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An internet of things adoption framework for the South African farming industry

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Abstract

The use of the Internet of Things (IoT) in farming processes is enabling the sector to be gradually transformed with real time data acquisition and resource optimization. However, IoT implementation in South African farming is constrained by the lack of infrastructure support, high expense, and limited digital literacy amongst farmers. Accordingly, this study develops an IoT adoption framework suitable for South Africa and applies the PRISMA-ScR framework to conduct a systematic scoping review. The article maps factors towards the IoT adoption, this includes interoperability and economic issues. The study recommends collaboration between technology providers and farmers in order to encourage adoption of IoT and make future research recommendations on real world use of the framework for evaluation. The paper presents a framework that the stakeholders could use to address adoption problems and foster sustainable digital transformation in farming .

Keywords: Internet of Things (IoT), IoT adoption framework, precision farming, South Africa, technology adoption

Introduction

Farming is the cornerstone of South Africa's economy (Zenda & Rudolph, 2024), but farming operations are disadvantaged by the lack of resources and climate change effects, as well as by output inconsistencies (Flores et al., 2022). Real time data collection, creation of better decision processes and improved resource utilization practices are seen as useful solutions (Dlamini et al., 2024) to some current farming problems and promise using IoT technologies.

There exist three key obstacles that constrain actual adoption of IoT technology by South African farmers after potential benefits, which include both technological impediments, as well as economic and socio-political hurdles. Existing implementation barriers of South African context-based adoption frameworks must be addressed for IoT adoption within South African context. This helps in providing a wide scope for synthesis of various contexts where typical scoping reviews provide efficient synthesis capabilities to produce knowledge about the factors affecting IoT adoption in farming.

This scoping review aims to address several objectives, including determining the technological, economic, social, environmental, and policy-related aspects affecting IoT adoption in farming. It also seeks to develop an IoT adoption framework for South African farmers.

Methodology

Hu et al. (2017) asserts that a research methodology is a plan of action, determined by the nature of the research question and the subject of investigation, which involves methods and results and controls the methods, processes, and techniques that will be used. A scoping review is a systematic approach to synthesizing knowledge on a topic. Its goal is to map evidence, identify key concepts, theories, sources, and knowledge gaps. It addresses research questions and explores concepts and gaps, especially in emerging fields. It also offers flexibility, allowing it to be tailored to the needs of decision-makers (McGowan et al., 2020). This scoping review complied with the PRISMA-ScR checklist to ensure methodological rigor and openness.

Eligibility Criteria

The inclusion and exclusion criteria for this review were clearly defined to ensure the selection of relevant studies. Studies focusing on the adoption of IoT in farming worldwide, with a specific emphasis on South Africa, were included. Only peer-reviewed articles, conference proceedings, and publications in English between 2018 and 2024 were considered for inclusion. Studies that were not related to IoT in farming or did not contribute to understanding adoption barriers and enablers were excluded from the review. The search was conducted across several databases, including ScienceDirect, AIS eLibrary (Association for Information Systems), Google Scholar, JSTOR, Emerald Insight, Web of Science, IEEE Xplore, ACM Digital Library (Association for Computing Machinery), and SpringerLink.

Search Strategy

The Keywords and Boolean operators were used to identify relevant studies. Examples of the search terms include combinations such as "Internet of Things" AND "Farming," "IoT adoption" AND "South Africa," "Smart farming" AND "Challenges," and "Precision Farming" OR "Digital farming" AND "Developing countries." Additional searches included terms like "IoT implementation" AND "Barriers" OR "Enablers," "IoT implementation" AND "Challenges" OR "Enablers," and "Farming technology" AND "Policy support." These search strategies were designed to capture a broad range of relevant literature related to the adoption of IoT in farming.

Selection of sources of evidence

The selection process was structured to ensure the inclusion of relevant studies focusing on IoT adoption in farming. A single reviewer conducted the entire process, following a systematic approach. To keep the study consistent, a standardized form was created to evaluate each study. Questions on the form included whether the study looked at IoT adoption for farming, if it had any relevance to South Africa or the same context or was published in the English between 2018 and 2024. To check the form, the reviewer tested it on a few relevant studies. The initial screening step was reviewing titles and abstracts to exclude irrelevant studies. Reference management software (Zotero) was utilized to remove duplicate records. To be confirmed for inclusion, full-text articles were then assessed. Any doubt about a study's relevance was carefully revisited and decisions reevaluated to be in line with the review objectives. This thorough and consistent process allowed the reviewer to carefully select sources that provide valuable insights into IoT adoption in farming while ensuring transparency and reliability in the selection process.

Data charting process

Data extraction captured several key pieces of information, including publication details such as the author, year, and title. Additionally, the study design and methodology were noted, along with the key findings of each study and the relevance of each study to IoT adoption in farming. The variables extracted included study objectives, geographical focus, adoption barriers and enablers, and proposed solutions and frameworks.

Critical appraisal of individual sources of evidence
Critical appraisal assessed methodological quality and relevance to ensure robust evidence informed the findings. Each study was evaluated for its design, sampling, and validity of conclusions. Thematic analysis synthesized the data, categorizing findings into technological, economic, social, environmental, and policy-related factors influencing IoT adoption.

Results

The initial search identified forty (40) records. After removing duplicates and irrelevant studies, fifteen (15) articles were included in the final review. A flow diagram summarizing the selection process is provided in Figure 1, adhering to PRISMA-ScR guidelines.

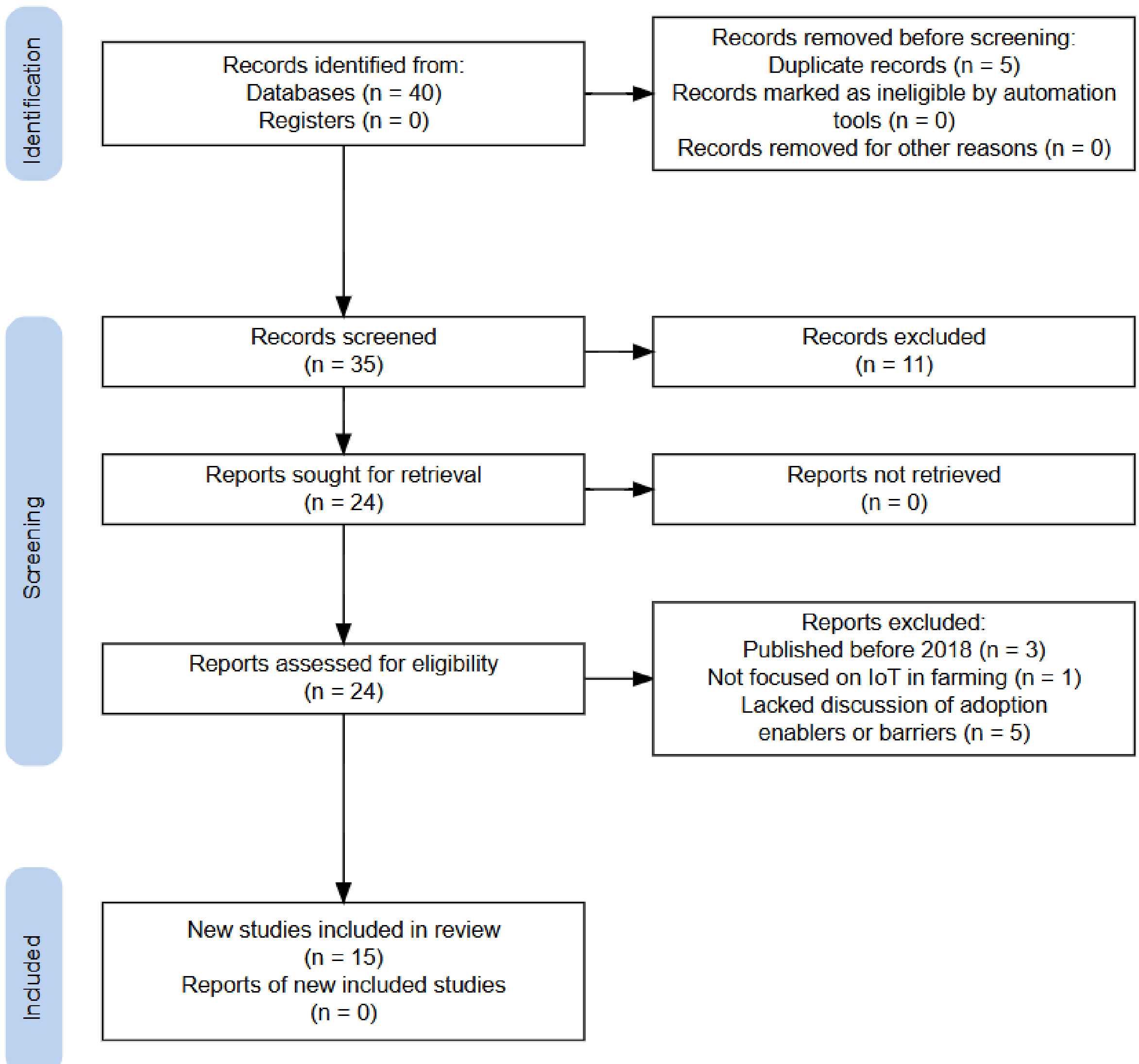

Figure 1: PRISMA flow diagram.

Characteristics of sources of evidence

This section provides an overview of the sources of evidence that have been included in the scoping review, referencing specific sources of evidence where applicable. Table 1 provides a summary of individual studies.

Table 1. Factors towards the IoT adoption characteristics

Source	Focus	Methodology	Key findings
(Ntshangase et al., 2018)	Social and economic factors	Quantitative	Highlighted the role of extension services in facilitating IoT adoption.
(Lufyagila et al., 2022)	Infrastructure challenges	Case Study	Identified infrastructure as a major barrier for smallholder farmers.
(Pivoto et al., 2019)	Economic and behavioral factors	Mixed-Methods	Found cost and lack of technical skills as barriers to IoT adoption.
(Reynoso et al., 2023)	Technological and environmental	Qualitative	Emphasized IoT's potential in climate adaptation and sustainability.
(Ramírez-Orellana et al., 2021)	Policy and sustainability	Quantitative	Highlighted the need for government incentives for IoT adoption.
(Verma & Sinha, 2018)	Training and educational factors	Mixed-Methods	Found that perceived usefulness and training increase IoT adoption rates.
(Morchid et al., 2024)	Technological factors	Qualitative	Showed how IoT technologies can optimize resource use and improve productivity.
(Dixit et al., 2023)	Technological factors	Qualitative	Highlighted the importance of interoperability and real-time analytics for IoT success.
(Mdoda et al., 2023)	Technological factors	Quantitative	Identified the need for reliable internet access and integration with local systems for success.
(Tu, 2018)	Economic factors	Quantitative	Found high initial costs as a barrier to IoT adoption, but demonstrated long-term benefits.
(Li et al., 2021)	Economic factors	Quantitative	Identified lack of awareness and digital literacy as challenges for IoT uptake in agriculture.
(Dyantyi & Njenga, 2022)	Environmental factors	Qualitative	Showed the role of IoT in improving climate resilience, focusing on water management and sustainability.
(Jayashankar et al., 2018)	Policy and regulatory factors	Quantitative	Addressed the importance of strong policy frameworks and subsidies for fostering IoT adoption.
(Serote et al., 2023)	Social factors	Qualitative	Emphasized the need for extension services to increase awareness of IoT technologies.
(Abegunde et al., 2022)	Social and economic factors	Quantitative	Discussed barriers such as financing, lack of technical expertise, and social constraints in South Africa.

Geographical focus:

- The studies cover various regions, with a particular focus on South Africa, sub-Saharan Africa, Southeast Asia, and South America. Studies focusing on South Africa-specific contexts are prioritized (Abegunde et al., 2022; Dyantyi & Njenga, 2022, 2022; Hundal et al., 2023; Mazwane et al., 2023; Mdoda et al., 2023; Moeti et al., 2024) to ensure relevance to the local challenges and opportunities.
- Southeast Asia and South America are also covered, providing comparative insights from regions with similar developmental challenges (Lufyagila et al., 2022; Pivoto et al., 2019; Reynoso et al., 2023).

Methodologies:

- **Qualitative Studies**: These studies utilized methods such as in-depth interviews, focus groups, and case studies to explore barriers and enablers of IoT adoption (Jayashankar et al., 2018; Ntshangase et al., 2018; Tabim et al., 2021).
- **Quantitative Studies**: Surveys and regression analyses were prominent, providing insights into key adoption factors such as cost, productivity, and perceived benefits (Li et al., 2021; Tu, 2018).
- **Mixed-Methods Studies**: Some sources combined qualitative and quantitative methods for comprehensive analyses, particularly in examining behavioral and economic aspects (Ramírez-Orellana et al., 2021; Verma & Sinha, 2018).

Thematic Coverage:

- **Technological Factors**: Common themes included interoperability, real-time data, scalability and infrastructure challenges. Studies highlight the need for IoT systems to integrate with existing farming practices to improve resource efficiency (Dixit et al., 2023; Lufyagila et al., 2022; Morchid et al., 2024).
- **Economic Factors**: Studies consistently emphasized the high initial costs of IoT technologies and the role subsidies, affordable solutions for small farmers and government support (Li et al., 2021; Pivoto et al., 2019; Ramírez-Orellana et al., 2021; Tu, 2018).
- **Social and Educational Factors**: Studies consistently emphasize the need for training programs and social networks to facilitate adoption, particularly in areas with low digital literacy (Li et al., 2021; Ntshangase et al., 2018; Verma & Sinha, 2018).
- **Environmental Factors**: IoT technologies have been shown to improve climate resilience and sustainability, particularly in addressing challenges such as water scarcity and droughts (Dyantyi & Njenga, 2022; Ramírez-Orellana et al., 2021; Reynoso et al., 2023)
- **Policy and Regulatory Factors**: Studies addressed the need for policy frameworks to tackle data privacy and infrastructure deficits (Jayashankar et al., 2018; Kusnandar et al., 2023; Ramírez-Orellana et al., 2021).

Temporal Scope:

Most of the sources were published between 2018 and 2024, reflecting the period of significant advancements in IoT technologies and their application in farming.

Critical appraisal within sources of evidence

Critical appraisal was conducted for all included studies to assess the methodological quality and relevance of their findings. The following criteria were applied during the appraisal process:

Study Design and Methodology:

- Peer-reviewed studies are prioritized for their methodological rigor. The inclusion of both qualitative and quantitative methods allows for a well-rounded exploration of IoT adoption (Ntshangase et al., 2018; Ramírez-Orellana et al., 2021).

Sampling and Data Collection:

- The sampling strategies and data collection methods, such as surveys, interviews, and case studies, were evaluated for their transparency and reliability (Li et al., 2021; Lufyagila et al., 2022).

Relevance to IoT Adoption:

- Only studies directly addressing IoT adoption in farming were included. Special focus was placed on studies that explore resource-constrained contexts such as South Africa (Mdoda et al., 2023; Mhlanga, 2024; Moeti et al., 2024).

Limitations Reported:

- Studies acknowledging their limitations, such as biases or challenges in generalizability, were considered more credible (Abegunde et al., 2022; Mhlanga & Ndhlovu, 2023).

The critical appraisal findings informed the synthesis process by weighing the reliability and applicability of evidence.

Results of Individual Sources of Evidence
The following key findings were extracted from individual sources:

Technological Factors

- Interoperability and real-time data are essential for ensuring that IoT solutions are practical and effective in the farming context (Dixit et al., 2023; Morchid et al., 2024). Studies highlighted the need for smart irrigation systems that are integrated with existing farm management tools to optimize resource use (Reynoso et al., 2023).
- Infrastructure challenges, such as poor internet connectivity and unreliable electricity in rural areas, are significant barriers to IoT adoption in South Africa (Lufyagila et al., 2022; Mdoda et al., 2023).

Economic Factors

- High initial costs continue to be a significant barrier to IoT adoption, particularly for smallholder farmers (Li et al., 2021; Pivoto et al., 2019). However, cost-saving potential and improved productivity from IoT technologies, especially in precision farming, demonstrate long-term benefits (Dlamini et al., 2024).

Social and Educational Factors

- Limited awareness of IoT benefits was a common theme, underscoring the need for targeted training programs (Ntshangase et al., 2018; Verma & Sinha, 2018).

Policy and Regulatory Factors

- Institutional support is critical for overcoming barriers such as financial constraints, infrastructure deficits, and technological challenges. Studies emphasize the role of government policies, subsidies, and private sector collaboration (Jayashankar et al., 2018; Kusnandar et al., 2023; Ramírez-Orellana et al., 2021).

These findings were systematically categorized to align with the thematic dimensions of the IoT adoption framework.

Synthesis of results
We conducted a thematic development process to create the themes which are facilitating the adoption of Internet of Things (IoT) in South African farming industry. We started by the collection and screening of articles, and we employed the PRISMA-ScR framework to outline the criteria of inclusion. After ensuring the relevance of articles, we extracted keywords and other phrases that resonated with each of the themes we set out to find. These were inductively coded, and particular attention was devoted to the mention of technological use, amounts of training deficiencies, economic barriers, environmental factors and the effects of policies. In multiple iterations, we generalized similar terms into themes.

To illustrate terms like real-time data collection, analytics, and interoperability were clustered under Technological Integration while keywords such as cost, financing, subsidies and resource constraints formed the basis of Economic Viability. This last part consolidated these categories to create a complete set of five themes as shown in Table 2. This categorization ensured a structured synthesis grounded in evidence from the literature while addressing the unique needs of the South African farming context.

Table 1: Synthesized themes for IoT adoption for the South African farming industry

Theme	Description
Technological Integration:	IoT technologies must be designed to integrate seamlessly with existing farming practices. Real-time analytics and predictive modeling emerged as critical enablers.
Economic Viability:	Cost reduction strategies, such as government subsidies and financing options, were emphasized as necessary to facilitate adoption among resource-constrained farmers.
Educational Outreach:	Capacity-building initiatives, including technical training and awareness campaigns, are essential for increasing IoT adoption rates.
Sustainability and Climate Resilience:	IoT applications in precision agriculture were shown to improve resource efficiency and reduce environmental impacts.
Policy and Regulatory Support:	Effective policies addressing data privacy, funding, and infrastructure are crucial to overcoming adoption barriers.

By synthesizing these findings, the study provides actionable insights for stakeholders and forms the foundation of the IoT adoption framework shown in figure 2, tailored to South African farming.

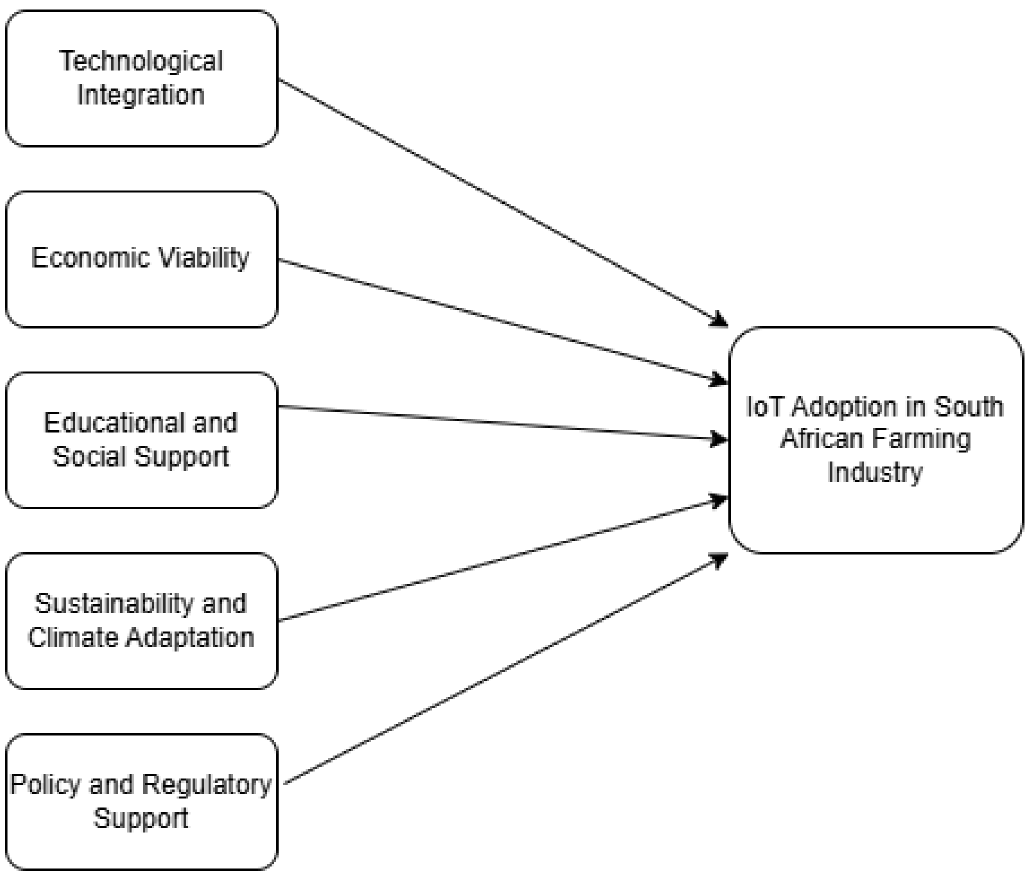

Figure 2. Proposed IoT adoption framework for the South African farming industry

Internet of Things Adoption Framework
The variables do not act independently but rather interact with each other in this framework. To give an idea, educational outreach can help to make farmers more comfortable with using new IoT technologies, which in turn will add to the success of technological integration of IoT systems. As with the example with government subsidies, policy support and economic viability can work together, as government subsidies could lower the cost of IoT devices to farmers who are then more likely to adopt IoT devices.

The framework assumes that IoT adoption is the outcome of an interaction among these variables, which are in balance and synergy. The adoption process may be hindered without addressing one or more of these factors. If there is no policy support, then farmers do not have a way to justify the high costs of IoT devices, even if the technology is beneficial for sustainability or economic viability. This framework presents a holistic view of all the factors to be dealt with for adoption of IoT in South African farms to be successful. Focusing on technological integration, economic viability, educational outreach, sustainability, and policy support will make it feasible for farmers to adopt IoT solutions. According to the framework, if all these factors are present, then IoT adoption is not only possible, but it is beneficial, and it can then lead to improved farming practices.

Discussion

The findings underscore the need for IoT solutions that address the unique challenges faced by South African farmers. Collaborative efforts among policymakers, technology developers, and farming services are vital to ensure successful implementation. The limitations in this review were: The search strategy only utilized the keywords, and therefore not all relevant studies may have been reviewed; and a sample of studies was possible to review based on the keywords in the search strategy. Furthermore, the use of secondary data may introduce biases inherent in original studies.

Implications for Practice
The suggested IoT implementation model provides practical guidelines that can respond to the problems within South African farming. Practicality must be achieved with the IoT tools that can be incorporated in the established farming practices. As an example, sensor-based irrigation may enrich vineyards, and the farmers of livestock can switch to health-monitoring gadgets. These applications enhance productivity. Alternatives to overcome the financial barrier can be subscription-based services and cooperative mode of ownership that lowers the initial costs. Such mechanisms should include government subsidies, grants and targeted incentives, especially among traditional disadvantaged farmers. Cost-effective and scalable solutions may also be created with the help of the public-private partnership.

The technical capacity of the farmers can be improved by community training centers and mobile resources in indigenous languages. The further advancement of knowledge and trust in the IoT systems can be achieved through demonstration projects and peer learning networks. IoT solutions are also important to sustainable farming and climate resiliency. Smart irrigation systems can promote water savings with no yield losses even in draught-stricken lands. Policy measures should focus on reducing financial barriers through subsidies and low-interest loans, enhancing digital and physical infrastructure in rural areas, and promoting knowledge dissemination through targeted awareness campaigns. The holistic and inclusive approach that encompasses the combination of technology and financial assistance as well as the training, sustainability, and the support of the powerful policy can ensure the successful adoption of IoT in the South African farming sector. Farmers must play an active role in it, sharing their knowledge to build locally relevant solutions.

Conclusion

A framework was proposed for IoT adoption as a part of the South African farming industry using this scoping review. The framework proposed in this study can be used to examine the multifaceted challenges and enablers of IoT adoption within the South African farming context. By integrating technological, economic, social, environmental, and policy themes, it responds to the specific dynamics that influence decision-making on farms, particularly in resource-constrained settings. Future research should focus on empirical validation through pilot implementations across diverse farming environments. Such efforts will not only test the framework's practical applicability but also offer critical insights for its refinement and broader relevance in supporting sustainable farming innovation.

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