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Abstract

The circular economy can be an effective approach to addressing negative impacts of agricultural waste. However, the extent of farmer engagement with the circular economy is poorly understood, especially in low- and middle-income countries. This study explores the extent to which postharvest practices and decisions of tomato farmers relate to the circular economy in Kenya, where several policies target the reduction of emissions in the agri-food sector through sustainable waste management. The results reveal a predominance of convenient and low-cost practices, such as composting, leaving residues on fields, and using damaged tomatoes as feed. Higher value-added practices based on processing such as biochar and biogas are rare and not well integrated into policy and financing programs. Circular economy adoption depends primarily on land and asset ownership, costs, infrastructure, and investment requirements, not necessarily on climate change appraisal. As such, the findings suggest that the gap between policy and practice does not primarily reflect a gap in knowledge and motivation, but rather a gap between formal frameworks and the constrained, risk-mediated realities through which farmers navigate everyday agricultural production. Policy targeting should consider farm endowments rather than socio-demographic characteristics to support the transition to more circular farming systems.

Keywords: Climate change; Development studies; Environment; Policy; Awareness; Collective Participation

1. Introduction

Agricultural waste is linked with environmental problems and emissions that contribute to global warming (Atinkut et al., 2020; FAO, 2023). One solution for the negative impacts of agricultural waste are circular economy (CE) practices, which contribute to improved economic, health, and environmental outcomes (Velasco-Muñoz et al., 2022). Although CE practices vary by country and sector, their adoption is generally low, due to social, economic, environmental, and political factors (Fridahl et al., 2021; Hounnou et al., 2024). Despite examples of both individual on-farm and collective CE solutions (Huang et al., 2019; Purnama et al., 2025), farmers' motivation to engage with different CE practices is not well understood even in areas where government and non-governmental agencies promote agricultural reform such as in Kenya.

Food insecurity affects about a quarter of Kenyans (Korir et al., 2020) while at the same time, one-third of crop production is lost after harvest (Ridolfi et al., 2018). The loss of food is estimated at 5.2 million tons, equivalent to 99 kilograms per person (UNEP, 2021), and valued at KES 72 billion annually (Mbeche et al., 2025). Food waste disposal contributes 11% of total food system greenhouse gas emissions in Kenya (Martius et al., 2023). Several policies, such as Kenya Vision 2030, call for a reduction of emissions in the agri-food sector through climate-resilient waste management (Martius et al., 2023). In such cases, public policies can play a decisive role in fostering CE practices (Losa, 2025); however, the extent of institutional support for CE and the design of incentive mechanisms supporting farmers' efforts in Kenya are insufficiently understood.

CE tends to be infrastructure-intensive, relying heavily on technology, processing capacity, and investment capital (McCauley, 2025). This indicates that the costs of adopting CE solutions would be high for Kenyan farmers. Uncertainty about public support compounds a broader neglect of how farmers' own practices and decisions relate to the formal CE framework. Formal frameworks offer useful categories for identifying CE practices but may not reflect how farmers themselves understand or prioritize them. Much of the existing research evaluates the CE framework normatively or focuses broadly on adoption and implementation, leaving everyday decision-making largely underexplored (Ma et al., 2026; Peng et al., 2025). This leaves a limited understanding of how circularity is negotiated within contexts characterized by uncertainty, resource constraints, market pressures, and competing livelihood priorities.

This study uses the case of the tomato sector in Kenya and combines policy analysis and farmer survey data with stakeholder semi-structured interviews to assess socio-economic, behavioral, operational, and institutional factors shaping farmers' choices about the adoption of CE practices. The research questions addressed in this study have a relevant policy focus. Revealing the key policy instruments supportive of CE in Kenya allows not only recognizing potential gaps in the regulatory framework but also enabling transition towards more just food systems. Illustrating the breadth of CE practices adopted among Kenyan tomato farmers and presenting the socio-economic, operational, behavioral, and institutional factors that shape their choices about the adoption of CE practices will be useful for policy targeting and awareness campaigns. Showing how CE practices and attitudes about CE vary among Kenyan tomato farmers by specific attributes (e.g., location, institutional engagement, farm size, etc.) is relevant for market-linked extension, enabling an overall deeper engagement of policymakers and policy beneficiaries.

This study relates to several earlier works. Evans et al. (2025) described farmers' decision-making and behaviors towards adopting circular agricultural practices in the UK, while Rótoló et al. (2022) captured CE perceptions and awareness in sectors related to agriculture in Argentina. de Lauwere (2022) explored the role of selected behavioral factors and external conditions on Dutch farmers' decision about transitioning towards circular agriculture. The research highlights a significantly positive role of personal attitudes and social norms, and a deterring role of complex regulations, lack of governmental support, lack of knowledge and information, and economic factors. Sekabira et al. (2022) analyzed the association of a limited number of socio-economic factors with awareness, knowledge, and support of CE practices in Rwanda, the Democratic Republic of the Congo (DRC), and Ethiopia.

This study adds institutional, behavioral, and farm-characteristic nuances to policy debates surrounding the promotion of CE practices. Our results reveal that Kenyan tomato farmers engage in convenient and low-cost CE practices such as composting, leaving residues on fields, and using damaged tomatoes as feed. Biowaste valorization practices based on processing are rare and not substantially covered by policy support and financing. Farm endowments, land ownership and specific practices such as crop diversification and standards show a positive association, while climate change considerations show a negative association with CE engagement. These findings suggest policy should be targeted based on farm endowments rather than socio-demographic characteristics, as costs, infrastructure, and investment requirements play a decisive role in CE engagement.

2. Literature review

The CE framework focuses on minimizing natural resource extraction through recycling and reuse, resource efficiency, waste reduction, closed-loop systems, and regeneration (Kirchherr et al., 2017). In agriculture, this includes composting, manure use, biomass valorization, nutrient cycling, water efficiency, waste reprocessing, and crop-livestock integration (Velasco-Muñoz et al., 2022). Van Rooyen et al. (2025) argue that African smallholder systems may be especially relevant for circular food systems because they often rely on diversified crop-livestock integration, nutrient cycling, and local resource reuse. However, these practices may arise from necessity rather than formal commitment to CE principles or support from policy channels. Several authors argue that farmer-centered co-design and community knowledge sharing produce more locally relevant sustainable production practices than top-down promotion (Bakker et al., 2022; Lacombe et al., 2018).

Empirical studies similarly note that a range of sustainable practices such as composting, crop diversification, mixed farming, and water conservation often arise through practical livelihood adaptation (Cooper and Wheeler, 2015; Girard et al., 2026; McCauley, 2025). Straub et al. (2026) reveal more bottom-up and informal practices in the Global South in contrast to top-down, policy- and industry-driven activities that are more prevalent in the Global North.

Besides being driven by necessity, farmers' decisions on the adoption of CE practices depend on a range of socio-economic, operational (farm-specific), and institutional factors (Fridahl et al., 2021). Socio-economic factors represent capacity, awareness, and willingness to engage in CE practices. Palm et al. (2024) recognize the importance of considering gender perspectives as crucial for addressing social, environmental, and justice dimensions within CE. Age is also a significant factor explaining farmers' willingness to accept CE, measured as returning wheat straw to the field (Huang et al., 2019) and integrated crop-livestock system (Zheng et al., 2026).

Larger and higher-income households with married household heads show higher awareness of CE practices (Sekabira et al., 2022). CE engagement also depends on education, farm size, and land availability (Carrer et al., 2020; Samantaray et al., 2026). Climate change perceptions and experiences are also important determinants of farmers' motivation to adopt CE (Opdenbosch et al., 2026; Wuepper et al., 2020). Behavioral factors such as risk aversion, time preferences and social capital are increasingly considered in adoption literature (Lai et al., 2025; Trujillo-Barrera et al., 2016; Wuepper et al., 2020).

Institutional factors, policy frameworks, and their enforcement also shape CE practices. Thompson et al. (2022) find that buyers influence farmers' adoption of sustainable practices, while Kirchherr et al. (2018) highlight the role of cultural and market-related barriers. Policy-related literature is fragmented into two strands. The first categorizes policy instruments and assesses the coherence of the policy mix through a top-down analytical approach. It finds that waste management and recycling regulation dominate CE policy while instruments for reuse, secondary markets, and demand-side support are comparatively underdeveloped (Hartley et al., 2020; Losa, 2025). Biomass waste is mostly addressed through fragmented and generic regulation rather than dedicated instruments (Duque-Acevedo et al., 2022).

The second strand is farm level, treating policy as one variable in adoption models, such as access to extension services (Samantaray et al., 2026) and rural credit (Carrer et al., 2020) or the stringency in enforcement of a residue-burning ban (Huang et al., 2019). In Kenya, agricultural policy is production-oriented and only loosely connected to sustainability goals (Daum et al., 2025). In addition, Kenyan circular practices are embedded in livelihoods and organized informally rather than driven by formal markets and regulation (Straub et al., 2026). However, both strands fail to capture the full picture. Instrument inventories rarely ask whether policies reach the practices farmers use, while adoption studies rarely examine what the surrounding policy framework offers.

3. Data

This article draws on three main data sources: policy documents, a survey of 540 tomato farmers, and 12 semi-structured interviews. These data cover the institutional and individual levels, facilitating a deeper understanding of how CE policies and government agendas might interact with the farmers they target.

3.1. Study setting

Tomato production has some of the highest post-harvest losses in the fruit and vegetable supply chains of sub-Saharan Africa. It is estimated that in Kenya, 30-40% of tomato crop is lost during or after harvest (Sibomana et al., 2016), which is about 16% of the market value (Gatere et al., 2022). Apart from high pre- and post-harvest loss rates, tomato crops also leave large quantities of solid waste after harvest, taking up to 60% of the amount produced with potentially negative environmental impacts (Manríquez-Altamirano et al., 2020; Quirós et al., 2014). Tomatoes damaged during harvest and transport could be processed into higher-value products (e.g., sauce, juice, paste, dried tomato, etc.), while tomato plant residues could be used

as a substrate for growing other plants, composting or production of biogas, biochar, construction materials and packaging (Stylianou et al., 2023). It is not clear to what extent postharvest practices of Kenyan tomato farmers align with CE principles and adhere to country agricultural and environmental policies.

3.2. Policy documents

The policy analysis draws on national policies, strategies, legislation, regulations, and public programs that govern agriculture, waste, and the green economy in Kenya and were in force or under development between 2016 and 2026. Documents were identified from government repositories (Ministry of Agriculture and Livestock Development (MoALD), Ministry of Environment, Climate Change and Forestry (MECCF), National Environment Management Authority (NEMA)), policy research archives at the Kenya Institute for Public Policy Research and Analysis (KIPPRA), and development partner project documentation. After reviewing 27 national CE and waste management instruments, 21 documents that contain provisions relevant to CE were retained for analysis.

3.3. Survey

The survey of tomato farmers took place over two weeks in November and December 2025 in 24 villages located in eight counties: Kajiado, Makueni, Machakos, Narok, Nakuru, Laikipia, Kirinyaga, and Kiambu. Selected sites were in regions with moderate to high rates of tomato production where farmers were accessible and open to interaction. The survey included key socio-demographic information as well as questions about institutional settings, farming practices, and preferences. In each village, 24 tomato farmers were surveyed. Due to missing and invalid responses to some questions, 36 responses were not considered; the final sample includes 540 observations.

3.4. Semi-structured interviews

The qualitative component of this study draws on twelve semi-structured interviews conducted in March and April 2026 with farmers and agricultural stakeholders in key tomato-producing areas of central Kenya, including Nairobi, Kiambu, Narok, and Machakos. Interview locations were selected to align with the geographical scope of the quantitative dataset, and participants were recruited through purposive sampling to capture diverse perspectives across farm sizes, production systems, and institutional roles. The sample comprised seven farmers operating farms ranging from 1 to 40 acres and five experts representing organizations and public

institutions involved in agriculture and sustainability. Semi-structured interview guides were developed for farmers and experts, enabling the exploration of key themes while allowing respondents' experiences and perspectives to emerge. Farmer interviews examined production systems, CE practices, and livelihood constraints, whereas expert interviews focused on agricultural extension, sustainable production and standards, CE, and sectoral challenges. The interviews lasted between 15 minutes and one hour and prioritized depth and contextual insight.

4. Methods

4.1. Policy analysis

A three-step qualitative content analysis of national policies, strategies, legislation, regulations and public programs that govern agriculture, waste, and the green economy is used for this study. First, each document was coded deductively against the ten practices that make up the CE index (defined in Section 4.2 and Table 2), and the document was checked for direct, implicit, or a lack of reference to each practice. Second, each document was classified by policy instrument using the Nodality, Authority, Treasure and Organization (NATO) framework as developed by Hood and Margetts (2007). Informational instruments such as dissemination plans, technical support, and training were classified as *nodality*, while regulatory instruments such as regulations and standards as *authority*. Financial instruments such as grants, loans, subsidies, and taxes were categorized as *treasure*. Lastly, institutional instruments such as direct provision of goods and services or public-private partnerships were categorized as *organization*.

Third, drawing on Sabatier and Mazmanian (1980), we recorded whether each provision specifies an implementing institution, dedicated resources, beneficiaries, and geographic coverage, and whether evidence of implementation was publicly available was recorded. This last step distinguishes policy intentions from instruments that are likely to reach farmers and draws on a broader review of Kenya's CE and waste management framework (KIPPRA, 2026). The document inventory is provided in Table 1 and the coding of CE practices by instrument type in Table 2.

4.2. Statistical analysis

The farmer survey data were analyzed using descriptive statistics and regression analysis that enabled revealing determinants of CE adoption. The estimations proceeded as in the following equation:

$$y_i = \alpha + \beta S_i + \gamma F_i + \delta I_i + \zeta B_i + \xi C_i + \omega_c + \varepsilon_i$$

where the dependent variable, y_i , is the CE index or a series of binary CE indicator variables described below, such as *high CE tier* and *value-added CE* for farmer i in county c . The explanatory variables reflecting socio-demographic characteristics of the main respondent and the household are denoted as S_i , farming practices as F_i , institutional setting as I_i , behavioral preferences B_i , and climate change beliefs as C_i . The estimations also include county fixed effects denoted ω_c . Poisson regressions were used for continuous variables, and logit regressions were used for binary dependent variables. All regressions specified robust standard errors. Tables report marginal effects.

Dependent variables measure the extent of engagement with CE. First, the CE index captures management and revalorization of waste that occurs either before or during tomato harvest and waste originating from stems, leaves, and branches of the tomato plant. Specifically, the index registers the application of the following practices: processing damaged tomatoes, using tomato waste as animal feed, composting damaged tomatoes, selling damaged tomatoes, returning tomato waste to fields, drying tomato waste, and producing biogas or biochar from tomato residues. The index was constructed by summing the ten relevant binary practices adopted by each farmer, resulting in a score from 1 to 10. Higher values indicate greater adoption of waste reutilization and circular resource management.

Second, a categorical variable called *CE tier* is constructed based on the CE index, which classifies farmers according to the intensity of their engagement with CE. The first tier (*No CE*) indicates the absence of CE practices on a tomato farm and captures respondents without any of the 10 considered CE practices. The second tier indicates limited engagement with CE (*Limited CE*) and captures respondents with low to moderate values of the CE index (CE index 0 to 5). The third tier reflects high CE engagement (*High CE*) and includes respondents with a CE index value of five and above (CE index value 6 to 10).

Third, CE indicators are grouped according to effort, costs, and value added into two groups. The first group reflects low effort and low costs and includes five indicators: using damaged tomato as feed, using damaged tomato as compost, using tomato waste as feed, using tomato waste as compost, and leaving tomato waste on the field. The second group reflects high effort or costs and value adding activities and it is measured over five indicators as well: processing damaged tomato, selling damaged tomato, converting tomato waste to biogas, making biochar from tomato waste and drying tomato waste. In both variables, if a farmer engages in specific

CE practices, the variable takes the value one and zero otherwise. Another variable indicates whether CE practices are or are not in the domain of public policy support. The variable *unsupported CE* takes the value of one if a farmer throws, burns or dries tomato biowaste or uses it to produce biogas or biochar and zero otherwise, as these do not constitute direct residue retention.

The socio-demographic variables include respondent's age, gender, and schooling level, household size, off-farm income or work, and asset ownership index (constructed from 16 different items). Farming operations are measured through farm size (in acres), owned land area size (transformed using inverse hyperbolic sine), crop diversification (a count of different crops grown), and tropical livestock units (TLU). Institutional conditions are measured as farmer group membership, compliance or certification against domestic or international quality or environmental standards, credit access (formal or informal borrowing in the past 12 months), and buyer diversification, that is, whether a farmer sells to one or several buyer categories.

Core behavioral preferences such as self-perceived risk tolerance, time preferences and trust, measured based on survey questions that are validated are considered highly consistent with measures obtained in experimental settings (Dohmen et al., 2011; Falk et al., 2018). Risk tolerance and time preference are measured on a scale from 1 indicating risk aversion (impatience in the case of time preference) to 10 indicating high risk-taking tendencies (patience in terms of time preference). Generalized trust is measured as a series of responses to five standard questions that assess respondent's tendency to trust others in general, trust others living nearby or trust those doing business with.

To measure contribution to public goods, we consider whether respondents contribute to village activities or services and whether they participate in any community-improving activities. The variable measuring respondents' climate change perceptions is an index calculated as an average of the extent of respondent's agreement on a 5-point scale with seven statements about climate change impacts as in Trifkovic et al. (2026).

4.3. Interview analysis

All interviews were audio-recorded and transcribed non-verbatim. The material was analyzed thematically through an initial, iterative coding developed both deductively from the research questions and analytical framework, and inductively from recurring themes emerging during the interviews. The coding process combines descriptive and interpretive coding, allowing both concrete farming practices and broader decision-making logics to be identified across

interviews. Codes were subsequently refined and grouped into broader analytical categories and themes used throughout the qualitative analysis. The coding framework focused especially on farmers' decision-making processes, sustainability practices, perceived constraints, knowledge and perceptions, standards, and institutional dynamics. The thematic approach enabled a systematic interpretation of how farmers and agricultural stakeholders understand, negotiate, and prioritize sustainability-related practices in everyday farming.

5. Results

5.1. CE policies in Kenya

Table 1 presents an overview of key policy initiatives related to CE in Kenya grouped in four tracks: development frameworks, agriculture, environment and waste, and programs and finance. Table 2 links the policies with the key on-farm CE practices measured in the survey.

Development frameworks, namely Vision 2030 and the Bottom-Up Economic Transformation Agenda (BETA) establish broad goals such as resource efficiency, value addition, and reducing agri-food emissions (NTEP, 2024), but are devoid of farm-level instruments. The agricultural sector track, led by the MoALD, puts Vision 2030 and BETA into operation through the Agricultural Sector Transformation and Growth Strategy (ASTGS) and several newer sub-sector strategies. The National Agricultural Policy calls for diversified, soil-friendly production, albeit without a clear implementation strategy. The National Agroecology Strategy (2024–2033) promotes organic inputs, nutrient cycling and integrated crop-livestock production, while the Climate Smart Agriculture (CSA) Strategy (2017–2026) discourages residue burning and promotes permanent organic soil cover. These documents use CE-adjacent language but rarely name CE explicitly (Daum et al., 2025).

The environmental sector track, led by the MECCF and NEMA, forms Kenya's explicit CE architecture. The Sustainable Waste Management Policy and Act from 2022 and the Extended Producer Responsibility (EPR) regulations name CE with binding obligations and penalties for irresponsible waste disposal. They also introduce compost and organic fertilizer standards, feasibility studies for composting plants, and the organic fertilizer subsidy quota of 40%. As indicated in Table 2, this is the most direct financial touchpoint between waste policy and mainstream input support, but we found no public reporting on its implementation. Even though the EPR regulations recognize agricultural and food waste as 60–70% of Kenya's waste stream, regulatory provisions primarily target packaging, e-waste, batteries, and other

manufactured products. On-farm organic waste is acknowledged in environmental policy but governed mainly through agricultural strategies that do not frame it as waste.

Public and donor-funded programs that finance farm-level practices show which policy intentions are backed by resources. Extension support comprises promotion, awareness, and technical guidance related to low-cost practices. Farmer field schools and the market-oriented smallholder promotion approach do not contain dedicated CE or waste management modules (MoALD, 2023). Financial support is limited, fragmented, and mostly project based. The donor-funded biogas programs subsidized domestic biogas production, although the subsidy was reduced from 30% to 20% of installation cost and withdrawn in 2014, while the distribution of biodigesters to individual households ended in 2020.

The Climate Change (Amendment) Act of 2023 creates a regulated carbon market in which land-based projects must share at least 40% of proceeds with communities through community development agreements, a channel that could in principle finance biogas or similar projects, but it is still untested for smallholders. Major agricultural donor co-funded projects mention value addition and cold chain investments, which are relevant to processing and selling damaged tomatoes, but do not contain identifiable composting, biogas, or residue management components. These projects are time-bound and have limited geographic coverage.

The policy review reveals tensions between different policy tracks. Input policy under the ASTGS centers on inorganic fertilizers, while waste policy asks for 40% of subsidized fertilizer to be organic; no reporting reconciles the two. The EPR regulations, the most enforceable CE instrument, leave agricultural and food waste outside their scope. Finance for farm-level circular practices has come mainly from donor projects rather than recurrent public budgets. Limited finance and technology access, and differing requirements in regulatory frameworks across national and county levels are identified as the main barriers to CE among agri-food enterprises, leaving the main CE policy framework largely inaccessible in practice (KNA, 2026). The coherence of Kenya's CE framework can be assessed as weak to moderate and the dependence on external financing is its main sustainability risk. Kenya's first dedicated Circular Economy Strategy and Implementation Plan, which names agriculture as one of five priority sectors (with plastics, textiles, electronics, and construction), is still under development but could reconcile the identified tensions in the regulatory framework.

5.2.CE practices among tomato farmers

Table 3 shows an overview of CE practices in the farmer sample and how the distribution of CE practices varies by respondent's gender, farm size, buyer diversification, adoption of standards and farmer organization (FO) membership. The average CE index score is 3.5 out of 10 practices, or 35%. While only a handful of respondents reported not applying any of the considered CE practices (the *No CE tier* takes up only 1% of the sample), the *High CE tier* is not common either (11% of the sample reported using 6-10 CE practices). The *Limited CE tier* is the most common, comprising 88% of the sample.

Given the resource-scarce setting, it is not surprising that low-cost CE practices dominate (63%). Basic recycling practices are widespread: 81% of respondents reported using damaged tomatoes as animal feed, 64% used tomato waste as feed, and 48% composted tomato waste. By contrast, advanced valorization practices such as biogas and biochar production were almost nonexistent, with only around 2% of respondents reporting these. The highest CE index value is observed on certified farms (4.9), followed by those selling to multiple buyers (3.8) and households with large landholdings (3.5). Certified farmers engage more in processing and composting compared to non-certified farmers. Farmers who sell to several buyers show a greater variation in CE practices, including more composting and processing. Male farmers have on average a higher CE index value, mainly due to converting tomato waste to compost.

Table 4 contains summary statistics for the full sample and for each CE subgroup. Female respondents comprise less than a third of the sample. The mean age is 45 years with 40% having completed secondary school; the mean household size is five members. Non-farm income is reported by 40% of respondents. The average farm size is just below 5 acres. Around half of respondents operate a farm larger than 2.5 acres, which is considered a large farm in this study.

With an average of 5 assets per household, asset ownership is modest. Livestock rearing is not widely integrated with tomato cultivation and production of other crops. The average TLU value is 4.2 (maximum is 104) and the average value of crop diversification index is 10.9 (maximum is 28). About half of respondents are FO members and 18% apply production standards or certification. Around one-quarter of respondents sell to more than one buyer category. Borrowing either from formal or informal sources is rather common as 70% of respondents reported having a loan. In terms of contribution to public goods, 80% of respondents reported contributing to community improvement projects and village activities. A high mean score of the climate change perceptions index (4.4) indicates a considerable

likelihood that the respondents are both perceiving and experiencing adverse effects of climate change.

Risk, time preferences, and trust are identified as key behavioral preferences. The average score for the risk-taking variable is 6.7, indicating a positive risk-taking aptitude among respondents. The lowest average risk-taking score was among farmers with higher CE engagement, and the highest was observed among farmers favoring low-cost CE practices. The average value of the time preferences variable is 7.5, indicating that respondents were on average self-declaring as being highly patient. There is not a linear pattern between time preferences and the level of CE engagement. For example, the average time preference value is the same in the *No CE* and the *High CE tier* while the highest value was in the *Limited CE tier*. The average trust score was 3.5 (out of a maximum of 5) indicating a slightly positive disposition among respondents towards trusting others. There is also a non-linear pattern between trust and CE engagement with the highest trust values observed in the *No CE tier* and the lowest in the *Limited CE tier*. Engagement with CE declines with participation in community projects and climate change impact perceptions.

5.3.Factors associated with CE

Table 5 presents the results of a regression analysis that examined the factors influencing tomato farmers' CE adoption decisions. Variables that significantly and positively affect the CE index include land owned, crop diversification, asset index, standards, and trust. The results indicate that increasing landownership by 1% is significantly associated with a 0.2-point increase in the CE practices index. One additional crop grown and one additional asset are significantly associated with a 0.07-point higher CE index. Standards are associated with a 1.5-point higher CE index, while higher trust implies a higher CE index by 0.28 points. Buyer diversification, trust and community improvement are also significantly associated with a higher CE index. Risk-taking is negatively associated with the CE index, indicating that risk-averse households are more likely to engage with CE. Another significant and negative predictor of CE is the climate change impact perceptions index.

Results in columns (2)-(4) are consistent with the results for the CE index in column (1) in the case of standards, while they lose statistical significance in several instances, including gender, off-farm income, and time preference. Standards are associated with a 1.34-point higher CE index and with a 15, 20, and 15 percentage-point higher probability of being in the *High CE tier* and engaging in value-added and policy-unsupported CE, respectively. Unlike in the case

of the CE index, results in columns (2) and (4) show a negative association with the total land area, while the association with owned land is not statistically significant. The results imply that 1% more land cultivated is associated with around 6 percentage points lower likelihood of placing in the *High CE tier* and around 8 percentage points lower likelihood of pursuing CE practices without public support. Access to credit shows a significantly positive association, while engagement with community improvement initiatives shows a negative association with CE practices unsupported by public policy.

5.4.Low- and high-cost CE practices

Across nearly all farmer interviews, respondents described some form of practical reuse and recycling of biowaste from tomato cultivation. Importantly, these practices were not framed in terms of CE principles or environmental ideology. Instead, they were presented as practical and economically sensible ways of reducing waste, feeding livestock, improving soils, or minimizing losses. One farmer described the circularity of plant waste in production: “*we cultivate it, then it becomes green manure. [...] It returns to the soil.*” Similarly, another interviewee explained how vegetable and tomato waste was integrated into his production:

“I combine them [horticulture and dairy farming]. There are some waste products, for example, those vegetables you can take to the animals as feed.” [...] “The remaining plants we plough with the tractor and it decomposes [...] The same with the tomatoes and the vegetables; we don't throw it out, we actually plough with the tractor.”

At the same time, the findings reveal important limits to circularity. Although simple recycling practices were widespread, more advanced forms of processing and waste valorization remained rare and often highly aspirational. This was especially evident in discussions surrounding biochar, biodigesters, and processing technologies. One of the few farmers is actively planning to invest in such technologies:

“[I am interested in biochar] because there is a lot of organic matter we are producing. [...] We are going to construct one [biodigester]. With the biodigester, we can convert that energy to cooking gas and also use it on the farm.”

Similarly, an expert described biochar projects as something still largely in the planning phase:

“We are in the process of planning it [biochar]. [We're getting] financial support from Caritas, but it is our own initiative.”

Importantly, even farmers who viewed such technologies positively often described them as financially difficult or inaccessible. For example, one large-scale farmer expressed interest in producing biochar and organic fertilizer locally but explained that the necessary infrastructure “*might be expensive*”, even for them. Similarly, a local officer described donor-supported programs where farmers only adopted technologies because projects subsidized 60% of the costs. These findings help explain why lower cost practices are relatively widespread, while more capital-intensive CE practices remain rare.

Farming intensity, which is approximated with farm size and ownership, appears to be a crucial dimension for predicting CE engagement. One of the large-scale farmers described farming as a highly commercial and intensive operation where CE and environmental concerns do not play an important role. For example, overripe tomatoes were frequently discarded in pits, thrown out alongside pesticide bottles mixed with general household waste. Intensive operations are built around leased land spread across multiple plots, which allows intensifying production without having to bear the long-term environmental consequences of soil degradation: “*we lease [...] so that after 10 years, you can quit to other areas.*” Although this farmer knows that intensive farming eventually damages the soil and increases pest pressures, his response was not primarily to reduce input intensity, but rather to abandon exhausted land:

“When diseases become many, we quit. [...] You cannot use this land for 10 years and continue using [intensive methods]. The results will become poor.”

In contrast, a farmer who owns his land described a much stronger long-term attachment to the farm and greater interest in investing in future-oriented sustainability practices. He framed farming less as short-term intensive extraction and more as a long-term process of improving and developing the land over time. His family farm had gradually been transformed from “*bare land*” with little water availability into a more productive and environmentally managed farming “*ecosystem*.” Whereas one respondent repeatedly emphasized the need to intensify production in response to declining soil productivity, another one discussed sustainability investments as ways of improving the farm’s long-term resilience and self-sufficiency. Hence, the degree to which they invested in long-term stewardship differed substantially, primarily driven by their contrasting land tenure statuses.

6. Discussion

The results align with earlier studies on a limited role of socio-demographic factors such as gender, marital status, household size, and education in CE adoption. For instance, Samantaray et al. (2026) found that household size does not significantly predict circular management of spent mushroom substrate. Similarly, Zheng et al. (2026) found that neither age, gender, nor education of the household head significantly determines adoption of an integrated crop-livestock system. Both survey and interview results indicate that operational characteristics shape CE decision-making. Holding other factors constant, CE engagement rises with owned land, crop diversification, and assets, and falls with total land area, so farmers who expand production on rented plots are a clear target group.

These results suggest that tenure security may shape incentives for long-term agricultural investment. Some CE practices, especially those involving biowaste processing, require planning over multiple seasons, which makes secure control over land especially important for their adoption. For example, biochar can be made from biowaste and applied to soil to improve its fertility, but this could take several seasons (FAO, 2023). Where land is rented, farmers may have weaker incentives to invest in such practices because the returns are delayed and future access to the land is less certain. By contrast, farmers who own land have stronger incentives to invest in long-term CE practices because they expect to continue farming the same land over time.

Market integration matters more than FO membership, which was not significant in any specification. Buyer diversification was positively associated with being in the *High CE tier* and compliance with standards with all CE measures. This could arise from considerably overlapping objectives with the CE framework. For example, GlobalGAP (2026) lists extensive criteria for on-farm systems for food waste management, resource efficiency, recycling, and regenerative production. However, certification may partly capture buyer requirements or unobserved farmer quality (Meemken, 2020), and it carries complex requirements and costs which are cited as a strong barrier for agri-food value chain participants (Henson and Humphrey, 2010). Recommending certification among smallholders to increase CE should be weighed against these drawbacks. FOs, a main delivery channel for extension do not by themselves appear to transmit CE practices, indicating a stronger role for market-linked extension if it pivots towards CE content, which it currently lacks.

Everyday farm-level CE in the context of Kenya does not seem to embody environmental and climate change concerns. Two quantitative results support this claim. First, the considered climate perceptions indicator shows a significant negative association with CE practices. This resonates with Mitter et al. (2019), who found that high climate change appraisal did not necessarily lead to higher adaptation intentions in Austria, as farmers were more concerned with the effectiveness and costs of available measures. Similarly, Straub et al. (2026) concluded that CE manifestations in the Global South are “primarily rooted in socio-economic needs and cultural practices rather than environmental concerns.”

Second, CE associations with contributions to public goods, measured as a monetary contribution to village activities or community-improving activities, are also either negative or not statistically significant. This resonates with Trifkovic et al. (2026), who found that stimulating a sense of public benefits and a clear indication of personal benefits from public goods are important for increasing farmers’ engagement with CE. Earlier literature shows that many African smallholder systems already contain forms of circularity through integrated crop-livestock systems and biomass recycling (van Rooyen et al., 2025). Interview results suggest that such practices emerge primarily from practical necessity and resource efficiency rather than formal CE frameworks. Farmers reused waste because it was useful, familiar, locally available, and low-cost. As such, this study challenges adoption-oriented literature, which implicitly assumes that environmental awareness leads to sustainability-related action. Instead, perspectives emphasizing constrained agency and unequal capacities come forward, suggesting that the ability to pursue CE depends as much on resources, opportunities, and livelihood security as on attitudes or intentions.

This study also finds that less than a half of the on-farm CE practices considered relevant for tomato farmers in Kenya are in the public policy domain. This could explain why higher value-added and more costly CE practices are not adopted more broadly. However, it does not explain why some reasonably more attainable CE activities are not practiced more, pointing to an unsystematic policy design or reach. The gap between formal policy frameworks and everyday agricultural realities may explain why sustainability frameworks can fail to resonate with farmers, even when their stated goals are relevant. Policies and standards may capture what is measurable, auditable, and administratively legible, while missing forms of everyday knowledge are harder to formalize (Scott, 1998).

Farmers' sustainability practices should be analyzed as lived and adaptive rather than merely as compliance or non-compliance with external models. Given the negative correlation between climate appraisal and on-farm CE practices, awareness campaigns that present composting, residue retention, or biogas as climate action are unlikely on their own to increase CE engagement. Messages built around the direct returns farmers already recognize, such as livestock feed, soil fertility, and income from damaged produce, fit better with the motives described in the interviews.

7. Conclusion

Tomato farmers in Kenya already practice a widespread but thin form of circularity. Nearly all farmers practice the reuse of waste, but these are overwhelmingly low-cost: feeding damaged tomatoes and residues to livestock, leaving residues on fields, and composting. Capital-intensive valorization such as biogas and biochar is only used by about 2% of farmers despite policy and donor initiatives. Moreover, farmers describe their practices as sensible farming rather than environmental action, and engagement is strongly shaped by differences in cost, infrastructure, and investment requirements. Low-cost recycling practices can often be integrated directly into existing farming systems, whereas more advanced circular technologies require upfront investment, technical knowledge, and infrastructure that many farmers do not possess.

Kenya's policy framework, then, is misaligned with the practices of its farmers. Its explicit, binding CE instruments target manufactured waste, while on-farm organic waste is governed through agricultural strategies that promote low-cost practices mainly through disseminating information. Finance for investment-heavy practices has been donor-funded and time-bound, and biochar, which several interviewees wished to pursue, is not addressed by any instrument reviewed.

To address the climate concerns of farmers and the need to implement circularity in the agricultural sector there is a need to reframe and retarget certain policies. Extension should carry CE content framed around private returns (livestock feed, soil fertility, income from damaged produce) rather than through climate benefits, since climate perceptions are not positively associated with CE. Furthermore, because engagement rises with owned land but falls with cultivated area, tenure security and longer or more secure lease terms may be important to encourage CE practices where returns can take several seasons to develop.

Practices that farmers cannot afford alone, such as the production of biogas and biochar, require sustained public finance rather than time-bound donor projects. For example, by implementing the organic-fertilizer subsidy quota and testing whether carbon-market revenues can reach smallholders, the Government of Kenya could more effectively bring sustained CE practices to small farms. The promotion of reuse practices should also be paired with agronomic safeguards, such as removing pest-infested residues and keeping pesticide-contaminated waste out of feed and compost, so that farms do not recycle risks along with nutrients. Future research should seek to establish whether farm-, and more importantly community-level circularity reduces losses and emissions and can serve as a viable financial tool for farmers. Kenya's tomato farmers have shown that circularity can take root without policy and can often be a default mechanism; the question now is whether policy and funding can help this circularity grow.

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Tables

Table 1. Policy documents reviewed

Track	Document	Period	Type	Relevance to on-farm CE
Development frameworks	Kenya Vision 2030 (Big Four Agenda) (SDG 6.3)	2008–2030	National blueprint	Resource efficiency; safe reuse and recycling (SDG 6.3)
Agriculture	BETA (Fourth Medium-Term Plan)	2023–2027	National plan	Value addition; reducing agri-food emissions
	Agricultural Sector Transformation and Growth Strategy (ASTGS)	2019–2029	Sector strategy	Productivity focus; horticulture market-access flagship
	National Agricultural Policy (Sessional Paper No. 2 of 2021)	2021–	Sector policy	Soil fertility, diversification; no implementation detail
	Kenya Climate Smart Agriculture Strategy and Implementation Framework	2017–2026/ 2018–2027	Sub-sector strategy	Discourages residue burning; organic soil cover, manure management
	National Agroecology Strategy for Food System Transformation	2024–2033	Sub-sector strategy	Organic inputs, crop–livestock integration, nutrient cycling
Environment and waste	Kenya Agricultural Sector Extension Policy (KASEP)	2023–	Sub-sector policy	Extension models (FFS, SHEP); no CE module
	Agricultural Soil Management Policy	2023–	Sub-sector policy	Soil health, fertilizer sector
	National Post-Harvest Management Strategy	2024–2028	Sub-sector strategy	Halve post-harvest losses; cereals and dairy focus
	Green Economy Strategy and Implementation Plan (GESIP)	2016–2030	Cross-sector strategy	Resource-efficient, low-carbon growth incl. agriculture
	National Sustainable Waste Management Policy	2021	Sector policy	Waste hierarchy; compost standards; 40% organic-fertilizer subsidy quota
	Sustainable Waste Management Act, No. 31 of 2022	2022	Legislation	CE principles; EPR; Waste Management Council
	Extended Producer Responsibility (EPR) regulations	2024	Regulation	Packaging, e-waste, etc.; organic waste outside scope
	Climate Change Act 2016 (amended 2023)	2016/2023	Legislation	Carbon market; county climate funds
	Circular Economy Strategy and Implementation Plan (CESIP)	Under development (2026)	Cross-sector strategy	Names agriculture as one of five priority sectors
	MoALD brief “Strengthening policy frameworks to empower agri-food SMEs towards a circular economy in Kenya”	2026	Policy brief	Finance, technology and certification barriers
Programs and finance	National fertilizer subsidy (with organic-fertilizer quota)	Ongoing	Subsidy	Organic-fertilizer quota (implementation unconfirmed)
	Kenya Climate Smart Agriculture Project (KCSAP), World Bank	2017–2022	Project	CSA practices; no CE-specific component
	National Agricultural and Rural Inclusive Growth Project (NARIGP), World Bank	c. 2016–2023	Project	Value-addition infrastructure (incl. Makueni)
	National Agricultural Value Chain Development Project (NAVCDP), World Bank	2022–2027	Project	Names tomato; storage, cold chain; 6 of 8 study counties
	Kenya National Domestic Biogas Program (KENDBIP)	2009–2014	Donor program	Biogas subsidy (30% → 20% → 0)
	Hivos, SNV (Netherlands Development Organization)	2009–2020	Public-private partnership	Develop commercially viable and sustainable domestic bio-digester sector

Table 2. Policy support for the CE index practices, by NATO instrument type

CE index practice (share of farmers)	Instruments identified (NATO type)	Assessment
Damaged tomato as feed (81%); tomato waste as feed (64%)	Agroecology Strategy – organic inputs, nutrient cycling, crop-livestock integration (N)	General promotion only; no finance
Tomato waste left on the field (59%)	Climate Smart Agriculture Strategy – no burning, permanent soil cover (N); Agricultural Soil Management Policy (N)	Explicit priority; informational only
Tomato waste as compost (48%); damaged tomato as compost (44%)	Sustainable Waste Management Policy – compost standards (A), composting plants (O), 40% organic-fertilizer subsidy quota (T); Agroecology and CSA Strategies – manure and organic inputs (N)	Strongest policy support of any practice; implementation of quota unconfirmed
Dries tomato waste (23%)	Post-Harvest Management Strategy – mobile dryers (O)	Maize only; horticulture not covered
Sells damaged tomato (18%)	ASTGS horticulture market-access flagship (N/O); NAVCDP market access (O)	Indirect; not targeted at damaged produce
Processes damaged tomato (6%)	BETA value-addition goal (N); NARIGP value-addition infrastructure (O/T); NAVCDP storage and cold chain (O/T)	Project-based, time-bound, partial county coverage
Tomato waste as biogas (2%)	Kenya National Domestic Biogas Program subsidy (T, donor-funded, ended 2014); Kenya Biogas Program (T, donor-funded, ended 2020); Climate Change Act carbon market (T, potential)	No current public finance
Makes biochar from tomato waste (2%)	None identified	Policy gap

Note: N = nodality (information, extension); T = treasure (finance); A = authority (regulation, standards); O = organization (direct provision, infrastructure, partnerships).

Table 3. Circular economy practices

	(1) All	(2) Single buyer	(3) Multiple buyers	(4) Non- certified	(5) Certified	(6) Not an FO member	(7) FO member	(8) Small farm	(9) Large farm	(10) Male	(11) Female
Processes damaged tomato	0.06	0.05	0.10	0.04	0.16	0.03	0.10	0.06	0.07	0.06	0.08
Damaged tomato as feed	0.81	0.81	0.83	0.82	0.78	0.82	0.80	0.79	0.83	0.80	0.84
Damaged tomato as compost	0.44	0.40	0.56	0.38	0.71	0.44	0.43	0.47	0.40	0.45	0.41
Tomato waste as feed	0.64	0.63	0.67	0.61	0.75	0.66	0.62	0.62	0.66	0.64	0.64
Tomato waste as compost	0.48	0.47	0.51	0.42	0.75	0.47	0.48	0.50	0.45	0.51	0.41
Sells damaged tomato	0.18	0.18	0.19	0.16	0.31	0.16	0.21	0.14	0.23	0.19	0.18
Tomato waste as biogas	0.02	0.01	0.07	0.01	0.06	0.02	0.03	0.01	0.03	0.03	0.01
Makes biochar from tomato waste	0.02	0.01	0.04	0.01	0.04	0.01	0.02	0.01	0.03	0.02	0.01
Tomato waste left on the field	0.59	0.58	0.60	0.52	0.88	0.62	0.55	0.60	0.57	0.60	0.56
Dries tomato waste	0.23	0.21	0.31	0.19	0.45	0.25	0.21	0.21	0.26	0.23	0.25
Circular economy index	3.47	3.33	3.86	3.16	4.89	3.49	3.45	3.40	3.54	3.51	3.37
No CE tier	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.01
Limited CE tier	0.88	0.90	0.81	0.93	0.64	0.87	0.88	0.86	0.89	0.88	0.87
High CE tier	0.11	0.09	0.19	0.06	0.35	0.12	0.11	0.12	0.11	0.11	0.12
Low-cost CE	0.63	0.65	0.57	0.68	0.42	0.65	0.61	0.69	0.56	0.63	0.65
High cost/Value added CE	0.37	0.35	0.43	0.32	0.58	0.35	0.39	0.31	0.44	0.37	0.35
Unsupported CE	0.53	0.51	0.57	0.49	0.70	0.55	0.51	0.54	0.52	0.53	0.53

Table 4. Sample characteristics and the intensity of CE practice adoption

	(1) Full sample	(2) No CE tier	(3) Limited CE tier	(4) High CE tier	(5) Low- cost CE	(6) Value added CE	(7) Unsupported CE
Female	0.29	0.33	0.29	0.31	0.30	0.28	0.29
Married	0.81	0.83	0.82	0.77	0.82	0.80	0.81
Age	45.10	49.00	45.53	41.38	46.03	43.50	45.32
Household size	5.01	4.67	5.02	4.98	5.02	5.00	4.99
No formal schooling	0.04	0.00	0.04	0.07	0.03	0.05	0.04
Primary school	0.34	0.67	0.33	0.33	0.34	0.33	0.34
Secondary school	0.40	0.17	0.39	0.46	0.39	0.41	0.41
Higher education	0.22	0.17	0.23	0.15	0.23	0.20	0.20
Off-farm income	0.40	0.17	0.41	0.34	0.40	0.40	0.41
Land area	4.94	2.02	4.96	5.05	4.50	5.70	4.66
Land area owned (acre)	3.49	0.56	3.43	4.29	3.14	4.11	3.35
Large farm	0.49	0.17	0.49	0.46	0.43	0.57	0.47
Crop diversification	10.86	9.50	10.61	12.93	10.43	11.60	11.15
TLU	4.19	0.34	4.11	5.21	3.98	4.56	4.13
Asset index	4.95	3.17	4.90	5.52	4.82	5.18	5.06
Farmer organization member	0.47	0.50	0.48	0.46	0.45	0.51	0.46
Standards	0.18	0.17	0.13	0.56	0.12	0.28	0.24
Buyer diversification	0.26	0.00	0.24	0.44	0.23	0.30	0.28
Loan	0.70	0.67	0.70	0.74	0.68	0.74	0.74
Risk taking	6.67	6.00	6.78	5.89	6.90	6.28	6.46
Time preference	7.48	7.33	7.50	7.33	7.46	7.50	7.35
Trust	3.52	3.72	3.51	3.58	3.50	3.56	3.55
Community improvement	0.80	0.83	0.81	0.70	0.82	0.77	0.75
Village contribution	0.80	0.67	0.82	0.64	0.81	0.77	0.78
Climate change impact perceptions index	4.38	4.79	4.38	4.29	4.42	4.31	4.32
Sample share	1.00	0.01	0.88	0.11	0.63	0.37	0.53

Table 5. Regression results

	(1) All	(2) High vs. no and limited tier	(3) High cost/Value added CE	(4) Unsupported CE
Female	-0.146 (0.144)	-0.008 (0.026)	-0.024 (0.043)	-0.007 (0.048)
Married	-0.047 (0.184)	-0.021 (0.032)	-0.057 (0.057)	-0.010 (0.058)
Age	-0.004 (0.006)	-0.002** (0.001)	-0.002 (0.002)	0.000 (0.002)
Household size	0.002 (0.032)	0.001 (0.006)	-0.013 (0.011)	-0.009 (0.011)
Primary school	0.222 (0.325)	0.021 (0.051)	-0.086 (0.091)	-0.066 (0.107)
Secondary school	0.413 (0.320)	0.014 (0.052)	-0.086 (0.092)	-0.030 (0.107)
Higher education	0.217 (0.357)	-0.047 (0.061)	-0.121 (0.103)	-0.085 (0.118)
Off-farm income	0.062 (0.135)	0.003 (0.027)	0.018 (0.041)	0.039 (0.045)
Land area (ln)	-0.243** (0.095)	-0.059*** (0.018)	-0.013 (0.030)	-0.078*** (0.029)
Land area owned	0.240** (0.097)	0.026 (0.023)	0.005 (0.031)	0.041 (0.031)
TLU	-0.001 (0.006)	0.000 (0.001)	-0.002 (0.002)	-0.000 (0.002)
Crop diversification	0.056*** (0.020)	0.011*** (0.004)	0.015** (0.007)	0.010 (0.008)
Asset index	0.082** (0.038)	0.013* (0.007)	0.016 (0.011)	0.017 (0.013)
Farmer organization member	-0.095 (0.125)	-0.007 (0.024)	0.052 (0.041)	-0.018 (0.043)
Standards	1.337*** (0.159)	0.147*** (0.024)	0.200*** (0.048)	0.153*** (0.056)
Buyer diversification	0.184 (0.142)	0.044* (0.024)	0.002 (0.043)	0.012 (0.048)
Loan	-0.024 (0.151)	-0.022 (0.028)	0.022 (0.042)	0.080* (0.045)
Risk taking	-0.064** (0.026)	-0.008* (0.004)	-0.024*** (0.007)	-0.014 (0.009)
Time preference	0.027 (0.029)	-0.002 (0.005)	-0.004 (0.009)	-0.013 (0.010)
Trust	0.268** (0.117)	0.018 (0.021)	0.084** (0.035)	0.079** (0.039)
Community improvement	0.217 (0.178)	-0.018 (0.026)	-0.079 (0.062)	-0.160*** (0.062)
Village contribution	-0.292 (0.178)	-0.050* (0.027)	0.006 (0.057)	0.064 (0.060)
Climate change impact perceptions index	-0.365** (0.142)	-0.020 (0.025)	-0.069* (0.039)	-0.102** (0.043)
County FE	Yes	Yes	Yes	Yes
Observations	540	540	540	540

Note: Significance levels: * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors in parentheses.



Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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