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RESEARCH

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Improving stakeholder collaboration for sustainable agricultural mechanisation in rice production: a case study from Asutsuare, Ghana

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Abstract
Sustainable agricultural mechanisation can help to achieve sustainable agricultural production using locally appropriate technology. It involves using machinery to remove the drudgery of farming practices while ensuring the environmental, socio-cultural and economic feasibility of the machinery used. In rice production, mechanisation can improve productivity, reduce methane emissions from fields, and remove low-skilled, physically-intensive, and monotonous labour requirements. It is important to recognise the challenges arising from the complex roles of the stakeholders involved in incorporating machinery into agricultural practices. There has been limited research on how these stakeholders interact in smallholder agricultural mechanization in Africa. To determine the modalities of the interactions between stakeholders and to propose a practical collaboration structure, this study evaluates the roles of various stakeholders involved in the rice production process in Asutsuare, a rice-producing region in Ghana. Stakeholders included smallholder farmers, policymakers, machinery sales agents, manufacturers, and agricultural extension agents. Using the pairwise ranking technique, the study found that smallholder farmers were the most influential stakeholders regarding mechanising rice production. However, focus group discussions and key informant interviews revealed their feelings of neglect, stemming from a lack of support and resources from other stakeholders. The study proposes establishing a multistakeholder platform supported by transactional communication models to improve collaboration and machinery utilization among smallholder rice farmers. This approach will harness the expertise of operators, extension agents, and farmers, while incorporating resources from sales agents and policymakers. Additionally, training Agricultural Mechanisation Extension agents in machinery skills is recommended to enhance their effectiveness. These strategies can be adapted for other smallholder farming communities as well.

Article Highlights

- Stakeholder collaboration is crucial for sustainable agricultural development.
- The smallholder farmer is an influential and important stakeholder in smallholder rice production mechanization.
- Implementing a multi-stakeholder platform and transactional communication models among stakeholders is an effective strategy to improve machinery utilization for small-scale rice farmers in Ghana.
- Capacity building for stakeholders is essential to maintain an engaging platform for stakeholders, enabling them to participate in and benefit from the mechanization process.

Keywords Stakeholders, Mechanisation multi-stakeholder engagement, Sustainable mechanisation, Smallholder, Rice production, Food security, GHG emissions, Labour

1 Introduction

1.1 Background

Agricultural production is critical to human existence, providing food for the growing population [26]. According to global data, the demand for food is projected to increase by 1.3% annually. Developing countries are expected to contribute disproportionately to this increase, with their populations anticipated to account for two-thirds of the projected population growth from 7.7 billion in 2018 to 8.5 billion in 2030 [24]. There are growing calls for more climate-adaptive agricultural production to meet global food requirements [29]. Given the concerns about environmental degradation, climate change, and the misuse of agricultural land, it is also essential to transition towards more sustainable farming practices.

With rice production globally covering 165 million hectares and yielding nearly 22 million tons, rice production significantly contributes to food security [25]. In Africa, where there is a projected 3% increase in demand for rice by 2025, the role of sustainable rice production becomes even more pronounced [46]. In 2021, rice production in Ghana amounted to 1,143,000 metric tons, an increase from 722,000 metric tons in 2017 [58]. Smallholder farmers contributed 43% of this agricultural output. However, the mechanisation of smallholder rice production predominantly focuses on land preparation and harvesting operations, highlighting the necessity to support the ongoing growth of local rice production. By leveraging locally appropriate technology, such as power tillers, drum-seeders, and mini combines, sustainable agricultural mechanisation (SAM) can remove low-skilled, labour-intensive tasks and monotonous labour requirements while augmenting the reduction in the availability of labour within farming communities and ensuring the environmental, socio-cultural, and economic feasibility of machinery.

SAM in rice production offers a promising future with potential benefits. Research has revealed that there are effective models for integrating SAM into farming practices [4, 17, 19]. This integration can lead to higher productivity, decreased labour costs, and substantially improved farmers' quality of life. For instance, Axmann's research in Nigeria revealed that the mechanisation of rice harvesting and threshing reduced losses, resulting in a 16% increase in total production, indicating the positive impacts of effective mechanisation [5]. In Vietnam, it has also been reported that effective mechanization has resulted in increased overall income, household expenditure, and participation in household decision-making for female rice farmers [45]. However, very few examples evaluate how best to enable sustainable agricultural mechanization in African farming systems with a specific focus on ensuring dynamic and efficient stakeholder collaboration.

From an environmental and climate adaptation perspective, it is estimated that rice production contributes approximately 24.5 million tons of methane annually to global greenhouse gas emissions [24]. Methane production mainly arises from field wetting and residue management, making wetland rice fields more susceptible to emissions. Using SAM techniques and improving irrigation can reduce methane emissions from rice fields by 44–46% [52], promoting timely field activities and a reduction in GHG emissions. In an African context, research in Nigeria has shown that adopting effective mechanized harvesting and threshing can prevent an estimated 1.7 tons of CO_2 emissions per hectare [5]. This showcases the potential for lowering methane emissions from smallholder rice farms, such as those in Asutsuare, which implement field wetting and have not fully integrated SAM in their operations.

Despite the advantages of SAM outlined, integrating SAM into agricultural practices involves different stakeholders who must work together to overcome challenges that can arise. These challenges, such as the high cost of equipment, limited access to credit, and the need for adequate training and technical support, can impede the effective use of equipment and prevent farmers from realising the benefits of SAM [15, 18, 23]. The role of a diverse set of stakeholders in SAM is crucial, and their active participation and collaboration are not just important but essential to ensure the availability and efficient use of machinery.

Engaging various stakeholders in developing viable and sustainable solutions benefits the agricultural sector and has wider-reaching implications [38, 39, 41, 47]. The urgency and responsibility of making informed decisions and taking decisive action are paramount in achieving positive results from these collaborations, which hold significant promise for sustainability endeavours across Africa. Research in Ghana has underscored the crucial need for stakeholder platforms in intricate stakeholder scenarios, as these platforms can lead to more targeted and effective outcomes. Bonye et al. [9] identified that the centralized management of national parks resulted in significant power dynamics challenges among various stakeholders, highlighting the complexities of governance in these environments. Furthermore, Aremu et al. advocated for the establishment of consensus in setting objectives as a strategic approach to enhance stakeholder engagement, fostering collaboration and mutual understanding in the process. The diverse nature of multi-stakeholder collaborations and the need to prioritise specific outcomes while navigating potential trade-offs present challenges in reaching consensus, which is essential for effective multi-stakeholder engagement [2, 21, 40, 49].

This study aims to develop strategies to improve stakeholder collaboration and machinery usage for smallholder rice production in Ghana. The strategies intend to establish clear lines of communication among stakeholders, identify the areas of expertise and resources required for successful mechanisation, and promote the sharing of knowledge and best practices. To address this, the following research questions are investigated: What difficulties do smallholder farmers face when using machines for farming? How do stakeholders influence the mechanisation of rice production in Ghana? What opportunities are available to promote multi-stakeholder collaborations for smallholder mechanisation in the agricultural sector?

While prior studies have highlighted the potential of sustainable agricultural mechanisation (SAM) in addressing labour shortages, increasing productivity, and reducing environmental footprints [4, 5, 15], few have interrogated the underlying dynamics of stakeholder collaboration that determine the long-term viability of mechanisation interventions. Much of the existing literature focuses either on the technical dimensions of machinery adoption or on institutional barriers, often treating stakeholder interactions as static inputs rather than evolving systems. Importantly, little attention has been paid to the communicative processes, particularly how differing values, capacities, and power relations shape collaboration within stakeholder ecosystems.

This study's contribution lies in integrating Innovation Systems Theory (IST) and the Participatory Development Framework (PDF) with a transactional communication model to analyse the relational dynamics driving mechanisation outcomes. By conceptualising communication not merely as an operational tool but as a structuring mechanism of collaboration, the study offers a hybridised framework capable of bridging institutional and grassroots perspectives. Our approach provides fresh insights into how stakeholder alignment can be operationalised in practice, offering a scalable, context-sensitive model for fostering collaboration across complex agricultural mechanisation systems in Ghana and beyond.

1.2 Agricultural mechanisation and stakeholder collaboration

The discourse on sustainable agricultural mechanization (SAM) in the Global South has evolved from a focus on technology transfer to a more nuanced understanding of innovation and stakeholder engagement. SAM is highly regarded as a transformative approach that reduces drudgery, enhances efficiency, and addresses socio-economic and environmental challenges [4]. Nevertheless, the challenges of implementing SAM, particularly for smallholder farmers in Sub-Saharan Africa, remain pervasive. Challenges such as high equipment costs, limited technical support, and inadequate credit facilities are recurrent obstacles undermining agricultural mechanisation efforts [16, 23].

The stakeholder engagement promises to be a potent strategy to address existing challenges that have bedevilled mechanization efforts. Evidence has proved that collaborative and partnership platforms are powerful drivers for innovation, knowledge exchange, and resource mobilisation, ultimately promoting the implementation of sustainable agricultural practices [2, 11]. In Ghana, for instance, smallholder farmers play an important role in rice production, yet they often feel marginalised in mechanisation initiatives, underscoring the need for more structured stakeholder collaborations [20].

The application of frameworks such as Innovation Systems Theory (IST) [37] and the Participatory Development Framework (PDF) [12] provides valuable perspectives on fostering effective collaborations. While IST emphasizes that innovation is not just about the invention of new technologies, but also involves the interplay between various stakeholders within an economic system, PDF focuses on the inclusion of local stakeholders in the development process, ensuring that innovations are culturally and economically appropriate. Spielman et al. [57] demonstrated in their study in Ethiopia how IST can facilitate the adoption of new farming techniques through collaborative platforms involving farmers, researchers, and policymakers. Johansson et al. [31] employed PDF in Tanzania to tailor farming solutions to smallholder needs, thereby enhancing adoption rates and sustainability. The synergy between IST and PDF has been explored in various studies, providing a model for how these theories can be practically applied to enhance mechanization. In Uganda, Klerkx et al. [35] revealed that combining these frameworks has the propensity to significantly reduce post-harvest losses by fostering a cooperative environment that curtail both endemic systemic and grassroots issues. Similarly, in Vietnam, Kawarazuka and Prain [33] showed how integrating both theories could address gender-specific constraints in mechanization, leading to broader social benefits. These examples emphasize the transformative potential of stakeholder collaboration in addressing mechanisation barriers.

This study builds on existing insights into stakeholder collaborations to explore the interactions among stakeholders involved in mechanizing rice production in Ghana. It proposes strategies aimed at fostering collaboration among these stakeholders. By applying the Innovation Support Theory (IST) and the Participatory Development Framework (PDF), the research seeks to develop a scalable model for stakeholder engagement that promotes sustainable mechanization for smallholder farmers. Going beyond the complexities of mechanization, the study integrates both IST and PDF theories to obtain a practical framework for operationalizing stakeholder collaboration. Ultimately, this contribution enhances the discourse on stakeholder partnerships and offers valuable insights that can improve the effectiveness of agricultural development initiatives.

2 Methodology

A qualitative approach was used to engage with key participants in the small-scale rice production process and understand their current activities. While meeting with some stakeholders, field observations were also carried out on existing machinery and production sites. A pairwise comparison method was employed to evaluate and rank the involved participants. Pairwise analysis was deemed appropriate due to its robustness and wide applications in decision-making processes and use in studying people's preferences among different products [14, 51].

2.1 Theoretical framework

This study employs two theoretical approaches—Innovation Systems Theory (IST) and the Participatory Development Framework (PDF), to analyze the mechanization of rice production for smallholder farmers in Ghana. We utilized these frameworks to provide the lens to understand the complex interactions and stakeholder engagements necessary for effective rice mechanization. IST highlights the importance of networks and interactions among various stakeholders, including farmers, government agencies, NGOs, and private sector entities, in fostering innovation [37]. Runkle et al. [53] utilized IST to analyse socio-technical changes for sustainable rice production, emphasizing the critical role of stakeholder interactions in implementing conservation irrigation and rice husk amendments. Verma et al. [63] highlighted the need for a systems-based approach to rice improvement, including robust knowledge-sharing mechanisms to ensure sustainable food security. We use IST to examine how stakeholder collaboration can lead to the adoption of appropriate mechanization technologies.

Participatory Development Framework (PDF), emphasizes the involvement of all stakeholders in the development process, ensuring that their voices and needs are fully respected and incorporated [12]. PDF champions bottom-up approaches to development, where local communities actively participate in decision-making. We employ PDF to involve farmers directly in the design and evaluation of mechanization strategies.

Thus, this study extends the application of IST and PDF by integrating a communication-based lens to stakeholder engagement, specifically through the proposal of a transactional communication model. While IST foregrounds the systemic and institutional interrelations that foster innovation, and PDF emphasizes bottom-up participation, our approach bridges these with a communicative infrastructure that facilitates iterative learning, transparency, and trust-building. This contributes a novel analytical dimension to both frameworks by treating communication not merely as an operational tool but as a structuring principle for stakeholder collaboration. In doing so, the study offers a hybridised approach that is particularly attuned to the multi-actor complexity and institutional fragmentation characteristic of agricultural mechanisation in sub-Saharan Africa.

2.2 Study area

The study aimed to evaluate the complex multi-stakeholder engagements involved in the mechanisation of rice production in Ghana. The research involved interviewing a wide range of stakeholders in two interconnected areas: the capital city Accra (study area 1), and Asutsuare (study area 2), a town known for rice production in the Shai Ossudoku District in the Greater Accra region (Fig. 1). The stakeholders involved in machinery availability and policy formulation, including manufacturers, importers, and policymakers, are located in Accra. Asutsuare is home to the stakeholders involved in machinery use, such as operators, extension officers, and farmers.

The Shai-Osudoku District is one of the hottest and driest parts of the country, with over 58.6% of its residents involved in agricultural production, including fruit production and rice cultivation [27]. Farming plots are approximately 1.5 hectares in size and are serviced by irrigation canals. The town's rice production activities result in two harvest seasons with high yields of 5.6 MT/Ha annually, averaging about 175% more yield

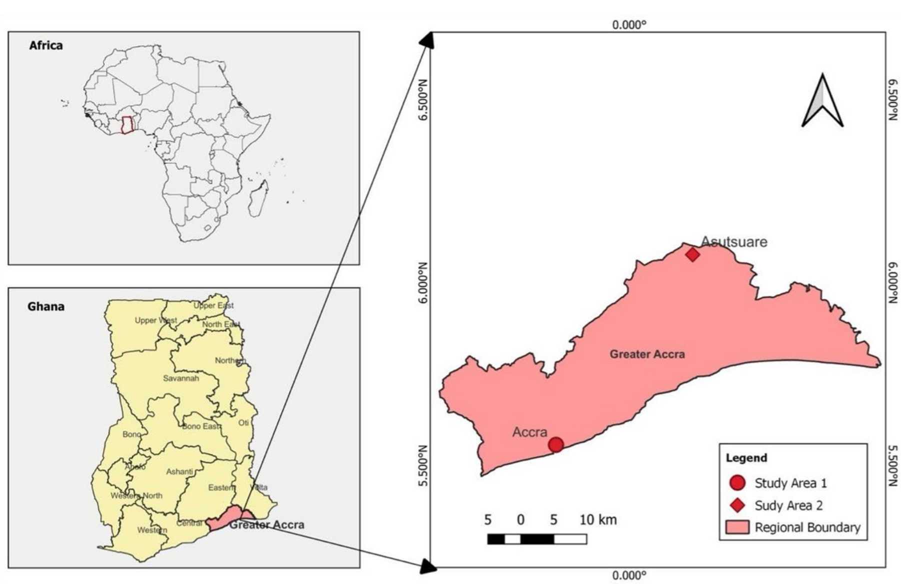

Fig. 1 Asutsuare and Accra (Source: Authors)

than the national average. As a result, Asutsuare plays a vital role in Ghana's rice production industry, which produces 1,143,000 metric tons of rice annually [58].

2.3 Qualitative data collection and analysis

Key informant interviews and focus group discussions were used to gather in-depth insights into the challenges and opportunities for mechanising rice production from the perspectives of different stakeholders. The research team engaged with smallholder farmers, policymakers, machinery sales agents, manufacturers, and an agricultural extension agent (Table 1). The stakeholder selection was based on a stakeholder interaction mapping process [19] that was used to identify the stakeholders needed for effective smallholder rice production mechanisation.

The sample size for this study was intentionally small to enable in-depth discussions during interviews and focus groups while reaching thematic saturation. Eight farmers, six machine operators, and other stakeholder groups were included based on a stakeholder interaction mapping exercise [19]. Efforts were made to ensure gender balance in farmer and sales agent groups,however, it is important to note that some stakeholder categories, such as machine operators and manufacturers, did not include female participants. This reflects the demographic and occupational realities in the Asutsuare rice production context, where technical machinery roles are currently male-dominated. We acknowledge this as a limitation and recommend targeted studies to further explore gender disparities in mechanisation access and participation.

2.3.1 Interviews

We first conducted key informant interviews with the various stakeholders on the rice mechanisation process. This was followed by focus group discussions, where we verified and validated the interview findings. Each participant was asked to share their insights, opinions, and experiences related to their role in agricultural mechanisation within rice production in Ghana. At the end of each interview, the respondents were asked to rank all the stakeholders ('rankings'), including themselves, based on their influence on rice production mechanisation.

2.3.2 Focus group discussion

After the key informant interviews, two focus group discussions were conducted: one group comprised seven participants, including the policy maker, machinery sales agent, manufacturing personnel, two machinery operators, and two farmers. The second group comprised eight participants: six farmers, one agricultural extension agent, and an operator. The participants were drawn from the initial interview participants. An invitation was extended to all the stakeholders to attend a focus group discussion. The discussions

Table 1 Number and location of study participants

Stakeholder	Location	Number of participants		
		Male	Female	Total
Farmers	Asutsuare	4	4	8
Machine operators	Asutsuare	6	0	6
Manufacturers	Accra	2	0	2
Sales agents	Accra	2	2	4
Policy makers	Accra	2	0	2
Agricultural Extension agent	Asutsuare	1	0	1

considered the challenges, barriers, level of machinery used in rice production in Ghana and opportunities for enabling more effective collaboration. This iterative process ensured a comprehensive understanding of stakeholder dynamics within rice production mechanisation and also validated the initial interview findings.

All interviews lasted between 60 and 90 min, were recorded, and later transcribed for further analysis. The interviews with the farmer groups were conducted in the local language to ensure full participation and were also translated and transcribed afterward. The transcribed files were uploaded into Atlas.ti, and a thematic analysis [43] was conducted to identify the main themes discussed in the interviews. The data collected from the stakeholder rankings was analysed using a pairwise comparison analysis [55], revealing each stakeholder's influence level.

Although this study primarily relied on qualitative methods such as key informant interviews and focus group discussions, the absence of primary quantitative data collection, such as structured surveys or machinery utilisation statistics, limits the degree of triangulation possible within the current design. The findings, therefore, need to be interpreted with caution and within the context.

2.4 Pairwise comparison analysis

Pairwise comparison is a useful technique for evaluating the relative importance of competing needs. It is rooted in decision theory and multi-criteria decision-making (MCDM), which are critical in deriving priorities and making informed decisions [55]. In the context of stakeholder analysis, pairwise comparisons play a crucial role in making structured and systematic evaluations, ensuring that all perspectives are considered and weighted appropriately [6, 30]. The technique has been applied to study diverse issues in Africa, including adoption of sustainable agricultural practices in Tanzania [32], climate variability on crop yields in Kenya [44] and determinants of antiretroviral therapy (ART) adherence among HIV patients in South Africa [65]. In applying the technique to the rice mechanisation process in Ghana, we aimed to derive critical insights into the relative influence of different stakeholders in shaping mechanisation adoption (Table 2).

The pairwise comparison method followed a modified version of the Analytic Hierarchy Process (AHP) developed by Saaty [54]. We adopted a simplified five-point scale (Table 3) to reduce cognitive load during ranking tasks, especially for non-academic participants. The scale ranged from 1 (equal importance) to 5 (absolute importance), with intermediate levels (2–4) reflecting increasing degrees of preference. This simplified version maps proportionally to the original 9-point scale by grouping similar intensity values, which has been shown to yield comparable decision reliability in participatory settings [14, 30].

Stakeholders were asked to rank all others (including their own group) in terms of their influence on the rice mechanisation process. These rankings were then used to

Table 2 Combined scores of all stakeholders

N x N	Farmers	Machine operators	Manufacturers	Sales agents	Policy makers	Repairers
Farmers	**1**	4	4	4	4	4
Machine operators	3	**1**	2	3	2	4
Manufacturers	3	3	**1**	4	4	4
Sales agents	4	3	3	**1**	3	3
Policy makers	3	3	4	3	**1**	3
Repairers	4	4	4	3	2	**1**

Table 3 Pairwise Comparison scale of relative importance (adopted from [54])

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak importance	Experience and judgement slightly favour one activity over another
3	Essential or strong importance	An activity is strongly favoured and its dominance demonstrated in practice
4	Demonstrated importance	The evidence favouring one activity over another is of a higher possible order of affirmation
5	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Table 4 Normalised scores for the pairwise analysis

N x N	Farmers	Machine operators	Manufacturers	Sales agents	Policy makers	Repairers	Total	Relative weight
Farmers	0.444	0.608	0.516	0.316	0.279	0.210	2.373	0.396
Machine operators	0.111	0.152	0.258	0.237	0.139	0.210	1.107	0.185
Manufacturers	0.111	0.076	0.065	0.316	0.279	0.210	1.320	0.220
Sales agents	0.111	0.050	0.032	0.079	0.209	0.158	0.639	0.107
Policy makers	0.111	0.076	0.032	0.026	0.069	0.158	0.472	0.079
Repairers	0.111	0.038	0.032	0.026	0.023	0.053	0.283	0.047

Table 5 Most influential stakeholder in rice mechanisation process in Ghana

Stakeholder	Score	Influence rank
Farmers	0.396	1
Manufacturers	0.220	2
Machine operators	0.185	3
Sales agents	0.107	4
Policy makers	0.079	5
Repairers	0.047	6

construct an $n \times n$ pairwise comparison matrix, where each element *aij* represents the perceived relative importance of stakeholder i over stakeholder j. The reciprocal property was maintained, i.e., if *aij* = 4, then *aji* = 1/4a.

Once the full matrix was established, we normalised each column by dividing each cell by the sum of its column. We then summed each row of the normalised matrix and divided by the number of stakeholders to obtain the final relative weight (influence score) for each stakeholder group. These weights (Table 4) form the basis for the influence ranking presented in Table 5. The final score ranges from (0–1), with 0 meaning no influence and 1 meaning highest influence. The higher the score, the higher the influence in the mechanisation process. The index was interpreted using three categorical thresholds: low (0–0.33), moderate (0.34–0.66), and high (0.67–1), in line with prior applications in related stakeholder research [7, 13, 42].

3 Results and discussion

3.1 Stakeholder influence mapping

While farmers scored 0.396 in the pairwise analysis (see Tables 4 and 5), this reflects a moderate level of influence according to the defined thresholds. However, they emerged as the most influential stakeholder group relative to others in the mechanisation process.

This finding points to a crucial tension: farmers play a pivotal role in adopting and sustaining mechanisation efforts but do not wield commensurate power or influence over mechanisation policies, machinery design, or distribution systems. This aligns with observations in previous studies (e.g., Simms and Kienzie 2017; [16]), which highlight smallholder farmers' centrality in agricultural systems yet persistent exclusion from strategic decision-making and technical support. The moderate score thus underscores their structural limitations, not a lack of significance. Future stakeholder engagement must focus on converting this latent influence into tangible decision-making power. Manufacturers and machine operators follow, with scores of 0.220 and 0.185 respectively, underscoring their importance in providing and effectively utilising machinery. Repairers, though least influential with a score of 0.047, play an important role in maintaining and repairing machinery, ensuring its longevity. Sales agents, policymakers, and repairers with lower scores also contribute to the mechanisation ecosystem by facilitating machinery distribution, shaping regulatory frameworks, and ensuring equipment maintenance. Apart from farmers, all the other stakeholders have relatively a low influence on the mechanisation process.

The position of farmers implies that their decisions directly impact the success of all efforts in the mechanisation process. Manufacturers are also vital as they provide the necessary machinery, indicating that their ability to produce efficient and affordable equipment significantly affects mechanisation adoption. The position of machine operators is not surprising, given that their skills and availability are crucial for operational efficiency. Similarly, sales agents facilitate the distribution and accessibility of machinery to farmers, impacting the spread of mechanisation. Policymakers create a regulatory framework that can either support or hinder mechanisation efforts through policies on subsidies, training, and import regulations. The analysis suggests that a coordinated approach that prioritises the roles of farmers, manufacturers, and machine operators while supporting the functions of other stakeholders is essential for the successful and sustainable implementation of rice mechanisation in Ghana.

3.2 Challenges faced by Stakeholders

The analysis of the Key Informant Interviews (KII) and Focus Group Discussions (FGD) with the stakeholders revealed the numerous challenges they faced in promoting the mechanisation of smallholder rice farming. We identified three main challenges facing the mechanisation of smallholder rice production. Firstly, there is a lack of personnel (operators, extension agents, etc.) to support the mechanisation process. Secondly, there is a challenge regarding the availability of machinery for rice production activities, whether through local manufacturing or import, to meet local demand. Finally, securing financing for the mechanisation efforts throughout the value chain presents an additional obstacle that must be addressed. These challenges have been extensively studied in the context of smallholder mechanisation, with researchers noting similar obstacles and their impact on effective mechanisation and sustainable agriculture production [15, 18, 56].

The farmer FGD underscored the challenge of finding operators due to a shortage of workers and insufficient machinery in the community to meet local demand. The farmers felt neglected, believing that the other stakeholders needed to be providing more support and prioritising their needs. They stressed the significance of supporting local farmers and acknowledging their contributions to the country's economy, stating: *"from the government to the bank, they have to prioritise the farmers just like some other countries…have laid down some protocols for valuing the role of smallholder farmers."* (Farmer FGD).

The group delved deeper into the potential implications of recognising the pivotal role of farmers. They underlined the critical nature of offering substantial support to the agricultural sector, particularly tailored to the specific needs of smallholder farmers. The group's insights highlighted the crucial role of farmers and underscored the importance of creating a conducive environment for the continued success of smallholder farmers in the agricultural sector. However, KII with policymakers highlighted the existence of several subsidy packages that farmers, including the farmers in Asutsuare, and other stakeholders have not fully utilised. One notable example is the ~ 40% subsidy on power tillers and other beneficial packages. With the potential for these subsidies to significantly benefit the farmers and those engaged in machinery hiring services, it is worth exploring ways to increase awareness and uptake of these opportunities. We found that most farmers were unaware of the subsidy, underscoring the need for awareness-raising of government initiatives, particularly in the agricultural sector.

The excerpts from the discussion with the operators shed further light on their concerns regarding financing mechanised rice production along the supply chain for smallholder farming communities. They emphasise the need to subsidise mechanisation to lower production costs and make machinery use more affordable for smallholder farmers: *"On the mechanisation side, the government should reduce the price of machines for farmers"* (Operators FGD). This demonstrates the extent to which machinery costs restrict access to mechanization in the community.

The sales personnel also suggested offering subsidies on machinery to encourage farmers to invest in this equipment. Several studies have demonstrated that the implementation of subsidies can bring about economic relief for farmers and lead to an immediate reduction in production costs, along with advancement in technology adoption [8, 48]. For instance, findings from smallholder farmers in Uganda indicate that a one-time subsidy contributed to an upturn in technology adoption for grain storage [48]. Therefore, supporting mechanisation in rice production through subsidies can decrease production costs for farmers and enhance accessibility for small-scale farmers who lack the financial resources to invest in costly machinery.

The stakeholders had varying perspectives on the availability of machinery for rice production. The farmers believed there was not enough machinery for them at the time, while policymakers and salespersons suggested that the machinery was available, but the farmers either did not purchase it or did not feel the need to use it. They emphasised this by mentioning the poor availability of several batches of power tillers and rice combine harvesters. The discussion with the operators clarified why the farmers had that perspective, describing how the available equipment, especially the power tillers, were not durable enough to be worth owning. One of the operators explained, *"The problem we have is that we need a machine that can work for around five years before [needing major repairs]. But the ones we have now only last about a year"* (Operator FGD).

This emphasises the critical nature of carefully evaluating machinery before making important decisions. This task is fundamental and can be effectively executed by research stakeholders, who can gather valuable input from other stakeholders, including sales teams, operators, and farmers. For example, in Indonesia, research into the causes of machinery breakdown in smallholder rice production fields have shown that 30% of component failures were primarily due to adverse field conditions, and 21% were caused by excessive use of machinery [50]. An inspection of the power tillers by the research team during the site visits to the smallholder rice fields showed that the power tillers referred to by the operators, usually under 5 HP, need to be used as specified by the manufacturers. Because these power tillers are not designed to easily handle very tough field conditions, such as the saturated soils common in rice fields like Asutsuare, especially when compared to larger tractors, mostly over 40 HP.

The issue is further compounded by the concern that spare parts are not readily available to repair such machinery when it breaks down. As such, if the machinery breaks down and cannot be repaired, it will be considered defective and then rendered non-durable and not worth owning. One operator recounted: *"the power tiller [they] brought. Even recently, the ones they brought the last time, I was there to buy something, even the spanner was not attached to it. So, they said they brought the machines without the parts, so if you go there to buy the machine, you have to go and look for the parts to buy"* (Operator FGD). This paints a gloomy picture for smallholder farmers on how sustainable their investments in machinery acquisitions will be.

In summary, these challenges hinder access to mechanisation within Asutsuare, and better access to mechanisation could greatly improve smallholder rice production and, by extension, meet the expectations of all stakeholders [3]. This calls for collaborative efforts among stakeholders to overcome these challenges and offer vital support for mechanised smallholder rice farming.

3.3 Opportunities for effective multi-stakeholder partnerships

The stakeholder engagement and discussions not only revealed the challenges faced by stakeholders as they strived for sustainable mechanisation for smallholder farmers, but also clarified issues within their activities and revealed potential opportunities. Seizing these could pave the way for a robust collaboration support system for rice production mechanisation, involving multiple stakeholders and leading to a sustainable rice production sector.

Communication, a crucial element in effective stakeholder collaborations, has been identified as a significant barrier. The impact of focus group discussions on stakeholder interactions has demonstrated the value of these discussions as a platform for engagement. Clear communication channels facilitating regular updates and information sharing are essential for effective collaboration [22]. Regular meetings and discussion forums will be pivotal in aligning each stakeholder's goals and objectives. These platforms will allow stakeholders to share their perspectives, feel actively involved, and provide a secure and reliable space to integrate their objectives well.

Inadequate communication among stakeholders caused difficulty accessing information about service providers and machinery parts suppliers, significantly hindering access to the needed machinery to mechanise the rice production process. Throughout the FGDs, there were instances where stakeholders clarified crucial misconceptions held by others, demonstrating the benefit of effective communication in overcoming these challenges. The operators and policymakers interacted and provided further clarifications: "*Right now, aside from what you are saying, if we encounter a power tiller fuel pump* *problem, can we purchase one from your location?*" To this, the policymaker stakeholder replied, "*Yes, you can get it from the local agents,"* and provided the exact location of the agent, emphasising that *"they have been contracted by the supplier."* (Mixed stakeholder FGD).

The example provided highlights the importance of addressing communication challenges. Furthermore, sales agents may struggle with low sales and be concerned about the lack of demand for their parts. However, machinery owners and operators frequently express frustration over the unavailability of spare parts in the market. The lack of spare parts is often a barrier to effective mechanisation [28]. From the interactions in the stakeholder group, it becomes evident that inadequate communication within the value chain can lead to such issues.

Another identified opportunity is the potential for stakeholders to collaborate on joint projects and initiatives. Past studies show that collaboration in the agricultural sector is critical for cross-fertilising ideas, innovations and increased productivity [62, 64]. Collaboration can leverage the unique strengths of each stakeholder, amplifying the collective impact and enhancing the utilisation of available resources. Programmes emerging from collaboration offer a platform to identify and overcome barriers, such as conflicting interests or competition, and foster a more harmonious and collaborative environment. For example, policymakers and sales agent stakeholders can spearhead the operationalization of the multi-stakeholder platform meetings. In the context of Asustsuare, sales agents can achieve their primary goal of increasing awareness of agricultural machinery and services. At the same time, the policymakers also attain the goal of a productive agricultural sector and ultimately increase smallholder rice production. As elaborated, each stakeholder's role in these interactions will be crucial, as their contributions align with their primary objectives and advance the collective benefit of their endeavours. These projects, initiatives, and example illustrate first-hand the alignment of each stakeholder group and provide a means to integrate their requirements into the overarching goal, making them feel valued and integral to the success of the initiatives.

Engaging in activities to build trust is fundamental for nurturing stronger working relationships among stakeholders. Establishing open platforms for exchanging feedback and ideas ensures the comprehensive representation of all stakeholders in providing services to support effective mechanisation within the value chain. This inclusive approach fosters a sense of ownership and belonging, which are vital for the success of such programmes, making the stakeholders feel a sense of belonging and ownership in the process. This can be directly linked to the discussions where the operator's expressed dissatisfaction with the method of pricing used for their services.

"That one, too, is part of the problem, but they start with the 10%. Later, the association (machinery owners association) and the machine owners meet and see that they have to pay the minimum wage, so that is what they are doing. We, as operators, must be paid minimum wage, so we told them that no, that couldn't be possible because I can't work for you and be paid minimum wage while you are not paying my [retirement benefits]." (Operators FGD).

Without resolution, this issue may lead to a decline in the number of machinery operators as their interest in performing machinery services wanes. This could result in a scenario where the mechanised rice production sector loses its vibrancy.

3.4 Strategies for sustaining an effective multi-stakeholder platform

The successful mechanisation of smallholder rice production is a collective effort that relies on the invaluable contributions of all stakeholders in the value chain. The identified opportunities highlight the importance of establishing a comprehensive multi-stakeholder engagement protocol to facilitate meaningful interactions and foster support for sustainable smallholder rice production mechanisation. Similar multi-stakeholder platforms have been documented to help promote change in stakeholder attitudes and the development of new products, resulting in improved sales [60]. When introduced into the mechanisation of smallholder rice production, this multi-stakeholder platform will comprehensively address stakeholders' practical needs, such as facilitating communication opportunities or strategic needs, including driving policy changes and implementing appropriate incentives. Therefore, it is crucial to create a robust multi-stakeholder engagement platform that considers the needs of all stakeholders and fosters effective collaboration and support for their perspectives. This requires a thorough understanding and careful attention to the diverse needs of all stakeholders.

In agriculture, researchers have studied communication dynamics within agricultural production, proposing two distinct models: the linear model and the complex model [34, 36, 59, 61]. The linear model, which involves one-way communication without expecting feedback, may have limited applicability in agriculture, especially in scenarios where dynamic and iterative interactions are necessary. Consequently, complex communication models, such as the iterative and transactional models, play a crucial role in agricultural production. The iterative model, which involves receiving feedback, allows for some interaction and adjustment based on the received feedback. However, with its dynamic feedback loop between the sender and receiver, the transactional model is particularly relevant in the current context of agricultural mechanisation stakeholder engagement, where continuous adjustments and information exchanges are essential for efficiency and productivity [34, 36]. Effective communication is essential for coordinating mechanisation activities, sharing knowledge among stakeholders and making informed time-sensitive agricultural mechanisation decisions [59, 61].

The potential implications of using a transactional communication model are significant when it comes to mechanising rice production. Mechanising rice production involves stakeholders such as farmers, equipment manufacturers, sales agents, policymakers, and researchers. Implementing a transactional communication model in this context would ensure a dynamic flow of information among these stakeholders. A transactional communication model would allow each stakeholder to feel heard and valued in the context of the proposed multi-stakeholder platform for mechanising rice production. It would enable dynamic information flow and feedback, facilitating better coordination, problem-solving, and decision-making. Moreover, regular stakeholder meetings can further reinforce the effectiveness of a transactional communication model in mechanising rice production. These meetings can serve as platforms for open discussions, feedback exchange, and collaborative problem-solving, ultimately leading to informed decisions and improved operational efficiency.

Utilising effective communication models, particularly transactional communication, in mechanising rice production can greatly improve stakeholder collaboration, facilitate knowledge sharing, and enhance decision-making. This level of interaction is crucial when implementing transformative changes, for example, to promote increased female participation in mechanisation and deal with the low number of female technical experts in the field. It will enable female farmers, operators, and other female stakeholders to continuously exchange insights, leading to enhanced participation based on the iterative nature of the communication model. This can positively impact the productivity, sustainability, and fairness of mechanisation interventions, as evidenced by the resolution of issues related to the availability of spare parts.

Another crucial strategy is providing comprehensive training to stakeholders, equipping them with the technical expertise to address specific strategic needs and ensure the effective implementation of sustainable mechanisation activities. This training should be organised through workshops, seminars, and hands-on demonstrations, allowing stakeholders to engage with the technology directly. For example, machinery operators can be trained through workshops organised by policymakers and supported by sales agents. Researchers can also train machinery manufacturers in the design and fabrication technologies available and how to improve the manufacturing process. The agricultural extension agents are another important stakeholder that can improve mechanisation when effectively trained.

Research has shown that farmers are more likely to adopt and use new technology when they receive direct demonstrations of the technology and that agricultural extension agents are a trusted source of information for farmers [10]. Building on these findings, enhancing the technical knowledge of existing extension personnel to become Agricultural Mechanization Extension (AMEX) agents will be important for the functioning of the multi-stakeholder platform. An AMEX agent is a highly skilled professional agricultural extension agent who undergoes specialised training in agricultural mechanisation [20]. These agents support farmers by helping them adopt cutting-edge technologies, providing guidance on new agricultural machinery practices, offering valuable information to machinery operators, and serving as a vital, timely link between farmers and other stakeholders. They work towards transforming existing attitudes and practices related to mechanisation within farming communities.

Consequently, it is imperative to prioritise the capacity building of these extension agents in agricultural mechanisation skills, such as knowing when to use specific machinery, field capacity, and operation of machinery, technical field tillage requirements, to ensure effective support for smallholder farmers and operators within the mechanisation value chain. The capacity building for AMEX agents has to be implemented through a detailed plan for their specialised training. This plan will include structured courses, on-the-job training, and mentorship programmes to ensure that AMEX agents acquire the essential skills and knowledge in agricultural mechanisation. For example, in the case of Asutsuare and other rice farming communities, agricultural extension agents who already exist within the farming community will be trained in field mechanization of wet paddy fields, determining the best field conditions for optimal machinery performance, incorporating intermittent wetting techniques in field activities, and executing appropriate harvesting operations among other technical skills to qualify as AMEX agents. Monitoring and evaluation processes will be implemented to track the progress and effectiveness of the capacity-building efforts.

Using the proposed communication models, a targeted communication strategy needs to be developed to ensure that the valuable information provided by agricultural extension agents reaches the intended stakeholders. As emphasised in research showing that farmers appreciate the wealth of knowledge extension officers and researchers have to share with them, it is also important that they feel connected to the knowledge-sharing process [1, 10]. As such, the strategy proposed involves leveraging various communication channels, such as farmer field schools, community meetings, and digital platforms, to disseminate information and engage with farmers effectively. Feedback mechanisms should be established to evaluate the impact of the information shared by the extension agents and to gather insights for continuous improvement.

To ensure sustainable support for the initiatives, it is crucial to establish strong financial models that incorporate subsidies, subscriptions, and commodity trading. During the FGDs and KII, the sales agents have already expressed interest in providing machinery for operator training, and the policymakers have indicated the availability of subsidies. Seizing this opportunity and leveraging the technical expertise of researchers, a robust financial model, making use of existing banking infrastructure and stakeholders, can be developed to support the activities of the stakeholders and establish a vibrant multi-stakeholder platform during stakeholder engagement and focus group discussions.

4 Conclusion

Sustainable agricultural mechanisation, particularly in rice production, holds great potential for enhancing productivity and reducing emissions. This study examined the dynamics of stakeholder collaboration in smallholder rice mechanisation in Asutsuare, Ghana, using a hybridised framework that integrates Innovation Systems Theory (IST), the Participatory Development Framework (PDF), and a transactional communication model. The findings revealed that while smallholder farmers are the most influential actors in the mechanisation process, they remain structurally marginalised in decision-making and resource allocation. Collaborative efforts among stakeholders, including smallholder farmers, policymakers, machinery sales agents, manufacturers, and agricultural extension agents, are vital for successfully integrating machinery into agricultural practices, particularly in smallholder rice production.

The joint application of IST and PDF in this study yields three unique insights. First, it reveals a disconnect between systemic provisions (e.g., subsidies, training) and local realities—a gap often missed when these frameworks are applied in isolation. Second, it shows how institutional actors (sales agents, policymakers) and grassroots actors (farmers, operators) often operate with different understandings of influence, power, and value. This reinforces the need for participatory alignment. Third, the integration of a communication model within this framework operationalises collaboration, offering a concrete strategy for addressing fragmentation in stakeholder engagement.

As the most influential stakeholders, smallholder farmers face challenges in adopting mechanisation for their rice production activities and require more support from other stakeholders. An effective multi-stakeholder platform should be developed and maintained to address this, leveraging transactional communication models to ensure each stakeholder feels heard and valued. Effective training of Agricultural Mechanization Extension agents in areas of technical expertise, such as technical skills in machinery operation, maintenance, and knowledge of local agricultural practices, is crucial for maintaining vibrant stakeholder interactions. These strategies can promote knowledge sharing and diverse perspectives and improve operational efficiency and productivity in smallholder rice production.

The study contributes to the literature by offering a novel analytical lens that treats communication as a structuring principle for stakeholder collaboration, rather than a functional add-on. A key limitation of the study is the absence of quantitative data to triangulate the qualitative findings. While the depth of insights gathered through FGDs and KIIs offers a rich understanding of stakeholder perspectives, future research would benefit from adopting a mixed-methods approach. Integrating structured surveys, machinery performance metrics, or subsidy uptake statistics would improve the robustness and generalisability of the findings and allow for a more nuanced examination of stakeholder influence and mechanisation impact.

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Author contributions
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Data availability
The data sets produced in this study can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted as per the Declaration of Helsinki and its subsequent amendments. It received approval from the Ethics Committee of the College of Basic and Applied Sciences, University of Ghana, under approval number ECBAS 032/23-24. Informed consent was obtained from all individual participants included in the study.

Consent for publication
The participant has agreed to allow excerpts from their interviews to be published.

Competing interests
The authors declare no competing interests.

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