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Article

The contribution of circular economy initiatives to sustainable food security in Rwanda: A case of Gensi Farms, Gasabo District

Nkundabaramye Vincent[1], Ayinshuti Remy Paul[2]

[1] Kigali Independent University ULK, School of Social Sciences, Department of Development Studies and International Relations, Kigali, Rwanda
[2] African Circular Economy Network (ACEN), Country Representative Office, Kigali, Rwanda

Abstract

This study investigates the contribution of circular economy initiatives to sustainable food security in Rwanda. The study analyzes the extent to which resource efficiency promotion affects sustainable food security, assesses the contribution of waste management to sustainable food security, and examines the contribution of closed-loop systems to sustainable food security as well as the challenges faced in implementation of circular economy initiatives in Rwanda. Employing descriptive statistics and thematic analysis, the study analysed data collected using questionnaire and interviews from a sample size of 238 respondents. Key findings reveal that resource efficiency, waste management, and closed-loop systems significantly enhance soil fertility, reduce post-harvest losses, and contribute to environmental conservation, thereby supporting sustainable food security. However, the challenges such as inconsistent policy frameworks, financial constraints, limited technological infrastructure, and low awareness levels hinder effective implementation of circular initiatives. The study highlights a need for enhancing multi-stakeholder collaboration, investing in advanced technologies, and engaging local communities, while calling for strengthening regulatory frameworks, providing financial incentives, and promoting the adoption of advanced technologies.

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Circular economy; Sustainable food security; resource efficiency; waste management; closed-loop systems

Introduction

Sustainability has emerged as a cornerstone for addressing global challenges, with scholars emphasizing its social, environmental, and economic dimensions. Central to these discussions is the circular economy (CE), a regenerative model designed to minimize resource input, waste, and emissions while maximizing efficiency through practices such as recycling, repair, and remanufacturing (Konietzko et al., 2019). The Ellen MacArthur Foundation (2019) underscores that CE seeks to replace the traditional linear "take-make-dispose" system with closed-loop systems that align with a no-waste philosophy. Globally, CE has demonstrated substantial benefits, including economic growth, resource conservation, and social inclusion. For instance, European countries like the United Kingdom (UK), France, and Germany have integrated CE principles into their policies to tackle climate change, biodiversity loss, and pollution, while boosting renewable energy use and resource efficiency (Ellen MacArthur

Corresponding Author Nkundabaramye Vincent ✉ Kigali Independent University ULK, School of Social Sciences, Department of Development Studies and International Relations, Kigali, Rwanda

Foundation, 2019). For example, large corporations in the United States (U.S.) and South America have embraced CE to build resilience, create new value, and achieve sustainability objectives (Ellen MacArthur Foundation, 2019). These examples highlight the transformative potential of CE in fostering sustainable development globally.

Rwanda, in particular, has made notable strides in economic development and poverty reduction but continues to face significant food security challenges. According to the World Food Programme (WFP), nearly 38% of its population lives below the poverty line, and 20% is classified as food insecure. Chronic malnutrition among children under five stands at 32.4%, reflecting deep-seated issues of limited arable land and a rapidly growing population (WFP, 2023). To address these concerns, Rwanda has embraced CE principles through initiatives outlined in its National Strategy for Transformation (NST1) and implemented policies like the ban on single-use plastics and agro-ecological practices (Dsilva, 2023). One illustrative case is Gensi Farms, which exemplifies the integration of CE practices. Initially a small-scale dairy operation, the farm diversified into poultry and agroforestry, utilizing organic waste to produce high-quality compost and biogas. This circular approach not only improved productivity but also reduced waste and contributed to environmental sustainability[2]. Such examples underscore the potential of CE to enhance resource efficiency and drive sustainable agricultural practices.

Despite these promising developments, Rwanda's integration of CE into agriculture remains in its infancy. Challenges like land degradation, resource limitations, and socio-economic disparities hinder the widespread adoption of CE practices (Dsilva, 2023). Addressing these barriers is essential to unlock CE's potential in achieving sustainable food security. This study aims to bridge the gap by exploring the nexus between CE initiatives and sustainable food security in Rwanda. It seeks to assess the impact of resource efficiency, waste management, and closed-loop systems on food security while examining the challenges faced by entities like Gensi Farms in implementing CE practices. The findings will offer evidence-based insights to guide policy development, enhance stakeholder engagement, and support Rwanda's pursuit of sustainable development goals. In this study, in addition to the introduction of the study, the literature review, research methodology and presentation of the findings as well as conclusion and recommendations are presented clearly.

Literature Review

This section of literature review existing literature on the key concepts, the theoretical foundation of the study and empirical studies on the variables.

Circular Economy Concepts

The concept of the circular economy originates from various schools of thoughts and has evolved significantly over time (Ghisellini et al., 2016). Initially introduced by environmental economists building on the foundational studies of ecological economist Boulding (1966), CE is conceptualized as a "closed system with practically no exchanges of matter with the outside environment." This closed-loop system emphasizes the sustainability of human life on Earth and aligns with principles found in General Systems Theory. Industrial ecology, a related field, has played a critical role in advancing CE by promoting the closure of material and energy

[2] https://www.gensifarms.rw/about-us/; Gensi Farms, About Us, March 25, 2025

cycles to enable less wasteful and more efficient industrial processes. Fundamentally, the CE remains deeply rooted in the principles of industrial ecology, which continues to shape its theoretical framework and practical applications (Ghisellini et al., 2016).

In recent years, the circular economy has garnered significant attention, particularly among policymakers and researchers. For instance, the European Commission has recognized CE as a tool to enhance global competitiveness, foster sustainable economic growth, and create employment opportunities (Brennan et al., 2015). This recognition culminated in the adoption of the first circular economy action plan in 2015, which aimed to facilitate Europe's transition toward a more sustainable economic model (European Commission, n.d). Similarly, the Chinese Circular Economy Promotion Law has been instrumental in advancing CE practices in Asia (World Bank, 2024). Businesses have also started embracing the value and opportunities of CE, contributing to its emergence as a prominent area of academic inquiry. The growing body of literature on CE reflects its importance in addressing contemporary challenges and highlights the necessity of defining the concept within a modern context to ensure its effective implementation.

Circular Economy and Sustainability

To comprehend the philosophy of the CE, it is crucial to explore its connection with sustainability and its dimensions. The World Commission on Environment and Development (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Initially, sustainability focused on preserving the environment and achieving social equity. Over time, this concept expanded to incorporate economic dimensions, urging businesses to minimize their environmental impact while promoting social responsibility and achieving economic growth. A significant evolution occurred post-2015 when sustainable development began aligning with the United Nations' Sustainable Development Goals (SDGs), further embedding the concept into global and corporate agendas (Nikolaou, 2021).

In recent decades, the "Triple Bottom Line" framework has become a central paradigm for sustainability, emphasizing the integration of economic, social, and environmental dimensions (Geissdoerfer et al, 2017). This approach challenges companies to pursue profitability while fulfilling social and environmental responsibilities. As an assessment framework, it measures how businesses, non-profits, and governments align with sustainability requirements, considering the three interconnected pillars. The overlap between CE and sustainability has increasingly intrigued researchers, highlighting shared objectives such as fostering sustainable economic growth and improving environmental performance (Zhao et al., 2018). However, CE principles appear to focus less on social dimensions compared to sustainability principles, emphasizing the need for innovative circular business models to achieve comprehensive sustainability goals (Murray et al., 2017).

Theoretical Review

This section provides a review of key relevant theories to the study, including the Food System Theory, Human-Environment Interaction Theory, and Sustainable Livelihood Theory. Each of these theories is examined to highlight how these frameworks contribute to understanding the dynamics of the study area, offering a robust theoretical foundation to inform the analysis and interpretation of findings.

Food System Theory

The Food System Theory offers a comprehensive framework for understanding the complex interrelations between food production, distribution, consumption, and their impact on the environment, society, and economy. Rooted in systems thinking, the theory emphasizes the interconnectedness of various components within the food system and their external influences (Ericksen, 2008). Proponents of this theory, such as Ericksen (2008) and Ingram (2011), argue that food systems must be viewed as dynamic networks influenced by global and local drivers, including climate change, economic policies, and technological advancements. This perspective is particularly valuable in addressing global challenges like food insecurity, as it highlights vulnerabilities and opportunities for intervention at multiple levels of the food system.

A key strength of the Food System Theory lies in its holistic approach, integrating environmental sustainability, social equity, and economic viability. By identifying feedback loops and interdependencies, the theory provides a robust platform for developing targeted strategies to enhance food system resilience and sustainability (Ingram, 2011). However, its complexity is also a notable weakness. The extensive scope of the theory can lead to challenges in operationalization, as it requires significant data and analytical resources to account for the myriad of interactions within and outside the food system (Ericksen, 2008). Additionally, critics argue that the theory does not adequately address power dynamics and inequalities in food systems, which are critical to achieving equitable outcomes (Patel, 2009). The significance of Food System Theory to the study of circular economy initiatives and sustainable food security is profound. The theory provides a lens for understanding how circular economy principles—such as waste minimization, resource efficiency, and closed-loop systems—can be integrated into food systems to address sustainability challenges. For instance, circular strategies like nutrient recycling, composting, and energy recovery align with the theory's emphasis on systemic sustainability (Borrello et al., 2020). By applying Food System Theory, this study can identify pathways for enhancing food security through circular economy initiatives while considering the environmental, social, and economic dimensions critical to long-term sustainability.

Human Environment Interaction Theory

The Human Environment Interaction (HEI) theory examines the complex relationships between humans and their surrounding environment, emphasizing how human activities influence environmental conditions and how the environment, in turn, impacts human societies. Proponents of this theory, such as Turner et al. (1990), emphasize the interconnectedness between human actions and natural systems, asserting that this relationship is not static but rather dynamic and reciprocal. The theory originates from the field of geography and environmental sciences and incorporates interdisciplinary perspectives to explore issues like resource use, environmental degradation, and sustainable practices. It builds on earlier work in cultural ecology and human geography, which analyzed the spatial and temporal interactions between people and their environments.

One of the strengths of the HEI theory lies in its capacity to integrate multiple disciplines, such as sociology, geography, and environmental science, to provide a holistic understanding of human-environment dynamics. It facilitates the identification of patterns and processes that underlie environmental challenges, such as deforestation, soil degradation, and water pollution, while offering insights into adaptive and mitigative strategies. However, the theory also has its weaknesses. Critics argue that its broad scope can sometimes lack specificity, making it challenging to develop precise models or solutions for localized issues (Ostrom, 2009). Additionally, the theory often assumes a linear relationship between humans and the environment, which may oversimplify complex, non-linear feedback mechanisms in ecological systems (Turner et al., 2007).

The significance of HEI theory to CE initiatives and sustainable food security lies in its emphasis on resource use and sustainability. By focusing on the interplay between human activities and environmental systems, the theory underscores the need for circular practices that minimize waste, promote resource efficiency, and restore ecological balance. For sustainable food security, HEI theory highlights the importance of maintaining the health of ecosystems that underpin agricultural productivity. For instance, adopting circular economy principles, such as composting organic waste to enrich soils, aligns with the theory's emphasis on sustainable resource management and adaptive strategies. This integration of HEI theory into CE initiatives provides a valuable framework for addressing food security challenges in a manner that balances human needs and ecological integrity.

Sustainable Livelihood Theory

Sustainable Livelihood Theory (SLT) focuses on understanding and enhancing the means through which individuals and communities secure a living in ways that are resilient, equitable, and environmentally sustainable. Originating from the works of Chambers and Conway (1992), the theory emphasizes the interplay between assets, strategies, and institutional processes in shaping livelihoods. According to SLT, a sustainable livelihood is one that can cope with and recover from stressors, maintain or enhance its assets, and provide sustainable benefits for future generations without depleting the natural resource base. This framework places significant emphasis on human, social, natural, physical, and financial capital as critical components of livelihoods, and it recognizes the importance of the external environment, including policies, institutions, and cultural norms, in influencing livelihood outcomes.

One of the key strengths of SLT is its holistic and people-centered approach, which integrates social, economic, and environmental dimensions of sustainability (Scoones, 1998). This inclusivity makes it particularly effective in addressing multidimensional challenges such as poverty, inequality, and environmental degradation. Additionally, the theory is highly adaptable and has been widely applied in diverse contexts, including rural development, disaster resilience, and resource management. However, SLT has been critiqued for its complexity and for providing insufficient attention to the power dynamics and structural inequalities that often constrain livelihood opportunities (De Haan, 2012). Its focus on local-level analysis can also overlook broader systemic factors such as globalization, market fluctuations, and policy shifts, which are critical in understanding livelihood vulnerabilities. SLT is highly relevant to the study of CE initiatives and sustainable food security. By emphasizing the importance of natural and social capital in sustaining livelihoods, SLT aligns with CE principles of resource efficiency, waste reduction, and regeneration of ecosystems. For instance, applying SLT in the context of sustainable food systems can highlight the role of smallholder farmers, their access to resources, and their ability to adopt circular practices such as composting, water recycling, and agroforestry. Moreover, SLT's focus on resilience and adaptive capacity provides valuable insights for designing CE initiatives that enhance food security in the face of climate change and other stressors. By addressing both livelihood and environmental concerns, SLT offers a comprehensive framework for advancing sustainable development goals in the context of food systems.

Empirical Review

The growing recognition of the need for more sustainable and resilient food systems has led to increased attention on circular bioeconomy (CBE) models. In light of the escalating challenges of food insecurity amidst a growing global population and diminishing agricultural resources, several studies underscore the importance of transitioning from linear production models to CBE approaches (Sekabira et al., 2022). CBE, which emphasizes the recycling and reuse of organic waste, has become a crucial strategy for achieving sustainable food production systems, particularly in sub-Saharan Africa (SSA). However, the transition to CBE practices in SSA has been slow, with limited scientific evidence and policy guidance to support the scaling of these practices (Sekabira et al., 2022; Sekabira et al., 2024).

Research in various African countries highlights the potential of CBE practices, such as composting, waste sorting, and using organic waste for livestock feed, to improve household food security. Sekabira et al. (2024) explore these practices across DRC, Ethiopia, Rwanda, and South Africa, finding that using organic waste as compost or livestock feed significantly contributes to improved food security, particularly in smallholder farming communities. Furthermore, their study suggests that socioeconomic factors—such as access to land, education, and income—play an essential role in the adoption of CBE practices. The findings emphasize the need for targeted interventions that consider local contexts and socioeconomic realities to maximize the impact of CBE innovations on food security (Sekabira et al., 2024). However, the status of CBE in SSA is far from ideal, with many regions still relying on traditional waste management practices. For example, in Nyanza district of Rwanda, waste management practices remain rudimentary, with low rates of waste sorting and minimal waste collection infrastructure (Sangwa et al., 2023).

Despite this, there is a strong willingness among communities to adopt CBE practices, especially with proper awareness and capacity building initiatives. Similarly, studies in Rwanda's urban slums reveal that while informal circular practices like repurposing and waste upcycling exist, there is a significant gap in the skills and knowledge necessary for effective waste sorting (Robertson et al., 2024). This suggests that raising awareness and fostering a deeper understanding of CBE among local communities is crucial for its successful implementation. The challenges faced by CBE in SSA are compounded by policy gaps and limited investment in CBE initiatives. Sekabira et al. (2022) note that in countries like Rwanda, Ethiopia, and DRC, policies to stimulate CBE investments are largely absent, limiting the potential for large-scale adoption. Moreover, research on CBE policies in Africa shows that while several countries are beginning to strengthen their governance and support CBE practices, the pace remains slow (Koech et al., 2023). The need for comprehensive policies that integrate CBE practices into national development strategies is critical for ensuring sustainable food production systems in SSA.

In addition, the adaptation of CBE principles in SSA's agricultural sector faces numerous barriers, including inadequate infrastructure, lack of technical expertise, and the persistence of linear waste management practices (Debrah et al., 2022). For example, in Rwanda, despite the government's commitment to a circular economy, the lack of locally available packaging materials and machinery poses significant challenges to implementing circular practices in agribusinesses (Kim et al., 2023). This highlights the need for systemic changes that support infrastructure development and the scaling of circular innovations in the agricultural sector. Overall, while CBE offers a promising pathway to enhance food security and sustainability in SSA, there are significant barriers that need to be addressed. These include the need for robust policies, improved infrastructure, and better awareness and education on CBE practices at the community level. Research indicates that CBE innovations are most effective when they align with local socioeconomic contexts and are supported by strong governance frameworks (Sekabira et al., 2023; Koech et al., 2023). As SSA continues to grapple with food insecurity, the transition to a circular bioeconomy, while complex, offers an opportunity to build more resilient and sustainable food systems.

Method

This section presents the research methodology, including data collection techniques and analysis methods employed in conducting the study.

Research Design, Population and Sampling

The study adopted a descriptive research design, serving as the foundational approach for interpreting and analyzing data. This design is essential for providing a clear and comprehensive understanding of the study's objectives and the phenomena under investigation. The population of the study consists of 585 individuals, including 23 employees, 554 clients/beneficiaries, and 8 stakeholders of Gensi Farms, from whom a sample size of 238 individuals to provide insights relevant to the research objectives. The sample size was determined using formula developed Yamane (1967) as illustrated below:

$n = \frac{N}{1+N\,(e)^2}$ whereby, n = sample size; N = target population and e = margin error, which is equal to 5% (0.05) in this case.

$n = \frac{585}{1+585\,(0.05)^2} = \frac{585}{2.4625} = 237.563 \approx 238$ respondents.

Given the heterogeneous nature of the population, stratified sampling was utilized to ensure that all relevant subgroups (or strata) within the population are adequately represented. This approach allowed the researchers to capture variations across different segments of the population. After dividing the population into distinct strata, simple random sampling technique was applied within each subgroup. A complete list of potential respondents within each stratum was compiled, and individuals were randomly selected, ensuring that every member of the stratum had an equal chance of being included in the sample. By combining both stratified and simple random sampling methods, the study aimed to enhance the representativeness of the sample and ensure that the findings are both reliable and generalizable.

Data Collection

A combination of questionnaires and interviews were employed to gather both quantitative and qualitative data that align with the research objectives. Questionnaire served as the primary tool for data collection and consisted of a series of closed-ended questions focused on key issues relevant to the study. The researcher distributed the questionnaire to all respondents, aiming to collect structured information related to the research objectives. Furthermore, interviews were conducted as part of the data collection process. A combination of face-to-face and virtual interviews was carried out with selected respondents, primarily focusing on employees from Gensi Farms. Interviews aimed to explore more in-depth, qualitative information, complementing the data collected through questionnaire.

Validity and Reliability

To ensure validity, a pilot study with a small sample of respondents was conducted. This allowed to identify potential issues in the research design and instruments. The pre-test provided an opportunity to assess the clarity of the questions and whether data could be easily processed and analyzed. Ambiguous questions were rephrased to ensure clarity and uniformity in interpretation across all respondents. Reliability was assessed using Cronbach's alpha coefficient to determine how closely related the items are as a group (Gliem & Gliem, 2003). The Cronbach's alpha coefficient for this study was 0.724, indicating a significant level of reliability as highlighted by George and Mallery (2003).

Data Analysis

Collected data were processed through editing and coding. Frequency distribution tables were constructed to summarize the findings based on the main themes in the questionnaire. Data analysis was conducted using both descriptive statistical analysis and thematic analysis. Descriptive statistics, including frequency and percentage calculations, were used to quantify and summarize survey responses. This analysis provided a clear overview of the distribution and prevalence of various factors related to circular economy practices and their impact on sustainable food security. In addition to the quantitative analysis, thematic analysis was applied to qualitative data collected from interviews and open-ended survey responses. This approach helped identify recurring themes and patterns, enriching the study's findings. The combination of these two analytical approaches allowed for a comprehensive understanding of both quantitative and qualitative aspects of the research. By utilizing descriptive statistics and thematic analysis, the study was able to examine how resource efficiency, waste management, and closed-loop systems contribute to sustainable food security at Gensi Farms in Gasabo District.

Results

The results on the contribution of resource efficiency promotion, waste management and closed-loop systems to sustainable food security are presented, analyzed and discussed, starting by demographic identification of the respondents. The respondents are described in terms of their age, gender, educational level, and marital status (see Table 2). These factors are essential for understanding the composition of the participants and provide a contextual background for the study's findings. Indeed, the profile of respondents provides critical insights into the composition of individuals involved in circular economy initiatives at Gensi Farm in Gasabo District, Rwanda. A total of 238 respondents participated in the study, including both males and females with 60.5% and 39.5% respectively, reflecting gender dynamics in engagement with activities at Gensi Farm. This implies that addressing gender inclusivity remains essential to ensuring balanced participation and equitable distribution of benefits derived from circular economy initiatives. Additionally, respondents exhibit a wide range of educational attainments, with 30.3% and 19.7% who completed primary and secondary school respectively. The majority possesses the university education, including 20.2% holding a diploma, 19.7% with a bachelor's degree and 10.1% with master's degree. Such a distribution highlights the potential for understanding and adopting circular economy concepts, particularly among those with higher educational qualifications.

Table 1. Demographic identification of respondents

Items		Number of respondents	Percentage
Gender	Male	144	60.5
	Female	94	39.5
	Total	**238**	**100.0**
Educational level	Primary	72	30.3
	Secondary	47	19.7
	Diploma	48	20.2
	Bachelor	47	19.7
	Masters	24	10.1
	Total	**238**	**100.0**
Age	Below 20	24	10.1
	21 – 30	95	39.9
	31 – 40	72	30.3
	41 – 50	24	10.1
	Above 50	23	9.7
	Total	**238**	**100.0**
Marital status	Single	72	30.3
	Married	66	69.7
	Total	**238**	**100.0**

Source: Field data, 2024

Furthermore, 70.2% of respondents fall within economically productive age range of 21 to 40 years, with 39.9% aged 21–30 and 30.3% aged 31–40. Younger individuals below 20 years and older adults above 50 years are less represented, making up 10.1% and 9.7%, respectively, while 10.1% of respondents are aged 41–50. This indicates that participants are generally in active age to engage in and contribute to innovative practices aligned with circular economy principles. Efforts to include younger and older age groups could, however, enhance intergenerational learning and sustainability of these initiatives. Moreover, 69.7% of respondents are married, implying the influence of family responsibilities in participation in sustainable food security activities. Married individuals are likely to prioritize the long-term benefits of initiatives that ensure stability and well-being for their households.

The first objective of the article is to examine the contribution of resource efficiency promotion to sustainable food security in Gensi farms. From respondents' perception, the results obtained shows that the adoption of circular economy has been promoting and contributing to the sustainable development attainment, including the promotion of resource efficiency leading to sustainable food security. Table 3 shows the descriptive statistics of the variables used to describe how resource efficiency promotion affects sustainable food security.

Table 2. Effect of resource efficiency promotion to sustainable food security

Item	Very High		High	
	n	**%**	**n**	**%**
Resource recovery programs affect sustainable food security	119	50	119	50
Reusable resources and recyclable packaging affect sustainable food security	95	39.9	143	60.1
Extended producer responsibility affects sustainable food security	142	59.7	96	40.3
Circular food systems improve soil fertility	166	69.7	72	30.3
Value addition reduces post-harvest losses	238	100		
Multi-stakeholder collaboration enhances circular economy projects	166	69.7	72	30.3
Circular economy practices aid environmental conservation	96	40.3	142	59.7
Food systems with circular strategies are resilient to climate change	144	60.5	94	39.5

Source: Field data, 2024

The results in Table 3 reveal that a notable outcome of resource efficiency promotion is the unanimous agreement (100%) on the role of value addition in reducing post-harvest losses, which directly impacts food security by preserving food quality and quantity. Circular food systems are also very highly and highly identified by respondents (69.7% and 30.3% respectively) as means to improve soil fertility. Furthermore. The study highlights multi-stakeholder collaboration (69.7% very high and high=30.3%) and circular economy practices (very high=40.3% and high=59.7%) as crucial elements for environmental conservation and project enhancement, reflecting the importance of an integrated approach to resource management. The resilience of food systems to climate change, as acknowledged with very high and high by 60.5% and 39.5% of participants respectively, further emphasizes the adaptability benefits of circular strategies. Reusable resources and recyclable packaging were very highly and highly supported by 39.9% and 60.1% of respondents respectively to affect sustainable food security. Moreover, resource recovery programs and extended producer responsibility initiatives received almost equal recognition across very high and high scales, each contributing significantly to sustainable outcomes.

The second objective of the article is to analyse the contribution of waste management to sustainable food security in Gensi farm. The study employed descriptive statistics (Table 4) to analyse the perceptions of respondents on the possible effects of waste management practices on sustainable food security through environmental conservation, resource recovery, and sustainable agricultural practices.

Table 3. The effect of waste management on sustainable food security in Gensi Farms

Item	Very High		High	
	n	**%**	**n**	**%**
Food waste audits affect sustainable food security	166	69.7	72	30.3
Waste reverse logistics affect sustainable food security	95	39.9	143	60.1
Waste segregation supports sustainable food security	48	20.2	190	79.8
Composting organic waste improves soil fertility and food security	95	39.9	143	60.1
Recycling programs contribute to sustainable food security	166	69.7	72	30.3
Proper waste disposal reduces environmental contamination and boosts food security	119	50	119	50
Reusable materials enhance the sustainability of food production	142	59.7	96	40.3

Source: Field data, 2024

From Table 4, the most notable finding is very high and high agreement (69.7% and 30.3% respectively) on the importance of waste audits and recycling programs in contributing to sustainable food security. Despite the dual role of maintaining environment healthy and ensuring a sustainable supply chain for food production, the role of waste disposal and use of reusable materials in reducing environmental contamination and boosting food security was marked by almost equal distribution across very high and high rankings. The contribution of proper waste disposal to sustainable food security received 50% rating for both very high and high scales, while the contribution of the use of reusable materials was acknowledged very high (59.7%) and high (40.3%). The contribution of waste segregation to food security received a lower rating of 20.2% and 79.8% representing very high and high respectively whereas that of composting organic received score of 39.9% and 60.1% standing for very high and high respectively.

The third objective of the article is to analyse the contribution of closed-loop systems to sustainable food security in Gensi farm. Employing descriptive statistics (Table 5), the study analysed the perceptions of respondents on how the integration of closed-loop practices contributes to enhancing resource efficiency, reducing waste, and fostering sustainable agricultural productivity to support food security.

Table 4. The contribution of closed-loop systems to sustainable food security

Item	Very High		High	
	n	%	n	%
Nutrient recycling in closed-loop systems enhances food security	95	39.9	96	40.3
Waste-to-resource initiatives boost sustainable food security	96	40.3	142	59.7
Closed-loop systems reduce resource wastage and improve food security	120	50.4	118	49.6
Soil fertility is increased through closed-loop agricultural practices	48	20.2	190	79.8
Closed-loop systems enhance resource efficiency and food security	48	20.2	190	79.8
Sustainable food production is supported by closed-loop systems	142	59.7	96	40.3
Closed-loop systems reduce environmental impact and improve food security	24	10.1	214	89.9
Water reuse in closed-loop systems supports food security	72	30.3	166	69.7
Renewable energy use in closed-loop systems enhances food security	166	69.7	72	30.3

Source: Field data, 2024

Refer to Table 5, the contribution of nutrient recycling in closed-loop systems to sustainable food security was identified as a key factor in enhancing sustainable food security, with 39.9% and 40.3% of respondents rating it very high and high respectively. The contribution of waste-to-resource initiatives is similarly recognized with 40.3% and 59.7% of respondents standing for very high and high rating respectively, highlighting their effectiveness in converting agricultural waste into valuable inputs to support sustainability. Closed-loop systems' ability to reduce resource wastage and improve food security was strongly emphasized the respondents with 50.4% with very high rating 49.6% with high rating. These systems are found to play a critical role in improving soil fertility through agricultural practices as shown by the respondents, whereby 20.2% and 79.8% confirmed the role of these systems with very high and high respectively. Enhancing resource efficiency and food security through closed-loop systems also received similar ratings, reflecting their importance in optimizing resource utilization.

Furthermore, sustainable food production is supported by closed-loop systems. The contribution of closed-loop systems to sustainable food production is rated very high by 59.7% of respondents and high by 40.3%, implying their pivotal role in ensuring stable food supply. In addition, 10.1% of respondents rated very high and 89.9% rated high the reduction of environmental. This implies that environmental benefits are acknowledged but may be perceived as indirect contributors to food security. Water reuse in closed-loop systems also garnered strong support, with 30.3% and 69.7% rating its contribution very high and high respectively, emphasizing its importance in addressing water scarcity. Finally, the contribution of the use of renewable energy in closed-loop systems to the sustainable food security was rated very high by 69.7% of respondents and high by 30.3% of respondents.

The fourth objective of the article is to find out the challenges faced in the implementation of circular economy initiatives. To do so, descriptive statistics, as shown in Table 6, were employed to analyse the perceptions of respondents on the challenges faced in the implementation of circular economy initiatives at Gensi Farms.

Table 5. The challenges faced in the implementation of circular economy initiatives

Item	SA		A		n		D		SD	
	n	%	n	%	n	%	n	%	n	%
Inconsistent policy frameworks	94	39.4	72	30.3	24	10.1	48	20.2		
Financial constraints and lack of market incentives	72	30.3	120	50.4			23	9.7	23	9.7
Limited technological infrastructure	238	100								
Low awareness levels and behavioral resistance	72	30.3	166	69.7						
Inadequate waste collection systems, landfill dependency, transportation issues and urban-rural disparities	24	10.1	214	89.9						
Lack of coordination, limited skills and expertise	238	100								
Limited natural resources, environmental degradation and climate vulnerability	120	50.4	118	49.6						

Source: Field data, 2024

Refer to Table 6, the challenges faced at varying levels in the implementation of circular economy initiatives at Gensi Farms include inconsistent policy frameworks; financial constraints and lack of market incentives; limited technological infrastructure; low awareness levels and behavioral resistance; inadequate waste collection systems, landfill dependency, transportation issues and urban-rural disparities; lack of coordination, limited skills and expertise; and limited natural resources, environmental degradation and climate vulnerability. Limited technological infrastructure and lack of coordination, skills, and expertise are the most critical challenges faced as shown by 100% of respondents with strongly agree. The second range of barriers faced include low awareness levels and behavioral resistance as approved by all respondents including 30.3% with strongly agree and 69.7% with agree. In this range, there is also inadequate waste collection systems, landfill dependency, transportation issues and urban-rural disparities revealed by 10.1% with strongly agree and 89.9% with agree.

Urban-rural disparities exacerbate these challenges, as rural areas often lack the necessary waste management infrastructure. In addition, all respondents (50.4% with strongly agree and 49.6% with agree) reveal that limited natural resources, environmental degradation, and climate vulnerability pose significant challenges. The last range of challenges include policy-related challenges, such as inconsistent policy frameworks, were affirmed by 69.7% of respondents, encompassing 39.4% with strongly and 30.3% with agree. Moreover, financial constraints and lack of market incentives are acknowledged by 80.7% of the respondents including 30.3% with strongly agree and 50.4% with agree.

Discussion

The results reveal that resource efficiency promotion plays an important role in value addition through reducing post-harvest losses, which directly affects food security by preserving food quality and quantity. These results are consistent with the study by Sibanda & Mwamakamba (2016) who assert that reducing post-harvest losses is critical for Africa's agricultural resilience and food security in the face of climate change. The results also underline the importance of sustainable agricultural practices in enhancing long-term productivity. In line with this, Hachigonta et al. (2013) highlight that improved soil fertility through circular systems is essential for mitigating climate risks and Rockström et al. (2016) show that sustainable intensification of agriculture is a cornerstone for achieving global food security and sustainability. The Rwanda National Circular Economy Action Plan (GoR, 2022) advocates for scalable circular economy practices to address environmental and food security challenges in the country. On the other hand, resource recovery programmes and extended producer responsibility initiatives contribute quite significantly to sustainable outcomes. According to Sangwa et al. (2023), the transformative potential of circular production models in agriculture, particularly in enhancing food security through sustainable practices like resource recovery and recycling.

The results emphasize the interlinkages between food security and waste management practices such as waste audits, disposal, segregation, recycling and reverse logistics. According to Nzabuheraheza & Nyiramugwera (2017), integrated approaches to waste recycling and resource recovery are vital in improving food availability and sustainability, particularly in rural and semi-urban areas. This is consistent with the conclusions of the study by Kabera et al. (2019) that proper benchmarking and optimization of waste management systems in East Africa can lead to improved environmental outcomes and enhanced food systems. Despite the dual role of maintaining environment healthy and ensuring a sustainable supply chain for food production, the role of waste disposal and use of reusable materials in reducing environmental contamination and boosting food security was marked by almost equal distribution across very high and high rankings. The proper waste disposal underlines the potential to sustain food production systems by minimizing dependency on virgin resources and by maintaining food system efficiency, environment healthy, and resource recovery. In line with this, Adedayo (2012) demonstrated that poultry waste management practices in urban agriculture improve resource efficiency and food production and Iraguha et al. (2022) highlight that effective solid waste management practices are essential for sustainable development. While waste segregation and composting organic are viewed as valuable in improving soil fertility and productivity, the results show that their contribution to food security is perceived less important compared to other interventions. In their study, Uwamahoro, Nyagatare & Shingiro (2019) however, found that compost application significantly improves soil chemical properties and crop yields, thereby enhancing food security in Bugesera District, Rwanda.

Furthermore, the results indicate a vital role played by nutrient recycling in closed-loop systems in maintaining soil fertility and reducing dependency on synthetic fertilizers. In the perspective of Cahyadi et al. (2024) and the Ellen MacArthur Foundation (2019), the integration of circular economy principles into food systems enhance sustainability and resilience. Additionally, the Ministry of Environment, Rwanda underscores the role of closed-loop practices in minimizing resource wastage and improving soil fertility. The Closed-loop systems are found to play a critical role in improving soil fertility through agricultural practices. Moreover, the use of renewable energy in closed-loop systems play a significant role in reducing energy costs and supporting food security. The results imply that Gensi Farms faces significant barriers in terms of technical capabilities and coordination frameworks necessary to execute circular economy principles. This underscores the importance of addressing technological limitations and the lack of coordination and expertise, which are significant obstacles to achieving circularity in agriculture. In line with this, Sangwa et al. (2023) highlights the significance of technological infrastructure and skilled labor as important challenges in adopting circular practices in Rwanda's agricultural sector. Low awareness levels and behavioral resistance are another set of challenges faced in implementing the circular economy initiatives, implying that stakeholder education and mindset shifts are necessary for wider acceptance of circular economy initiatives. Additionally, macro-environmental factors such as limited natural resources, environmental degradation, and climate vulnerability further constrain the adoption of circular practices. In line with this, Hillsdon (2024) highlights that agriculture in Africa face the pressing environmental issues.

Policy-related challenges are found to create gaps in regulatory and policy alignment that hinder effectiveness of circular economy initiatives. Policy misalignment creates uncertainty and hinders progress, making it essential to establish clear and harmonized regulations. In support of this, the World Resources Institute (2023) highlights the inconsistency of policy frameworks to further complicate the implementation process. Limited financial support and the absence of market-driven rewards discourage investment in circular practices. This reflects observations in the Chatham House (2019) identifying economic barriers as a key impediment to scaling circular economy initiatives in developing countries. There is a need for financial investments and economic incentives to encourage farmers and stakeholders to adopt circular practices effectively. Addressing these challenges requires a comprehensive approach that integrates environmental sustainability with circular economy initiatives.

Conclusion and Implications

The study concludes that circular economy initiatives contribute to sustainable food security in Rwanda. The findings highlight the pivotal role of resource efficiency, waste management, and closed-loop systems in fostering food security. Resource efficiency initiatives, such as reusable resources, recyclable packaging, and circular food systems, improve soil fertility, reduce post-harvest losses, and build resilience to climate change. Similarly, waste management practices, including food waste audits, composting, and recycling, enhance environmental conservation and ensure sustainable food production. Closed-loop systems further boost food security through nutrient recycling, waste-to-resource strategies, water reuse, and renewable energy adoption, which collectively optimize resource utilization and reduce environmental impact. Despite the benefits circular economy initiatives, their implementation face a number of challenges, including inconsistent policy frameworks, financial and technological limitations, low public awareness, and inadequate waste collection systems.

Based on the findings of the study, the following suggestions are made:

To the government

a) Focus on strengthening and harmonizing regulatory frameworks that support the implementation of circular economy practices in the agricultural sector.
b) Offer financial incentives such as subsidies, grants, and low-interest loans for circular economy projects to agricultural enterprises and work on creating market incentives that encourage the adoption of sustainable agricultural practices.
c) Drive innovation in circular economy solutions in collaboration with research institutions by promoting research and development in sustainable agricultural practices.
d) Support the implementation of advanced technologies and sustainable business models in collaboration with agricultural enterprises to facilitate resource sharing, innovation, and the overall success of circular economy initiatives.

To other actors involved:

a) Prioritize increased collaboration with relevant stakeholders including supply chain partners to overcome challenges related to resource inefficiency and improve resilience of food systems against climate change.
b) Consider investing in advanced technologies to improve efficiency in waste management, resource recovery, and closed-loop systems.
c) Develop and adopt new business models that integrate circular economy principles and focus on sustainability and long-term resource efficiency.
d) Actively engage with local communities to raise awareness and encourage participation in circular economy initiatives.

Declarations

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Orcid ID

Nkundabaramye Vincent https://orcid.org/0009-0007-1401-2431

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