alternatively referred to as precision agriculture or smart farming, pertains to the amalgamation of sophisticated technologies such as AI, the Internet of Things (IoT), and data analytics, to enhance agricultural production and management methodologies (Tzounis et al. 2017). The integration of AI technologies into agricultural practices offers a wide range of applications, including precision farming, automated decision-making, predictive analytics, and intelligent monitoring systems (Wolfert 2017; Dzinomwa et al. 2023). These AI-powered solutions can enhance crop yields, optimize resource utilization, disease and pest detection, livestock health monitoring and reduce environmental impact, thereby contributing to the sustainability and efficiency of food production systems (Liakos 2018; Dzinomwa et al. 2023; Mana et al. 2024).

While AI holds immense promise for the future of agriculture, its widespread adoption remains limited. Understanding the factors influencing this adoption is crucial for accelerating the integration of AI in smart agriculture practices. Despite the promising potential of AI in agriculture, the adoption of these technologies has been relatively slow compared to others (Klerkx et al. 2019). Understanding the factors that influence the adoption of AI in Smart Agriculture is crucial for accelerating the implementation of these transformative solutions and capturing their full benefits (Waaswa et al. 2021). However, there is limited literature discussing factors influencing the adoption of AI for smart agriculture, particularly in Africa where such research is still in its development stage (Barasa et al. 2021)
It is against this background that this research aims to identify the factors that influence the adoption of AI for smart agriculture within a developing country context.

2. Methodology

This study employed a qualitative research approach through semi-structured interviews to explore the factors influencing the adoption of AI in smart agriculture practices among farmers in Mashonaland Central, Zimbabwe. The research design included in-depth interviews with a diverse set of stakeholders, including farmers, agricultural experts, policymakers, and technology providers. The participants were selected using a combination of purposive and snowball sampling techniques. The sample included 10 farmers. The sample included small-scale, medium-scale, and large-scale farmers, with varying levels of experience and exposure to agricultural technologies, actively engaged, and range of farm sizes) from the Mashonaland Central region of Zimbabwe. Five agricultural experts, including researchers, agriculture extension officers, industry consultants, and three policymakers from the Ministry of Lands, Agriculture, Fisheries and Rural Development and the Ministry of Information Communication Technology and Courier Services, and relevant government agencies focused on technology and innovation in agriculture.

2.2. Theoretical Underpinning

The investigation was grounded in the Technology-Organization-Environment (TOE) framework, a theoretical construct employed to elucidate the factors that impact the adoption and utilization of novel technologies. These factors encompass the attributes of the technology itself, the organizational setting in which it is implemented, and the external environment in which the organization functions. Technology pertains to the intrinsic features of the technology, encompassing its functionality, intricacy, interoperability with existing systems, and user-friendliness. Organization denotes the internal environment in which the technology is deployed, incorporating elements such as the organization's size, structure, culture, and resources. Environment pertains to the external environment in which the organization operates, encompassing aspects such as market dynamics, regulatory mandates, and societal and cultural norms (Tornatzky and Fleischer 1990).

2.3. Data Collection

The Semi-structured interviews were conducted face-to-face with each participant in their preferred location (farm or residence), allowing for open-ended discussions. The interview guide was tailored to each stakeholder group, addressing themes relevant to their expertise:

- Farmers: Awareness, perceived benefits/drawbacks, barriers, and facilitating factors for AI adoption.
- Agricultural Experts: Knowledge of existing AI applications, potential benefits and challenges, and recommendations for promoting adoption among farmers.
- Policymakers: Government initiatives related to AI in agriculture, perceived impact of AI, and policy considerations for fostering adoption.
- Technology Providers: Types of AI solutions offered, understanding of farmer needs and challenges, and strategies for making AI more accessible and user-friendly.

The interview guide covered various aspects related to the adoption of AI-based solutions, including organizational factors, economic considerations, policy and regulatory conditions, and environmental concerns. Awareness and understanding of AI in agriculture, perceived benefits and drawbacks of AI adoption, existing barriers hindering AI adoption, and facilitating factors that could encourage AI use.

2.4 Data Analysis

The interviews were audio-recorded with informed consent and transcribed verbatim for analysis. The collected data was analysed using a combination of thematic analysis and content analysis. The thematic analysis involved the identification and categorization of key factors influencing the adoption of AI in Smart Agriculture, while the content analysis examined the specific perspectives and narratives of the different stakeholder groups. Codes were assigned to identify recurring themes and categorize the factors influencing AI adoption.

3. Results

The findings of the study reveal a multifaceted set of factors that influence the adoption of AI in Smart Agriculture, as perceived by the diverse stakeholders interviewed.

3.1 Technological Factors

The complexity of artificial intelligence (AI) systems and their compatibility with current farm infrastructure can impede the acceptance and implementation of such systems (Van der Burg et al. 2018). Moreover, apprehensions regarding data privacy and security can act as a deterrent, especially for farmers who are reluctant to disclose their sensitive agricultural data (Ray et al. 2020).

Reliability and User Friendliness of AI Systems

The farmers expressed concerns about the reliability and user-friendliness of AI-based solutions, as highlighted by their responses: *Farmer 3: "The AI systems we've seen so far are still quite complex and require a lot of technical expertise to operate. We need solutions that are more intuitive and accessible for us as farmers."*

Another farmer highlighted the importance of integrating AI technologies with existing agricultural infrastructure, saying: *Farmer 2: "It's crucial that any AI-powered systems can seamlessly work with the equipment and systems we already have in place. Compatibility is a major concern for us."*

In contrast, the technology providers (TP) emphasized the rapid advancements in AI capabilities and the potential for these technologies to revolutionize agricultural practices. As one technology provider stated the following:*TP: "The latest AI-powered tools can automate a wide range of tasks, from pest detection to crop yield prediction. The challenge is to make these solutions more seamless and user-friendly for farmers."*

The respondents (farmers, and technology providers) highlighted a couple of technological issues in the adoption of AI-based agrarian solutions, which were largely lack of infrastructure and complexity of the systems.

Lack of Infrastructure

Lack of infrastructure emerged under this theme. Both the farmers and technology providers seemed aware of the impact of reliable connectivity/ internet in the adoption of AI-powered solutions in agriculture. Two large-scale farmers (LSF) indicated that: *LSF1: "Reliable internet connectivity is a major challenge in our rural area. How can AI work without good connectivity?"* whilst *LSF2: "Without reliable internet access in rural areas, using AI applications becomes very challenging"*

As recommended by Nani and Maguraushe (2022), internet service providers need to take a patriotic stance by providing efficient and reliable internet at affordable prices as this is an enabler for a digitally enabled environment.

Complexity of AI Systems

Another factor that raised concerns amongst the farmers was hinged on the complexity of AI-powered solutions in agriculture. Mostly small-scale farmers do not have the know-how to effectively navigate and manoeuvring through the solutions, thereby inhibiting them from deriving value from the AI-powered agriculture solutions. This is attested by one small-scale farmer (SSF), who indicated that:*SSF1: "AI seems complicated, and I'm not sure I have the technical skills to use it effectively"*

As a solution, the farmers indicated the importance of training and support:*SSF2: "I'm interested in learning more about AI, but I would need proper training and ongoing support to feel confident using it on my farm".*

The technical providers also reiterated the need for an enabling environment, where there are no connectivity glitches.*TP1: "We are developing offline AI solutions that can function with limited internet access"*

There is a need for improved accessibility and transparency of AI algorithms. Furthermore, compatibility with existing farm infrastructure and interoperability between different technologies can pose challenges

Data and Privacy Concerns

Data and Privacy Concerns also emerged as an organisation factor with one farmer noting

Farmer 7: "You know am the best farmer in my area especially when it comes to cattle breeding. I have farming secrets spanning generations and how we can fatten our cows before going to the Agricultural show. Imagine now that I put this information out there in there trusting technology and my trade secrets come out. I would have lost the competitive edge that I bring to this field"

Similar sentiments were echoed by another Farmer who notes

Farmer 8: "Farming is our livelihood and a generational inheritance. Everyone always asks me how I manage to have a bumper harvest each year despite harsh weather conditions at times. As an organisation, there are farming recipes best known to us that should not be known by others. I do not trust these AI technologies as they might mess all this up"

*Technology Provider***:** "*Collaboration with policymakers and agricultural institutions is crucial to establish guidelines for data privacy and security in AI applications"*

These sentiments are in line with literature as Shang et al. (2021) note that the data collected by these technological systems may cause skepticism amongst farmers as they do not know how other stakeholders involved may use it

3.2 Organisational Factors

The effectiveness of implementing and supporting farmers can be hindered by the limited capacity and lack of expertise in AI within agricultural extension services (Vanclay et al. 2021).

Level of Digital Literacy and Technological Readiness

The level of digital literacy and technological readiness among the farmers was a significant organisational factor, as noted by one farmer:

Farmer 1: "Many of us here are still getting used to using basic digital tools and technologies. Adopting more advanced AI-based solutions would require a substantial amount of training and support. I acknowledge that "I'm neither educated nor very bad with technology so learning new things is difficult at my age. I have been farming successfully with no help of technology. There is nothing new that technology can help me with at this age "

Farmer 2 indicated that "while I appreciate the idea of implementing AI-based technologies that would result in smart agriculture, I fear losing my investment in the event that these technologies fail to work, my hard-earned cash would have gone to waste. technologies keep coming and going, which means keeping up with technology is so stressful so I would rather continue with my traditional methods of farming""

Farmer 4 supported these sentiments in that *"I would not mind trying these AI-based technologies to help me with my farming activities, however, what will happen if they do not work as expected, it means I will have risked my children's legacy by throwing it down the drain*". Farmer 5 argued that AI-based technologies are will only be a successful initiative if only supported by the policymakers.

The agricultural experts (AE) highlighted the importance of capacity-building and skills development, with one

expert stating, *Agriculture Expert: "We need to invest in training and knowledge-sharing programs to ensure that farmers, extension officers, and other stakeholders are equipped to leverage AI technologies effectively."*

On the other hand, Farmer 6 indicated that despite being a fair user of technology, he gets assistance from his grandson who is a Computer Science expert, he however feared that he could face technological challenges when his grandson decides to relocate or migrate to greener pastures. To counter these challenges relating to technological savviness, perhaps training programs could be offered specifically for older. In conclusion, Pivoto et al. (2019) suggest that adoption of AI-based technologies requires education and knowledge about how technology uses AI-based technologies. The works of Shang et al. (2021) also acknowledge the influential role of age in technology adoption by farmers

Policymakers: "We recognize the need for capacity-building programs to address the skills gap and empower farmers to use AI effectively"

Similarly, Musa et al. (2022) recognizes the policymakers' role in influencing the adoption of AI-based technologies for agriculture

Availability of Training and Technical Support
The availability of technical support and the willingness of agricultural organizations to collaborate with technology providers were also identified as important organizational factors. Farmer 1 expressed, *Farmer 1: "We need assurance that there will be ongoing technical assistance and maintenance for any AI systems we implement. Without that support, we can't trust the technology." Farmer 2: "Training programs and technical support would be crucial to ensure successful implementation of AI in our farms"* .

Limited awareness of AI capabilities
The limited awareness of the potential of AI technologies was also noted in this study
*Farmer 10: "I do not know what this AI is and I am not interested. Next, money will be involved and instead of focusing on my crops I am now busy with useless technology".*Similar sentiments were also echoed by *Farmer 7: "You new generations think you can teach us something new about farming. It is in our blood. Only lazy people will want machines and funny things. A tractor, fertiliser, water and hoes are the main tools that any farmer would need. In your language, I would say the rest is now drama"*

The promotion of AI integration necessitates the tackling of these issues through educational initiatives, instructional sessions, and presentations that highlight the possible advantages of AI in the realm of agriculture (Iqbal et al. 2022).

Gender of the Head of the Household
In addition to digital literacy, these research findings revealed that the gender of the head of the household has an important role in the adoption of AI technology for smart agriculture. For example, male-headed households tend to lead in the adoption of technologies than the female-headed families. Farmer 3, argued that:

> *Farmer 3: "After losing my husband to COVID-19, I ventured into small-scale farming and have always followed the traditional means of agriculture because I am not well versed with technology and fear that incorporating technology in my farming processes might affect the yield, so I rely on the expertise of the Agronomists".*

Similar sentiments were echoed by Farmer 5, a male head of the household who observed that: *Farmer 5: "It has been easy for me to acquire and install the appropriate sensors that monitor and regulate the soil moisture and temperatures for my plants because I understand how these technologies work".*

Existing literature also confirms that the head of the household is an important factor that cannot be ignored when discussing the factors influencing the adoption of AI technologies for smart agriculture (Amadu et al. 2019; Lam et al. 2019; Kurgat et al. 2020; Musa et al. 2022). Furthermore, Waaswa et al. (2021) and Smidt and Jokonya (2022) emphasizes the need to understand such determinants as the organizational factors that are imperative for shaping the adoption of AI for smart agriculture.

3.3 Social Psychological Factors

Shang et al. (2021) note that social psychological factors play an influential role in farming technology-based adoption yet it is least investigated.

Attitude Towards Technology

The attitude of farmers was also identified as the major factor that influences the adoption of AI to result in smart agriculture. For example, Farmer 5 displayed his positive attitude towards AI technologies by saying that:

> *Farmer 5: "I really like technology in farming because it makes my life very easy. I do not have to worry about regulating the temperatures because the sensors notify me if the soil is either too wet or too dry for me to make informed decisions on whether to turn on or turn off the sprinklers and drip pipes and this protects my plants from suffering from moisture stress".*

Farmer 3 echoed similar sentiments by saying that:

> *Farmer 3: "The AI-based technologies simplified my work and life for example, the AI technologies regulate the application of fertilizers on my plants, which means I have more time time to do other chores without worrying about fertilizer application. This means I am psychologically stable and free of any stress related to regulating fertilizer application".*

Literature supports these sentiments, for example, studies by Lam et al. (2019) concurs that the farmer's attitude influences the decision to adopt or not to adopt AI technologies by farmers. On this note, Chuang and Wang (2020) emphasize the need for policymakers to incorporate the psychological needs of farmers if the implementation of AI for smart agriculture is to be a success.

Cultural Beliefs

Interestingly Farmers' culture and associated farmers' groups also played an influential role in technology adoption.
Farmer 6: "Technology does not work. Having good harvests is a blessing from the ancestors. All you need to do is carry out family traditions such as brewing beer before the rains and you will have a bumper harvest"
Similar sentiments were echoed by *Farmer 9 "Our people have been farming way before the Europeans came in. There was no technology and all was well. Zimbabwe was the breadbasket because we would go to places like Njelele and ask for the rain. Now these technologies you are introducing are the ones causing drought. Most farmers surrounding me know that we brew beer and dance all night long to have a good grain and our livestock to be kept safe by our ancestral fathers"*
Literature alludes that Farmers' inclination to avoid risk and adhere to conventional perspectives may present a challenge in the acceptance of novel technologies such as AI (Yamin et al., 2020).

3.4 Context factors

Constant Power Cuts

The findings from this research show that the context is central to the adoption of AI for smart agriculture. Farmer 1 indicated that while he is a proponent of AI technologies, he has been failed by his context, which is not in favour of smart agriculture because the untimely and consistent electricity power cuts interfere with the smooth running of AI technologies that are implemented at his farm. Farmer 5 agreed with this observation by arguing that his electricity-powered irrigation system is not performing up to its expectations due to electricity power failures.

Lack of Reliable Internet Connectivity

Farmer 3: "Our farms are far from boosters and networks. You need to have a Netone sim card to access the internet. Calling people is a problem what more adding this technology? We might want this technology but our situation does not permit it".
Technology Providers also supported this as they echoed that "*there is a need for internet access across the whole of Zimbabwe. Maybe the inclusion of Starlink might be a game changer in the Zimbabwe internet connectivity landscape"*

Land Tenure Systems and Farm Size

The size of the farms and land tenure systems were also observed to be a dominant factor in adopting AI technologies. Farmers echoed that some of their farms are small in size and there was no need for such technologies. Moreso, other farmers alluded that they did not have the 99-year lease given to other farmers thus they could not invest in something they have no guarantee would benefit future generations. Concurring with other farmers was a farmer who alluded that

Farmer 6: "It is no secret the struggle for farms in Zimbabwe. As is I do not know if the government will come and oust me of my farm and give it to somebody. I do not want to delve into politics but what we think we own as farmers might one day be said is not ours. So how can I invest in this?"

Existing literature agrees with these observations regarding the role of the context in the adoption of AI for smart agriculture (Lam et al. 2019). In agreement, Mizik (2021) revealed that the context, particularly, the land use security and policies are critical factors that influence the farmers' adoption of AI for smart agriculture. Furthermore, the utilization of AI applications that depend on real-time data collection and analysis can be greatly hindered by the lack of reliable internet connectivity in rural areas (Ricker et al., 2020). Moreover, the dissemination of information and decision-making processes can be influenced by socio-cultural norms and land tenure systems, which in turn can affect the implementation of AI (Ojha et al., 2023).

3.5 Economic Factors

Initial Investment Required and perceived return on investment

The farmers were particularly concerned about the initial investment required for the deployment of AI-based solutions, as expressed by Farmer 4 who indicated that:

Farmer 4: "The costs associated with these AI technologies are still quite high, and it's a significant barrier for us, especially the smaller-scale farmers. We need more affordable options or financial support to make it feasible. There are no guarantees that what I will invest in AI technology will bring me high returns".

Farmer 3 concurred that:

> *Farmer 3: "My innovation advancements in farming activities are constrained by the finances which are very low, and I would be very grateful if I find a donor to sponsor me with finances or the AI-based technologies".*

This is not a unique observation since existing literature has also identified economic factors as a determinant for the adoption of AI for smart agriculture (Smidt and Jokonya 2022; Mizik 2021; Georgopoulos et al. 2023).

Access to financial incentives and subsidies for AI adoption

The policymakers and Agriculture Experts acknowledged the need for financial incentives and subsidies to support the adoption of AI in the agricultural sector, as one policymaker stated

PolicyMaker: "We recognise the potential of technology, but we also understand the financial challenges faced by farmers. Providing targeted subsidies and low-interest loans could help overcome the cost barriers and accelerate the adoption of these technologies. Government incentives, like subsidies for AI adoption, would be a big encouragement "

Agricultural Experts: "Government support through subsidies and tax breaks could significantly encourage AI adoption".

These sentiments have been echoed in such studies as Mizik (2021) and Waaswa et al. (2021), who confirm that the level of access to the necessary financial resources can influence the uptake of AI for smart agriculture. Similarly, Musa et al. (2022) highlight the important role of policymakers and relevant stakeholders in improving the adoption of AI-based technologies for agriculture. Akter et al. (2019) suggest that the lack of credit and financing options acts as an additional obstacle to the adoption process. To tackle these challenges, potential solutions could include government subsidies, tax incentives, or loan guarantee programs to encourage investment in AI technologies (Ray et al., 2020).

3.6 Environmental Factors

Government policies and regulations have a substantial impact on influencing the utilization of artificial intelligence (AI) within the agricultural sector, as noted by Iqbal et al. (2022). The presence of accommodating policies, like explicit directives concerning data confidentiality and rights, has the potential to promote the responsible advancement and application of AI.

The potential of AI to address environmental challenges in agriculture

The farmers recognised the potential of AI to address environmental challenges in agriculture, as highlighted by this quote from Farmer 1 who argued: "*If these AI systems can help us be more efficient with water, fertilizers, and other inputs, that would be a significant advantage for us and the environment.".* Furthermore, Farmer 4 concurred that *"I*

operate under very unstable environmental and economic conditions, which might affect my initiative to adopt these AI-based technologies, for example, what would happen if the policies changed and I am expected to pay monthly tax for implementing the AI technologies in my small scale farm?". Farmer 3 was also concerned about the effects of environmental degradation on AI-based technological investments.

Alignment of AI-based solutions with sustainable farming practices

The agricultural experts emphasized the importance of aligning AI-based solutions with sustainable farming practices, with one expert noting, *Agriculture Expert*: *"The AI technologies must be designed and implemented in a way that supports the long-term sustainability of our agricultural systems, reducing the environmental impact and promoting eco-friendly practices."*

Farmers also expressed the need for AI-based solutions to align with sustainable farming practices. As a farmer stated, *Farmer 8: "We don't want to adopt technologies that might compromise the long-term sustainability of our land and resources. The AI solutions need to be compatible with our goal of eco-friendly agriculture."*

Optimizing resource use and reducing the environmental impact of farming practices

The farmers recognized the potential of AI to address environmental challenges in agriculture, such as optimizing resource use and reducing the environmental impact of farming practices. As one farmer noted, *Farmer 2: "If these AI systems can help us be more efficient with water, fertilizers, and other inputs, that would be a significant advantage for us and the environment."*

Supportive Policy and Regulatory Environment

The policymakers acknowledged the need for a supportive policy and regulatory environment to facilitate the adoption of AI in Smart Agriculture. As one policymaker stated, *Policymaker: "We are working on developing a comprehensive policy framework that addresses issues like data governance, privacy, and ethical AI deployment in the agricultural sector. This will provide the necessary guidance and certainty for farmers and technology providers."*

The technology providers highlighted the importance of clear and consistent regulations, as expressed by this representative: *Technology Provider: "We need a well-defined regulatory landscape that provides clarity on data usage, liability, and the overall integration of AI-powered solutions into the agricultural ecosystem. This will enable us to develop and deploy our technologies with confidence."*

4. Discussion

Table 1 shows a summary of the factors found in this study.

Table 1. Summary of factors Influencing Adoption

Context Factors: Constant Powercuts Land Tenure Systems and Farm Size Unreliable Internet Connectivity	**Social psychological Factors** attitude towards technology cultural beliefs
Economic Factors: Initial Investment Required and perceived return on investment (ROI) Access to financial incentives and subsidies for AI adoption	**Environmental Factors:** The potential of AI to address environmental challenges in agriculture Alignment of AI-based solutions with sustainable farming practices Supportive Policy and Regulatory Environment
Technological Factors: Reliability and user-friendly AI-based systems Lack of Infrastructure Complexity of AI Systems Integration of AI technologies with existing agricultural infrastructure Concerns about data security and privacy in AI-driven systems	**Organizational Factors:** digital literacy and age household head's gender technological readiness Availability of technical support and training for AI implementation Limited awareness of AI capabilities

The outcomes of this research suggest that the utilisation of artificial intelligence (AI) in intelligent agriculture is impacted by a variety of elements, encompassing economic, socio-psychological, contextual, technological, organizational, and environmental factors. The findings substantiate the TOE framework in technology adoption. These factors align with the existing body of literature on the drivers of the adoption of technological innovations in the agricultural domain through leveraging TOE. **Technological factors**, such as the dependability, compatibility, and scalability of AI systems, are also essential in determining their adoption within the agricultural sector (Tzounis et al. 2017). Farmers and agricultural entities are more inclined to adopt AI technologies that smoothly integrate with their current systems, exhibit consistent performance, and provide scalable solutions to address their specific requirements. **Organisational factors**, encompassing the availability of technical know-how, digital infrastructure, and organizational ethos, can also influence the adoption of AI in intelligent agriculture (Klerkx et al. 2019). Agricultural organizations that possess the requisite technical and human resources, along with a culture that is open to technological innovation, are more likely to effectively incorporate AI-based solutions into their practices. Lastly, **Environmental Factors**, such as climate change, scarcity of resources, and concerns about sustainability, can also impact the adoption of AI in intelligent agriculture. With the agricultural sector encountering escalating challenges related to environmental sustainability, AI-driven solutions that offer enhanced resource management, increased productivity, and reduced environmental footprint can become increasingly appealing to farmers and policymakers (Rose and Chilvers 2018; Liakos et al. 2018).

There were additional factors that emerged that were not underpinned by the TOE framework such as **Economic factors**, including the expenses associated with AI systems and the perceived financial advantages, which are widely acknowledged as pivotal factors for farmers and agricultural entities when considering the integration of new technologies (Rezaei et al. 2018; Khanal et al. 2020). The affordability and potential enhancements in productivity and profitability linked with AI-driven solutions can significantly affect their acceptance among the agricultural community (Dutta et al. 2021; Marques et al., 2022**). Socio-psychological factors**, which involve the attitudes, perceptions, and social influences of farmers, also play a significant role in influencing the adoption of AI in intelligent agriculture. Research has indicated that the perceived simplicity of use, perceived usefulness, and compatibility of AI technologies with existing farming methods can positively impact farmers' willingness to adopt these innovations (Pierpaoli et al. 2013; Meijer et al. 2015). Moreover, the influence of social connections, peer experiences, and the availability of training and support can further contribute to the acceptance and spread of AI-based solutions among agricultural stakeholders. **Contextual factors**, such as farm size, land ownership, and geographical location, have been recognized as crucial determinants of AI adoption in intelligent agriculture (Tey and Brindal 2012; Lamallem et al. 2020). Larger farms and those with more secure land tenure may have greater resources and adaptability to invest in AI technologies, while the geographical context can impact the availability of supporting infrastructure, access to pertinent information, and exposure to successful implementation instances.

The findings of the study reveal a complex interplay of factors that influence the adoption of AI in Smart Agriculture. The findings of this study underscore the multidimensional nature of the factors influencing the adoption of AI in Smart Agriculture, as perceived by the diverse stakeholders involved. Farmers highlighted the potential benefits of AI in optimizing resource use, increasing yield, and improving decision-making. However, concerns about data privacy and security were also expressed. Agricultural experts emphasized the need for developing user-friendly AI solutions tailored to the specific needs and contexts of small-scale farmers in Mashonaland Central. Policymakers acknowledged the importance of creating an enabling environment for AI adoption, including infrastructure development, capacity-building programs, and supportive regulatory frameworks. Technology providers expressed their commitment to developing affordable and accessible AI solutions while collaborating with stakeholders to address challenges and build trust among farmers.

5. Limitations, Recommendations and Future Works

Limitations and Future Research

This qualitative study relies on the perspectives of farmers from one region in Zimbabwe and may not capture all the nuances influencing AI adoption in specific geographic contexts. Future research can explore these factors through case studies or more regions focused on particular regions or farm types as adoption factors may vary. Additionally, longitudinal studies can track changes in adoption rates over time and assess the impact of different interventions. The qualitative nature of the research may limit the generalizability of the findings, and a larger-scale quantitative study could provide additional insights. Furthermore, the research is based on the perspectives of stakeholders within a specific geographical context, and the adoption factors may vary across different regions and agricultural systems.

Despite the relevance of TOE in technology adoption, additional factors emerged in this study. There is a need to extend this framework or combine it with other theories. Mutunhu et al. (2022) argues that integrating multiple theories on technology adoption provides a more comprehensive understanding and can uncover more relevant factors, given the distinct phenomenological conditions in each country.

Recommendations

The widespread adoption of AI in agriculture necessitates a collaborative effort from governments, research institutions, technology developers, and extension services. By addressing the identified barriers, creating supportive environments, and investing in capacity building, stakeholders can unlock the immense potential of AI for achieving sustainable and efficient food production practices.

- **Economic incentives:** Governments and financial institutions can offer subsidies, tax breaks, and loan programs to reduce the upfront costs of AI adoption for farmers.
- **Technological advancements:** User-friendly AI solutions, tailored to specific farm sizes and needs, are crucial for wider accessibility.
- **Capacity building:** Educational programs, training workshops, and technical support can empower farmers to understand and utilize AI technologies effectively.
- **Data privacy frameworks:** Establishing clear data security protocols and ensuring data ownership can address privacy concerns.
- **Investment in rural infrastructure:** Expanding broadband internet access in rural areas is essential for utilizing AI applications effectively.
- **Social factors:** Consider including social factors like farmer cooperatives or cultural beliefs towards technology that might influence adoption.

6. Conclusion

By incorporating the perspectives of various stakeholders, this study provides a comprehensive understanding of the factors influencing AI adoption in smart agriculture practices in Mashonaland Central, Zimbabwe. The verbatim quotes offer valuable insights into the diverse viewpoints and needs of each group, informing future strategies for promoting a successful transition toward AI-powered agriculture. Ultimately, the extensive integration of artificial intelligence (AI) within the agricultural sector holds the promise of transforming farming methodologies, enhancing the efficient utilization of resources, boosting crop yields, and fostering the development of a more sustainable food production framework. By addressing these recommendations, the agricultural sector can overcome the barriers to AI adoption and harness the transformative potential of this technology.

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