Navigating Psychological Barriers in Agricultural Innovation Adoption: A Multi-Stakeholder Perspective

Nopparuj Chindasombatcharoen [a,b], Naoum Tsolakis [a,c], Mukesh Kumar [a] and Eoin O'Sullivan [a]
[a] Department of Engineering, University of Cambridge, UK
[b] Thailand Development Research Institute, Thailand
[c] Department of Supply Chain Management, International Hellenic University, Greece

Abstract
Agricultural innovation is pivotal for enabling cleaner production within the sector. Nonetheless, smallholder farmers in the Global South encounter functional and psychological challenges impeding innovation adoption efforts. Existing literature tends to narrowly focus on common barriers associated with individual innovations, often limiting the broader significance of psychological hindrances. This study takes a unique approach by delving primarily into the realm of psychological barriers, encompassing internal challenges that impede adoption, and explores external support strategies to overcome such hindrances. A multi-stakeholder approach was employed to gather validated insights based on data from eighteen semi-structured interviews involving rice farmers and agricultural technology companies. Research findings revealed that trust, effort, attitudinal, and normative barriers are prominent psychological hindrances to innovation adoption. To this effect, pertinent enabling factors and overcoming strategies should demonstrate clear benefits, infuse trust, reduce effort requirements, and develop human capital. This research is among the first to demystify and categorise psychological barriers and corresponding overcoming strategies into an integrated framework. The resulting framework allows for a novel and comprehensive analysis of the potential strategies to overcome the psychological barriers collectively, a complex issue involving interrelations and hidden dynamics that are challenging to explore otherwise. This study contributes to the Innovation Resistance Theory through its application within the context of smallholder farmers and leads to implications to expedite the transformation towards a more sustainable and innovative agriculture sector.

Keywords: psychological barriers; innovation resistance; innovation adoption; sustainable agriculture development; smallholder farmers.

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1. Introduction

The agricultural sector currently encounters a significant dilemma. On the one hand, smallholder farmers living under constrained financial conditions encounter sustainability challenges related to climate change impacts, health issues, fluctuating prices, well-being, and financial uncertainties (Fan and Rue, 2020). Indicatively, in Thailand, approximately 40% of agricultural households have an annual income below the national poverty threshold (United Nations, 2020). On the other hand, global food production activities are accountable for around 30% of global greenhouse gas emissions (WWF, 2023), mainly attributed to livestock methane emissions, nitrous oxide from chemical fertilisers, and crop residue burning (Ritchie *et al.,* 2020). Pressures for cleaner agricultural production are prompting a shift towards the adoption of innovative agricultural techniques, hence offering a promising pathway that could enhance sustainability across the environmental, social, and economic sustainability pillars (Zul Azlan *et al.*, 2024). Exemplar sustainability-oriented applications in agriculture regard water-savings (Alves *et al.*, 2023) and reduced chemical fertilisers (Zhang *et al.*, 2024). However, their uptake encounters obstacles that impede innovation adoption and limit sustainable growth potential, including limited financial resources, insufficient technical knowledge, and inadequate infrastructure (Benyam *et al.*, 2021; Raza *et al.,* 2021).

Extant investigations into the adoption of agricultural innovation have primarily focused on functional barriers (e.g., technological, organisational, and environmental). This leads policies to adopt a top-down approach and overlook a crucial aspect that shapes human decision-making and affects non-adoption: psychological aspects (Messmer *et al.,* 2021). The presence of disparity between adoption intention and actual adoption behaviour, the "intention-behaviour gap", has not only limited the ability of traditional models to explain adoption trends but has also led individuals to resist innovation adoption, despite harbouring positive attitudes toward them (Bhattacherjee and Sanford, 2009). Existing research points to the potential influence of psychological barriers in explaining such disparities (Lacroix et al., 2019); hence, the necessity of embracing a broader viewpoint by incorporating human psychology is highlighted (Gonella *et al.*, 2024).

We recognise two types of barriers causing resistance to innovation adoption following the seminal work by Ram and Sheth (1989): (i) functional, and (ii) psychological. In line with the typologies, we delineate functional barriers as obstacles associated with the suitability of a product's characteristics for an individual's functional use or value creation, along with the risks connected to the ensuing changes. Conversely, psychological barriers pertain to the internal conflict experienced by individuals due to disparities in their beliefs, values, cognition, emotions, or societal and traditional norms (Ram and Sheth, 1989). Prior investigations have adopted a narrow perspective of psychological barrier identification by primarily concentrating on identifying common barriers to adopting a single agricultural innovation. This results in a blend of functional and psychological barriers, with much less emphasis being placed on the latter. This approach has led to an uneven distribution of psychological barriers across the existing body of adoption literature, a limitation acknowledged by researchers (Roberts *et al.,* 2021). In addition, conventional adoption studies typically employ quantitative survey data and regression analyses utilising pre-defined adoption frameworks such as the theory of planned behaviour (e.g., Despotović *et al.*, 2019), which may limit the comprehensive study and identification of psychological factors. While integrated research into psychological barriers has been contemplated in various other sectors, to the best of the authors' knowledge, no integrated frameworks specifically emphasising psychological barriers affecting farmers' innovation adoption exist. Such a framework could prove beneficial, particularly in sectors characterised by resistance to innovation (Roberts *et al.,* 2021), as is the case for smallholder farmers in developing regions. This is important as research suggests poverty could significantly impede their cognitive functioning and lead to more pronounced psychological barriers (Mani *et al.,* 2013).

The uniqueness of this study lies in its ability to offer a comprehensive understanding of the diverse

psychological challenges encountered by smallholder farmers. It diverges from existing perspectives, where psychological barriers are often treated as incidental outcomes overshadowed by predominantly functional barriers. Crucially, this study delves deeper by outlining the external support mechanisms required to overcome these psychological barriers collectively. Such perspective was not possible in the existing literature given the lack of an integrated framework for psychological barriers. This addresses the concerns Gonella et al. (2024) raised, who noted the limited research focus on addressing psychological barriers in the literature.

Research evidence highlights the catalytic role of innovation adoption within dominant smallholder areas to enhance eco-environmental production systems' sustainability (Wang *et al.*, 2024). In this regard, this study employs a qualitative approach to underscore the importance of systematically understanding and addressing relevant psychological barriers. We employ a multi-stakeholder approach in our study by conducting semi-structured interviews with technology companies and rice farmers across the country. This allows a comprehensive exploration of the complex research topic from the perspectives of stakeholders situated at various positions in the agricultural ecosystem. The aim of this research is to study the factors hindering the successful adoption of agricultural innovation through the psychological lens and attempts to address the following research questions:

- RQ1 – What psychological barriers hinder innovation adoption among smallholder farmers in a developing country context?
- RQ2 – How can external support from farming ecosystem stakeholders overcome prominent psychological barriers to innovation adoption?

This study contributes to the Innovation Resistance Theory (IRT) through its application to the context of agricultural innovation adoption, which enhances the understanding of potential psychological barriers in an industrial context. The identification of psychological barriers could guide policymakers to devise bespoke external support measures (Roberts *et al.,* 2021), closing the gap between research and practice. By prioritising external support mechanisms, this research can help overcome obstacles and expedite the innovation diffusion process. Given that agricultural innovations inherently result in more efficient input usage and economic benefits for farmers, coupled with the focus on some sustainable innovations in the interviews, this study offers insights with implications for ultimately fostering sustainable agricultural transformation.

The paper is structured as follows. Section 2 reviews the pertinent literature on barriers to innovation adoption, focusing particularly on psychological barriers within the agricultural sector, and establishes a conceptual framework for the study. Section 3 delineates the methodology employed, including details on the interview sample and data analysis approach. Section 4 elucidates the research findings, while Section 5 offers a discussion thereof. Finally, the paper concludes in Section 6 by highlighting the research contributions and suggesting avenues for future research.

2. Literature Review

2.1 Innovation Adoption Barriers

A crucial aspect in adoption studies often investigated is the barrier towards adoption. Two types of barriers causing resistance to innovation can be delineated based on the IRT: functional and psychological (Ram and Sheth, 1989), as shown in Figure 1. Functional barriers consist of usage, value, and risk barriers, whereas psychological barriers encompass tradition and image barriers, as defined in Table 1. The IRT sheds light on the factors influencing individuals' resistance to new ideas or technologies, seeking to comprehend the reasons behind their reluctance towards adopting new innovations. Through a deeper comprehension of the underlying causes of resistance, more effective strategies can be devised to tackle the prevalent issues leading to a low rate of innovation adoption. The IRT has been used as a framework to investigate innovation adoption barriers in a wide range of

contexts, such as the resistance to mobile payment solutions (Kaur *et al.*, 2020), smart internet-of-things devices (Mani and Chouk, 2018), hydrogen-electric motorcycles (Chen *et al.*, 2018), and participation in the sharing economy (Huynh and Gurtner, 2023).

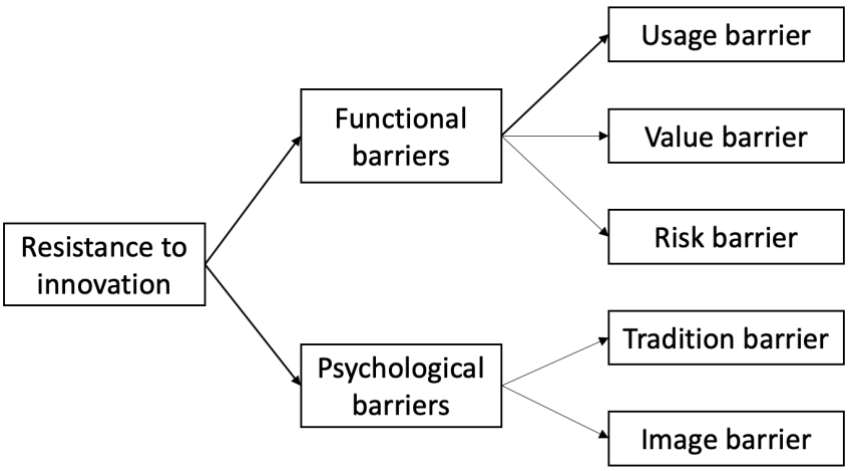

Figure 1. Innovation Resistance Theory

Table 1. Definitions of Innovation Resistance Theory components

Barrier Category	Subcategory	Description
Functional	Usage	Barriers relating to the usage of the innovation by the adopter, including the compatibility with existing workflows or the required competencies
	Value	Barriers relating to the benefits of the innovation in comparison to the substitute product
	Risk	Barriers relating to the uncertainties regarding potential advantages and drawbacks of the innovation
Psychological	Tradition	Barriers relating to the required changes in usage behaviours and departure from established traditions
	Image	Barriers relating to any unfavourable image that could be established on the adopters based on the identity of the innovation, such as product class, industry, or country

Additionally, research studies have extended the theoretical framework in various ways. For instance, in their study of the resistance to participation in the sharing economy, Huynh and Gurtner (2023) adapted the IRT in two key dimensions. First, a separation was made between passive resistance, containing adopter-specific and situation-specific barriers, and active resistance, containing the IRT's original functional and psychological barriers. Second, the functional barriers category was expanded to include both economic and functional risks. Moreover, Mani and Chouk (2018)'s study extended the IRT by including three additional psychological barriers: (i) technological vulnerability barrier (technology anxiety and dependence);(ii) ideological barrier (scepticism); and (iii) individual barriers (inertia). Along the lines of these extensions, this research suggests a more thorough investigation into the elements of psychological barriers within a particular cohort of innovation adopters, namely smallholder farmers. This examination aims to broaden the scope of the IRT to encompass a user group known to face substantial challenges in adopting innovations.

2.1.1 Functional Barriers to Agricultural Innovation Adoption

An examination of literature concerning barriers to farmers' adoption of agricultural innovations led to their classification into five primary domains, i.e., financial, knowledge/competency, regulatory, infrastructure, and accessibility, as captured in Table 2. Across the reviewed studies, the prevailing

approach involved identifying a range of common barriers —both functional and psychological— to the adoption of specific agricultural innovations (i.e., smart farming technologies, agricultural drones, green farming practices), with a stronger emphasis on functional barriers. Lee and Gambiza (2022) provide a more thorough review of barriers to smallholder farmer adoption.

Table 2. Critical taxonomy of functional barriers to agricultural innovation adoption.

Barrier Category	Description	References
Financial	▪ Fixed investment costs of technology	Bacco et al. (2019); Benyam et al. (2021); Kendall et al. (2022);
	▪ Increased operating costs of technology	Benyam et al. (2021); Jaiswal et al. (2019);
	▪ Limited access to credit	Kendall et al. (2022); Sher et al. (2019);
Knowledge/ Competency	▪ Obscured understanding over the benefits of technology	Bacco et al. (2019); Kernecker et al. (2020); Puppala et al. (2023)
	▪ Limited capacity to interpret data generated from technology	Kernecker et al. (2020); Pivoto et al. (2018)
	▪ Limited capacity to implement or operate technological applications	Jerhamre et al. (2022); Puppala et al. (2023);
Regulatory	▪ Uncertainties regarding data ownership and privacy	Bacco et al. (2019); Jerhamre et al. (2022);
	▪ Regulatory hurdles impeding adoption	Akenroye et al. (2021); Puppala et al. (2023)
Infrastructure	▪ Lack of or unreliable internet connectivity	Bacco et al. (2019); Benyam et al. (2021); Kernecker et al. (2020)
	▪ Insufficient data gathering and analysis infrastructure	Ayre et al. (2019); Darnell et al. (2018)
Accessibility	▪ Lack of access to technology	Kendall et al. (2022); Stewart et al. (2020)
	▪ Lack of access to required resources	Akenroye et al. (2021); Stewart et al. (2020)
	▪ Lack of access to information and extension	Kendall et al. (2022); Sher et al. (2019); Stewart et al. (2020)

2.1.2 A Psychological View

Psychological barriers have been recognised as having a significant role in hindering innovation adoption in various sectors. Research works in several industries have developed taxonomies of psychological barriers hindering the adoption of innovations. For example, in the oil and gas industry, Roberts *et al.* (2021) devised a framework tailored explicitly to technology adoption, identifying six subcategories of factors: personality, motivation, attitude, cognitive, social, and organisational. With respect to meat consumption, Graves and Roelich (2021) identified habits, ethical considerations, perceived difficulty, lack of understanding, and societal norms as the predominant mediating factors to meat consumption reductions. Similarly, concerning climate change mitigation and adaptation, Gifford (2011) identified seven categories of psychological barriers hindering pro-environmental behaviour: limited cognition, ideologies, social comparisons, sunk costs, scepticism, perceived risks, and constrained behavioural patterns. With respect to digital banking services, Santos and Ponchio (2021) found that, in addition to the functional barriers of value, complexity, and trialability, psychological and emotional barriers positively influence an individual's resistance to innovation. Such psychological barriers refer to the existing image held, information asymmetries, subjective risk perceptions, and the emotional barriers of pleasure (satisfaction) and arousal (excitement).

2.1.3 Psychological Barriers to Agricultural Innovation Adoption

Extant studies on barriers that inhibit agricultural innovation adoption share a common objective of examining the set barriers that obstruct the adoption of a single type of innovation. Notably, as mentioned previously, psychological aspects often receive less prominent attention and are revealed as a secondary focus among a multitude of functional barriers (see Lee and Gambiza, 2022). The review of innovation adoption studies among farmers from Section 2.1.1 revealed no such instance of studies devoted specifically to the psychological barriers of farmers. In addition, some quantitative studies can be seen that applied specific theoretical lenses, leading to a fixated category of findings due to the nature of quantitative approaches. In contrast, qualitative studies, which do not rigidly adhere to specific theoretical frameworks but instead apply a framework derived from prior literature, offer a more adaptable and diverse approach, resulting in a broader range of findings. Table 3 identifies psychological barriers' components to agricultural innovation adoption.

Table 3. Psychological barriers to agricultural innovation adoption.

References	Innovation Type	Research Methodology	Psychological Aspects
Akenroye *et al.* (2021)	Sustainable coffee farming practices	Qualitative	• Insensitive attitude towards water scarcity hindering drip irrigation adoption
Mankad *et al.,* (2017)	Area-wide management of insect pests	Qualitative	• Lack of interest in area-wide management
Keshavarz and Sharafi (2023)	Climate-smart regenerative agriculture	Qualitative	• Low level of motivation for climate adaptation • Fear of change • Mistrust in government services
Zamasiya *et al.* (2017)	Adaptation to climate change	Quantitative & Qualitative	• Existing negative attitudes toward climate adaptation techniques
Gerli *et al.* (2022)	Smart farming technologies	Qualitative	• Conservative mindset and reluctance to abandon traditional methods • Fear of data loss and information sharing • Annoyance in learning and usage • Trust towards technology and the suppliers
McCaig *et al.* (2023)	Internet of things	Qualitative	• Fear of data loss • Stress from reliance on a working technology
Rübcke von Veltheim *et al.* (2022)	Autonomous field robots	Quantitative	• Anxiety in innovation usage • Required/expected effort in adoption
Jangid *et al.,* (2012)	Biofertilisers	Quantitative & Qualitative	• Credibility of purchasing source • Lack of usage by fellow farmers

Several attitudinal factors can present barriers to the adoption of innovative agriculture practices. First, farmers may demonstrate a lack of interest in embracing sustainable practices. An illustrative example refers to farmers' indifference toward water scarcity, which results in a disinterest in implementing technologies such as drip irrigation (Akenroye *et al.,* 2021). Another instance involves the lack of interest in managing pests through techniques like area-wide management (Mankad *et al.,* 2017). Additionally, a lack of motivation to adapt to climate-smart agriculture can hinder adoption due to the challenges associated with addressing climate change (Keshavarz and Sharafi, 2023). Negative

attitudes and beliefs concerning new agricultural practices also significantly obstruct climate change adaptation (Zamasiya *et al.,* 2017). Overall, a conservative mindset among farmers can lead to resistance to transitioning away from traditional farming methods (Gerli *et al.,* 2022).

Emotional barriers, including fear, anxiety, stress, or annoyance, have been identified as significant obstacles to the adoption of innovation. These emotional barriers can manifest in various ways within the context of innovation adoption. For instance, farmers may experience a general fear related to change (Keshavarz and Sharafi, 2023). Regarding digital innovations, specific fears, such as the fear of data loss and concerns about information sharing, have been highlighted as barriers to adoption (Gerli *et al.,* 2022; McCaig *et al.,* 2023). Additionally, anxiety arising from using innovative technologies (Rübcke von Veltheim *et al.,* 2022), and stress associated with the reliance on functioning technologies (McCaig *et al.,* 2023), are also components of emotional barriers. Moreover, farmers might find themselves uncomfortable when confronted with the necessity to learn and employ unfamiliar technologies (Gerli *et al.,* 2022).

The expected effort involved in innovation adoption also influences farmers' decision-making processes. For example, Rübcke von Veltheim *et al.* (2022) tried to understand farmers' intention to use autonomous field robots and found a significant negative influence of effort expectancy on adoption intention. Trust issues also emerge as a key theme, which includes mistrust in government support services (Keshavarz and Sharafi, 2023), mistrust towards the technology and its suppliers (Gerli *et al.,* 2022), and mistrust in the sources of purchasing (Jangid *et al.,* 2012). Finally, Jangid et al. (2012) found that the lack of biofertiliser usage by fellow farmers hinders self-usage.

2.2 Conceptual Model

In light of the reviewed literature and theoretical background, a conceptual framework is derived, shown in Figure 2. An explanation of each component of the psychological barriers is provided in Table 4. This framework focuses on two aspects, i.e., psychological barriers and external support. Upon evaluating the adoption rate of technologies among farmers, policymakers and stakeholders enter a feedback loop that necessitates informed decision-making. In this context, decision-makers are responsible for modifying the external support mechanisms available to farmers, targeting psychological barriers that impede technology adoption. Through this iterative process, policymakers and other stakeholders can enhance the innovation adoption process, fostering enduring advancements in the sector.

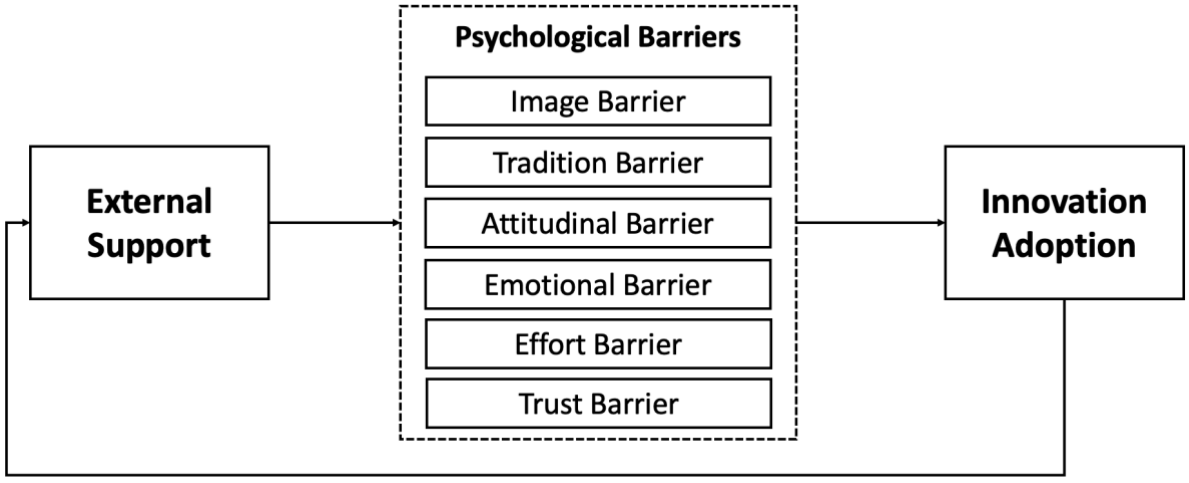

Figure 2. Conceptual research model.

Table 4. Explanation of psychological barriers identified in the literature.

Psychological Barrier	Explanation
Image	Barriers relating to any unfavourable image that could be established on the adopters based on the identity of the innovation, such as product class, industry, or country.
Tradition	Barriers relating to the required changes in usage behaviours and departure from established traditions.
Attitudinal	Barriers relating to existing negative attitudes, beliefs, mindsets, or lack of interest towards the innovation.
Emotional	Barriers relating to the psychological hurdles stemming from individuals' emotional reactions that hinder their ability to embrace new innovations, such as fear, anxiety, stress, or annoyance.
Effort	Barriers relating to the increased effort required in learning about or in using the innovation.
Trust	Barriers relating to the lack of confidence or scepticism on the reliability, credibility, or effectiveness of new innovations or of the individuals involved in the adoption process.

3. Methodology

3.1 Research Design

This study employed semi-structured interviews as the approach provides flexibility in understanding the contexts and behaviours underlying complex issues (Myers, 2009) based on the interviewees' experiences and perspectives (Vickers, 2010). A list of predetermined interview questions allowed for probing, while follow-up questions facilitated the exploration of underlying motivations and beliefs (Bell *et al.,* 2022). This study's overall research process involved three stages (Figure 3).

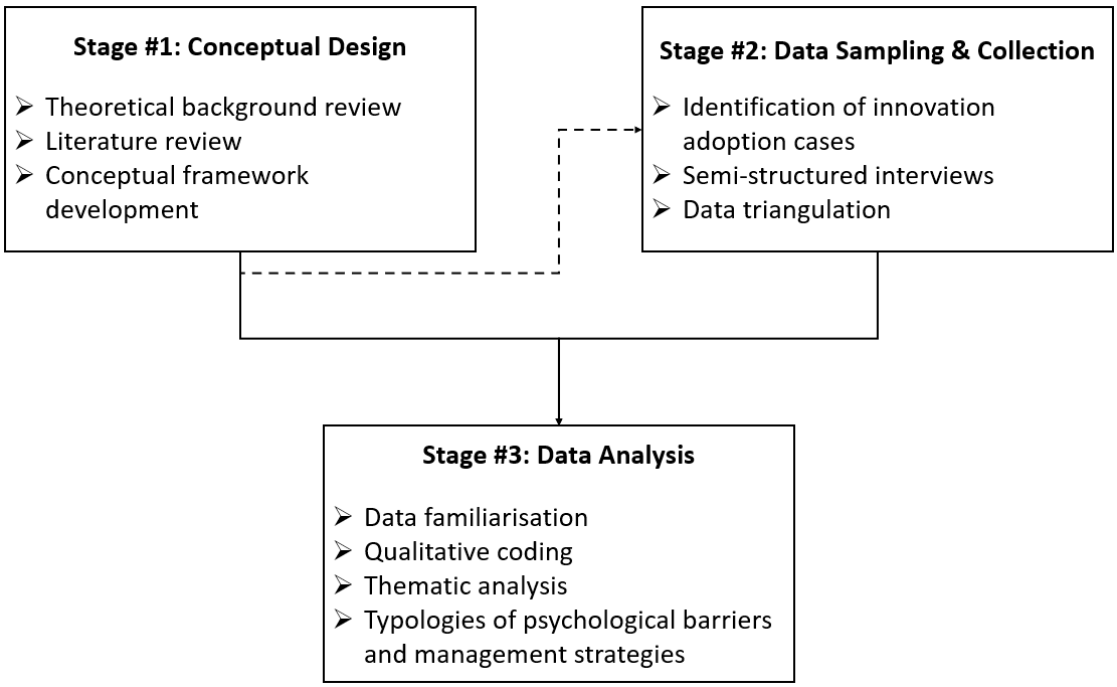

Figure 3. Methodology flowchart.

3.2 Data Sampling and Collection

Based on the intention to propose a practical framework deriving from theoretical foundations, this research used purposive sampling to identify interview candidates (Schutt, 2018) from a real-world

case (Yin, 2003). To this end, the case of smallholder rice farmers and technology suppliers in Thailand was selected. Including farmers and technology developers in this research was of utmost importance, particularly in gaining insights into the psychological aspects surrounding technology adoption. The collaboration between the aforementioned groups of informants was a determinant in their selection; collaboration is an intensive field of inquiry for knowledge-intensive development in rural regions (Kolehmainen *et al.,* 2016).

Technology adoption among rice farmers in Thailand is imminent due to the country's prominent character as the leading global producer and exporter of rice, offering valuable perspectives into the obstacles confronted by farmers operating within a fiercely competitive agricultural sector. Thailand is the second global rice exporter after India, accounting for about 13.5% of total rice exports in 2021 (World Bank, 2023). Embracing innovative agricultural techniques and technologies has a pivotal sustainability role as it helps farmers improve economic viability, conserve natural resources, and ensure food security for future generations (Zul Azlan *et al.*, 2024). Samples of farmers were selected from the three regions of Thailand that produce most of the country's rice output, namely the Central, North, and North-eastern regions. This representative sample provides a comprehensive understanding of the Thai rice farming context on a nationwide level. Conducting interviews with farmers enabled a direct exploration of the barriers they encountered and their experiences working alongside fellow farmers within their respective groups.

Technology companies were also meticulously chosen to ensure a diverse representation of available technologies in the market and their direct engagement with rice farmers, which allowed the gathering of insights into the various approaches employed to promote technology adoption. Engaging with technology companies provided a complementary perspective from the companies collaborating with farmers, offering a third-party viewpoint that enhanced our understanding of behavioural dynamics in the context under study.

Data triangulation was used to increase the internal validity of the research through information from various data sources, which were used to verify evidence and facts provided by interviewees (Myers, 2009). Such sources included government documents, news media coverage, and online articles. In addition, interviews with diverse types of stakeholders allowed the researcher to obtain an understanding of the same phenomenon from different perspectives. For example, obstacles recognised by technology companies, when exclusively examined from their standpoint, might not offer a complete view unless supplemented with insights from farmers. Some counterarguments reveal biased views, emphasising the need for careful interpretation.

Participants' contacts were obtained through the Department of Agricultural Extension, which provided farmers' contact details. Additionally, a government agency supporting agricultural technology projects provided details of technology developers, with further interviews obtained through formally contacting well-known companies (Schutt, 2018). Interviewees were selected based on their understanding and involvement with innovation adoption and dissemination activities among rice farmers. We continued conducting interviews until a saturation of findings was obtained. A total of 18 informants, consisting of 9 rice farmers and 9 technology companies, were ultimately interviewed. The description of interviewees is provided in Table A in the Appendix.

Semi-structured interviews of thirty minutes to an hour were held with the interviewees. Farmers were interviewed based on any of the past innovation adoptions. Technology companies were interviewed based on experiences in promoting proprietary technologies to farmers. Throughout the interviews, probing questions were utilised to elicit responses that naturally revealed insights into the psychological aspects of the informants. The interviews were conducted in Thai language. The interview questions were formulated to encompass a broad spectrum of potential responses from the

interviewees. The survey tool was designed to be open-ended, allowing for diverse perspectives, and included follow-up questions to guide interviewees toward discussing psychological barriers and potential solutions, aligning with the research objectives. The interview questions posed to both groups of interviewees can be found in Table B in the Appendix.

3.3 Data Analysis

The six-phase thematic analysis by Braun and Clarke (2006) was used to analyse the qualitative data, which includes data familiarisation, initial code generation, theme identification, theme reviewing, theme naming, and report production. This method is selected over other methods (such as discourse analysis) due to the focus on identifying patterns and themes within the qualitative, as opposed to the focus on nuances of language and communication for discourse analysis (Braun and Clarke, 2021). First, after data gathering, the transcripts were reviewed repeatedly to improve familiarity with the content before the analysis. The transcripts were then manually coded using spreadsheet software, with initial codes assigned next to the relevant text. The coding was not guided by prior categories from the literature to ensure unbiased views and realise this study's exploratory nature. To ensure consistency, a second iteration of coding was conducted. Third, after all interviews were coded, the codes were collected and organised into themes, followed by naming the themes. The original transcripts in Thai were translated into English for only the quotes representing the codes and themes. During the translation process, meticulous attention was paid to maintaining the original mood and tone of the interviewees to preserve the authenticity of their expressions and perspectives.

4. Findings

This section presents the categories of psychological barriers identified through the exploratory interviews and recommendations for overcoming these barriers. Salient informants' quotes regarding psychological barriers are inserted in Table C in the Appendix, while those concerning enabling factors and recommendations are inserted in Table D in the Appendix.

4.1 Psychological Barriers

4.1.1 Trust barrier

Trust is a common barrier mentioned by farmers and technology developers, consisting of two pillars: (i) the lack of trust in new technology or processes; and (ii) the change agent delivering the information about innovative applications and processes. Regarding trust in change agents, TC1 shared farmers' experiences with past government projects to assist with technology adoption and ownership, where budget cuts resulted in decreased quality and lifespan of the equipment being supported. TC1 mentioned that *"Farmers might not trust change agents as they have had bad experiences with these people in the past. Farmers learn not to trust these people easily as there have been stories where they followed the recommendations, and it doesn't actually work long-term."* RF9 also mentioned that trust in public extension agencies decreased as farmers followed the provided recommendations that were outdated and not geared towards each location's specific context (e.g., use of inappropriate fertilisers or machinery). Experiences with such failures caused farmers to resist following government recommendations and became very careful in trusting the recommendations of people outside their inner circle.

Trust in new technologies or processes per se is also a key issue. Although farmers might have seen new and sophisticated technologies through social media [TC1], they might not understand operational characteristics (e.g., using drones to spray fertilisers) or do not trust the use of smartphone applications for making bookings [TC4], and especially for making payments [TC8]. There is also a lack of trust in whether new technologies or processes would generate actual value for the farmers [TC1, TC9]. There is a higher importance on trust (both in the technology and the change agents) for technologies with a higher risk of process changes [TC2].

4.1.2 Effort barrier

Effort cost is the most cited barrier to adoption by the interviewees and refers to the tendency of farmers to prioritise convenience when evaluating alternative options. While financial incentives have a crucial role, farmers also consider the convenience of adopting innovations. If the proposed changes are perceived as onerous, farmers are less likely to adopt them [TC2]. For example, TC2 reported the case of adopting site-specific nutrient management practices that have proven to improve yields significantly. However, many farmers avoid adopting such new practices as soil samples need to be dispatched to a lab for testing, and the procurement of specific fertilisers is more problematic than commonly used farm inputs. Additionally, RF1 mentioned that farmers resent any new information once they realise it is complicated.

An additional effort barrier concerns rice farmers and the opportunity to increase their income through post-harvest technologies. TC3 and RF1 reported a case where rice farmers could leverage community facilities to process their paddy harvests into milled rice, engage in marketing and branding of their products, and sell directly to end consumers. Post-harvest processing increases income from 7THB per kg of paddy rice to 50THB per kg of milled rice. However, farmers perceive the process as troublesome, thus selling paddy rice to other rice mills at a low price. RF1 stated that *"Farmers have the opportunity to improve their income through adding value to their products by processing the paddy rice into milled rice and selling the product to end consumers by themselves. However, they see it as troublesome and sell their farm output (paddy rice) straight to the rice mills at a very low price."*

Specific processes also increase the effort costs for farmers. RF2 and RF5 mentioned the elevated effort required to manage residues sustainably, hence opting to burn agricultural residues. Residue burning to clear the fields requires minimal effort in contrast to applying appropriate management practices, leading to high environmental damage. Farmers voiced the difficulty in finding contractors willing to perform residue management practices due to the complexity of operations [RF2]. The lack of equipment availability (e.g., baling machines) in certain regions adds to these difficulties.

Similar arguments were raised for organic rice growing where, despite the apparent benefits, a significant effort increase compared to standard rice growing was mentioned as a critical barrier [RF6, RF7]. Other examples include drone license requirements [TC6] and the legal processes for switching to grow hemp [TC7]. Specifically, for hemp, TC7 stated that filling out and obtaining legal documents (e.g., criminal records) hinder farmers' adoption. Finally, the effort factor also refers to the complexity of understanding and linking the technology to the benefits for the farmers. An example is the slow adoption of farm analytics applications or farm management software in which the benefits could not be immediately recognised and appreciated [TC5].

4.1.3 Attitudinal barrier

Barriers related to farmers' subjective attitudes are identified as a hindrance. First, they exhibit short-term attitudes, also referred to as "present bias", representing the inclination towards short-term gains rather than investing in long-term enhancements. This study revealed several instances of farmers' short-term behaviours. An example barrier illustrating such behaviour is the tendency of farmers to rely on government monetary support instead of proactively considering long-term improvements [RF1]. As mentioned by RF1, despite experiencing losses, most rice farmers have benefited from government programs offering unconditional cash transfers over the years. This led to the perception that they would receive support regardless of their crop cycle outcomes. Consequently, these cash transfers are often diverted towards non-farm-related expenditures, as farmers anticipate receiving further support in subsequent cycles [RF1]. Similarly, RF9 mentioned that government-organised training programs encourage farmers' participation, causing farmers to focus on attending

just to receive the provisioned remuneration rather than engaging and acting upon the training content.

In the same vein, sustainable residue management leads to long-term benefits (e.g., improvement in yields, reduction in costs of fertilisers) but short-term costs (e.g., land preparation). Nevertheless, farmers cannot comprehend these benefits and cite the increase in costs as their primary barrier to adoption [RF2]. Short-term costs are a reality; however, in the long term, the increases in soil fertility lower the costs of fertilisers and increase yield and profit for the farmers, which signals farmers' myopic attitudes. RF2 stated that "*Many people cannot separate between increases and decreases in cost. People say residue management increases land preparation costs by two times as they need to do an additional round of ploughing. However, they don't realise that there is a greater reduction in future production cost from the decreased need for chemical fertilisers".*

In addition, many farmers lack motivation in enhancing their agricultural production techniques. Many farmers in Thailand are not full-time employed and spend only a small amount of time managing their farms by mobilising agricultural contractors to perform most services, from land preparation to spraying of fertilisers to applying pesticides and herbicides to harvesting [TC3]. This outsourcing allows farmers to explore complementary income sources, for example, as taxi drivers. In addition, as most farmers are aged, some rely primarily on their children and grandchildren [TC3]. Agricultural income is, therefore, not crucial for the survival of these groups of farmers. Moreover, such farmers continue growing rice to claim farmer status and collect government incentives, reducing their necessity and motivation to optimise operations [TC3]. TC3 stated that "*A crucial factor is that many farmers are not full-time. As they have incomes from part-time jobs or rely on children & grandchildren's income, they are not always trying to optimise their process and just grow rice to get government incentives as farmers".* Furthermore, TC6 mentioned that farmers whose heirs do not enter agriculture have limited incentives to innovate as they soon will cease agriculture operations, and TC9 suggested that older generations also exhibit a natural resistance to learning new methods.

4.1.4 Normative barrier

Farming, as a traditional industry, relies on tacit knowledge that shapes farmers' "mental models" or belief systems about the processes involved. However, these mental models may not always be contemporary and informed due to the limited availability of scientific information of previous generations. Consequently, new technologies or innovative processes often contradict traditional thinking, becoming a barrier to adoption. TC6 and TC9 noted farmers' strong inclination to adhere to traditional agricultural methods because they have operated such a modus operandi for generations. Farmers tend to believe that traditional practices are sufficient and may not be willing to explore or adopt new farming processes. In this vein, TC2 mentioned the case of the adoption of weather forecasts and predictive analytics for production planning. Farmers rely on conventional wisdom instead of data and science to predict the rain and plan their crops, neglecting mobile applications' recommendations.

Another example regards the use of drones for fertiliser applications. Farmers are accustomed to the belief that spraying fertilisers using manual labour instead of drones generates a better outcome as the chemical substances are sprayed closer to the plants [TC6]. Therefore, this belief delays the adoption of drones. TC6 mentioned that "*Farmers have the belief that spraying fertilisers traditionally through manual labour gives them more confidence that the substances reach the plants. As drones are sprayed above ground, farmers are not confident that the substances reach the crops".* Additionally, TC6 mentioned a different case of organic fertiliser adoption by farmers. As organic fertilisers naturally lead to crop plants with a less intense green colour than chemical fertilisers, farmers are concerned that the plants are not as healthy as when chemical fertilisers were used.

Further cases relate to changes in agricultural processes. In an extension project to encourage farmers to change the rice sowing process, RF9 cited cases of farmers who tried the new process but eradicated the paddy field to revert to the original process. Indeed, the new process reduced the number of paddy seeds required in the sowing process by approximately sixfold, significantly reducing the cost and increasing yield. However, farmers felt that the small number of rice plants growing within the first month was contradictory to what they were used to seeing and hence removed their whole rice field and resowed using their old process.

Lastly, some farmers within the irrigated regions of Thailand decided to grow 6-7 cycles of rice per two years, in contrast to the recommended two cycles per year. The reason is that farmers believe that producing and selling more leads to more revenue and, hence, more profits [RF3]. However, many farmers do not record their costs and incomes, so they do not realise the lost profits, as growing too many cycles reduces yields and increases unit costs.

4.2 Enabling Factors

4.2.1 Trust creation

Creating trust with farmers was consistently emphasised by interviewees as a prerequisite for innovation adoption. For example, interviewees suggested using demonstration sites to pilot the processes and show value addition for the farmers in person, especially for new technologies [TC1, TC2, TC5, TC6]. Additionally, in the case of hardware, farmers are concerned about product breakdowns and required repairs, which are often neglected by change agents [TC1]. After-sales services such as call centres for consultation are crucial to alleviate such concerns [TC1, TC6].

Furthermore, endorsements from other parties can also be crucial to increase trust in new technologies. For example, many farmers are initially afraid to use online cash transfers as it is a new concept for them [TC4, TC8]. However, TC8 described the Thai government's case promoting online transfers during the pandemic to reduce virus dispersion from bank notes by only providing subsidies through transfers to government-backed bank accounts. This strategy catalysed the adoption of mobile payments in rural areas and directly benefited agricultural technology companies that rely on online payments. Additionally, support with dissemination from governments [TC1] and village heads or farmer leaders through public endorsements can also increase farmers' trust [TC2, RF9].

Moreover, knowledge of success cases is crucial to increase trust [TC2, TC4, TC5, TC7, RF9]. TC4 stated that *"There is still a big trust issue as farmers might not know whether the technology actually works. While this is not a problem with rice farmers as there were already a lot of success cases of drones, use of drones for cassava, corn and sugarcane crops are still less trusted".* RF9 mentioned that it is difficult for farmers to trust new procedures even if these are being encouraged by neighbours. For example, RF9 had to start by performing the new processes in a small portion of other farmers' lands for free to show success. Once the results were revealed, other farmers followed in subsequent crop cycles.

4.2.2 Human capital development

Many interviewees stated the need for a change in the government's support mechanism for farmers to increase farmers' long-term prospects and mindsets. Firstly, the sluggishness of the remedial funding provision must be countered by providing services for the long-term development of farmers, such as training and skills development curricula [RF1]. Similarly, TC9 mentioned that government funding and programs to assist farmers in technology adoption are not focused on farmer outcomes; they are out of training scope or have an outdated knowledge base that is not practical. Hence, farmers realise limited value by attending such programs.

RF1 also mentioned that the government must develop farmers' entrepreneurial mindsets. Farmers

must become entrepreneurs and always explore opportunities through new markets (e.g., cultivating high-value crops), new technologies to improve productivity, or new value-added processes [RF1]. RF1 mentioned *"While technology can help with processes and cost reduction, the more important issue is the markets and prices. Farmers must do more than just grow crops, but must become an entrepreneur and always look for opportunities to improve income, whether through new markets or through technology, if available".* For example, training farmers to add value to their crops and sell directly to end consumers can remarkably increase their income [RF2].

4.2.3 Effort reduction

Reducing the effort required for farmers to adopt the desired technologies or processes is also essential, entailing two distinct aspects: (i) technology design; and (ii) enabling environment creation. TC2 mentioned how user experience design is one of the most critical aspects, as the design must cater for less experienced users. An updated version of a digital application with a simplified layout led to a considerable boost in farmers' usability and acceptability. TC9 suggested that to minimise the effort required, technologists are recommended to become familiar with farmers' needs and expectations gradually. Technologies with a less complicated adoption pathway that ensure the convenience of farming operations are more likely to be adopted [TC4, TC8].

From a different perspective, developing an enabling environment can reduce the effort costs of doing specific processes. Regarding crop residue management, RF2 and RF5 mentioned that farmers with access to tractors and baling machines located near residue purchasers are more likely to manage residues sustainably. As baling machines are not widely available and contractors are not always willing to perform residue management practices due to the involved technical complexity, a solution recommended by RF5 is for governments to build up utility and demand for rice straw through, for example, developing the bioenergy market. This policy would increase the availability of contractors and residue buyers and hence decrease the effort required for individual farmers. A similar case applies to post-harvest technologies, from rice milling to branding and selling directly to end consumers [RF1]. The high complexity in downstream supply chain activities causes farmers to halt their involvement at the paddy production stage and sell to private rice mills rather than performing their own value-addition processes. Creating community rice mills and barns is an example of how the downstream supply chain can be supported, as well as training and support for packaging and branding.

Farmer groups can also play a vital role in facilitating this "enabling environment" for farmers. In the context of organic farming, farmers have reported that the transition from conventional to organic farming practices, which involves numerous processes, becomes significantly easier with the support and provision from their farmer groups [RF4, RF8]. RF4 stated that "*As organic rice requires multiple processes, the farmer group facilitated the operations of these processes for farmers, and this helped us significantly. Two examples include soil analysis and mixing of organic fertilisers".* Additionally, sharing machinery within the group helps reduce the need to hire contractors to perform farming operations, one of the critical enablers for residue management practices, and leads to general cost reductions [RF1, RF2].

4.2.4 Understanding benefits

A critical enabling factor specified by the interviewees is the magnitude of the benefits associated with innovation adoption and the related income increase. An example is the adoption of chemical fertiliser spray drones, where there is a clear comparison point between human sprays and drone sprays. Drone sprays are significantly quicker, have no health consequences compared to human sprays, and are cheaper per unit area [RF2]. Albeit the other barriers stated above, drone sprays are quickly diffused due to the clear benefits.

Similarly, switching to organic rice farming has clear benefits over conventional rice and is a key driving force of adoption [RF6, RF8, RF9]. Clear benefits to income can be observed as organic rice can be sold at almost double the price of conventional rice, further allowing organic farmers to exert greater negotiation power and set their market price [RF8]. RF8 mentioned *"There is a clear comparison between normal and organic rice. The price of normal rice is very low, and organic rice is almost double the price. Clear economic benefits can be seen here".* Moreover, conventional rice production costs increase yearly due to the higher requirement for chemical fertilisers, which deteriorates soil quality, while organic rice production saves on these chemical costs [RF6, RF7]. Health benefits are also clearly seen as using chemicals causes health issues for farmers [RF6]. RF7 also quoted the benefits to their psychological desires as they prefer to grow quality and healthy products.

An avenue to improve farmers' understanding and induce their desire for change is through success cases from neighbours [TC7, TC8]. In the case presented by TC8, farmers initially demonstrated a lack of interest in an innovative offering, i.e., a digital platform for agriculture supply chain management. However, as neighbouring farmers started experiencing tangible financial gains from participating in the digital platform, interest among other farmers was stimulated.

Additionally, TC2 mentioned that technological buzzwords, such as Artificial Intelligence and data analytics, do not induce farmers' desire to adopt; farmers only care about the associated value that would improve their livelihoods. Similarly, TC4 mentioned that farmers care more about basic functional features that help tackle their challenges than the intrinsic level of technological advancement.

5. Discussion

5.1 Integrated Framework

The interviews and subsequent thematic analyses yielded an integrated framework that illustrates the interrelations between psychological barriers and the enabling factors influencing farmers' innovation adoption, as visually represented in Figure 4. The insights obtained not only provide deeper knowledge into the different dimensions within previously identified taxonomies from the literature reviews but also enable a comprehensive understanding of the external support needed to address the psychological barriers collectively. This holistic perspective of psychological barrier resolution was traditionally impossible due to the lack of an integrated framework for smallholder farmers' psychological barriers.

Overall, the integrated framework comprises three main components: the identification of psychological barriers impeding innovation adoption, the enabling factors for mitigating these barriers, and the recommended interventions by external stakeholders. The arrows connecting these components illustrate how each intervention contributes to addressing both enabling factors and psychological barriers. The Discussion section reaffirms the primary insights gained from the interviews and contextualises them within the broader literature on innovation adoption.

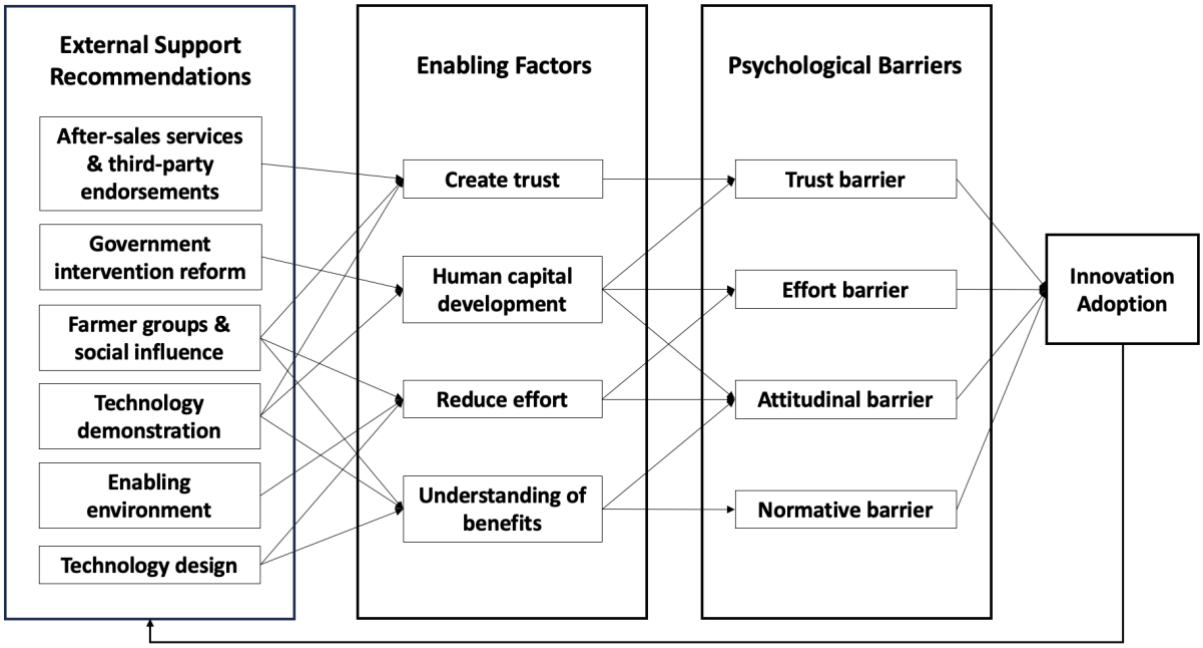

Figure 4. Integrated framework.

Furthermore, employing a multi-stakeholder approach has yielded insightful findings from both technology companies' and rice farmers' perspectives. While the two groups generally provided comments that aligned with each other, they offered unique perspectives that enhanced comprehension beyond what could be achieved with a single type of interviewee.

5.2 Psychological Barriers

First, interview evidence revealed that trust in both the technology and change agents are significant hindrances. While technology companies offered an overview of the lack of adoption attributed to trust issues, farmers' perspectives illuminated the underlying causes of this lack of trust, stemming from past experiences. This aligns with burdens mentioned in the literature in various dimensions. McCaig *et al.* (2023) mentioned the mistrust towards data transparency. Additionally, trust in government support services (Keshavarz and Sharafi, 2023), technology suppliers, and the technology itself have also been discussed (Gerli *et al.,* 2022). However, these are not explicitly mentioned in conventional technology adoption frameworks and could provide a valuable addition that could assist policymakers in their decision-making.

Secondly, regarding the effort barrier, although many technology companies perceive farmers' lack of effort somewhat negatively, the perspectives from farmers shed light on the challenges of participating in certain practices due to unfavourable environmental conditions. For example, the scarcity of specific machinery increases the effort needed to handle crop residues. The factor of effort is mentioned in multiple frameworks and extant adoption theories, for instance, the aspect of simplicity in the diffusion of innovations theory within the domain of innovation characteristics (Rogers, 1962). In alignment with the theories, the cost of effort is also the barrier most cited by the interviewees in this study. It could be contended that the effort requirement constitutes a functional barrier falling within the usage barrier category. However, we posit that an individual's reluctance to adopt innovation, despite the potential benefits, primarily driven by the perception of high effort costs, should be classified as a psychological barrier. Agreeing with previous studies identifying negative associations between effort expectancy and adoption of innovations (Rübcke von Veltheim *et al.,* 2022), this study provides a further contextual understanding of various cases of high effort requirements causing unwillingness to adopt. This contextual frame includes both the unwillingness to exert effort into adopting the innovations during the learning phase as well as in performing the

required operational changes associated with the innovation. Such indisposition can pose significant challenges when considering transformation towards cleaner production of the agriculture sector, as sustainable agriculture is widely regarded as requiring significant efforts from farmers (Piñeiro *et al.*, 2020).

Moreover, the attitudinal barrier involves the short-term preference of farmers, preventing them from investing in innovations that lead to long-term outcomes. These behaviours are significant as they result in farmers being trapped in the low productivity loop, leading to the inability to escape the poverty cycle. Moreover, akin to the concerns regarding effort costs, this issue is especially concerning for the adoption of sustainable agriculture as the immediate consequences of adoption often negatively affect productivity and income, given the delayed benefits inherent in sustainable practices. (Piñeiro *et al.*, 2020). This behaviour can be attributed to human tendencies toward self-control scarcity, where individuals tend to prioritise instant gratification, resulting in procrastination (Datta and Mullainathan, 2014). This aspect is also seen elsewhere in the decision to use fertilisers, in which their present biasedness causes them to postpone fertiliser purchases (Duflo *et al.,* 2011). In addition, the issue of lacking motivation to innovate also constitutes an attitudinal barrier and has implications towards adoption. Along the same lines, prior research has found that part-time farmers with multiple sources of income are less dependent on agricultural income, focusing more on those off-farm incomes, and therefore are less likely to adopt advanced agricultural production technologies (Zheng *et al.,* 2022). Likewise, the anticipation of future government subsidies is an issue found to cause farmers to refuse to invest in grain storage bags in Uganda (Omotilewa *et al.,* 2019).

Finally, the case of innovation providing conflicting recommendations or outcomes to perceived norms is especially prominent in the agriculture sector, where many practices result from tacit knowledge passed on through generations. While the IRT theory defines this as the "Traditional barrier", we propose the term "Normative barrier" to encapsulate not only the conflict with traditional processes in the past but also the conflict with social norms in the present. While this may be considered a functional "knowledge" barrier, the psychological aspect lies in the farmers' adherence to traditional practices or knowledge despite the contradictory evidence provided by the technologies. This observation complements prior research findings in not only focusing on the social influence aspects, such as following neighbours' practices (Jangid *et al.,* 2012) but also on the hindrance caused by conflicting knowledge and recommendations that result from the use of technology. In alignment with the discussion on effort costs, technology companies express a slightly negative perspective on this matter, while insights from rice farmers tend to elucidate the conflict arising from traditional or social norms regarding knowledge.

5.3 Recommended Interventions

First, in countering trust issues among farmers, after-sales services and third-party endorsements are effective strategies mentioned by interviewees. Research suggests that timely after-sales services are a strong driver of adoption by first-time users of solar home systems (Kundu and Ramdas, 2022). Furthermore, third-party endorsements have improved perceived value and customer loyalty within a B2B firm context (Yuan *et al.,* 2020). Exploring after-sales services and endorsements to resolve trust issues, especially in agriculture, is scarce in the literature. Given farmers' financial characteristics leading to lower risk tolerance, we argue that this effect could be especially potent for the farming community.

Second, considering the contextual backdrop of Thailand's existing government policies as a significant contributor to psychological barriers, several interviewees highlighted the need for intervention reform. Although this problem might appear specific to Thailand, it indicates a potential aspect of policy issues impacting the adoption of technology by smallholder farmers. While previous reports have advocated for the repurposing of government interventions toward more sustainable

agricultural production (Gautam *et al.*, 2022), this research establishes a link between government policies and barriers to innovation adoption from a psychological perspective.

Furthermore, the findings highlight that social influence and the utilisation of farmer groups act as underlying solutions for various psychological barriers. This research aligns with Gonella *et al.* (2024) who identified social influence as a promising strategy to overcome psychological barriers towards embracing circular economy principles, as well as with Qiao *et al.*, (2023) who found social learning to influence safe pesticide use positively. It enriches current findings by identifying the specific mechanisms through which social influence interacts with the psychological aspects of adoption. By shedding light on this aspect, this research enhances the understanding and anticipation of the situations in which external stakeholders can strategically leverage farmers' social circles to promote behavioural change. This aligns with the social aspect of the "EAST" framework by the Behavioural Insights Team, suggesting four ways of applying behavioural insights to solve psychological hindrances, including "Easy", "Attractive", "Social", and "Timely" (The Behavioural Insights Team, 2014). For example, such approaches, like Farmer Producer Organisations, can be valuable in building trust among farmers or disseminating the complex benefits of certain agricultural practices to propel equity and welfare further (Srai *et al.,* 2022).

Technology demonstration, another strategy recommended by interviewees in solving psychological barriers, has been widely used as a mechanism for innovation diffusion. These demonstrations can enhance farmers' thinking skills and facilitate adaptation strategies and reasoning abilities, ultimately leading to a higher potential for climate change adaptation (Antwi-Agyei and Stringer, 2021). In addition to the enabling factors of further understanding of benefits and human capital development, this study added to the argument of the trust factor that technology demonstration alleviates.

Creating an environment conducive to adoption, which helps reduce effort, is also necessary. In spite of the size of potential benefits of any innovation, should the environment for operating those innovations be too troublesome, individuals will face difficulties in adopting them. The "Easy" strategy from the EAST framework suggests that the hassle factor of adoption must be reduced, which would greatly enhance the likelihood of individuals actions (The Behavioural Insights Team, 2014). Emphasis must be placed on breaking farmer's status quo by reducing the effort costs required to adopt new technologies or practices (Rübcke von Veltheim *et al.,* 2022). The creation of an enabling environment is implied in Keshavarz and Sharafi (2023)'s findings on the requirement to improve institutions and structures to facilitate climate-smart agriculture adoption, specifically on the provision of appropriate infrastructures, training modules, and linkages between organisations.

Finally, this study reveals that designing the technology with consideration of farmers' needs, ability to comprehend, and effort requirements can be a crucial aspect of guiding technology adoption. While the former two, catering to individual needs and ability to comprehend, lead to the "functional" value and usage barriers (Ram and Sheth, 1983), the latter aspect regarding the effort requirements can be a factor that causes psychological hindrances. As an example, the nature of precision agriculture providing higher convenience is found to be a significant factor in encouraging adoption, with some farmers finding it more compelling than yield improvements and cost savings (Thompson *et al.,* 2019). This paper provides evidence supporting the need to cater technology designs for functional characteristics as well as farmers' psychological characteristics.

6. Conclusions

This study conducted a literature exploration and a qualitative study to outline key psychological barriers hindering the adoption of innovative agricultural technologies and processes, hence responding to RQ1. Thereafter, a six-phase thematic analysis helped identify enabling factors and propose targeted strategies to overcome the enunciated psychological barriers, thus addressing RQ2.

6.1 Theoretical Contributions

The unique contribution of this study is its holistic exploration of psychological barriers among smallholder farmers, making it, to the best of our knowledge, the first to approach this perspective comprehensively in one integrated framework. This provides an addition to Ram and Sheth (1983)'s seminal IRT by providing expanded typologies of psychological barriers as well as applying it to the context of smallholder farmers. Extant studies provide snapshots of psychological barriers by identifying barriers to specific processes (e.g., Akenroye *et al.,* 2021) or document isolated cases of psychological impact through experimental research designs (e.g., Li *et al.*, 2023). This study goes beyond by expanding upon existing psychological barriers that encapsulate these multifaceted challenges faced by smallholder farmers. In addition, this study provides a crucial linkage between external factors hindering adoption and the internal psychological factors of farmers that were previously unexplored. For instance, ecosystem inefficiencies resulting in a lack of supply of machinery lead to psychological effort hindrances, while unconditional government support results in attitudinal barriers. This research aligns with the perspective of the growing behavioural school of thought, which emphasises the need to complement economic reasoning with insights from psychological perspectives (Datta and Mullainathan, 2014). Identifying taxonomies of psychological barriers as well as the overcoming strategies highlights the significant potential for enhancing the rate of innovation diffusion within the agricultural community.

Moreover, despite much of the psychological aspects having been previously explored in the literature, this study provides an additional insight towards enabling adoption through psychological barrier alleviation. In addition to the prior studies investigating the aspects, integrating all these aspects into a convenient framework provides a great addition to the technology adoption literature from the psychology angle. This is in alignment with Roberts *et al.* (2021), who devised the "Psychology Technology Adoption Framework" within the oil and gas industry. We concur with Roberts *et al.* (2021) that this is necessary for many industries, especially for traditional industries with a high resistance to innovation adoption.

6.2 Practical Implications

The barriers and enabling factors identified in this study serve as a valuable blueprint for designing external support mechanisms to promote farmers' innovation adoption. In particular, many of the identified barriers directly conflict with the nature of sustainable practices, such as the effort and attitudinal barriers. External stakeholders typically overlook psychological factors due to the limited understanding of farmers' perspectives and the complex dynamics involved in adoption processes. This study provides the psychological barriers and an industrial stakeholders' accounts of overcoming those barriers. For instance, while effort costs are a central aspect in many technology adoption frameworks, this study provides the recommended strategies to translate existing frameworks into actual policy implementation, thereby providing significant practical implications. Nonetheless, policymaking at a national level should provide targeted support mechanisms to address climate-smart agriculture (Branca and Perelli, 2020). Consequently, these factors should be considered by agricultural extension services as well as technology companies when working with farmers, as they can play a crucial role in hindering farmers' decision-making.

6.3 Limitations & Future Research

A limitation of this qualitative study is the narrow focus on the specific population of smallholder farmers in Thailand, which hinders the generalisability of the findings. The bounded scope of the population could result in a lack of representativeness and restrict the transferability of the study's conclusions to other settings. However, this exploratory study aims to provide in-depth insights and understanding in specific contexts rather than achieve statistical generalisability. Future research should incorporate quantitative data collection and analysis to establish statistical significance and strengthen the validity of the findings. This may involve conducting surveys and field experiments to

validate the significance of psychological barriers and assess potential interventions for alleviation. Despite the bounded scope, the study's findings may offer valuable insights into general human behaviours related to technology adoption. By exploring these avenues, researchers can offer further explanations for generalisation and advance our understanding of evidence-based policies for promoting behavioural change.

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References

Akenroye, T.O., Dora, M., Kumar, M., Elbaz, J., Kah, S. and Jebli, F. (2021), "A taxonomy of barriers to the adoption of sustainable practices in the coffee farming process", Journal of Cleaner Production, Vol. 312, p. 127818, doi: 10.1016/j.jclepro.2021.127818

Alves, R.G., Maia, R.F. and Lima, F. (2023), "Development of a Digital Twin for smart farming: Irrigation management system for water saving", *Journal of Cleaner Production*, Vol. 388, p. 135920, doi: 10.1016/j.jclepro.2023.135920.

Antwi-Agyei, P. and Stringer, L.C. (2021), "Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana", *Climate Risk Management*, Vol. 32, p. 100304, doi: 10.1016/j.crm.2021.100304

Ayre, M., Mc Collum, V., Waters, W., Samson, P., Curro, A., Nettle, R., Paschen, J.-A., et al. (2019), "Supporting and practising digital innovation with advisers in smart farming", NJAS - Wageningen Journal of Life Sciences, Vol. 90–91, p. 100302, doi: 10.1016/j.njas.2019.05.001

Bacco, M., Barsocchi, P., Ferro, E., Gotta, A. and Ruggeri, M. (2019), "The Digitisation of Agriculture: a Survey of Research Activities on Smart Farming", *Array*, Vol. 3–4, p. 100009, doi: 10.1016/j.array.2019.100009.

Bell, E., Bryman, A. and Harley, B. (2022), Business Research Methods, Oxford University Press.

Benyam, A. (Addis), Soma, T. and Fraser, E. (2021), "Digital agricultural technologies for food loss and waste prevention and reduction: Global trends, adoption opportunities and barriers", Journal of Cleaner Production, Vol. 323, p. 129099, doi: 10.1016/j.jclepro.2021.129099

Bhattacherjee, A. and Sanford, C. (2009), "The intention–behaviour gap in technology usage: the moderating role of attitude strength", Behaviour and Information Technology, Vol. 28 No. 4, pp. 389–401, doi: 10.1080/01449290802121230.

Branca, G. and Perelli, C. (2020), "'Clearing the air': common drivers of climate-smart smallholder food production in Eastern and Southern Africa", *Journal of Cleaner Production*, Vol. 270, p. 121900, doi: 10.1016/j.jclepro.2020.121900.

Braun, V. and Clarke, V. (2006), "Using thematic analysis in psychology", Qualitative Research in Psychology, Vol. 3 No. 2, pp. 77–101, doi: 10.1191/1478088706qp063oa.

Braun, V. and Clarke, V. (2021), "Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches", *Counselling and Psychotherapy Research*, Vol. 21 No. 1, pp. 37–47, doi: 10.1002/capr.12360

Chen, H.-S., Tsai, B.-K. and Hsieh, C.-M. (2018), "The Effects of Perceived Barriers on Innovation Resistance of Hydrogen-Electric Motorcycles", *Sustainability*, Multidisciplinary Digital Publishing Institute, Vol. 10 No. 6, p. 1933, doi: 10.3390/su10061933.

Datta, S. and Mullainathan, S. (2014), "Behavioral Design: A New Approach to Development Policy", Review of Income and Wealth, Vol. 60 No. 1, pp. 7–35, doi: 10.1111/roiw.12093.

Darnell, R., Robertson, M., Brown, J., Moore, A., Barry, S., Bramley, R., Grundy, M., et al. (2018), "The current and future state of Australian agricultural data", Farm Policy Journal, Vol. 15 No. 1,

pp. 41–49.
Despotović, J., Rodić, V. and Caracciolo, F. (2019), "Factors affecting farmers' adoption of integrated pest management in Serbia: An application of the theory of planned behavior", Journal of Cleaner Production, Vol. 228, pp. 1196–1205, doi: 10.1016/j.jclepro.2019.04.149
Duflo, E., Kremer, M. and Robinson, J. (2011), "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya", *American Economic Review*, Vol. 101 No. 6, pp. 2350–2390, doi: 10.1257/aer.101.6.2350.
Eberhard, R., Coggan, A., Jarvis, D., Hamman, E., Taylor, B., Baresi, U., Vella, K., et al. (2021), "Understanding the effectiveness of policy instruments to encourage adoption of farming practices to improve water quality for the Great Barrier Reef", Marine Pollution Bulletin, Vol. 172, p. 112793, doi: 10.1016/j.marpolbul.2021.112793.
Fan, S. and Rue, C. (2020), "The Role of Smallholder Farms in a Changing World", in Gomez y Paloma, S., Riesgo, L. and Louhichi, K. (Eds.), The Role of Smallholder Farms in Food and Nutrition Security, Springer International Publishing, Cham, pp. 13–28, doi: 10.1007/978-3-030-42148-9_2.
Gautam, M., Laborde, D., Mamun, A., Martin, W., Pineiro, V. and Vos, R. (2022), *Repurposing Agricultural Policies and Support: Options to Transform Agriculture and Food Systems to Better Serve the Health of People, Economies, and the Planet*, World Bank, Washington, DC.
Gerli, P., Clement, J., Esposito, G., Mora, L. and Crutzen, N. (2022), "The hidden power of emotions: How psychological factors influence skill development in smart technology adoption", *Technological Forecasting and Social Change*, Vol. 180, p. 121721, doi: 10.1016/j.techfore.2022.121721.
Gifford, R. (2011), "The dragons of inaction: Psychological barriers that limit climate change mitigation and adaptation", American Psychologist, American Psychological Association, US, Vol. 66, pp. 290–302, doi: 10.1037/a0023566.
Gonella, J. dos S.L., Godinho Filho, M., Ganga, G.M.D., Latan, H. and Chiappetta Jabbour, C.J. (2024), "A behavioral perspective on circular economy awareness: The moderating role of social influence and psychological barriers", *Journal of Cleaner Production*, p. 141062, doi: 10.1016/j.jclepro.2024.141062.
Graves, C. and Roelich, K. (2021), "Psychological Barriers to Pro-Environmental Behaviour Change: A Review of Meat Consumption Behaviours", Sustainability, Vol. 13 No. 21, p. 11582, doi: 10.3390/su132111582.
Huynh, T. and Gurtner, S. (2023), "Resistance to the sharing economy: Why some consumers and providers do not participate in P2P sharing", *Journal of Cleaner Production*, Vol. 422, p. 138628, doi: 10.1016/j.jclepro.2023.138628.
Jangid, M., Khan, I. and Singh, S. (2012), "Constraints faced by the organic and conventional farmers in adoption of organic farming practices", *Indian Research Journal of Extension Education*, Vol. 2, pp. 28–32.
Jerhamre, E., Carlberg, C.J.C. and van Zoest, V. (2022), "Exploring the susceptibility of smart farming: Identified opportunities and challenges", *Smart Agricultural Technology*, Vol. 2, p. 100026, doi: 10.1016/j.atech.2021.100026.
Kaur, P., Dhir, A., Singh, N., Sahu, G. and Almotairi, M. (2020), "An innovation resistance theory perspective on mobile payment solutions", *Journal of Retailing and Consumer Services*, Vol. 55, p. 102059, doi: 10.1016/j.jretconser.2020.102059.
Kendall, H., Clark, B., Li, W., Jin, S., Jones, Glyn.D., Chen, J., Taylor, J., *et al.* (2022), "Precision agriculture technology adoption: a qualitative study of small-scale commercial 'family farms' located in the North China Plain", *Precision Agriculture*, Vol. 23 No. 1, pp. 319–351, doi: 10.1007/s11119-021-09839-2.
Kernecker, M., Knierim, A., Wurbs, A., Kraus, T. and Borges, F. (2020), "Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe", *Precision Agriculture*, Vol. 21 No. 1, pp. 34–50, doi: 10.1007/s11119-019-09651-z.

Keshavarz, M. and Sharafi, H. (2023), "Scaling up climate-smart regenerative agriculture for the restoration of degraded agroecosystems in developing countries", *Sustainable Production and Consumption*, Vol. 38, pp. 159–173, doi: 10.1016/j.spc.2023.04.003.

Kolehmainen, J., Irvine, J., Stewart, L., Karacsonyi, Z., Szabó, T., Alarinta, J. and Norberg, A. (2016), "Quadruple Helix, Innovation and the Knowledge-Based Development: Lessons from Remote, Rural and Less-Favoured Regions", Journal of the Knowledge Economy, Vol. 7, pp. 23-42.

Kundu, A. and Ramdas, K. (2022), "Timely After-Sales Service and Technology Adoption: Evidence from the Off-Grid Solar Market in Uganda", *Manufacturing & Service Operations Management*, INFORMS, Vol. 24 No. 3, pp. 1329–1348, doi: 10.1287/msom.2021.1060.

Lacroix, K., Gifford, R. and Chen, A. (2019), "Developing and validating the Dragons of Inaction Psychological Barriers (DIPB) scale", Journal of Environmental Psychology, Vol. 63, pp. 9–18, doi: 10.1016/j.jenvp.2019.03.001.

Lee, M. and Gambiza, J. (2022), "The adoption of conservation agriculture by smallholder farmers in southern Africa: A scoping review of barriers and enablers", *Journal of Rural Studies*, Vol. 92, pp. 214–225, doi: 10.1016/j.jrurstud.2022.03.031.

Li, C., Zhao, M. and Shi, Y. (2023), "Farmers' preferences for diversifying compensation policy for mulch film pollution control: A discrete choice experiment in Northwest China", *Journal of Cleaner Production*, Vol. 416, p. 137962, doi: 10.1016/j.jclepro.2023.137962.

Mani, A., Mullainathan, S., Shafir, E. and Zhao, J. (2013), "Poverty Impedes Cognitive Function", Science, American Association for the Advancement of Science, Vol. 341 No. 6149, pp. 976–980, doi: 10.1126/science.1238041.

Mani, Z. and Chouk, I. (2018), "Consumer Resistance to Innovation in Services: Challenges and Barriers in the Internet of Things Era", *Journal of Product Innovation Management*, Vol. 35 No. 5, pp. 780–807, doi: 10.1111/jpim.12463.

Mankad, A., Loechel, B. and Measham, P.F. (2017), "Psychosocial barriers and facilitators for area-wide management of fruit fly in southeastern Australia", *Agronomy for Sustainable Development*, Vol. 37 No. 6, p. 67, doi: 10.1007/s13593-017-0477-z.

McCaig, M., Dara, R. and Rezania, D. (2023), "Farmer-centric design thinking principles for smart farming technologies", *Internet of Things*, Vol. 23, p. 100898, doi: 10.1016/j.iot.2023.100898.

Messmer, L., Thom, B., Kruetli, P., Dawoe, E., Assefa, K., Six, J. and Joerin, J. (2021), "Beyond feasibility—the role of motivation to implement measures to enhance resilience", Mitigation and Adaptation Strategies for Global Change, Vol. 26 No. 5, p. 19, doi: 10.1007/s11027-021-09952-7.

Myers, M.D. (2009), Qualitative Research in Business & Management, Sage Publications Ltd, Thousand Oaks, CA, pp. xii, 284.

Omotilewa, O.J., Ricker-Gilbert, J. and Ainembabazi, J.H. (2019), "Subsidies for Agricultural Technology Adoption: Evidence from a Randomized Experiment with Improved Grain Storage Bags in Uganda", *American Journal of Agricultural Economics*, Vol. 101 No. 3, pp. 753–772, doi: 10.1093/ajae/aay108.

Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., Ibáñez, A.M., Kinengyere, A., Opazo, C.M., *et al.* (2020), "A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes", *Nature Sustainability*, Nature Publishing Group, Vol. 3 No. 10, pp. 809–820, doi: 10.1038/s41893-020-00617-y.

Pivoto, D., Waquil, P.D., Talamini, E., Finocchio, C.P.S., Dalla Corte, V.F. and de Vargas Mores, G. (2018), "Scientific development of smart farming technologies and their application in Brazil", *Information Processing in Agriculture*, Vol. 5 No. 1, pp. 21–32, doi: 10.1016/j.inpa.2017.12.002.

Puppala, H., Peddinti, P.R.T., Tamvada, J.P., Ahuja, J. and Kim, B. (2023), "Barriers to the adoption of new technologies in rural areas: The case of unmanned aerial vehicles for precision

agriculture in India", *Technology in Society*, Vol. 74, p. 102335, doi: 10.1016/j.techsoc.2023.102335.

Qiao, D., Luo, L., Chen, C., Qiu, L. and Fu, X. (2023), "How does social learning influence Chinese farmers' safe pesticide use behavior? An analysis based on a moderated mediation effect", *Journal of Cleaner Production*, Vol. 430, p. 139722, doi: 10.1016/j.jclepro.2023.139722.

Ram, S. and Sheth, J.N. (1989), "Consumer Resistance to Innovations: The Marketing Problem and its solutions", *Journal of Consumer Marketing*, MCB UP Ltd, Vol. 6 No. 2, pp. 5–14, doi: 10.1108/EUM0000000002542.

Raza, M.H., Abid, M., Yan, T., Ali Naqvi, S.A., Akhtar, S. and Faisal, M. (2019), "Understanding farmers' intentions to adopt sustainable crop residue management practices: A structural equation modeling approach", Journal of Cleaner Production, Vol. 227, pp. 613–623, doi: 10.1016/j.jclepro.2019.04.244.

Ritchie, H., Roser, M. and Rosado, P. (2020), "CO_2 and Greenhouse Gas Emissions", Our World in Data.

Roberts, R., Flin, R., Millar, D. and Corradi, L. (2021), "Psychological factors influencing technology adoption: A case study from the oil and gas industry", Technovation, Vol. 102, p. 102219, doi: 10.1016/j.technovation.2020.102219.

Rogers, E.M. (1962), Diffusion of Innovations, Free Press of Glencoe, New York.

Rübcke von Veltheim, F., Theuvsen, L. and Heise, H. (2022), "German farmers' intention to use autonomous field robots: a PLS-analysis", Precision Agriculture, Vol. 23 No. 2, pp. 670–697, doi: 10.1007/s11119-021-09854-3.

Santos, A.A. dos and Ponchio, M.C. (2021), "Functional, psychological and emotional barriers and the resistance to the use of digital banking services", *Innovation & Management Review*, Emerald Publishing Limited, Vol. 18 No. 3, pp. 331–348, doi: 10.1108/INMR-07-2020-0093.

Sher, A., Mazhar, S., Zulfiqar, F., Wang, D. and Li, X. (2019), "Green entrepreneurial farming: A dream or reality?", *Journal of Cleaner Production*, Vol. 220, pp. 1131–1142, doi: 10.1016/j.jclepro.2019.02.198.

Schutt, R.K. (2018), Investigating the Social World: The Process and Practice of Research, Sage publications.

Srai, J.S., Joglekar, N., Tsolakis, N. and Kapur, S. (2022), "Interplay between Competing and Coexisting Policy Regimens within Supply Chain Configurations", Production and Operations Management, Vol. 31 No. 2, pp. 457–477, doi: 10.1111/poms.13553.

Stewart, Z.P., Pierzynski, G.M., Middendorf, B.J. and Prasad, P.V.V. (2020), "Approaches to improve soil fertility in sub-Saharan Africa", *Journal of Experimental Botany*, Vol. 71 No. 2, pp. 632–641, doi: 10.1093/jxb/erz446.

The Behavioural Insights Team. (2014), *EAST: Four Simple Ways to Apply Behavioural Insights*.

Thompson, N.M., Bir, C., Widmar, D.A. and Mintert, J.R. (2019), "Farmer perceptions of precision agriculture technology benefits", *Journal of Agricultural and Applied Economics*, Cambridge University Press, Vol. 51 No. 1, pp. 142–163, doi: 10.1017/aae.2018.27.

United Nations. (2020), "Thai Agricultural Sector: From Problems to Solutions | United Nations in Thailand", December, available at: https://thailand.un.org/en/103307-thai-agricultural-sector-problems-solutions, https://thailand.un.org/en/103307-thai-agricultural-sector-problems-solutions (accessed 1 May 2023).

Vickers, M.H. (2010), "The creation of fiction to share other truths and different viewpoints: A creative journey and an interpretative process", Qualititative Inquiry, Vol. 16 No. 7, pp. 556–565.

Wang, X., Cui, C., Xu, M., Cheng, B. and Zhuang, M. (2024), "Key technologies improvements promote the economic-environmental sustainability in wheat production of China", *Journal of Cleaner Production*, Vol. 443, p. 141230, doi: 10.1016/j.jclepro.2024.141230.

World Bank (2023). Cereals; rice, broken exports by country in 2021. Available at: https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2021/tradeflow/Exports/partner/WLD/product/100640

WWF. (2023), "What's in store for the planet: The impact of UK shopping baskets on climate & nature

- 2023". Available at: https://www.wwf.org.uk/sites/default/files/2022-11/WWF-Whats-in-Store-for-our-Planet-the-Impact-of-UK%20Shopping-Baskets-on-Climate-and-Nature-2022-v1.pdf

Yin, R.K. (1993), Applications of case study research, Sage.

Yuan, C.L., Moon, H., Kim, K.H., Wang, S. and Yu, X. (2020), "Third-party organization endorsement impacts on perceived value and B2B customer loyalty", *Industrial Marketing Management*, Vol. 90, pp. 221–230, doi: 10.1016/j.indmarman.2020.07.021.

Zamasiya, B., Nyikahadzoi, K. and Mukamuri, B.B. (2017), "Factors influencing smallholder farmers' behavioural intention towards adaptation to climate change in transitional climatic zones: A case study of Hwedza District in Zimbabwe", Journal of Environmental Management, Vol. 198, pp. 233–239, doi: 10.1016/j.jenvman.2017.04.073.

Zhang, L., Jiang, G., Xiao, R., Hou, K., Liu, Xin, Liu, Xinyu, Yuan, P., Tian, F., Yin, L., Zhu, H., Tian, C., Yang, L., Yan, X., Rong, X., Han, Y., 2024. An appropriate amount of straw replaced chemical fertilizers returning reduced net greenhouse gas emissions and improved net ecological economic benefits. Journal of Cleaner Production 434, 140236. https://doi.org/10.1016/j.jclepro.2023.140236.

Zheng, S., Yin, K. and Yu, L. (2022), "Factors influencing the farmer's chemical fertilizer reduction behavior from the perspective of farmer differentiation", *Heliyon*, Vol. 8 No. 12, p. e11918, doi: 10.1016/j.heliyon.2022.e11918.

Zul Azlan, Z.H., Junaini, S.N., Bolhassan, N.A., Wahi, R. and Arip, M.A. (2024), "Harvesting a sustainable future: An overview of smart agriculture's role in social, economic, and environmental sustainability", *Journal of Cleaner Production*, Vol. 434, p. 140338, doi: 10.1016/j.jclepro.2023.140338.

Appendix

Table A. List of interviewees.

Interviewee		Interviewee Characteristics
Rice Farmer	RF1	▪ Rice farmer in Saraburi province, Central region
	RF2	▪ Rice farmer in Petchaburi province, Central region ▪ President of a farmer group of 42 households
	RF3	▪ Rice farmer in Nakhon Pathom province, Central region ▪ Member of the committee of the farmer group
	RF4	▪ Rice farmer in Kamphaeng Phet province, Central region ▪ President of a farmer group of 400 households
	RF5	▪ Rice farmer in Kanchanaburi province, Central region ▪ President of a farmer group of 200+ households
	RF6	▪ Rice farmer in Phayao province, Northern region ▪ Vice president of the village
	RF7	▪ Rice farmer in Chiang Rai province, Northern region
	RF8	▪ Rice farmer in Ubon Ratchathani province, North-eastern region
	RF9	▪ Rice farmer in Roi Et province, North-eastern region. ▪ Leader of a farmer extension project of 100+ households
Technology Company	TC1	▪ IoT hardware company that sells precision agriculture solutions to farmers
	TC2	▪ Farm analytics, weather forecasting, and financial solutions company that utilises satellite imagery and machine learning to provide recommendations to farmers
	TC3	▪ Company who develops rice inspection machines for rice mills that cannot afford experts to inspect rice quality
	TC4	▪ Matching platform between spray drone pilots and farmers who are looking for drone service
	TC5	▪ Agricultural farm management, analytics software, and drone company
	TC6	▪ Agricultural machinery company that sells drones to farmers
	TC7	▪ Cannabis seedbank and farm consultation company that also engages in contract farming with farmers
	TC8	▪ Agricultural supply chain management company that decreases farmers' reliance on intermediaries and matches farmers with farm service providers
	TC9	▪ Rural community advisory, product development, and financial service provider company

Table B. Central questions raised to both groups of interviewees

Interview Questions	
1	What are some of the recent innovations you have promoted/considered for adoption?
2	How was the promotion/adoption journey?
3	What were the barriers faced hindering adoption?
4	Are there other unexpected barriers?
5	What was the required support to overcome these barriers?
6	What were your learning points on key enablers and recommended solutions to overcome these barriers?

Table C. Salient quotes of interviewees: Psychological barriers.

Psychological Barrier	Salient Quotes	
	From Technology Companies	**From Rice Farmers**
Trust	*"Farmers might not trust change agents as they have had bad experiences with these people in the past. Farmers learn not to trust these people easily as there have been stories where they followed the recommendations, and it doesn't actually work long-term." (TC1)* *"Farmers need to learn to use smartphones and trust the use of smartphones to make bookings. There is still a big trust issue. Farmers might not know whether the technology actually works. Another example is with drones. While this is not a problem with rice farmers as there were already a lot of drone success cases, use of drones for cassava, corn and sugarcane crops are still less trusted." (TC4)*	*"Governments are performing extension as a PR activity rather than to improve farmers' productivity. Government extension providers are not real experts. They train farmers with outdated knowledge or with knowledge that does not apply to our region. We followed these recommendations in the past and it failed." (RF9)*
Effort	*"As an example, one simple practice for significant yield improvement by farmers is site-specific nutrient management. However, farmers said this is too troublesome as it requires some process changes, which they don't want to do." (TC2)* *"Legal processes and paperwork are making it difficult for farmers to switch crops [to grow Cannabis]. It takes a lot of time and cost to reach the point where they can apply for certification - 1 to 6 months of idle time waiting for inspection. Document filling and obtaining required legal documents are troublesome for the farmers." (TC7)*	*"Farmers have the opportunity to improve their income through adding value to their products by processing the paddy rice into milled rice and selling the product to end consumers by themselves. However, they see it as troublesome and sell their farm output (paddy rice) straight to the rice mills at a very low price." (RF1)* *"It is troublesome for us to find contractors to perform the practice as baling machines are not widely available, and contractors don't want to perform residue incorporation as it is more difficult. This adds to our effort and is not worth our time." (RF2)* *"In organic farming, a prevalent barrier is that it requires a significantly higher effort to operate without the use of chemicals. For example, instead of spraying to kill weed, we have to manually perform the weeding process." (RF7)*
Attitudinal	*"A crucial factor is that many farmers are not full-time. As they have incomes from part-time jobs or rely on children & grandchildren's income, they are not always trying to optimise their process and just grow rice to get government incentives as farmers." (TC3)*	*"Majority of farmers make a loss and wait for government support, but the money received was not used for farm improvements. Next year, they still make a loss. If the government can support the farmers in the process of adding value to their output, there would be a great opportunity for farmers to earn more income. This must also come together with the farmers' attitude to improve income." (RF1)* *"Many people cannot separate between increases and decreases in cost. People say*

Psychological Barrier	Salient Quotes	
	From Technology Companies	**From Rice Farmers**
		residue management increases land preparation costs by two times as they need to do an additional round of ploughing. However, they don't realise that there is a greater reduction in future production cost from the decreased need for chemical fertilisers." (RF2)
Normative	*"Farmers have looked at the sky for their whole life [to predict the weather]. Why believe an application [weather forecast]?" (TC2)* *"Farmers have the belief that spraying fertilisers traditionally through manual labour gives them more confidence that the substances reach the plants. As drones are sprayed above ground, farmers are not confident that the substances reach the crops." (TC6)*	*"Farmers are accustomed to growing 6-7 cycles of rice every two years, rather than the recommended 2 cycles per year. We previously earned more revenue from the higher number of cycles, but do not realise the higher economic costs involved because we did not make records. The more times you grow, the higher the unit cost due to soil deterioration."* (RF3) *"New processes contradict farmer's understanding. The new process is a very big change. It required only 1kg of seeds per rai instead of the 35kg per rai from the previous method. Farmers believe that more seeds mean more yield, which is wrong. Many small farmers reverted back to the previous process because they thought it failed due to the lower number of rice stalks." (RF9)*

Table D. Salient quotes of interviewees: Enabling factors and recommendations.

Enabling Factor	Salient Quotes	
	From Technology Companies	**From Rice Farmers**
Understanding benefits	*"Farmers consider whether joining the platform can make money for them. They have seen success cases from others that this platform can really increase their yield and quality at no extra cost. If the monetary value is obvious to them, they will join." (TC8)*	*"Farmers want to see clear benefits. For example, the adoption of drones ensures that farmers do not have to be in close contact to chemicals, in contrast to the previous method of using humans to spray. It also costs less to hire drones than human sprayers as well as being significantly faster." (RF2)* *"Organic rice leads to clear financial and health benefits. In growing conventional rice, chemical fertilisers cause health issues, with annual health check-ups constantly returning bad results. Additionally, costs increase every year due to deteriorating soil leading to the need to increase fertiliser usage." (RF6)* *"There is a clear comparison between conventional and organic rice. The price of conventional rice is very low, and organic rice is almost double the price. Clear economic benefits can be seen here." (RF8)*
Effort reduction	*"We went out to test our application with farmers. It was so difficult for them at first, and this demotivated them significantly. The team spent huge efforts in simplifying the interface, and this tremendously boosted their usability and interest." (TC2)*	*"We need support from the Government which could help reduce effort barriers in multiple ways. For example, supporting better management of farmer groups allow easy access to tractors and baling machines, allowing less reliance on contractors for residue management. Improving utility and demand for rice straws decreases effort required to find residue purchasers." (RF5)* *"As organic rice requires multiple processes, the farmer group facilitated the operations of these processes for farmers, and this helped us significantly. Two examples include soil analysis and mixing of organic fertilisers." (RF4)* *"In our village, there is a 'cow bank' where farmers can utilise to get free manure for their fields, reducing the need to mix organic fertilisers." (RF8)*
Trust creation	*"There is still a big trust issue as farmers might not know whether the technology actually works. While this is not a problem with rice farmers as there were already a lot of success cases of drones, use of drones for cassava, corn and sugarcane crops are still less trusted." (TC4)* *"Farmers want to see success cases from somebody they know as well as try using*	*"Farmers require those that they trust to help disseminate the idea. As an example, village head competency is crucial. Influential village heads are more trusted by the farmers and significantly assist with technology diffusion within the village." (RF9)*

Enabling Factor	Salient Quotes	
	From Technology Companies	**From Rice Farmers**
	it in-person before trusting and purchasing the product. Demonstration plots have worked well in this respect." (TC5) *"The company must provide knowledge to the farmers face-to-face and show that it really helps with their farming processes. One reason farmers purchase from us is that we provide leasing and after-sales service. After-sales service is very important as product breakdowns are costly for them due to the very specific timeframe to spray chemicals." (TC6)*	
Human capital development	*"Governments providing support to rural communities are not focused on outcome towards farmers, but just focused on completing the job. While governments provided many funding and incentives for farmers, they did not provide farmers with the knowledge required to succeed." (TC9)*	*"While technology can help with processes and cost reduction, the more important issue is the markets and prices. Farmers must do more than just grow crops. They must become an entrepreneur and always look for opportunities to improve income, whether through new markets or through technology, if available." (RF1)*