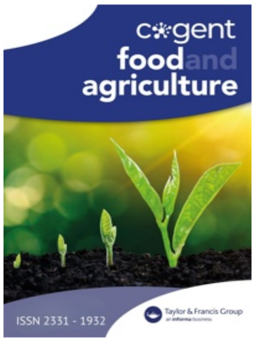

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Industrial symbiosis and scalability of smallholder farming in Uganda

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ABSTRACT
This study explored smallholder farmers' perceptions of scalability, the industrial symbiotic practices they undertake, and the contribution of industrial symbiosis to farm scalability in Uganda. A multiple case study design was adopted, involving a purposive sample of 35 smallholder farmers from registered farmer groups in Luwero District, with data saturation reached at the 29th interview. Data were collected through semi-structured interviews conducted in the local language to ensure depth and clarity. It was then analyzed using thematic content analysis to identify key patterns and themes. The findings indicate that smallholder farmers perceive scalability as a multidimensional, practice-based process characterized by increased production, market expansion, efficient resource utilization, and enhanced operational capacity. Scalability is viewed as a dynamic process embedded in everyday farming activities. Industrial symbiosis is practiced through waste reuse, crop-livestock integration, alternative feed production, resource sharing, and knowledge exchange. These practices improve productivity, efficiency, and income, making industrial symbiosis a practical strategy for achieving farm scalability in resource-constrained settings. The study contributes to knowledge by providing a contextually grounded understanding of smallholder farm scalability, moving beyond linear interpretations. It offers empirical evidence on farm-level industrial symbiosis and demonstrates how these practices enhance productivity, efficiency, and adaptive capacity, providing novel insights into how resource-constrained farmers in Uganda achieve scalability.

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1. Introduction

Scalability is crucial for transforming subsistence farming into a more commercial and sustainable agricultural system. For smallholder farms, scalability presents the capacity to expand agricultural practices, technologies, and innovations from a limited scale to a larger one to enhance production, improve livelihoods, and strengthen food security (Hansen et al., 2022). As a result, scalable farms increase their revenue faster than their costs, allowing them to grow without significant resource constraints (Ainembabazi & Mugisha, 2014). This approach unlocks the potential of smallholder farms to expand their operations and output in response to market changes and growth opportunities (Hultberg & Pal, 2021). In addition, scaling farms develop innovative solutions that are beneficial to the economy, society and the environment in general (Aldieri & Vinci, 2021). This results in food security, poverty reduction, rural development, market integration and improved standards of living in both developed and developing economies (Gulati et al., 2022).

For Uganda in particular, scalability of smallholder farms is crucial since they contribute 80% to the country's food crop production, 25% of national GDP, employ 70% of the labour force, and enhance community resilience against economic shocks and food insecurity (Achieng et al., 2025; Apanovich &

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Nyairo, 2025). Thus, the government is implementing the Parish Development Model (PDM), the investment fund through the Small and Medium Agribusiness Development Fund (SMADF), the irrigation scheme, the agricultural extension services, access to finance and market, technology innovation and climate-smart agriculture as conduits to foster smallholder farms' scalability potential (Atube et al., 2021; Mfitumukiza et al., 2024).

Despite the aforementioned interventions, about 68.9% of the households in agriculture (smallholder farmers) still operate in the subsistence economy, consuming more than 50% of the food crops produced (National Planning Authority, 2025). In addition, smallholder farmers operate on fragmented pieces of land that limit their capacity to engage in commercial farming (Muhanguzi & Ngubiri, 2022). Moreover, a significant number of smallholder farms practice labor-intensive farming, rely mostly on family labour, lack efficient means of transport, and have inadequate knowledge and skills on value addition (Atube et al., 2021). Relatedly, smallholder farms in Uganda have limited access to essential agricultural inputs and are vulnerable to climate changes that hinder efforts to improve food security and rural livelihoods (Apanovich & Nyairo, 2025; Piemontese et al., 2021).

Engagement with existing literature shows that scholars who have interrogated smallholder farmers have focused on climate change adaptation (Atube et al., 2021); factor misallocation (Morando, 2023); smallholder farmer performance (Agole et al., 2022); agricultural information (Muhanguzi & Ngubiri, 2022); gender disparities (Midamba & Ouko, 2024); and ICT (Van Campenhout et al., 2021). Consequently, the scalability of smallholder farmers as an issue of investigation has received less attention. For scholars who have attempted to explore scalability, the focus is on agricultural value chains (Gulati et al., 2022); Black Soldier Fly Larvae (Mulyanti et al., 2025); and co-creation (van der Horst et al., 2022). On the other hand, scholars who have investigated industrial symbiosis in the context of smallholder farms (see Alfaro & Miller, 2014), seem to have paid less attention to scalability. Overall, a synthesis of the literature reveals a scanty documentation of the role of industrial symbiosis in promoting scalability in smallholder farms, using evidence from Uganda.

The above weaknesses in the extant literature are unfortunate because Wadström et al. (2021) argued that through industry symbiosis, smallholder farms can create mutually beneficial relationships with other stakeholders such as landlords, input suppliers, government agencies, and research institutions, which enables them to share resources, reduce waste, and enhance productivity. In addition, industrial symbiosis permits smallholder farmers to get varied support to produce for the market (Kimuli et al., 2025). As a result, smallholder farmers acquire more land, capital, technology, energy and water resources, markets and knowledge, as well as by-products that can be used for further production. From an environmental perspective, industrial symbiosis can reduce waste and improve resource utilisation, allowing smallholder farmers to make more profits in a way that adds a net positive impact on the environment and society (Gulati et al., 2022; Short et al., 2023).

Against that background, this study addresses the research question: *how does industrial symbiosis catalyse scalability of smallholder farms in Uganda?* Answering this question lays a foundation for suggesting strategic interventions for increasing productivity of smallholder farmers for commercialization purposes as a conduit for transforming the Ugandan society from a peasant to a modern and prosperous country within 30 years as per the Uganda Vision 2040 (Republic of Uganda, 2013). Moreover, the study demonstrates that industrial symbiosis promotes farm scalability through enhanced productivity, efficiency, and income among the farmers. This ultimately reduces poverty and hunger (SDG 1&2) and promotes decent work & economic growth (SDG 8) in resource-constrained contexts.

2.1. Theoretical foundation

This study adopted the resource-based view (RBV) to explain the influence of industrial symbiosis on scalability of smallholder farms in Uganda. The RBV was initially developed by Penrose (1959) through her theory of firm growth. It was later advanced by Wernerfelt (1984), who formally introduced the resource-based view of the firm. The theory was further developed by Barney (1991), who argued that the resources possessed by a firm can generate a sustainable competitive advantage. Accordingly, this advantage is realised when a firm possesses resources that are valuable, rare, imperfectly imitable, and non-substitutable. Subsequently, Peteraf (1993) consolidated the RBV by identifying resource heterogeneity, imperfect resource mobility, ex ante limits to competition, and ex post limits to competition as the core conditions underlying a firm's sustainable competitive advantage.

The RBV assumes resource heterogeneity, implying that firms possess varied bundles of tangible and intangible resources and capabilities, which explain why firms operating under similar conditions may realise different outcomes (Arbelo et al., 2024). The theory also assumes imperfect resource mobility, indicating that vital resources cannot be easily acquired, transferred, or replicated across firms (Helfat et al., 2023). The possession and effective utilisation of differentiated resources can result in variations in firm competitiveness, performance, growth, and, in the context of this study, scalability. Accordingly, Ferreira and Ferreira (2025) define resources as the assets, capabilities, knowledge, information, relationships, technologies, organisational processes, and physical inputs possessed and controlled by a firm.

The RBV provides a strong theoretical foundation for explaining the contribution of industrial symbiosis to fostering farm scalability. In particular, smallholder farms are resource-constrained, and industrial symbiosis enables farmers and other actors in the agricultural ecosystem to share, exchange, or reuse underutilised resources. These resources include agricultural waste materials, storage facilities, transportation services, equipment, technical knowledge, and market information. Through such exchanges, smallholder farmers gain access to resources, knowledge, and capabilities that they may be unable to develop or own independently. For instance, using animal waste as organic fertiliser can minimise expenditure on commercial fertilisers and improve soil productivity. In addition, sharing machinery, knowledge, storage facilities, and transportation services can reduce farm operating costs, thereby facilitating scalability.

Thus, it is important to note that industrial symbiosis catalyses farm scalability through resource access, combination, and utilisation pathways. In particular, industrial symbiosis provides access to resources, allows farms to recombine resources and waste materials, and improves efficiency. This mitigates the resource-constraint challenges faced by a significant number of smallholder farmers and ultimately increases their productive capacity, diversification, and market access. This indicates that farmers who actively and efficiently engage in industrial symbiosis are more likely to increase farm output without a corresponding increase in operational costs compared with their counterparts. This study extends the RBV by demonstrating that smallholder farmers can obtain strategic value and scale their operations not only through the resources they own but also through those they access and mobilise through industrial symbiosis. Therefore, industrial symbiosis is viewed as a resource-mobilisation mechanism that enables smallholder farmers to overcome individual resource constraints by sharing, exchanging, and reusing resources, thereby facilitating farm scalability through increased farm productivity and market access.

2.2. Literature review

2.2.1. Smallholder farming in Uganda

Smallholder farms are typically defined by the scale of their operations, which are characterised by limited resources, including land, capital, and technology. According to Fan and Rue (2020), smallholder farms involve the usage of family labour, small-scale production, and depend on traditional farming methods. In Uganda, smallholder farms are often less than two hectares in size (Atube et al., 2021). These farms are predominantly rain-fed and often involve mixed farming systems, combining crop and livestock production. The socio-economic profile of smallholder farmers in Uganda is diverse, many are subsistence farmers, producing primarily for household consumption, with any surplus sold in local markets (Apanovich & Nyairo, 2025).

Smallholder farmers are integral to Uganda's Agricultural sector, which is a cornerstone of the National economy. In particular, smallholder farms contribute approximately 24% to Uganda's GDP and employ over 70% of the population (Uganda Bureau of Statistics, 2024). Their contribution to food security is significant, as they are responsible for producing the bulk of the country's staple foods, including maize, beans, and bananas (National Planning Authority, 2025). In addition, they contribute to rural development by creating employment opportunities and stimulating local economies. According to a study by Van Campenhout et al. (2021), smallholder farms can drive economic growth by enhancing rural incomes and reducing poverty.

Despite their importance, smallholder farmers in Uganda face numerous challenges that hinder their productivity and economic contribution. These challenges include; limited access to markets, inputs and technology (Mubiru et al., 2018). Relatedly, climate change poses an additional threat to smallholder farmers in Uganda (Kansiime et al., 2026). This is because of over-reliance on rain-fed agriculture that makes them particularly vulnerable to climate variability and extreme weather events. These issues present significant challenges to the scalability of smallholder farmers, that justify the need for the current study to develop strategies for their scalability.

2.2.2. Scalability of smallholder farms

Farm scalability refers to the capacity of agricultural enterprises to expand production efficiently while maintaining or improving performance (Monteiro et al., 2023). Scalability is critical for transforming subsistence farming into commercially viable agribusiness. In agriculture, scalability is often associated with the ability of a farming system to increase its output proportionately with the input (Yu et al., 2025). For smallholder farms, scalability encompasses more than just the quantitative increase in production. According to Gebreyes et al. (2026), scalability involves the adoption and adaptation of agricultural innovations that can be effectively integrated into existing systems, thereby improving productivity and livelihoods. This perspective highlights the need for scalable solutions that are context-specific and adaptable to the diverse conditions of smallholder farms.

Scalability in smallholder farming can be examined through several dimensions, including technological, economic, social, and environmental aspects (Pranuthi & Srikanth, 2023). Technological scalability involves the dissemination and adoption of innovations such as improved seed varieties, mechanisation, and digital tools that can enhance productivity (Padhiary et al., 2024). Economic scalability, on the other hand, refers to the ability of smallholder farmers to access markets, finance, and resources necessary to expand their operations (Kilthau et al., 2025). Social scalability is crucial for understanding how innovations can be adopted within the community context, considering factors such as cultural acceptance, knowledge dissemination, and community engagement (Guan et al., 2023). Environmental scalability addresses the capacity of farming practices to maintain ecological balance and biodiversity while increasing production (Achar, 2021). From the above literature review, it is evident that the concept of scalability is variedly perceived and operationalized in different contexts. Thus, presenting the need for the current study to address the following research question:

RQ1: What are the perceptions of the smallholder farmers regarding the concept of scalability in Uganda?

2.2.3. Industrial symbiosis (IS)

The concept of industrial symbiosis (IS) is variedly viewed by scholars in different disciplines from several contexts. In particular, Herczeg et al. (2018) present it as the collaboration among different enterprises to use each other's by-products, infrastructure, or expertise, leading to cost reduction and environmental gains. Neves et al. (2019) add that IS is an approach in which wastes or by-products of one company are used by another company as raw materials. In the same light, Boom-Cárcamo and Peñabaena-Niebles (2022) look at IS as a collaborative approach between firms involving physical exchange of materials, energy, and waste, hence creating economic advantages for farms and environmental benefits for society.

IS describes an industry ecosystem where 'consumption of materials and energy is optimized; waste generation is minimized, and effluents from one process are used as raw material for another process' (Boom-Cárcamo & Peñabaena-Niebles, 2022). The concept of IS focuses on the flow of materials and energy from one industrial process to another aimed at increasing value and reducing the environmental footprint, and this can be applied to systems like agriculture (Alfaro & Miller, 2014). As such, we conceptualized IS as a practice that involves the exchanging and sharing of waste materials, energy, working space, employees as well as other support services like transport and storage facilities (Kimuli et al., 2023; Kosmol & Leyh, 2019). Alfaro and Miller (2014), however note that few studies have been conducted to analyze IS in smallholder farming, even though agricultural systems especially the smallholder farms are essential to food supply, security and poverty reduction especially in developing nations like

Uganda. Thus, it is vital for the current study to unearth the symbiotic practices undertaken for smallholder farmers in Uganda, guided by the following research question.

RQ2: What are the industrial symbiotic practices being undertaken by smallholder farmers in Uganda?

2.2.4. Industrial symbiosis and scalability of smallholder farms

The concept of industrial symbiosis (IS) is significantly associated with scalability. This is because IS promotes the use of agricultural by-products such as manure or crop residues which is not only associated with environmental, but with economic and social benefits. In particular, Kimuli et al. (2025) show that Micro and Small Enterprises in Uganda benefit from IS by creating new revenue streams, lowering operational costs, and accessing shared infrastructure. With access to these resources, smallholder farms are in position to double their productive capacity with the goal of meeting the increasing market demand. In addition, as farms engage in symbiotic networks, they gain access to innovations and market opportunities that may otherwise be inaccessible independently (Guan et al., 2023). These benefits contribute to growth in both scale and scope of farm enterprises. Thus, industrial symbiosis is not only environmentally sustainable but also economically strategic for scaling businesses in resource-constrained settings.

Despite the benefits of industrial symbiosis in fostering scalability of smallholder farms, less is documented about their association. As such, current studies focus on the influence of formal credit and social capital on scalability (Qiu et al., 2026); political will, stakeholder involvement, and context-appropriate technology in scaling climate-smart agriculture in Uganda and Kenya (Kirina et al., 2022); extension services and digital tools enhance knowledge dissemination, promoting scalability (Lukuyu et al., 2021); network actors in enabling the scaling of sustainable land and water management practices (Irshaid et al., 2024). However, further review of the literature shows that barriers such as limited access to markets, infrastructure, and resource inputs can be mitigated by adoption of industrial symbiosis to unlock the potential of smallholder farms in Uganda to scale their operations.

In particular, Buda and Ricz (2023) argue that IS can support sustainable development in Uganda by linking agriculture with industry, such as textile manufacturing from banana fibers. Kimuli et al. (2025) further observe that IS supports sustainability among micro and small enterprises (MSEs) by optimizing resource use. IS enables agro-enterprises to reduce input costs, manage waste, and access new value chains. Al-Btoush (2025) demonstrates how Swedish farms implement IS as part of circular business models, suggesting its potential for Ugandan agriculture. Katana et al. (2024) note that knowledge-sharing platforms and facilitators are crucial in initiating and scaling IS networks. Thus, industrial symbiosis not only contributes to environmental goals but also unlocks operational and economic scalability, particularly when supported by industrial policy tools and stakeholder coordination. Thus, the above gaps in the literature and the contribution of industrial symbiosis in fostering farm scalability present the need for the current study to address the following research question:

RQ3: What is the influence of industrial symbiosis on scalability of smallholder farmers in Uganda?

3. Research methodology

3.1. Study context

This study focused on smallholder farmers in Luwero district as the study context. Luwero is one of the districts in the central region of Uganda, lying North of Kampala. Luwero was considered since it was economically, socially, administratively and infrastructurally divested by the 5-year guerrilla war that took place between 1981 and 1986. In addition, the government and other development partners are trying to support people in the district through the Parish Development Model (PDM) to support their commercialisation agenda (Uganda Bureau of Statistics, 2022). Despite the support, most households are still undertaking subsistence farming. Thus, it was imperative to investigate how industrial symbiosis can enable smallholder farmers to scale their operations in order to undertake commercial farming.

3.2. Research design, sample size and sampling procedure

In this study, a multiple case study design was adopted to enable an in-depth understanding of the scalability of smallholder farms. A total of 35 smallholder farmers were sampled and purposively selected by the researcher. Specifically, only smallholder farmers who are members of registered farmers groups in Luwero district were considered. These participants were selected because they were well organized and could easily be accessed to partake in the data collection exercise. Moreover, belonging to formal groups that accepted to participate in the study was considered as opportunity to gather accurate and unbiased information regarding the study phenomenon. However, during the data collection exercise, the point of saturation was attained at the 29th key informant, beyond which no new insights were emerging from the additional interviews.

3.3. Data collection

Qualitative data were gathered using a semi-structured interview guide (Adeoye-Olatunde & Olenik, 2021). The interview guide contained questions capturing the respondents' and farms' characteristics, such as age, educational level, marital status, social group membership, farming experience, poultry farming, and crop farming. The interview guide also contained questions on industrial symbiosis and farm scalability. The interview guide was adopted because it facilitates flexibility and interaction between the researcher and respondents, enabling the collection of in-depth data on the research topic and, most importantly, allowing respondents to express their feelings regarding the contribution of industrial symbiosis to farm scalability. In addition to the interview guide, recorders, notebooks, and pens were used during the data collection exercise. Overall, the interviews lasted between 30 and 40 minutes. The interviews were physically conducted in the local language to ensure that participants could freely express themselves.

3.4. Trustworthiness of qualitative data

In this study, different strategies were adopted to ensure the trustworthiness of the findings as recommended by Adler (2022) and Ahmed (2024). Specifically, credibility was enhanced by conducting the interviews in the local language (Luganda), enabling participants to express their views freely and authentically. In addition, the interviews were transcribed verbatim in Luganda and subsequently translated into English by a third party who was proficient in both Luganda and English to preserve the meaning of participants' responses and minimize translation bias. Regarding transferability, it was realized by providing a detailed description of the study context (see subsection 3.1), participant characteristics (age, educational level and marital status), sampling procedures, and data collection process, thereby enabling readers to determine the applicability of the findings to similar or related contexts. Dependability on the other hand was ensured by maintaining methodological consistency throughout the research process. A clear record of the research procedures, including participant recruitment, data collection, transcription, translation, coding, and theme development, was maintained. Moreover, a deductive thematic analysis guided by the research questions was consistently applied across all transcripts. Lastly, confirmability was achieved by presenting the findings using participants' verbatim accounts, ensuring that the interpretations reflect the participants' views rather than the researchers' assumptions or biases, thereby minimizing researcher bias and enhancing the neutrality of the findings (Marlina et al., 2025).

3.5. Data analysis

The data analysis process began with the verbatim transcription of the interviews in the local language (Luganda) to preserve the authenticity of the participants' responses. The transcripts were then translated into English by a third-party translator who was fluent in both Luganda and English to minimize potential bias during the analysis process. The translated transcripts were subsequently coded manually using a deductive thematic analysis approach (Kim & So, 2022). Thematic analysis was adopted and considered appropriate because the study sought to identify, analyze, and interprete recurring patterns in participants' views regarding the role of industrial symbiosis in fostering the scalability of smallholder farms. It provides a flexible and systematic approach for organizing qualitative data into meaningful themes while capturing both explicit and implicit meanings within participants' responses.

A deductive approach was adopted, whereby the study's research questions served as the initial coding framework (Neuendorf & Kumar, 2015). The resulting codes were then organized into themes for the presentation and interpretation of the findings. Unlike phenomenological analysis, which focuses on individuals' lived experiences, narrative analysis, which examines personal stories, discourse analysis, which investigates language use and social interaction, or content analysis, which primarily emphasizes the frequency of categories, thematic analysis enabled the researchers to identify and interprete patterns that were directly relevant to the study research questions.

3.6. Ethical consideration

Ethical considerations were strictly observed throughout the study to safeguard the rights, dignity, and well-being of participants (Dave et al., 2023). The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. As such, ethical approval was obtained from the College of Business and Management Sciences Research Ethics Committee (COBAMS–REC–2025-76), and the study was subsequently registered with the Uganda National Council for Science and Technology (UNCST Registration No. SS4430ES). Prior to participation, written informed consent was obtained from all respondents after clearly explaining the purpose of the study, the voluntary nature of participation, and their right to withdraw at any stage without any consequences. Confidentiality and anonymity were ensured by assigning codes to participants and excluding personally identifiable information from the data. Interviews were conducted in the local language to enhance understanding and allow participants to express themselves freely. All data were securely stored and accessed only by the researcher. Furthermore, the researchers ensured that the study did not expose participants to any form of psychological, social, or physical harm and that all procedures adhered to established ethical guidelines for research involving human participants.

4. Study results and discussion

4.1. Respondents characteristics

The participant characteristics explored during the study included age, marital status, education level, farming activity, farming experience, and membership in farmers' groups, as presented in Table 1.

Table 1. Participants' characteristics.

Characteristic	Category	Frequency	Percentage
Age (years)	20–29	5	17
	30–39	13	45
	40–49	7	24
	≥50	4	14
	Total	29	100
Marital status	Married	15	52
	Single/Not married	11	38
	Widowed	3	10
	Total	29	100
Highest education	Primary	10	34
	Secondary (S1–S6)	15	52
	Diploma	3	10
	PhD	1	3
	Total	29	100
Farming activity	Poultry	12	41
	Crop farming	7	24
	Dairy	2	7
	Mixed farming	8	28
	Total	29	100
Farming experience	Less than 5 years	11	38
	6–10 years	14	48
	More than 10 years	4	14
	Total	29	100
Farmer group membership	members of farmer groups	29	100
	Total	29	100

Source: Primary data.

Study results presented in Table 1 indicate that most of the participants are in the 30–39 age bracket (45%), followed by those aged 40–49 years (24%), 20–29 years (17%), while the least are aged 50 years and above (14%). Regarding the marital status of the participants, most of the smallholder farmers who participated in the study are married (52%), followed by those who are single (38%), while the least are widowed (10%). As such, the participants represented diverse age groups and marital statuses. For example, one participant stated, 'I am 39 years old, married with two children' (Participant 28), while another explained, 'I am 43 years old, not married, and a single mother' (Participant 21). Similarly, another participant noted, 'I am 53 years old. I am married and have five children' (Participant 13), whereas another remarked, 'I am 26 years old. I have two children, and I am currently not married' (Participant 29).

Concerning the education levels of the participants, the majority had attained secondary education, ranging from Senior one (S.1) to Senior Six (S.6) (52%), followed by those with primary education (34%), diploma holders (10%), and one participant who held a PhD. This level of education is considered to enhance their knowledge and skills regarding the application of industrial symbiosis in fostering the scalability of their farms. As such, one participant indicated that, 'I studied and reached Primary Seven; that's where I stopped' (Participant 4), while another noted, 'I hold a PhD, and my education has greatly helped me to manage the farm, especially in aspects such as financial management' (Participant 5).

In line with membership in farmers' groups, all participants belonged to farmer groups, which functioned as platforms for collective production, financial intermediation, and shared decision-making. These groups often had structured roles and, in some cases, jointly owned farms. This is evident from the participants' responses. For example, one participant stated, 'I am a member of the Bakyala Kulakulana Women's Group' (Participant 15), while another explained, 'I belong to the Twekembe Farmers Group, where we work together to improve our farming activities' (Participant 19). Similarly, another participant noted, 'I joined the farmers' group because it enables us to learn from one another and access training' (Participant 1).

Regarding the farming activities undertaken by the participants, a significant proportion of the smallholder farmers are engaged in poultry farming (41%), followed by mixed farming (28%), crop farming (24%) while the least are engaged in dairy farming (7%). For example, one participant explained, 'I am engaged in poultry farming, where I rear broilers and layers for both meat and egg production' (Participant 5), while another stated, 'I am involved in dairy farming, where I keep dairy cattle for milk production' (Participant 17). Similarly, another participant noted, 'We grow bananas as one of our major farming activities' (Participant 21), demonstrating the diversity of agricultural enterprises represented in the study.

Lastly, the study results indicate that most participants had been engaged in small-scale farming for a period of 6–10 years (48%), followed by those with less than 5 years of farming experience (38%), while the least had more than 10 years of farming experience (14%). For example, one participant stated, 'I have been farming for four years now' (Participant 8), while another explained, 'I have been practicing poultry farming for almost six years now' (Participant 16). Similarly, another participant remarked, 'I started farming in 2003 when we formed our group, and I have continued farming up to now' (Participant 2), indicating over two decades of farming experience.

4.2. Perceptions of the smallholder regarding the concept of scalability

The findings indicate that smallholder farmers perceive scalability as a multidimensional process involving expansion in production, market access, resource base, and operational capacity.

4.2.1. Increasing output

Farmers primarily associate scalability with the progressive increase in production levels, particularly in the number of animals, birds, and crops, as well as improvements in yields. Growth is often measured through expansion in stock and continuous reinvestment. For example, one participant noted, '…I started with 150 birds… I am between 500–600 birds… I am targeting having 1000 birds…' (Participant 12), while another explained, '…we started with one cow and now we have five… and yet we have sold off

2…' (Participant 25). These accounts reflect a strong orientation toward incremental growth and productivity enhancement.

4.2.2. Market expansion

Scalability is also understood in terms of expanding market access and strengthening customer networks. Farmers emphasized the importance of securing reliable buyers and diversifying market channels, including institutional clients and social networks. One participant stated, '…we have secured buyers who collect eggs directly from the farm in trucks…' (Participant 7), while another noted, '…I go to schools… we supply maize… they reach out when they need more…' (Participant 21). This highlights the role of market linkages in sustaining and scaling farm enterprises.

4.2.3. Farm size and diversification

Participants further perceive scalability as expansion in farm size and diversification of activities to increase output and mitigate risks. This includes acquiring additional land and integrating multiple farming enterprises. For instance, one farmer explained, '…I started with two gardens… now my farm is on 4 acres…' (Participant 12), while another reported, '…we have just acquired another big piece of land… and expand…' (Participant 7). These strategies demonstrate efforts to enhance production capacity and resilience.

4.2.4. Manpower optimization

Scalability is also linked to effective labor organization. Farmers described reliance on family labor, group-based arrangements, and selective hiring to manage increasing workloads. One participant noted, '…we don't hire external workers. The 30 group members operate the farm ourselves…' (Participant 13), while another stated, '…during the planting season, we hire people…' (Participant 29). This reflects adaptive labor strategies aimed at supporting farm expansion.

4.2.5. Access to machinery

Finally, farmers associate scalability with access to appropriate machinery and technology, although this remains a major constraint due to high costs. As a result, many rely on improvisation, borrowing, or renting equipment. One participant explained, '…we don't have sprayers… we just use a basin…' (Participant 26), while another added, '…I sometimes borrow or rent sprayers…' (Participant 6). This suggests that while mechanization is recognized as critical for scaling, limited access hinders optimal productivity.

Our results demonstrate that smallholder farmers conceptualise scalability as a holistic process involving increase in production, markets, resources, and operational efficiency, although constrained by structural and financial limitations. The study results are in agreement with Monteiro et al. (2023), who indicated that scalability includes increasing farms' production capacity and efficiency. Yu et al. (2025) added that increasing output without a corresponding increase in inputs is a key component of scalability. Our results are further supported by Jabłoński (2016), who included aspects of adoption and adaptation in measuring and operationalising scalability.

These findings can be explained through the resource-based view (RBV), which attributes differences in firm growth and performance to variations in the resources and capabilities available to firms. From this perspective, farm scalability depends on the ability of smallholder farmers to access, combine, and efficiently utilise tangible and intangible resources, such as land, labour, machinery, knowledge, finance, and market information. Therefore, the structural and financial limitations identified by the farmers represent resource constraints that may restrict their ability to increase production, diversify their activities, improve efficiency, and access wider markets.

Moreover, Pranuthi and Srikanth (2023) presented scalability in terms of the economic, social, and environmental aspects that businesses may undertake in response to the varied needs of different stakeholders. However, the identified perceptions directly relate to the agricultural sector and appear to have been overlooked in the existing body of knowledge. Thus, based on this study, we present farm scalability as the ability of a small-scale farm to grow sustainably by producing more output, accessing better or wider markets, gradually expanding and diversifying farm activities, efficiently using limited household labour, and improving access to affordable or shared machinery to increase productivity and efficiency. Consistent with the RBV, this conceptualisation demonstrates that farm scalability is influenced by farmers' ability to mobilise and effectively utilise the resources and capabilities required to support sustainable farm growth.

4.3. Industrial symbiotic practices by smallholder farmers

The findings demonstrate that smallholder farmers engaged in multiple interrelated symbiotic practices that enhance resource efficiency, reduce costs, and support farm productivity and scalability.

4.3.1. Reuse of animal waste as organic manure

Farmers consistently reused livestock waste such as chicken droppings, cow dung, pig dung, and urine as organic manure for crop production. This practice reduced reliance on external inputs while improving soil fertility. As one participant explained, 'From chicken rearing, I use the droppings in banana planting holes. They improve growth. When I don't have enough, I buy from fellow farmers' (Participant 18). Similarly, another noted, 'I use pig manure from my own farms in my plantation and sometimes it may not be enough' (Participant 14).

4.3.2. Utilization of crop residues for mulching and soil management

Crop residues such as maize stems, husks, banana leaves, and soya bean residues were repurposed as mulch to conserve soil moisture, suppress weeds, and enhance soil quality. For example, one participant stated, 'I use maize stems as mulch in my banana plantation to suppress weeds and retain soil moisture during the dry season' (Participant 15). Another added, 'Now for maize, after harvest, we get the husks and put them in our banana plantation for mulching' (Participant 8).

4.3.3. Conversion of waste into animal feed

Farmers innovatively converted organic waste into alternative feed sources, particularly through maggot and black soldier fly production. This reduced feed costs and enhanced circular resource use. One participant explained, 'We use chicken droppings to produce maggots, which we feed to the birds as protein' (Participant 12). Another reported, 'We do back fly breeding to get pupa… these are used to feed fish' (Participant 6).

4.3.4. Commercialization and exchange of farm waste

Farm waste was not only reused internally but also sold or exchanged with other farmers, creating additional income streams and reinforcing inter-farm linkages. One participant noted, 'We rear poultry birds, get their waste, and sell it to banana plantation farmers and tomato farmers' (Participant 1). Another explained, 'Some manure we use, and the rest we sell' (Participant 16).

4.3.5. Integration of crop and livestock systems

Farmers deliberately integrated crop and livestock enterprises, where outputs from one activity served as inputs for another such as maize grown for feed, residues used for mulch. This enhanced internal resource circulation. One participant explained, 'We use chicken droppings as fertilizer in our maize gardens… this helps our crops grow well' (Participant 19).

4.3.6. Sharing, borrowing, and hiring of farm assets

Farmers engaged in collective utilization of assets such as sprayers, storage facilities, and machinery through borrowing, hiring, or group ownership arrangements. This enabled access to resources despite financial constraints. One participant stated, 'We still have like four traditional sprayers which belong to the group… non-members also come and borrow from our farm, but at a small fee'

(Participant 2). Another noted, 'We hire equipment… we pay 4,000 shillings per sack for threshing' (Participant 3).

4.3.7. Collective labor and rotational work systems

Group-based labor sharing was widely practiced, with members contributing labor through organized schedules. This reduced labor costs and ensured continuity of farm operations. As one participant explained, 'We don't hire external workers. The 30 group members operate the farm ourselves. We follow a timetable where three members care for the chickens each day and night' (Participant 15).

4.3.8. Adoption of renewable energy and water management innovations

Farmers adopted solar energy, water harvesting, and water storage systems to sustain operations while minimizing costs. These practices supported efficient resource utilization. One participant stated, 'As a group we installed solar' (Participant 9). Another added, 'We use solar energy to power the pump… it is very efficient and sustainable for the farm' (Participant 6).

4.3.9. Knowledge sharing and learning networks

Farmers actively engaged in knowledge exchange through groups, trainings, and extension services, enabling diffusion of best practices and continuous learning. One participant noted, 'Every Sunday during our savings meetings, we share knowledge on farming methods, medications, and more' (Participant 17). Another stated, 'We interact and share ideas, best practices of farming' (Participant 1).

The study results reveal that smallholder farmers practice industrial symbiosis characterized by waste-material utilization, resource sharing, integrated farming systems, and collaborative learning. These practices collectively enhance efficiency, resilience, and scalability of farm enterprises. Our results are supported by Neves et al. (2019), who present industrial symbiosis as an approach in which the waste or by-product of one enterprise is used by another company as raw material. This is evident among smallholder farmers, who use chicken droppings, cow dung, pig manure, and urine as organic manure for crop production within their farms or provide these materials to other farmers in their social groups.

These practices are consistent with the resource-based view (RBV), which emphasises the strategic value obtained from accessing, combining, and effectively utilising resources and capabilities. From the RBV perspective, agricultural waste, shared equipment, knowledge, and social relationships represent valuable resources that smallholder farmers can mobilise to improve their farm operations. Through waste-material utilisation and resource sharing, farmers transform underutilised resources into productive inputs, while integrated farming systems enable them to recombine existing resources to generate greater value. Collaborative learning also facilitates access to knowledge and capabilities that individual farmers may be unable to develop independently. Industrial symbiosis therefore enables resource-constrained smallholder farmers to overcome limitations in individually owned resources by accessing and mobilising resources available within their farming networks.

Our results are further supported by Boom-Cárcamo and Peñabaena-Niebles (2022), who introduced the aspect of collaboration among farms through which they exchange materials, energy, and waste. However, some unique practices, such as integrating crop and livestock systems, using crop residues for mulching and soil management, and converting waste into animal feed, emerged as distinctive to the agricultural sector. These practices strengthen the application of industrial symbiosis to the context of developing countries, with a particular focus on smallholder farmers. Consistent with the RBV, they also demonstrate that the strategic value available to smallholder farmers originates not only from the resources they own but also from resources accessed, exchanged, reused, and recombined through symbiotic relationships.

4.4. The influence of industrial symbiosis on scalability of smallholder farmers

The findings indicate that smallholder farmers perceive industrial symbiosis as a critical mechanism for enhancing farm scalability through its effects on output, revenue generation, and operational efficiency.

These contributions are presented below in line with APA 7th edition qualitative reporting standards, with clear points, explanations, and verbatim supporting quotes.

4.4.1. Industrial symbiosis and farm output

Farmers reported that industrial symbiosis enhances farm output through the internal reuse of resources, particularly the conversion of animal waste into manure and crop residues into feeds. This cyclical use of resources improves soil fertility and accelerates animal growth, leading to increased yields and higher production volumes. For instance, one participant noted, 'I no longer use chemical fertilizers. I use poultry waste, and my crops like beans and bananas look good and yield better' (Participant 13). Similarly, another explained, 'Once you provide them with maize feed, they grow so fast' (Participant 21). These accounts demonstrate that symbiotic practices improve both crop and livestock productivity, thereby increasing overall farm output.

4.4.2. Industrial symbiosis and farm revenue

Industrial symbiosis contributes to increased farm revenue through both direct and indirect pathways. Increased output leads to higher sales, while the commercialization of farm waste such as manure and residues creates additional income streams. Farmers also emphasized cost savings as a form of implicit revenue gain. One participant explained, 'Using chicken manure… has made my soil fertile, improving harvests and increasing profits' (Participant 26). Another stated, 'At times we just sell the waste off, and it also increases our earnings' (Participant 23). These findings indicate that industrial symbiosis not only enhances production but also strengthens the financial performance of farm enterprises.

4.4.3. Industrial symbiosis and operational efficiency

Farmers further associated industrial symbiosis with improved operational efficiency through reduced input costs and better resource utilization. By recycling waste within the farm or exchanging it with neighboring farms, farmers minimize expenditure on fertilizers, feeds, and waste disposal. One participant explained, 'I can go there, get that waste freely or pay a little money, then take it to my garden to improve my productivity' (Participant 10). Another highlighted the cyclical nature of resource use, stating, 'If you have cows, they give you manure and use that manure to grow for the cow healthy grass… they move hand in hand' (Participant 11). Additionally, the use of crop residues reduced labor and time costs, as noted by one farmer: 'Using maize stems for mulching reduces weed growth. This saves time and money that would otherwise go to weeding' (Participant 15). These practices collectively enhance efficiency, enabling farmers to achieve more with limited resources.

Study results indicate that industrial symbiosis facilitates farm scalability by simultaneously increasing output, enhancing revenue, and improving operational efficiency. Through waste valorisation, resource exchange, and integrated farming systems, farmers can expand production, reduce costs, and strengthen resilience. These findings are consistent with the resource-based view (RBV), which proposes that enterprise growth depends on access to valuable resources and capabilities and how effectively these resources are combined and utilised (Barney, 1991; Wernerfelt, 1984). From an RBV perspective, industrial symbiosis strengthens the resource base of smallholder farms by enabling farmers to access, exchange, and productively utilise resources that may be unavailable or unaffordable to them individually. These results demonstrate that industrial symbiosis is not merely an environmental practice but also a strategic resource-mobilisation approach that underpins sustainable farm growth and scalability among smallholder farmers.

The findings agree with Kimuli et al. (2025), who reported that micro and small enterprises in Uganda benefit from industrial symbiosis by creating new revenue streams, lowering operational costs, and accessing shared infrastructure. This results in the generation of greater profits without a corresponding increase in the costs of operating the farm. From an RBV perspective, shared infrastructure and exchanged resources expand the resource bundles available to farmers and enable them to overcome resource constraints that would otherwise limit their scalability. Guan et al. (2023) added that as farms engage in symbiotic networks, they gain access to innovations and market opportunities that might otherwise be inaccessible to them independently. These benefits contribute to growth in both the scale and scope of farm enterprises. This finding is also supported by Katana et al. (2024), who noted that industrial symbiosis facilitates knowledge-sharing, which is important for adopting better farming methods, understanding appropriate farm inputs, and accessing markets that are vital for attaining farm scalability. In line with the RBV, such knowledge, innovations, market opportunities, and collaborative relationships constitute valuable resources and capabilities that farmers can mobilise to enhance productivity, efficiency, and farm scalability.

5. Summary and conclusion

This study demonstrates that smallholder farmers conceptualize scalability as a multidimensional and practice-driven process encompassing increased output, expanded market access, efficient resource utilization, and strengthened operational capacity. Rather than a linear progression, scalability is understood as a dynamic and adaptive process embedded in routine farm practices. Central to this process is industrial symbiosis, which farmers perceive as the cyclical use and exchange of resources, where waste or by-products from one activity serve as inputs for another. The findings further reveal that farmers actively engage in a range of symbiotic practices, including waste reuse such as application of manure, crop–livestock integration, alternative feed production, resource sharing, and knowledge exchange. These practices collectively contribute to enhanced farm output, improved revenue streams, and increased operational efficiency. Consequently, industrial symbiosis emerges as a practical and contextually grounded strategy that enables smallholder farmers to achieve scalability within resource-constrained environments.

6. Implications of the study

The findings of this study have several implications to the policymakers, smallholder farmers and the academia. For the policymakers, there is a need to institutionalize industrial symbiosis within agricultural policy frameworks by promoting integrated farming systems, organic input use, and circular agriculture models. Policies should incentivize waste valorization such as manure processing and bio-feed production through subsidies, training programs, and extension services. In addition, the government should invest in enabling infrastructure and shared resource systems, including affordable machinery hubs, water systems, and renewable energy solutions like solar-powered irrigation, to reduce operational constraints that limit scalability.

For the smallholder farmers, they should strengthen and formalize symbiotic practices such as integrating crop and livestock enterprises, recycling waste, and engaging in cooperative resource sharing. These practices not only reduce costs but also enhance productivity and resilience. Additionally, farmers should leverage collective action through farmer groups and networks to access markets, share knowledge, and pool resources, thereby improving both efficiency and scalability outcomes.

7. Limitations and areas for future research

This study is subject to several limitations. First, the findings are based on cross-sectional qualitative data, which limits the ability to establish causal relationships between industrial symbiosis and scalability outcomes. Second, the study relies primarily on self-reported farmer perceptions, which may introduce subjective bias. Third, the focus on smallholder farmers within a specific context limits the generalizability of the findings to other regions or agricultural systems. As such, future research should adopt longitudinal and mixed-method designs to track the impact of symbiotic practices on scalability over time. There is also a need to incorporate multi-actor perspectives, including input suppliers, extension workers, and policymakers, to better understand the broader symbiotic ecosystem. Additionally, future studies could explore quantitative measurement models of industrial symbiosis and examine moderating factors such as technology adoption, institutional support, and market dynamics. Moreover, future studies need to conduct a comparative study of farmers who have applied industrial symbiosis successfully and those who have also adopted industrial symbiosis but continue to struggle with scaling their farms. This will provide actionable strategies to foster successful application of industrial symbiosis in developing countries with positive outcomes.

Author contributions

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Data availability statement

The data supporting the findings of this study consist primarily of qualitative interview transcripts and related field notes collected from participants under conditions of confidentiality and informed consent. Due to ethical, privacy, and confidentiality considerations, the raw interview data cannot be made publicly available in an open repository. However, de-identified excerpts and supporting data relevant to the findings presented in this study are included within the article. Additional anonymized data may be made available by the corresponding author upon reasonable request and subject to approval in accordance with institutional ethical guidelines and participant consent agreements.

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