# Designing an Agricultural Digitalization Policy Model to Enhance Agricultural Performance in Indonesia: A Case Study of Sambas Regency, West Kalimantan

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## Abstract

This study aims to design an agricultural digitalization policy model to improve agricultural performance in Indonesia, focusing on Sambas Regency, West Kalimantan. Utilizing the Fuzzy Analytical Hierarchy Process (FAHP), the research analyzes key factors, actors, objectives, and strategies influencing agricultural digitalization. The findings reveal that farmers' characteristics and perceptions, along with the role of facilitators, regulations, and digital infrastructure, are crucial factors. The Ministry of Agriculture emerges as the most influential actor while increasing agricultural productivity and farmers' income are identified as primary objectives. The development of integrated agricultural digitalization from upstream to downstream is prioritized as the key strategy, supported by government-provided big data, optimized extension worker roles, and the creation of digital markets for agricultural services and products. This research provides valuable insights for policymakers in formulating effective strategies to drive digital transformation in Indonesia's agricultural sector, emphasizing the need for a holistic, multi-stakeholder approach to realize the benefits of agricultural digitalization for farmers, businesses, and society at large.

**Keywords:** agricultural digitalization, digital transformation, FAHP, Indonesia, policy model.

The agricultural sector plays a crucial role in Indonesia's economy. With agricultural land spanning 36,817,086 hectares, comprising paddy fields, dry fields, shifting cultivation areas, and temporarily unused land (BPS, 2019), agriculture significantly contributes to the nation's GDP. In 2021, the agricultural sector accounted for 13.28% of the national GDP and grew by 1.84% (year-on-year) (BPS, 2023). Even amidst the COVID-19 pandemic, the agricultural sector maintained positive growth, serving as a pillar of the national economy. The GDP growth by the business field in 2022 indicates that the agricultural sector ranked third after the industrial and trade sectors, reaching 12.40% (Prihandarini, 2023).

Nevertheless, Indonesia's agricultural performance remains suboptimal. Productivity and farmer welfare remain low, while Indonesia continues to routinely import food. The welfare level of farmers is substantially lower compared to other sectors, such as traders who act as intermediaries between farmers (producers) and consumers (the public) (Susilowati, 2016). Factors such as education level, age, and openness to innovation influence the low agricultural performance (Stern & Cooper, 2011; Pierpaoli et al., 2013). This disparity demonstrates that the vast expanse of agricultural land and the large agricultural workforce do not automatically address issues of food sufficiency or farmer welfare.

This problem is further complicated by the rapid technological developments that are changing patterns and habits across all sectors, including agriculture. The VUCA (Volatility, Uncertainty, Complexity, Ambiguity) phenomenon presents a challenge that the agricultural sector must face (Bennis et al., 1985). The volatility of agricultural input prices, instability of paddy prices at the farmer level, and fluctuations in agricultural output prices are concrete examples of the VUCA phenomenon in the agricultural sector. The complexity of food policies and ambiguity in improving farmer welfare also pose distinct challenges (Ilyas, 2022).

The adoption of agricultural digitalization emerges as a potential solution to enhance agricultural performance. By leveraging digital technology, agricultural efficiency and productivity can be improved (Wolfert et al., 2017; Klerkx et al., 2019). Various agricultural digitalization applications that have developed in combination with Artificial Intelligence (AI), such as precision agriculture, crop monitoring, pest and disease detection, weather prediction, and data integration, can help farmers optimize agricultural practices and increase productivity (Hopkins, 2023). However, the adoption of agricultural digitalization in Indonesia remains minimal, partly due to low internet usage among farmers and the lack of interest from the millennial generation in becoming farmers (Ilyas, 2022).

Various countries such as Japan, China, India, Kenya, Bangladesh, and Uganda have adopted agricultural digitalization in various forms and shown positive results (Nasir, 2022; Brugger, 2011). In Indonesia, the implementation of agricultural digitalization has been proven to increase farmers' income by 8.5% (Chulwa et al., 2022) and streamline supply chains, thereby increasing farmers' profits (Banar, 2019). Smart irrigation systems have also been able to increase productivity by up to 40% and save operational costs by up to 50% (Permana, 2021). However, the application of agricultural digitalization in Indonesia is still limited and has not become a comprehensive policy. Research on agricultural digitalization is also limited and tends to be partial.

This research aims to design an agricultural digitalization policy model to improve agricultural performance in Indonesia, with a case study in Sambas Regency, West Kalimantan. This study will analyze existing conditions, build a conceptual model, review related policies, formulate policy, and design strategies and policy models for agricultural digitalization. Through this research, it is expected that comprehensive and applicable policy recommendations can be produced to encourage the widespread adoption of agricultural digitalization in Indonesia. This will contribute to improving agricultural performance, both in terms of productivity and farmer welfare, while simultaneously strengthening national food security and sovereignty in the digital era.

## Material and Method

Research objective and context

This research aims to design an agricultural digitalization policy model to improve agricultural performance in Indonesia, with a case study in Sambas Regency, West

Kalimantan. Sambas Regency, as one of the rice production centers in West Kalimantan, has great potential for agricultural digitalization development. With the largest rice-harvested area in West Kalimantan (BPS, 2022), Sambas Regency can serve as a model for implementing agricultural digitalization. However, the characteristics of farmers in West Kalimantan, who are typically smallholders with low income and relatively older age (Hendrayana, 2020; Susilowati, 2016), present unique challenges. This study is a continuation of previous research on developing agricultural digitalization to support farmer independence in Sambas Regency (Johan et al., 2022).

Fuzzy Analytical Hierarchy Process (FAHP)

The Fuzzy Analytical Hierarchy Process (FAHP) is an analytical method developed from the conventional Analytical Hierarchy Process (AHP). Generally, humans find it somewhat difficult to make quantitative estimates, as the ambiguity in decision choices leads to inconsistencies in decision-making (Elveny and Rahmadsyah 2014). Some literature mentions inaccuracies in decisions when using ratio comparisons (Faisol et al. 2014).

While conventional AHP is used to handle qualitative and quantitative criteria in Multi-Criteria Decision Making (MCDM), fuzzy AHP is considered better at describing vague decisions than traditional AHP (Chang, 1996). In more complex systems, human experience and judgment are often described in linguistic forms and unclear patterns. Therefore, a better representation can be developed into quantitative data using fuzzy theory. Traditional AHP still cannot fully represent human judgment. To avoid this risk, fuzzy AHP was developed to solve fuzzy hierarchical problems (Elveny and Rahmadsyah, 2014).

Fuzzy Comparison Scale

Table 3.1 presents the fuzzy comparison scale of importance levels:

| Importance Level | Fuzzy Number | Definition | Membership Function |
|---|---|---|---|
| 1 | 1 | Equally Important | (1,1,2) |
| 3 | 3 | Slightly More Important | (2,3,4) |
| 5 | 5 | More Important | (4,5,6) |
| 7 | 7 | Much More Important | (6,7,8) |
| 9 | 9 | Absolutely More Important | (8,9,10) |

Source: Marimin (2013)

Triangular Fuzzy Number (TFN)

FAHP uses Triangular Fuzzy Numbers (TFN) to determine the degree of membership. TFN consists of three membership functions: lowest value (l), middle value (m), and highest value (u). The TFN helps in measurements related to subjective human assessments through linguistic terms. The core of fuzzy AHP lies in pairwise comparisons depicted with ratio scales related to fuzzy scales (Shega et al. 2012).

FAHP Steps

1. Create a hierarchical structure and determine pairwise comparison matrices between criteria using the TFN scale.
2. Determine the fuzzy synthesis value (Si):

$$S_i = \sum_{j=1}^{m} M_i^j \times \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{m} M_i^j}$$

Where $\sum_{j=1}^{m} M_i^j$ is the row sum in the pairwise matrix, and $\sum_{i=1}^{n}\sum_{j=1}^{m} M_i^j$ is the column sum in the pairwise comparison matrix.

1. Determine the vector value (V) and defuzzification ordinate value (d').
2. Normalize the fuzzy vector weight value (W):

$W' = (d'(A1), d'(A2), \ldots, d'(An))T$

Where Ai = 1,2,...,n are n decision elements.

The weight vector value is shown in the equation:

$W = (d(A1), d(A2), \ldots, d(An))T$,

where W is a non-fuzzy number.

The weight vector, still in fuzzy number form, is normalized with the equation:

$$d(A_i) = d'(A_i) / \sum_{i=1}^{n} d'(A_i)$$

Basic Principles of FAHP

1. Decomposition Principle: Breaking down complex systems into simpler elements.
2. Comparative Judgment Principle: Assessing criteria and alternatives, often shown in pairwise comparison matrices.
3. Priority Synthesis: Determining the priority of criteria elements.
4. Logical Consistency: Ensuring consistency in judgments.

In the Fuzzy AHP method, the acceptable level of inconsistency is 10% or below. If the consistency ratio CR <= 0.1 (10%), then the preference comparison results are consistent, and if CR > 0.1 (10%).

## Result and Discussion

Based on existing data and facts in the field, results from studies and in-depth interviews, as well as expert justification based on the FAHP questionnaire, matrix weighting can be performed for the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement. The analysis to determine strategy priorities using the FAHP method is conducted to determine the best alternative strategy based on the analysis of influential factors or objectives according to the perspective of interest. In this FAHP analysis, results are also obtained for the priority of the most influential factors, the most important actors, the implicit/objective goals of the prioritized strategies to be implemented, and the most appropriate strategy to be applied in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement. Based on the FAHP framework, an FAHP questionnaire was compiled as attached. The FAHP questionnaire was distributed to 16 experts who interact directly with the agricultural sector. The questionnaire results from each expert's justification were inputted and processed with online FAHP software.

Factors in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

The Factor Analysis in this case aims to identify which factors are most important in influencing the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement based on priority weights from FAHP results, as shown in Table 1.

Table 1: Weights of Factors Influencing the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

| Factor | Priority Vector | Priority |
|---|---|---|
| Farmers' Perception | 0.206 | 2 |
| Farmers' Characteristics | 0.218 | 1 |
| Role of Facilitators | 0.197 | 4 |
| Regulation | 0.198 | 3 |
| Digital Infrastructure | 0.181 | 5 |

The analysis results show that the most influential factors in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement are Farmers' Characteristics (0.213), Farmers' Perception (0.202), Role of Facilitators (0.201), Regulation (0.198), and Digital Infrastructure (0.185). Farmers' characteristics such as education level, age, and openness to innovation determine the success of digital technology adoption (Trendov et al. 2019; Stern & Cooper, 2011; Pierpaoli et al. 2013). Farmers' positive perception of the benefits and ease of use of digital technology encourages wider acceptance and use (Aubert et al. 2012; Pivoto et al. 2018; Farooq et al. 2018). Competent facilitators facilitate the effective adoption and utilization of digital technology (Karavidas et al. 2021; Munthali et al. 2018; Mwangi et al. 2021). Supportive regulations create a conducive environment for agricultural digitalization (Shepherd et al. 2018; Eastwood et al. 2017; Rotz et al. 2019). Although digital infrastructure is an important prerequisite (Trendov et al. 2019), the main focus is directed more towards factors directly related to farmers and the agricultural ecosystem (Klerkx et al. 2019). By considering the role of each factor, policymakers can design effective strategies for realizing successful agricultural digitalization, focusing on improving farmers' characteristics, building positive perceptions, strengthening the role of facilitators, developing supportive regulations, and providing adequate digital infrastructure (Wolfert et al. 2017; Klerkx & Rose, 2020).

Actors in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

The Actor Analysis in this case aims to identify which actors are most important in influencing the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement based on priority weights from the Fuzzy Analytical Hierarchy Process (FAHP) results, as shown in Table 2. Several key actors play important roles in supporting the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement. Based on the analysis conducted, the Ministry of Agriculture becomes the most influential actor with a weight of 0.173. The Ministry of Agriculture has the authority and responsibility to formulate policies, develop regulations, and coordinate the implementation of agricultural digitalization nationally (Klerkx et al. 2019). As a government institution overseeing the agricultural sector, the Ministry of Agriculture plays a vital role in setting policy directions, allocating resources, and facilitating collaboration among stakeholders to realize effective agricultural digitalization (Shepherd et al. 2020).

Table 2: Actors Involved in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

| Actor | Priority Vector | Priority |
|---|---|---|
| Ministry of Agriculture | 0.173 | 1 |
| Legislative Bodies | 0.170 | 3 |
| Other Ministries and Institutions | 0.171 | 2 |
| Farmers | 0.164 | 5 |
| Extension Workers | 0.167 | 4 |
| Community and Business Actors | 0.156 | 6 |

The analysis results show that the actors playing important roles in agricultural digitalization are Other Ministries and Institutions (0.171), Legislative Bodies (0.170), Extension Workers (0.167), Farmers (0.164), and Community and Business Actors (0.156). Coordination and synergy among ministries and institutions are crucial to producing comprehensive policies and aligning programs in supporting agricultural digitalization (Klerkx and Rose, 2020; Wolfert et al. 2017). Strong legislative support is needed to create a conducive legal framework and allocate adequate budgets (Poppe et al. 2015; Kingsley et al. 2022). Extension workers play roles as facilitators, mentors, and liaisons between farmers and sources of innovation and digital technology (Munthali et al. 2022; Das et al. 2021; Karavidas et al. 2021). Farmers' characteristics greatly determine the acceptance and adoption of digital technology, so farmers need to be actively involved in the process of developing and applying technology (Steinke et al. 2020; Adeyemo et al. 2023; Barrett and Rose, 2021). Community and business actors, although having the lowest weight, also play important roles in providing support, input, and supervision for the implementation of agricultural digitalization policies (Rotz et al. 2019; Pivoto et al. 2018).

Analysis of Main Objectives in the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

The objective analysis aims to identify which objectives are most important in influencing the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement based on priority weights from the Analytical Hierarchy Process (AHP) results, as shown in Table 3.

Table 3: Objectives of the Agricultural Digitalization Policy Model Design to Support Agricultural Performance Improvement

| Objective | Priority Vector | Priority |
|---|---|---|
| Facilitate decision-making | 0,234 | 4 |
| Efficiency of agricultural inputs | 0,247 | 3 |
| Increase agricultural productivity | 0,265 | 1 |
| Increase farmers' income | 0,254 | 2 |

The analysis results show that the main objective of agricultural digitalization with the highest weight is Increasing agricultural productivity (0.265), followed by Increasing farmers' income (0.254), Efficiency of agricultural inputs (0.247), and Facilitating decision-making (0.234). Productivity improvement becomes the main focus because it directly relates to food security, agricultural sector competitiveness, and farmers' welfare. The application of digital technology can help farmers optimize cultivation practices, reduce crop failure risks, and increase production yields (Balafoutis et al. 2017). Agricultural digitalization also aims to increase farmers' income and welfare through access to market information, direct relationships with consumers, better prices, and income diversification opportunities (Schimmelpfennig, 2016; Bahn et al. 2021). Efficiency of agricultural inputs becomes an important objective to reduce production costs and negative environmental impacts through the use of digital technologies such as soil moisture sensors, drones, and precision irrigation systems (Kamilaris et al. 2017; Soto-Garcia et al. 2013). Lastly, agricultural digitalization aims to facilitate farmers' decision-making by providing accurate, relevant, and timely information, thereby increasing productivity and reducing the risk of losses (Navarro et al. 2016; Lindblom et al. 2017).

Alternative Strategies for Agricultural Digitalization Policy to Support Agricultural Performance Improvement

The alternative analysis aims to identify which alternatives are most important in influencing the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement based on priority weights from the Analytical Hierarchy Process (AHP) results, as shown in Table 4.

Table 4: Alternatives for the Design of Agricultural Digitalization Policy Model to Support Agricultural Performance Improvement

| Policy Alternative | Priority Vector | Priority |
|---|---|---|
| Provision of big data by the government | 0,239 | 2 |
| Optimization of Extension Workers' role through farmer guidance | 0,228 | 3 |
| Development of integrated agricultural digitalization from upstream to downstream | 0,24 | 1 |
| Creating a digital market for agricultural services | 0,219 | 4 |
| Creating a digital market for agricultural product marketing | 0,121 | 5 |

Based on the analysis conducted, the strategy with the highest weight is the Development of integrated agricultural digitalization from upstream to downstream with a weight of 0.24. This strategy aims to create a comprehensive and integrated digital ecosystem that covers the entire agricultural value chain, from input provision, cultivation, harvesting, post-harvest, to marketing of agricultural products. The development of an integrated digital system can increase efficiency, transparency, and collaboration among actors in the agricultural value chain, thereby improving the competitiveness and sustainability of the agricultural sector (Basso and Antle, 2020).

The second strategy is the Provision of big data by the government with a weight of 0.239. Big data becomes one of the important aspects of agricultural digitalization, as it can provide valuable insights and information for decision-making. The government can play a role in providing important agriculture-related data, such as climate data, land data, commodity price data, and agricultural production data, which can be accessed and utilized by farmers and agricultural businesses (Kamilaris et al. 2017). The provision of big data by the government can encourage innovation, increase transparency, and facilitate the development of better digital services for the agricultural sector (Wolfert et al. 2017).

Optimization of Extension Workers' role through farmer guidance ranks third with a weight of 0.228. Agricultural extension workers play an important role in facilitating the adoption of digital technology by farmers and providing technical guidance related to its application. Optimization of the extension workers' role can be done through increasing the capacity of extension workers in mastering digital technology, providing extension materials relevant to farmers' needs, and increasing the intensity and quality of interaction between extension workers and farmers (Steinke et al. 2020). With optimal guidance from extension workers, farmers can better understand the benefits of digital technology, adopt it better, and use it effectively to increase productivity and farmers' income (Klerkx et al. 2019).

The fourth strategy is Creating a digital market for agricultural services with a weight of 0.219. The digital market for agricultural services aims to connect farmers with agricultural service providers, such as agricultural equipment rental, consulting services, and post-harvest services. Through digital platforms, farmers can access agricultural services more easily, quickly, and affordably (Bahn et al. 2021). The digital market can also increase transparency and competition among service providers, so farmers have more choices and get better quality services (Lezoche et al. 2020).

The fifth strategy is Creating a digital market for agricultural product marketing with a weight of 0.121. The digital market for agricultural product marketing aims to connect farmers directly with consumers, reduce the role of intermediaries, and increase supply chain efficiency. Through e-commerce platforms specifically for agricultural products, farmers can sell their crops directly to consumers at better prices (Zeng et al. 2020). The digital market can also expand market reach for farmers, facilitate the sale of more diverse agricultural products, and increase consumer involvement in supporting local agriculture (Bahn and Barratt-Pugh, 2021).

In designing agricultural digitalization policies, it is important to consider the linkages and synergies between these strategies. The development of integrated agricultural digitalization from upstream to downstream becomes an important foundation, supported by the provision of big data by the government and optimization of the role of extension workers in guiding farmers. Creating digital markets for agricultural services and marketing of agricultural products also needs to be integrated into a comprehensive digital agricultural ecosystem. With coordinated implementation involving various stakeholders, these strategies can drive digital transformation in the agricultural sector that positively impacts farmers, businesses, and consumers.

The analysis using the Fuzzy Analytical Hierarchy Process (FAHP) method shows that the most influential factors in designing the agricultural digitalization policy model are farmers' characteristics, farmers' perceptions, the role of facilitators, regulations, and digital infrastructure. These findings align with previous studies that emphasize the importance of considering social, institutional, and technical aspects in the development and implementation of digital technology in the agricultural sector (Klerkx et al. 2019; Wolfert et al. 2017).

From the perspective of actors, the Ministry of Agriculture plays the most important role in designing and coordinating agricultural digitalization policies at the national level. However, the success of agricultural digitalization also depends on synergy and collaboration among related ministries and institutions, legislative support, the active role of extension workers and farmers, as well as community and business involvement. These findings emphasize the need for a multi-stakeholder approach and inclusive governance in the digital transformation process in the agricultural sector (Shepherd et al. 2020; Klerkx and Rose, 2020).

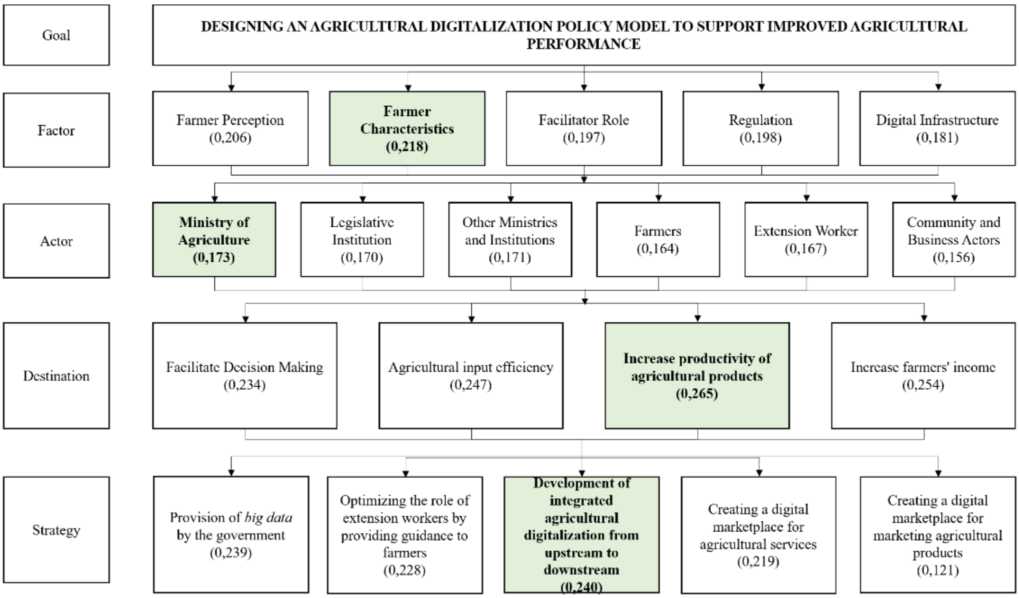

Figure 1. Hierarchical structure of AHP processing results

The objective analysis shows that the main priorities of agricultural digitalization are increasing agricultural productivity and farmers' income, followed by efficiency of agricultural inputs and ease of decision-making. These results underline the potential of digital technology to improve the performance and competitiveness of the agricultural sector, as well as contribute to farmers' welfare (Balafoutis et al. 2017; Bahn et al. 2021). However, realizing these benefits requires a comprehensive and integrated strategy.

Based on the analysis of alternative strategies, the development of integrated agricultural digitalization from upstream to downstream becomes the main priority. This strategy is supported by the provision of big data by the government, optimization of the role of extension workers, and the creation of digital markets for agricultural services and product marketing. This holistic and integrated approach is necessary to create an inclusive, efficient, and sustainable digital ecosystem in the agricultural sector (Wolfert et al. 2017; Basso and Antle, 2020).

Nevertheless, this research has several limitations. First, the analysis is based on subjective expert assessments. Second, this research focuses on the national level and has not yet considered regional variations. Further research is needed to explore the dynamics and challenges of implementation at the local level.

Overall, this research provides important insights into key factors, actors, objectives, and strategies in designing an agricultural digitalization policy model. These findings can serve as input for policymakers in formulating effective strategies to drive digital transformation in the agricultural sector. Coordinated implementation involving various stakeholders will be crucial to realizing the benefits of agricultural digitalization for farmers, businesses, and society at large.

## Conclusion

Based on the analysis using the Fuzzy Analytical Hierarchy Process (FAHP) method, it can be concluded that agricultural digitalization is an important agenda in improving the performance of the agricultural sector in Indonesia. Key factors influencing the success of agricultural digitalization include farmers' characteristics, farmers' perceptions, the role of facilitators, regulations, and digital infrastructure. The Ministry of Agriculture plays a central role in designing and coordinating agricultural digitalization policies, but synergy and collaboration with various stakeholders are also crucial.

The main priorities of agricultural digitalization are increasing agricultural productivity and farmers' income, followed by efficiency of agricultural inputs and ease of decision-making. The priority strategy is the development of integrated agricultural digitalization from upstream to downstream, supported by the provision of big data by the government, optimization of the role of extension workers, and the creation of digital markets for agricultural services and product marketing.

However, this research has limitations in terms of the subjectivity of expert assessments and has not yet considered regional variations. Further research is needed to explore the dynamics and challenges of implementation at the local level. By considering these findings, it is expected that comprehensive and integrated strategies and policies can be formulated to promote inclusive and sustainable digital transformation in Indonesia's agricultural sector.

## Recommendations

To support the successful implementation of the agricultural digitalization policy model in Indonesia, the government needs to develop comprehensive and integrated policies considering key factors such as farmers' characteristics, farmers' perceptions, the role of facilitators, regulations, and digital infrastructure. Optimizing the role of agricultural extension workers through capacity building, provision of relevant materials, and intensification of interactions with farmers is also key to facilitating the adoption of digital technology by farmers.

The development of digital markets for agricultural services and agricultural product marketing needs to be integrated into a comprehensive digital agricultural ecosystem. Further research is needed to explore the dynamics and challenges of implementation at the local level so that policies can be adapted and refined to be more effective and sustainable. By implementing these recommendations consistently and in a coordinated manner, Indonesia is expected to accelerate the adoption of digital technology in the agricultural sector, increase productivity and competitiveness, and achieve better farmer welfare. Inclusive and sustainable digital transformation in the agricultural sector will become an important foundation for food security, economic growth, and sustainable development in Indonesia.

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