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Evaluating agroecological practices using the FAO TAPE (tool for agroecological performance evaluation): a case study of the Lake Bosomtwe Biosphere Reserve, Ghana

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The Food and Agriculture Organization (FAO) Tool for Agroecological Performance Evaluation (TAPE) is a participatory framework for assessing the performance of agroecological systems. Using Lake Bosomtwe Biosphere Reserve (LBBR) in Ghana as a case study, the tool was applied in engagement with farmers to assess the agroecological status of agrosystems in the biosphere reserve and to explore drivers to foster agroecological transition. The findings indicate that the elements of efficiency, recycling and food traditions ($p > 0.77$, $p < 0.001$) are key drivers of agroecological transition. It could be shown that the dependency on external inputs, the utilization of recycling practices and the presence of local food traditions strongly influence the transition of farms toward agroecological systems. Recommendations include the development of locally adapted strategies to enhance financial resilience, strengthen agroecological knowledge sharing among farmers, and providing access to credit, training and insurances.

KEYWORDS

agroecology, food systems, SDG 2, TAPE, Biosphere reserves, agricultural transformation, agroecological transition

1 Introduction

The Food and Agricultural Organization of the United Nations (FAO) views agroecology “as an integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of food and agricultural systems. It seeks to optimize the interactions between plants, animals, humans and the environment, while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system (FAO, 2018; FAO, 2024).” This definition reflects the fact that agroecology brings together three interlinked dimensions: ecological, economic, and social, all of which are essential for sustainable food systems (Wezel et al., 2020; Mouratiadou et al., 2024) The objective of the concept of agroecology is to provide a basis for a comprehensive understanding of food systems, recognizing the significance of social elements in addressing its challenges. Bickler et al. describe how agroecology is increasingly being recognized as a means of achieving the Sustainable Development Goals (SDGs) through the promotion of sustainable

food systems (Bicksler et al., 2023). The strongest contribution of agroecology is seen for SDG 2, which aims to “end hunger, achieve food security and improved nutrition and promote sustainable agriculture” (Khan, 2021). A meta-review of African smallholder systems found that over 90% of measured outcomes from agroecological practices were positive for at least one SDG, particularly those relating to zero hunger (SDG 2), poverty reduction (SDG 1), and life on land (SDG 15) (Madsen et al., 2025).

Agroecological practices are defined as those that diversify cropping systems, integrate crop-livestock-tree interactions, recycle nutrients and organic matter, enhance biodiversity, and reduce external dependence on synthetic inputs (Elouattassi et al., 2023). These practices yield multiple benefits: improved soil health and nutrient cycling, enhanced ecosystem services (such as pollination or pest regulation), greater resilience to climate variability, and pathways to more equitable and locally embedded food systems (Knapp and Sciarretta, 2023).

Between 2015 and 2019, the FAO developed a conceptual framework comprising 10 elements of agroecology, which provides a comprehensive and inclusive description of the field of agroecology. The 10 elements encompass the social, environmental, and economic dimensions of sustainability, each of which is interdependent with the others (Bicksler et al., 2023; Barrios et al., 2020).

In order to provide evidence of the positive impact and contribution of agroecology toward sustainable food systems and the SDGs, the FAO, in collaboration with various partners, developed the Tool for Agroecology Performance Evaluation (TAPE). The tool was developed through a participatory process between 2018 and 2020, which included consultations, stakeholder workshops and pilot implementations with partners and other relevant actors (FAO, 2019). Mottet et al. provide a comprehensive review of frameworks that served as the foundation for the development of the TAPE and shaped its key attributes and methodology (Mottet et al., 2020). According to the FAO, the tool should “build knowledge and empower producers,” “support agroecological transition processes at different scales and in different locations,” and “inform policy makers and development institutions by creating references on the multidimensional performances of agroecology and its potential to contribute to the SDGs” (FAO, 2019).

2 Rationale and research context: the need for agroecology in the Lake Bosomtwe Biosphere Reserve

Agroecology as a practice and policy discourse in Ghana has expanded in recent years. Despite a limited governmental participation, a growing number of NGO projects, mapping exercises and syntheses documenting practitioner networks, pilot interventions, and novel sustainable-farming approaches have evolved. Most national assessments to date are project-level mappings or reviews that describe interventions and stakeholder activity rather than providing harmonized, farm-level empirical metrics of agroecological performance suitable for monitoring transitions over time (Ouko et al., 2024; PARI - Program of Accompanying Research for Agricultural Innovation and CSIR-Science and Technology Policy Research Institute, 2024).

The FAO TAPE has been implemented in various African contexts, providing valuable insights into the multidimensional performance of agroecological systems. In Mali’s Kayes region, TAPE was applied to 233 farms, revealing that farms more advanced in agroecological practices exhibited reduced pesticide use, improved soil health, increased biodiversity, and enhanced food security and nutrition outcomes. Socially, these farms demonstrated greater youth empowerment and higher family employment in agriculture (Lucantoni et al., 2023).

Similarly, the “Measuring Agroecology and its Performance” (MAP) project, implemented in Benin, Ethiopia, Kenya, and Madagascar, utilized TAPE to assess the effectiveness of agroecological practices. The study found positive correlations between agroecological integration and improved biodiversity, soil health, productivity, and household income. Notably, enhanced food security and dietary diversity were observed among participating households (Geck et al., 2024).

These applications underscore the adaptability of TAPE in diverse socio-ecological settings and its utility in informing about sustainable agricultural practices. However, the application of TAPE within Ghana, as well as the application of TAPE in a specific setting of a biosphere reserve, with its specific governance and management conditions, remains underexplored.

Biosphere Reserves are well-placed to serve as living labs for interdisciplinary research, promoting pilot projects, place-based innovations, and experiment with sustainability transitions, in order to achieve resilience and equity (Leibenath et al., 2025). UNESCO’s MAB Program explicitly promotes BRs as “learning sites for sustainable development” where agroecological transitions can be tested and refined (Dabard et al., 2024). Moreover, agroecology can support biosphere reserves in fulfilling their functions by promoting sustainable food systems coupled with community participation, knowledge generation and biodiversity conservation (de Lucio and Seijo, 2023). Studies focused on the Lake Bosomtwe Biosphere Reserve (LBBR) have documented land-use and land-cover changes, shoreline pressure, limited livelihood alternatives and poverty, indicating intense agricultural pressure and ecosystem change in the catchment (Adams et al., 2024; Asare et al., 2021). These works provide important context on environmental drivers and human pressures in the biosphere reserve, but stop short of applying structured agroecological performance assessments (household/farm-level multidimensional indicators) that would allow comparison across communities or the establishment of a monitoring baseline for agroecological transition. In other words, while landscape and socio-ecological changes at Lake Bosomtwe are relatively well described, there is an absence of systematic agroecological surveys using established tools (such as FAO’s TAPE) to quantify on-farm sustainability dimensions across the reserve. In the case of LBBR, agroecology can serve to address unsustainable farming practices including reliance on chemical inputs and help to adapt to climate change induced impacts by diversifying the production system and increasing its resilience. The agroecological transition can be monitored using the TAPE methodology, which provides baseline data needed to monitor the area’s progress and offers recommendations for improving sustainability to both local communities and political leaders (Geck et al., 2024).

3 Research objectives

This article fills the gaps described above by demonstrating the application of TAPE as an applied, small-scale case study in selected Lake Bosomtwe communities. The paper aims to (1) produce the first farm- and household-level agroecological performance baseline in the specific settings of the LBBR, (2) assess the tool's practical suitability and data requirements under local field conditions, and (3) identify context-specific entry points to improve the management and monitoring, that managers of the biosphere reserves and local stakeholders can adopt, to support the agroecological transition in the biosphere reserve.

4 Materials and methods

4.1 Study area

4.1.1 The Lake Bosomtwe Biosphere Reserve

Lake Bosomtwe is situated in the Ashanti Region of Ghana at 06°30'N and 01°25'W, close to the metropolis of Kumasi. The lake has a meteoric origin and is characterized by steep crater walls and a tropical climate and vegetation (MAB National Committee, 2014). Anim et al. describe the lake as “the only naturally occurring inland freshwater lake in Ghana” which has emerged as “one of the richest areas of biodiversity in the country” (Anim et al., 2013). Due to its meteoric origin, the lake lacks outflows, which results in the accumulation of pollutants in the water and poses a risk to the quality of the water and the availability of fish (Anim et al., 2013).

In 2014, the entire area was designated as the Lake Bosomtwe Community Resource Management Area, encompassing an area of 28,907 hectares (MAB National Committee, 2014). Such Community Resource Management Areas (CREMA) exist in other parts of Ghana and afford communities the right to utilize and administer their land in a sustainable manner (Dzekoto and Bosu, 2018). The CREMA provided the basis for the designation of the biosphere reserve and the approval in the world network by UNESCO in 2016. The CREMA legislation is based on the existing traditional decision-making processes and structures (MAB National Committee, 2014). The biosphere reserve is managed by the CREMA and supervised by the Pra Basin Secretariat of the Water Resource Commission and the Man and the Biosphere Secretariat of Ghana (Ghana Commission for UNESCO, 2022).

The lake plays an important role in the lives of the local community, who rely on it as a source of water and sustenance through fishing. In addition to fishing, the residents primarily engage in agricultural activities as their primary occupation and means of income. The main crops cultivated at Lake Bosomtwe are plantain, cassava, cocoyam and yams, tomatoes, onions as well as cocoa as a cash crop. Fishing and farming products are utilized for the purpose of self-subsistence, with a smaller proportion of products being sold in local markets. Additional sources of livelihood that have emerged in recent years include bee keeping and grass cutter rearing (Obiri et al., 2013; Ofosu, 2024).

4.1.2 Challenges within the biosphere reserve

Communities living within the LBBR face several challenges to the sustainability of their food system. The natural environment in the

Lake Bosomtwe catchment has been subjected to persistent degradation: the expansion of built-up infrastructure and agricultural lands being the primary reasons of forest cover changes (Albert et al., 2024; Asare et al., 2021), also leading to soil erosion (Obiri et al., 2013).

Unsustainable farming practices, such as slash-and-burn and farmers' reliance on chemical inputs are a major contributor to the degradation of soil quality and the intensification of food insecurity in the area (Obiri et al., 2013). Both factors are also largely impacting the water quality of Lake Bosomtwe and are enhancing eutrophication and mortality rates among fish populations (Adom, 2018a). The variability of climate, which encompasses irregular rainfall patterns, elevated temperatures and augmented pest infestations, intensifies the challenges faced by farmers and heightens the risk of poverty among those engaged in agricultural activities (A Rocha Ghana, 2021; Yesutanbul et al., 2021). The agricultural sector is not a viable economic activity due to its low yields and income potential. Nevertheless, it persists as the principal source of revenue due to the absence of alternative income streams (A Rocha Ghana, 2021).

4.1.3 Selection of target area

The case area of the LBBR was selected based on several factors, including its designation as a biosphere reserve, and the ecological and economic importance of the lake for the surrounding communities. Additionally, the CREMA's community-based management structures align not only with those of biosphere reserves, but also with agroecological principles, positioning it as a notable case study in the field. Given that TAPE had not previously been implemented in Ghana nor in Biosphere Reserves (to the best of our knowledge), and in consideration of the limited timeframe available for this pilot study, a case study approach was adopted, within a small, context-specific sample. Three villages were purposively selected to ensure spatial representation along the lakeside and coverage of the two administrative districts surrounding Lake Bosomtwe. Following consultations with well-informed representatives from the Forestry Research Institute of Ghana (FORIG), the NGO A Rocha Ghana, and the academic partners, the villages of Adwafo and Atafam (Bosomtwe District) and Esaase (Bosome Freho District) were included in the study as visible in Figure 1.

The selection of farming households within these villages was guided by purposive sampling to capture diversity in agroecological practices and social characteristics. A Rocha Ghana's work on Participatory Integrated Climate Services for Agriculture (PICSA) (A Rocha Ghana, 2021; A Rocha Ghana, 2022) in the LBBR suggested that farmers participating in these training programs would potentially exhibit higher levels of agroecological transition. To ensure representation across varying levels of agroecological engagement, households were selected based on participation in A Rocha training programs, gender (including female-headed households), and willingness to participate. Given the foreseen timeframe, in total, four to five farming households per village were included, comprising both trained and untrained farmers (see Table 1). A total of 14 households and 19 farmers (9 male, 10 female) were interviewed using TAPE. In order to achieve a balanced representation of A Rocha and non-A Rocha farmers, there is an uneven distribution of households across villages. Interviews were conducted with the household head, irrespective of gender, with additional questions addressed to female participants, to assess gender-related issues such as empowerment of women and food security. This approach allowed for an initial

exploration of TAPE's applicability while capturing a range of agroecological practices within the pilot target group.

4.2 Instrument and data collection

4.2.1 Application of the tool for agroecological performance evaluation

The tool for agroecological performance evaluation (TAPE) process is structured in four-steps: (Step 0) description of systems and context, (Step 1) Characterization of Agroecological Transition (CAET), (Step 2) Criteria of Performance and (Step 3) Analysis and Participatory Interpretation. The initial stage, Step 0, comprises a situation and background analysis founded upon a comprehensive literature review and interviews with key stakeholders situated within the research area.

Step 1, CAET is based on the 10 elements of agroecology as described by the FAO and consists of a set of interview questions to the head of household and a farm visit. The score for each element is derived from the mean of three to four components that reflect the respective element, as visible in [Table 2](#).

The following example illustrates the interplay of components. For the resilience score these components reflect both social and environmental dimensions. The method considers the existence and effectiveness of mechanisms that reduce vulnerability, such as access to credit, insurance, and the strength of community support, particularly

in the aftermath of shocks. Furthermore, it evaluates the environmental resilience of the local system, considering the frequency of climatic shocks and the system's capacity to adapt through natural capital and climate-smart practices. Furthermore, the score incorporates the level of resilience derived from the element diversity, which is calculated as the mean of various diversity-related indicators. Finally, it reflects the degree of food self-sufficiency and the empowerment of producers, indicating their ability to make decisions and sustain their livelihoods. Collectively, these four components constitute a comprehensive metric of resilience within agroecological systems.

The CAET results are most effectively presented in a spiderweb diagram, which illustrates each of the 10 elements and clearly demonstrates deficiencies and advantages using a color code that progresses from red (non-agroecological) to green (agroecological) (FAO, 2019).

Step 2 is defined as the Key Performance Criteria, which is designed to measure the impact of agroecology across five dimensions of sustainability, namely "Environment & Climate Change, Health & Nutrition, Society & Culture, Economy, and Governance (FAO, 2019)." The objective is to establish a link between the performance of agroecology and the Sustainable Development Goals (SDGs). This step is conducted using interview questions, with some criteria being differentiated according to gender. The complete TAPE methodology and questionnaire, comprising all questions for steps 1 and 2, is assessable via FAO's TAPE application guidelines (FAO, 2019).

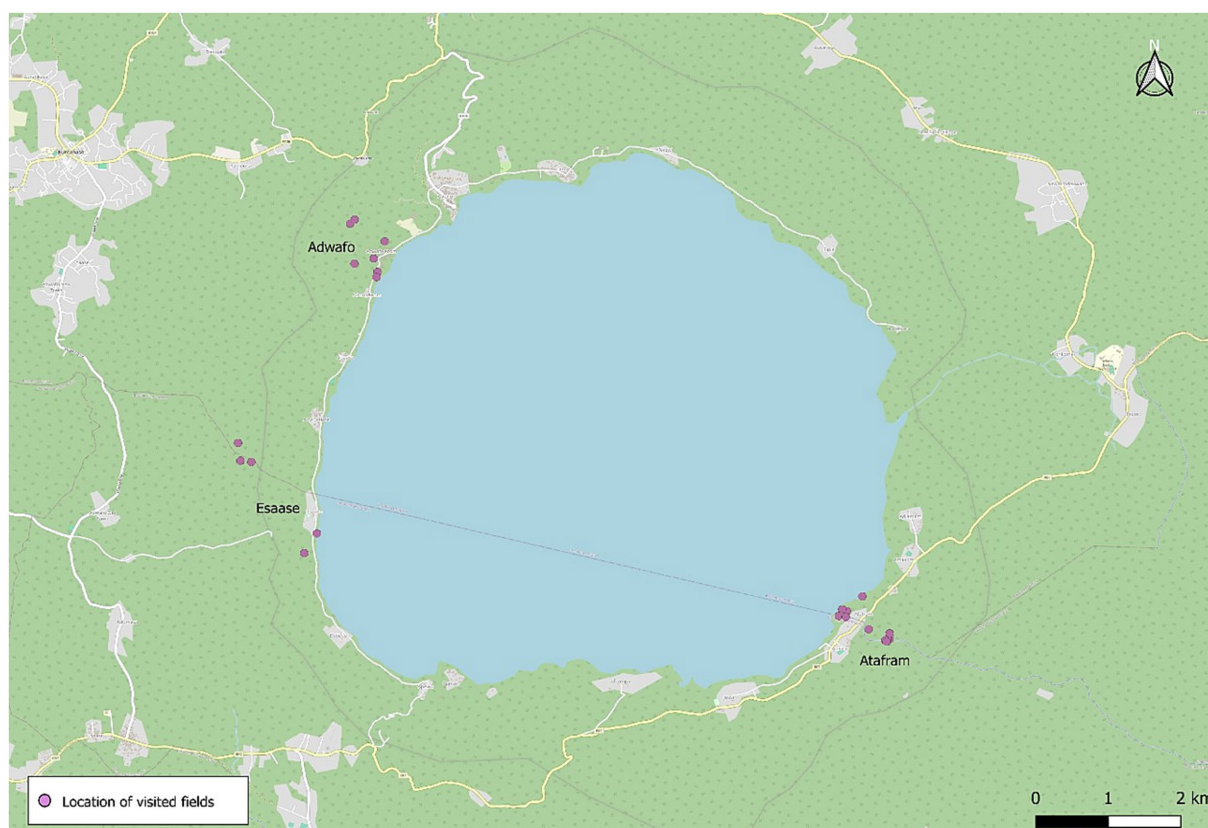


FIGURE 1

Map of the project location: Lake Bosomtwe, Ashanti Region, Ghana, including the visited agricultural fields of the participating farming households. The map was created in QGIS (Bryan et al., 2024).

TABLE 1 Number of households surveyed by TAPE and total number of individuals participating in TAPE.

District	Village	Number of households (total)	A Rocha trained households	Total farmers (w/m)
Bosomtwe District	Adwafo	4	2	6 (2/4)
Bosomtwe District	Atafram	5	3	6 (4/2)
Bosome Freho District	Esaase	5	2	7 (4/3)
Total		14	7	19 (10/9)

Figures in brackets indicate the number of women and men surveyed (w/m).

The final step 3 is designed to facilitate an Analysis and Participatory Interpretation of the results obtained. This step may be conducted in a workshop format with the participants present (FAO, 2019). The TAPE therewith combines quantitative results from steps 1 and 2 with qualitative data obtained in, e.g., workshops, farm visits and preliminary interviews with key stakeholders.

4.2.2 Implementation of the TAPE assessment

In a first step, an extensive literature review (Step 0) was conducted to understand the local context. Furthermore, consultations were conducted with the FAO to clarify methodological questions and obtain support for the planned study in Ghana. Interviews were conducted with key stakeholders of the LBBR, including FORIG, A Rocha Ghana, the WRC, and the Ministry of Food and Agriculture (MOFA) in Kuntanase.

The present study placed a particular emphasis on the CAET score (Step 1) in conjunction with the Health and Nutrition dimension of Step 2. Household visits were conducted in August 2024, with each of the three target villages being visited for a period of 2–3 days. Steps 1 and 2 were covered in joint interviews which were conducted using the TAPE questionnaire via the KoboCollect app, provided by the FAO. A translator helped in translating between English and the local language Twi. The TAPE methodology was tested during a first field visit to ensure its applicability in the local context. Prior to data collection, the translator received training during preparatory meetings where the concept of agroecology was explained, the TAPE methodology was jointly reviewed, and the entire questionnaire was discussed in detail, with any questions addressed.

Following the completion of Steps 1 and 2, a data analysis was conducted using the results from Step 1, with the objective of characterizing the agroecological transition across the target group and differentiating between A Rocha and non-A Rocha farmers. For Step 3, posters were prepared for each village to explain the 10 elements of agroecology and the study results. These posters were displayed during the concluding workshops (Step 3) on August 20th and 21st 2024. Nineteen farmers, including all household heads, attended the workshops where the results of the interviews were shared. Further, the farmers participated in a prioritization exercise to identify the most important agroecological elements, followed by a discussion of the underlying reasons for the farmers' choices.

4.3 Data analysis

The FAO provided the code for R (R Core Team, 2023) to be used in RStudio (Posit Team, 2023) for the analysis of the TAPE results, which can be accessed via GitHub (FAO Agroecology Team, 2023).

A focus was placed on the Step 2 category of “Health and Nutrition” with the indicators Minimum Dietary Diversity for Women (MDD-W) and the Food Insecurity Experience Scale (FIES) score, which were then visualized and further analyzed in MS Excel (Microsoft Corporation, 2024). Detailed information on the methodology of the different indices is assessable via FAO's TAPE application guidelines and additional sources (FAO, 2019; FAO and FAO, 2021; FAO and FHI 360, 2016; International Food Policy Research Institute, 2012; FAO, 2025).

In this study, the Spearman's rank correlation coefficient (ρ) was employed to assess the strength and direction of associations between the agroecological scores derived from TAPE. Spearman's correlation is a non-parametric method that does not assume normality of the data and is appropriate for ordinal or non-normally distributed continuous variables and small datasets. The Spearman's rank correlation coefficient was calculated in MS Excel using the following function (DATAtab Team, 2024):

$$R_s = 1 - \frac{6 \sum d_i^2}{n * (n^2 - 1)}$$

While calculating the Spearman's rank correlation coefficient, it became evident that the dataset encompassed a considerable number of tied ranks. To mitigate the impact of tied ranks, a corrective method was employed, namely the averaging of tied ranks (DATAtab Team, 2024; Forthofer et al., 2007; ScienceDirect Topics, 2024).

The Spearman's rank correlation coefficient ranges from -1 to 1 . A value of 1 indicates a strong positive correlation, 0 indicates no correlation, and -1 indicates a negative correlation. The results were interpreted in accordance with the methodology proposed by DATAtab Team (2024) and Kuckartz (2013), assuming a significance level of $p < 0.05$. For visualization, a color code was applied, ranging from light to dark colors, to symbolize the strength of the correlation (see Table 3).

Subsequently, the resulting Spearman's rank correlation coefficients were subjected to a linear regression analysis. A scatter plot was constructed, and the visual observation, the coefficient of determination (R^2), and the function were included in the conclusions regarding the statistical relevance of the regression between the two variables in question.

5 Results

5.1 Farm characteristics

The mean household size in the target area is approximately six to seven individuals (Table 4). The majority of men in the sampled households (94%) are engaged in agricultural work. The proportion of women involved in agricultural activities is slightly lower, at 76%. It is uncommon for young people (15–35 years) to be engaged in agricultural activities, with a percentage ranging from 10% for male youth to 22% for female.

TABLE 2 Overview of the TAPE methodology, with details on the sub-indices of the CAET score and the health and nutrition dimension of Step 2 (FAO, 2019).

Element of agroecology	Description
Step 1: Characterization of agroecological transition (CAET)	
System and context	Location (district/village and coordinates of farms); N of people in household/ working in agriculture; Size of field and main agricultural outputs
Diversity	Assessment of diversity (number of different) of Crops; Animals; Trees; Activities generating income
Synergies	Crop-livestock integration; Soil management system; Integration of trees; Connectivity between elements of agroecosystem and the landscape
Recycling	Recycling of biomass and nutrients; Waste production and management; Water recycling and saving; Energy reduction and renewable energy
Efficiency	Use of external inputs; Management of soil fertility; Management of pest and diseases; Emerging efficiency from good practices (Diversity, Synergies, and Recycling)
Resilience	Existence of social mechanisms to reduce vulnerability; Environmental resilience and capacity to adapt to climate change; Emerging resilience from diversity; average score of the indices measuring self-sufficiency and empowerment
Culture and food traditions	Appropriate diet and nutrition awareness; Food self-sufficiency; Local and traditional food heritage; Management of seeds
Co-creation and knowledge sharing	Access to agroecological knowledge and interest in agroecology; Social mechanisms for the horizontal creation and transfer of knowledge; Participation of producers in networks
Human and social values	Women's empowerment; Labor (productive conditions, social inequalities); Youth motivation in agricultural work
Circular and solidarity economy	Products marketed locally; Network of producers and presence of intermediaries; Local sourcing and circularity
Responsible governance	Producer's empowerment; Producers organizations; Inclusive decision-making
Dimension of sustainability	Description
Step 2: Core criteria of performance	
Food security and dietary diversity	Food Insecurity Experience Scale (FIES): during last 12 month worried about too little food/unable to eat healthy food/skip a meal/starving Minimum Dietary Diversity for Women (MDD-W): food groups eaten/drunk in last 24 h (Grains, tubers, pulses/dairy/meat, poultry, fish/ eggs/ Fruits and vegetables/salty and fried/sweets)

The average number of different crop species cultivated per household is 6.3, with subsistence food crops such as plantain, cassava and cocoyam being grown together in one field and cash crops such as cocoa being cultivated separately in another field. A total of 19 different crops were reported by participants, with cassava, cocoa, maize, plantain, yam and cocoyam identified as the most important crops. The main livestock species raised in the target area are goats and chickens, with only one farmer rearing grass cutters and two having a pig farm. In this region, livestock are typically kept near the household and allowed to graze freely.

5.2 Characterization of agroecological transition at Lake Bosomtwe Biosphere Reserve

The characterization of agroecological transition (CAET) scores the analyzed farming households on a scale from 0 to 100 for the 10 elements of agroecology (FAO, 2019). The mean CAET score of the targeted farming households is 48.82%, indicating that the system is currently non-agroecological but has considerable potential for transitioning toward greater agroecological sustainability. Figures 2A,B illustrate that none of the assessed households are classified as advanced agroecological systems, with values greater than CAET 70%. Nevertheless, 43% of the households are currently undergoing a transition to agroecological practices, while the

TABLE 3 Color code for the interpretation of the Spearman's rank correlation coefficient results based on the methodology by Albert et al. (2024) and Asare et al. (2021).

Value	Description	Value	Description
0.00–0.10	Very weak positive correlation	0.00 (–0.10)	Very weak negative correlation
0.10–0.30	Weak positive correlation	–0.10 (–0.30)	Weak negative correlation
0.30–0.50	Moderate positive correlation	–0.30 (–0.50)	Moderate negative correlation
0.50–0.70	Strong positive correlation	–0.50 (–0.70)	Strong negative correlation
0.70–1.00	Very strong positive correlation	–0.70 (–1.00)	Very strong negative correlation

remaining majority of 57% are not engaged in adopting agroecological techniques.

A review of Figure 2B reveals a clear distinction between the CAET results of farmers associated with A Rocha activities and those not participating in A Rocha training programs: All farming households undergoing a transition to agroecology belong to A Rocha-trained farmers.

The CAET scores indicate varying levels of agroecological transition across the different elements. The highest score was observed in the element of culture and food traditions (64%) (Figure 3), which is indicative for strong local food traditions and

TABLE 4 Farm characteristics (averages) for the three target villages and all households.

Village	Farm size (ha)	Household size (N)	Crop species (N)	Animal species (N)
Adwafo	5.76	5.25	5.3	1.3
Esaase	3.24	9.2	6.0	1.0
Atafram	4.40	6.2	7.4	1.8
Total	4.46	6.88	6.3	1.4

the utilization of local varieties; however, indicators such as appropriate diet and nutritional awareness were found to be lacking. A comparatively high score for the element of circular economy (60%) in the TAPE assessment reflects two distinct trends among the surveyed farmers. On the one hand, farmers who primarily cultivate cocoa as a cash crop and who seem to strongly rely on external markets. Their income therewith is closely tied to government-regulated cocoa prices and global market trends, and they depend on selling their produce via COCOBOD (governmental body responsible for cocoa farming) intermediaries. This often results in limited local value creation and increased vulnerability to external price fluctuations.

On the other hand, some farmers cultivate few or no cash crops, often making them less dependent of global markets. Instead, such farmers often rely on local markets for exchange of products. Despite these differences, both groups grow food for subsistence and supplement their income by selling surplus produce at local markets. Most inputs, such as seeds and fertilizers, are sourced locally or exchanged between farmers, except for the origin of the cocoa seeds. The TAPE assessment values both facts and show potential for agroecological transition. However, income from food crop sales remains minimal, due to low prices and little value addition. The study further found a deficiency in producer networks and support for developing marketing capacity. These divergent patterns of market engagement and self-sufficiency contribute to an overall moderate score for circular economy.

Early signs of an agroecological transition were evident in the areas of co-creation and knowledge sharing (55%) and responsible governance (54%). Organizations, that provide platforms for knowledge sharing, and that are often linked to the biosphere reserve, such as the CREMA, A Rocha Ghana, MOFA, and COCOBOD meetings, are in place; however, these are not being utilized to the full extent for the sharing of agroecological knowledge. While the participation rate in these forums is satisfactory, the majority of interviewed farmers seem to lack knowledge of agroecological practices. Those engaged with A Rocha demonstrated slightly higher knowledge levels, presumably due to training in climate-adapted practices such as composting and biological pest control. The element responsible governance indicates a moderate empowerment of the producer and acknowledges the CREMA structures as a means of participation in the decision-making processes of farmers, although the mechanism functions incompletely. Three individuals interviewed were part of the CREMA, and two of them exhibited notable higher scores, as their perception of empowerment in decision-making is high.

The elements of efficiency and diversity both received scores that were slightly below 50%. Efficiency indicates that a range of

inputs, including energy, fuel, fertilizers, seeds, young animals and the workforce, are produced on the farm. With regard to soil fertility and pest management, the target groups exhibit a distinction between farmers who regularly utilize synthetic fertilizers and chemical pesticides, and those who employ these methods on a limited number of crops and integrate biological substances into their management practices. With respect to the element diversity, crops cultivated demonstrate a notable degree of diversity, although the introduction and diversity of animals and trees is relatively limited. Additionally, the income is derived from a constricted range of activities, being mainly the selling of fish products and crops.

The human and social values received a score of 42%, which reflects challenges such as a lack of interest among young people in pursuing farming as a career option and poor working conditions. Despite the integration of women in decision-making processes, limitations persist. Women typically allocate a greater proportion of their time to paid and unpaid work. This is often due to their traditional role in household maintenance and food preparation. Furthermore, some women have expressed concerns regarding unequal decision-making powers within their households, particularly with regard to the decision on household items and the decision on the use of generated income.

The synergies and recycling (both 41%) scores were also found to be low. The integration of livestock and crop production is limited on the interviewed farms, and the recycling of manure and biomass is uncommon. While many farms exhibit favorable soil cover, the integration of trees and the overall connectivity between the agroecosystem and the landscape, is notably low. The low score for recycling is attributed to the little reuse of manure and biomass, as well as the lack of water saving techniques. However, the positive aspects of recycling include the exchange of seeds and the minimal use of non-renewable energy.

The lowest score was recorded for resilience (31%). This encompasses the ecosystem's ability to recover from climatic shocks, the resilience of households to financial and social challenges, and the resilience of agricultural land. The area's vulnerability to droughts and flooding, along with a lack of social support mechanisms such as credit or insurance, contributed to the low resilience score.

5.2.1 Comparison of farmers related and non-related to A Rocha

As shown in Figure 4 the results demonstrated that A Rocha farmers exhibited significantly higher CAET scores. The mean CAET score for A Rocha farmers is 54%, indicating that they are in the early stages of transitioning to agroecological practices, compared to 44% for non-A Rocha farmers. A t-test for independent samples showed that the mean values of the two groups differ significantly from each other, $t(df) = [t\text{-value}]$, $p < 0.001$.

The most significant disparity was observed in efficiency, where A Rocha farmers demonstrated a score of 61%, while non-A Rocha farmers attained a score of 38%. This element examines the use of external inputs, soil fertility management, and pest control. A Rocha-trained farmers exhibited a decrease in the use of synthetic fertilizers and chemicals, and incorporated compost and

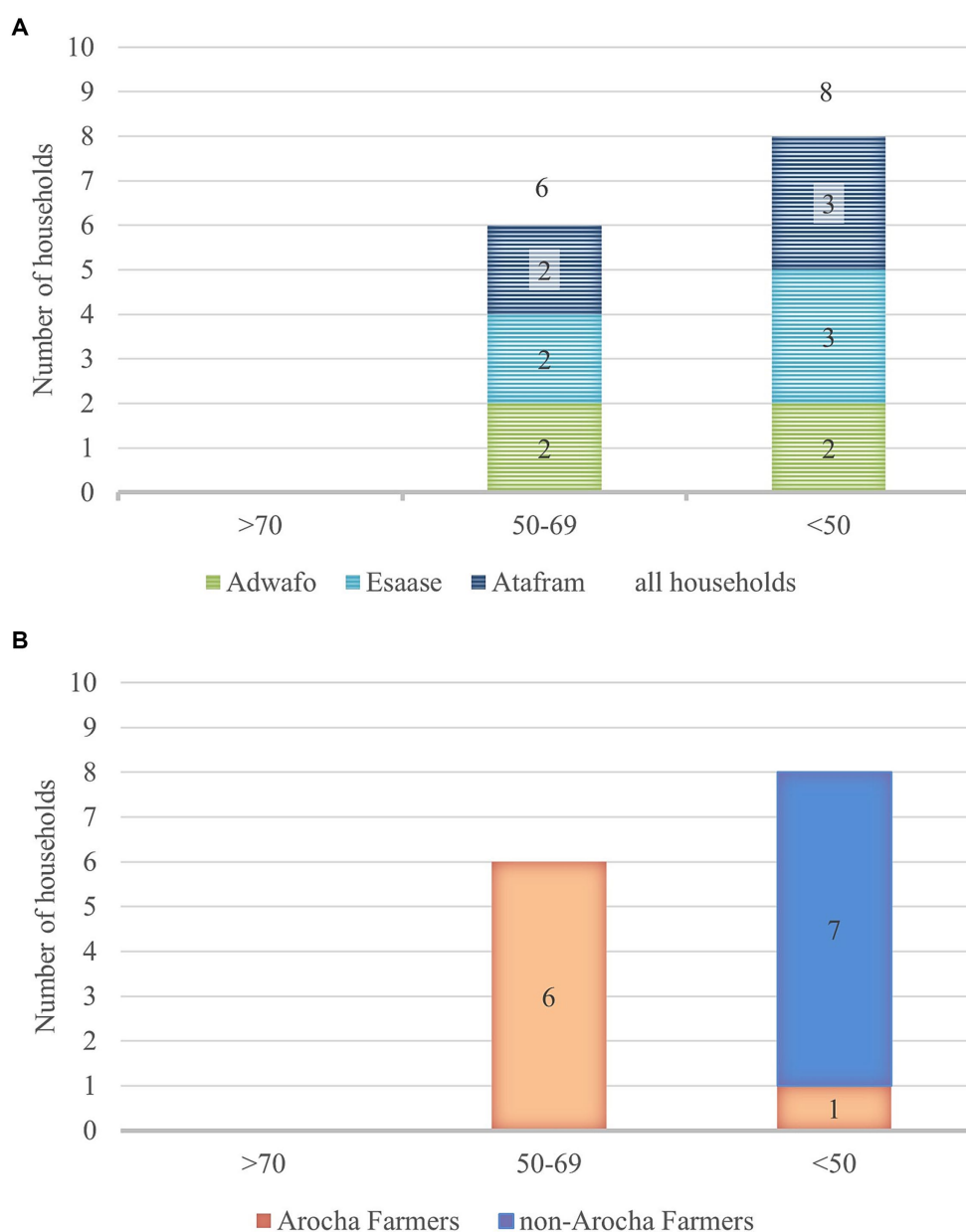


FIGURE 2 Level of agroecological transition separated by categories. **(A)** Shows results separated by village and **(B)** by A Rocha participation. CAET categories: Advanced agroecological systems (>70 CAET); in transition to agroecology (50–69 CEAT); non-agroecological (<50 CAET) (Khan, 2021).

biological fertilizers into their practices. A Rocha’s emphasis on self-producing compost and utilizing neem trees for pest management was identified as a pivotal factor contributing to these enhancements, and the outcome supports the efficacy of A Rocha’s approach (Antwi, 2024).

Another important difference can be seen in the element of co-creation and sharing of knowledge with 64% for A Rocha farmers and 46% for non-A Rocha farmers. This element of the study focuses on access to agroecological knowledge and platforms for knowledge exchange. A Rocha’s provision of additional opportunities for farmers to engage with one another, share insights, and acquire knowledge about sustainable farming techniques can be a contributing factor to the higher scores

attained by its participants. In contrast, other institutions such as COCOBOD and CREMA focus less on agroecology and are criticized for primarily distributing seeds and chemicals for the management of cocoa (Agyee, 2024; Antwi, 2024; Ohenewaa, 2024).

Improvements were also seen in responsible governance: As A Rocha supports producers, farmers scored higher in this category. The same was true for inclusive decision-making, with A Rocha farmers of our study being involved in decision-making more than others. This may be because three of the A Rocha farmers that were interviewed are part of the CREMA as well, and as they are seen as having high status and playing an active role in their community.

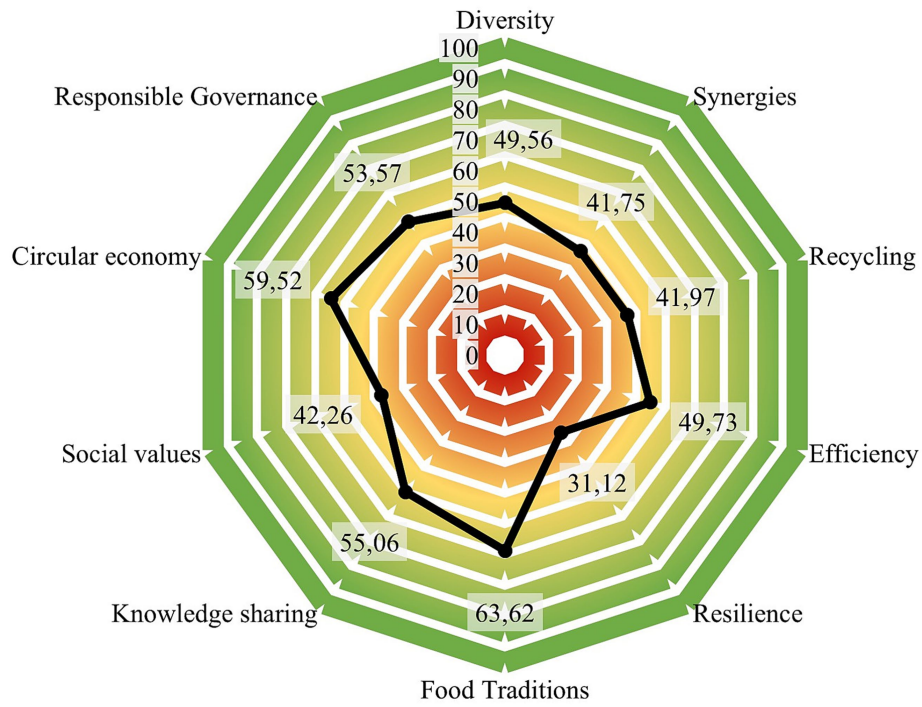


FIGURE 3
CAET scores for the whole target area. Values are averaged across all household surveys.

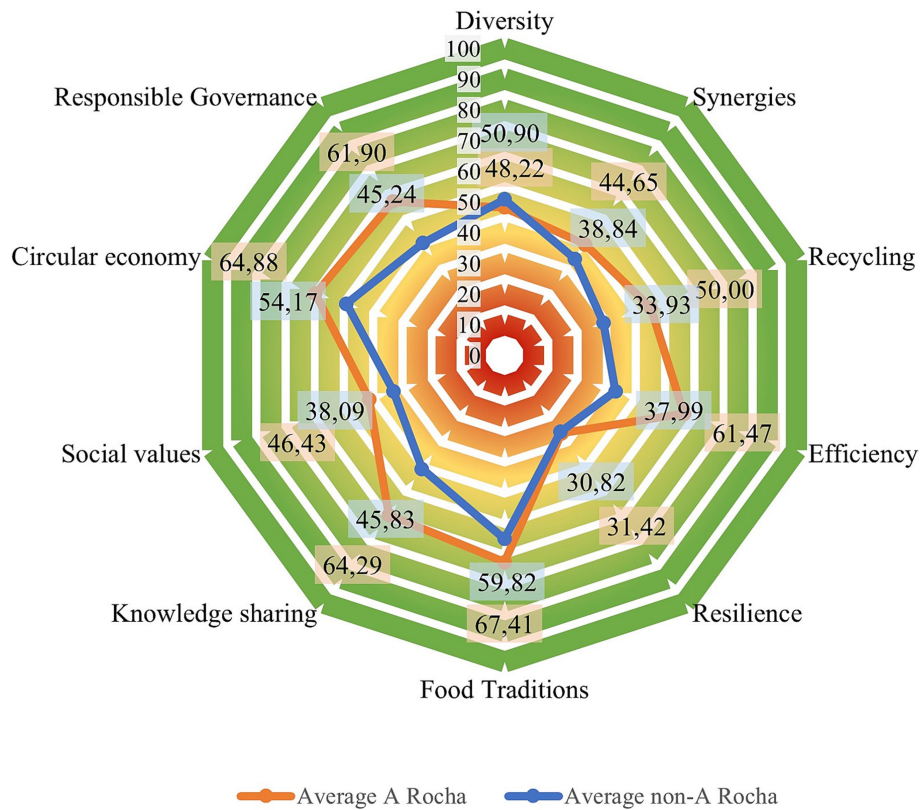


FIGURE 4
CAET scores for the whole target area, differentiated by farmers relation to A Rocha activities and trainings. Values are averaged across all household surveys.

These farmers also demonstrated a higher level of engagement in recycling, as evidenced by their practice of reusing more residues and by-products on their farms. Measures such as composting and collecting plastic bottles were also implemented to reduce waste.

While A Rocha farmers included in our study exhibited superior performance in most agroecological practices, the diversity element was an exception. This element, which considers crop, tree, and animal diversity, was lower for A Rocha farmers. This can be related to two outliers who did not engage in livestock rearing or have alternative income sources. Excluding these outliers, A Rocha farmers demonstrated the highest overall animal diversity, including not only the rearing of chickens and goats but also individuals engaged in the rearing of pigs, sheep, grass cutters, turkeys, and rabbits.

5.2.2 Relationship between agroecological elements and transition to agroecology

The statistical analysis indicates that all 10 elements of agroecology are positively associated with the overall CAET score, reflecting their varying contributions to the agroecological transition in the LBBR (see Table 5). The strongest correlations were observed for efficiency ($\rho = 0.84$, $p < 0.001$), recycling ($\rho = 0.83$, $p < 0.001$), food traditions ($\rho = 0.77$, $p = 0.001$), and responsible governance ($\rho = 0.73$, $p = 0.003$), highlighting these elements as key drivers of transition.

Efficiency showed the highest impact, explaining 64% (see Figure 5) of the variance in CAET scores. Households reducing dependency on external inputs, such as fertilizers and pesticides, achieved higher CAET values in our study. Similarly, recycling practices, including composting and reuse of food leftovers, were strongly associated with higher CAET scores ($\rho = 0.83$, $p < 0.001$; 70% of the variance explained).

Cultural elements, such as food traditions, were also correlated positively with CAET ($\rho = 0.77$, $p = 0.001$), indicating that households prioritizing local food heritage and self-sufficiency attain higher scores. Responsible governance showed a significant relationship as well ($\rho = 0.73$, $p = 0.003$), with greater participation in decision-making and organizations linked to higher CAET outcomes. The scatter plot (see Figure 5) for responsible governance reveals two distinct trends: half of the participants exhibit increased empowerment and involvement in organizations and decision-making processes, and these individuals consistently attain higher CAET scores in our study. This differentiation is likewise visible in Figure 4, where the A Rocha farmers received notably higher scores than those who did not participate in the training.

Moderate but significant correlations were found for knowledge sharing ($\rho = 0.61$, $p = 0.021$), circular economy ($\rho = 0.60$, $p = 0.024$), and synergies ($\rho = 0.59$, $p = 0.025$), suggesting that co-creation, local market integration, and agroecological practices such as tree integration and soil management can contribute to transition as well.

Conversely, social values ($\rho = 0.50$, $p = 0.071$), resilience ($\rho = 0.08$, $p = 0.79$), and diversity ($\rho = 0.10$, $p = 0.74$) did not show significant correlations in our study, indicating a negligible influence on overall CAET in the LBBR.

5.3 Multidimensional performance of agroecology

This part of our study focused on the health and nutrition dimension, including the FIES (Food Insecurity Experience Scale) score and the MDD-W (Minimum Dietary Diversity for Women). The TAPE assessment indirectly addresses several sub-indicators of SDG 2, notably 2.1.1, “Prevalence of undernourishment.” TAPE provides data on the minimum dietary diversity for women, which is a key factor in addressing malnutrition (Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs), 2017). The sub-indicator 2.1.2, defined as the “prevalence of moderate or severe food insecurity in the population based on the Food Insecurity Experience Scale (FIES),” is informed directly by the TAPE assessment (Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs), 2017).

The mean FIES score for the entire target group is 55.6%, which indicates moderate levels of food insecurity. As the value approaches 100%, the level of food security increases. Figure 6 illustrates that, based on our interviews, Adwaf households have the highest FIES score, followed by Atafam, which are both notably higher than the Esaase scores. There is also a rather obvious differentiation between A Rocha and non-A Rocha farmers (65.1 versus 49.0), with the A Rocha farmers tending to have higher food security scores.

The mean score for the MDD-W for the interviewed households around Lake Bosomtwe is 4.2 (42%), indicating that, on average, out of the 10 available food groups that would constitute a balanced diet, the target group consumes only four on a daily basis. The predominant food groups consumed are white roots and plantains (plantain, cassava, and yam), fish (occasionally chicken), other vegetables (primarily tomatoes and onions), and sporadically dark green leafy vegetables such as cocoyam leaves. Legumes, nuts, dairy products, eggs, and notably other vegetables and fruits are absent. Consequently, the MDD-W indicates an unsustainable and imbalanced diet. Only two individuals (out of 14) obtained scores that met the criteria for acceptability. The highest score of 60% was achieved by a woman of high social status in Atafam, who presumably has greater financial resources and opportunities to enhance her diet.

A review of the statistical correlation between CAET scores and the food dimension (FIES; Table 6) indicates generally weak to moderate correlation: The overall correlation between the FIES score and CAET is low and not statistically relevant ($\rho = 0.36$, $p = 0.31$), which may be attributable to the relatively low CAET scores and the small sample size. Consequently, the scatter plots exhibit high variability, with no clear patterns emerging, and the findings can hardly be generalized beyond this sample.

Among the CAET elements, responsible governance showed the highest correlation with FIES ($\rho = 0.58$, $p = 0.08$), suggesting at least a trend in which households more engaged in decision-making and community organizations tend to have higher FIES scores. This may reflect that socially empowered individuals often have greater financial means to supplement their diets. Additionally, many farmers practicing agroecological methods seem to be more active in community meetings and hold respected positions, such as CREMA representatives, which could support dietary awareness. Other CAET

TABLE 5 Spearman's rank correlation coefficient for the total CAET score and the 10 elements of agroecology.

Criteria	Diversity	Synergies	Recycling	Efficiency	Resilience	Food traditions	Knowledge sharing	Social values	Circular economy	Responsible governance
CAET	0.10	0.59	0.83	0.84	0.08	0.77	0.61	0.50	0.60	0.73
<i>p</i> -value	0.735	0.025	0.000	0.000	0.788	0.001	0.021	0.071	0.024	0.003

Lighter colors symbolize a very weak positive correlation, while strong colors indicate a very strong correlation between the values.

elements, did not demonstrate statistically significant correlations with the FIES score.

Overall, these results indicate that none of the CAET elements show strong statistical relevance for food insecurity in this sample. As well, due to the small sample size, the findings should be interpreted with caution and cannot be generalized to the wider population.

5.4 Participatory evaluation workshop

The TAPE workshops (Step 3) enabled a participatory exchange of perspectives on agroecological elements, fostering dialog both with and among the farmers. A prioritization activity (see Figure 7) revealed resilience as a central concern across all three villages. Farmers consistently highlighted the lack of access to credit, loans, and insurance as a critical barrier to improving their livelihoods. The absence of financial safety nets and limited community-based support in the face of climatic or economic shocks were identified as major vulnerabilities. The restricted access to credit was frequently mentioned as a key obstacle to diversifying income sources, particularly with regard to expanding small-scale animal husbandry (e.g., pig farming) or investing in processing techniques that would enable better storage and value addition to agricultural products.

The participants expressed a strong interest in the element of circular economy, with a focus on the local processing and value addition of their crops. Overall, the participants demonstrated a considerable interest in training programs concerning biological agricultural practices and livelihood diversification, including pig farming.

6 Discussion

6.1 Methodological reflection

The selection of participants for the TAPE methodology was based on purposive sampling, aiming at finding typical rural households in the region and building upon farmers' willingness to participate, which may have introduced a certain bias as respondents were often engaged and interested already. The relatively limited sample size serves to further reduce the representativeness of the results. In further studies it would be advisable to randomly select farmers and expand the sample size for each village of the LBBR.

In specific cases, a notable discrepancy was observed between the Spearman's rank correlation coefficient and the linear regression analysis. Such discrepancies can be attributed to the presence of non-linear relationships between the variables. In the event that the relationship between the variables is monotonic but not linear, the Spearman's rank correlation coefficient may demonstrate a high degree of correlation that is not reflected in the R^2 value of the regression model (Lund Research Ltd, 2018). Additionally, it is important to consider the strong influence of outliers on the R^2 . The Spearman's rank correlation coefficient can effectively handle small sample sizes and is less sensitive to outliers, which may explain the observed discrepancy (Leon, 1998; Rahman and Al-Amri, 2011). To mitigate any potential misinterpretation of the Spearman, all results underwent further testing

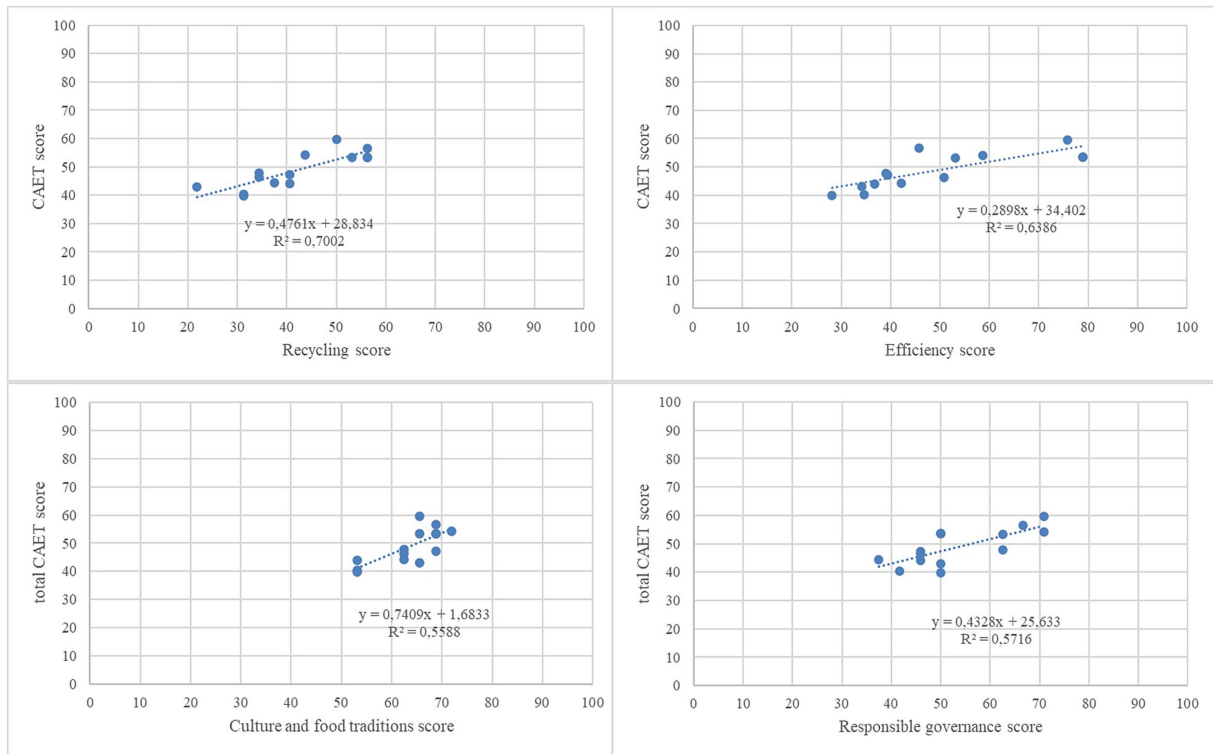


FIGURE 5 Scatter plots of the elements with the highest Spearman’s rank correlation coefficient: recycling, efficiency, culture and food traditions, and responsible governance with the CAET score.

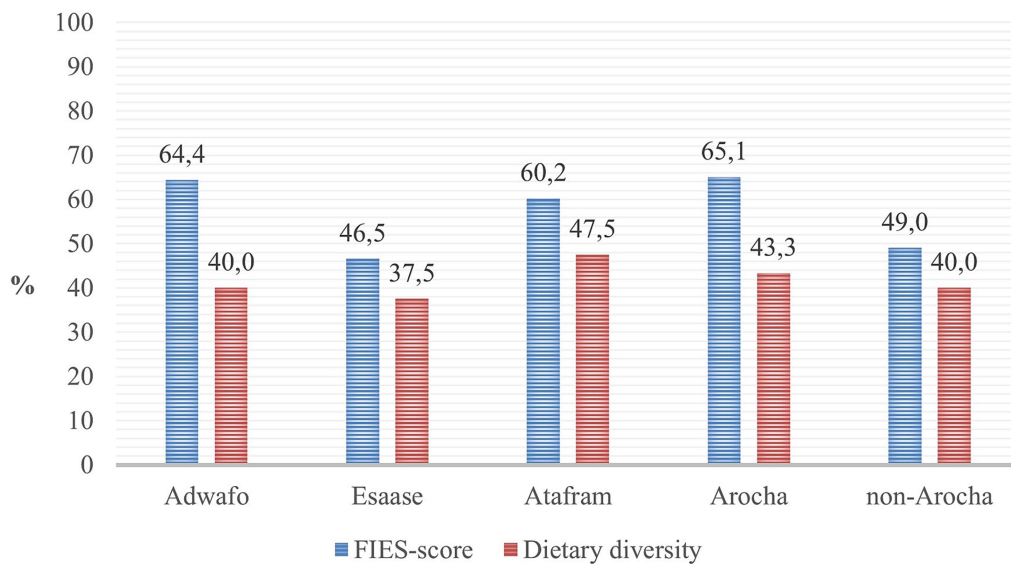


FIGURE 6 Comparison of the FIES score and minimum dietary diversity for women for all target villages and for A Rocha and non-A Rocha participants.

using linear regression analysis and were interpreted through the analysis of scatter plots, which visualized outliers.

The study shows that TAPE could be useful for NGOs, researchers, and the management of the Biosphere Reserve for assessing the impact of activities and monitoring the status of the food system. As well as

assessing the status of agricultural fields, the tool generates robust data that can be compared globally, e.g., within the world network of biosphere reserves, in areas such as women’s empowerment and dietary diversity monitoring. TAPE has also demonstrated its usefulness in comparing different groups of farmers, as evidenced by the clear

TABLE 6 The spearman's rank correlation coefficient for the FIES score in correlation with the CAET score and the 10 elements of agroecology.

Criteria	CAET	Diversity	Synergies	Efficiency	Recycling	Resilience	Food traditions	Knowledge sharing	Social values	Circular economy	Responsible governance
FIES score	0.36	0.07	0.52	-0.10	-0.01	0.34	0.16	0.32	0.20	-0.40	0.58
P-value	0.310	0.855	0.120	0.777	0.973	0.333	0.664	0.375	0.574	0.252	0.080

Lighter colours symbolise a very weak positive correlation, while strong colours indicate a very strong correlation between the values.

differences revealed by spiderweb diagrams between groups involved in A Rocha activities. The potential of TAPE for intergroup comparisons and tracking changes over time should be further assessed.

Furthermore, TAPE fosters collaboration and knowledge sharing among farmers and stakeholders, as demonstrated by their active participation in evaluation workshops. This enhances awareness and understanding of agroecological principles.

Further study is needed to determine whether TAPE has the potential to empower farmers by enabling them to identify challenges and needs, make informed decisions, and improve their practices with the support of scientifically grounded evidence when used as a self-assessment tool. Self-assessment processes such as these should be tested, supported, and guided by NGOs or other relevant organizations.

6.2 Characteristics of the agroecological system (diversity; synergies; efficiency; resilience; recycling; co-creation and sharing of knowledge)

In line with earlier findings of *A Rocha Ghana (2021)* the pilot study indicates that the majority of the interviewed households employ mixed intercropping systems, combining at least two crops, with food crops predominantly intercropped compared to monoculture cash crops like cocoa. The farms demonstrate an overall satisfactory soil coverage with crop remnants. While formal engagement in agroforestry practices was limited, participants expressed interest in exploring tree integration, highlighting potential opportunities for agroforestry adoption in the LBBR (*Obiri et al., 2013; A Rocha Ghana, 2021*).

Structures for capacity building and agroecological knowledge sharing are already in place and are further supported through the key actors of the LBBR (e.g., CREMA meetings, A Rocha, MOFA, COCOBOD), yet these structures are not fully operational. Consistent with prior studies from *Obiri et al. and A Rocha Ghana (Obiri et al., 2013; A Rocha Ghana, 2021)* our results indicate a scarcity in information services on sustainable agriculture and demonstrate the need for awareness on climate-adapted agriculture practices such as composting, integrated livestock management, and the use of neem-based biopesticides. Institutional support for access to information and inputs should be strengthened, as also emphasized by the Measuring Agroecology and its Performance (MAP) project in Benin, in order to support income-generating activities (*Chabi et al., 2025*). Farmer-to-farmer exchanges and Farmer Field Schools (FFS) have been widely recommended and implemented globally to support climate-adapted agriculture and environmental education, with positive outcomes and seem to be a viable solution in the LBBR as well (*Chocholata et al., 2015; González et al., 2015; Kiptot and Franzel, 2015; Tavares et al., 2018; Van Mourik, 2012*). Studies further show the potential of farmer-to-farmer extension to promote gender balance (*Tchuwa et al., 2015*).

The CAET results from our pilot study indicate limited financial and social resilience among farming households within the LBBR, particularly in relation to access to credit, insurance, and organized community support. While these findings cannot be generalized, they provide important exploratory insights into constraints that may hinder the agroecological transition in the area.

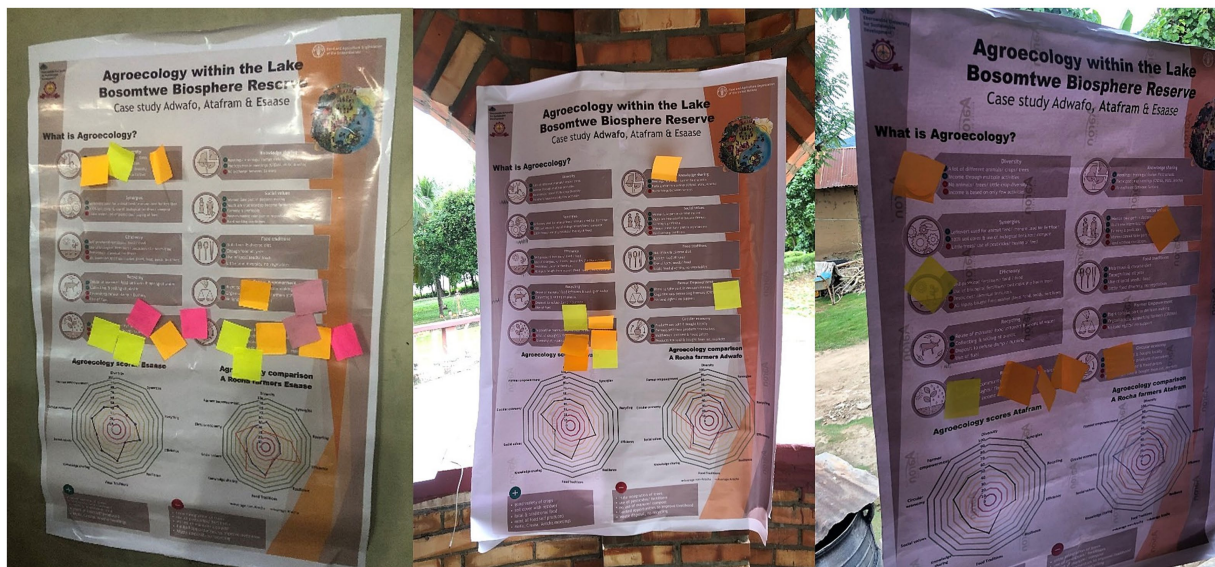


FIGURE 7
Results of the prioritization exercise in the target villages. From left to right: Esaase, Adwafo, Atafam.

Formal agricultural insurance remains largely inaccessible to smallholders, consistent with findings across Ghana where limited institutional coverage and high premiums restrict participation (Hazell et al., 2021). Weather-index insurance has shown promise in managing climatic risks and stabilizing livelihoods in parts of Sub-Saharan Africa (Tadesse et al., 2015; Waithaka, 2024), but its applicability in the context of the biosphere reserve Lake Bosomtwe would require adaptation to local financial capacities. Group-based insurance or insurance-for-work schemes (Tadesse et al., 2015) may offer more feasible alternatives.

Access to credit was also reported as insufficient, limiting the capacity of farmers to invest in equipment, training, and sustainable practices. Although causality cannot be inferred, qualitative evidence suggests that improved financial inclusion could support the adoption of agroecological practices. Microcredit systems, particularly those organized at the community level, have proven effective when paired with training, supervision, and repayment terms aligned with agricultural cycles (Siyoun et al., 2012; Omega, 2010). Group-based repayment models (Thomsen et al., n.d.) and Village Savings and Loans Associations (VSLAs) promoted by the Forest and Farm Facility (FFF) (Macqueen, 2022) could provide context-appropriate models for the farmers in the biosphere reserve. The hypothesis that increased access to credit and loans would result in a more significant agroecological transition could not be substantiated by the statistical analysis. It is advisable that an assessment be conducted to determine whether an augmentation in access to funds would indeed precipitate the desired enhancements in agroecology.

Low resilience scores further reflect exposure to climate variability, as documented by A Rocha Ghana (2021). Farmers identified erratic rainfall, high temperatures, and pest outbreaks as major challenges, conditions that align with patterns observed in Tanzania and Lesotho (Antwi, 2024; Chabi et al., 2025). Enhancing adaptive capacity will therefore require training in climate-resilient farming, soil conservation, and water

management, alongside support for livelihood diversification (Yamba et al., 2017). Finally, diversification of income sources emerged as a key strategy for adaptation. Consistent with earlier research (Yamba et al., 2017), several respondents of our study indicated an interest in non-farm activities to stabilize household income under changing climatic conditions. Supporting such livelihood diversification through targeted training and market access, facilitated by institutions such as MOFA and CREMA, could significantly strengthen resilience of their farms.

Although rather indicative, our results highlight the potential of small-scale, community-based financial mechanisms and capacity-building initiatives to strengthen resilience and support the agroecological transition in the LBBR.

In our study, the element of synergies also received low CAET scores, indicating for the farms in the LBBR the need for better integration of crop and livestock systems, recycling of organic matter, and incorporation of natural structures such as trees and ponds. While these findings cannot be generalized, they suggest a need to enhance awareness of ecological interactions within farming systems in the LBBR. The limited incorporation of trees in agricultural landscapes and the lack of knowledge about their environmental and economic benefits point to a gap in agroforestry understanding.

Inadequate waste management, particularly in proximity to lakeshores, and over-reliance on agrochemicals for cocoa cultivation, impede progress toward sustainable farming (Amankwaa et al., 2021; Amankwaa et al., 2020). The reliance of the farms participating in our study on subsidized inputs and government spraying programs limits their transition to biological farming systems. Although no causal inferences can be made, promoting organic cocoa production and peer exchanges with experienced farmers may support a gradual shift toward more sustainable practices. A study by Bandanaa et al. shows that organic farming outperforms conventional methods “in terms of land degradation, greenhouse gasses, profitability and gender equity” (Bandanaa et al., 2021).

Furthermore, the utilization of co-creation and knowledge sharing practices appeared limited across existent structures. Although the A Rocha meetings offered valuable training in composting, biopesticides, and intercropping (A Rocha Ghana, n.d.), other platforms, such as those from COCOBOD and MOFA, mainly focus on conventional cocoa management. This discrepancy reflects a broader challenge in agricultural extension services beyond our study, which often prioritize pest control over climate adaptation and water management (Obiri et al., 2013; A Rocha Ghana, 2021). Although the small sample precludes generalization, these observations highlight the potential need for extension services in the biosphere reserve to broaden the scope of their training to include agroecological practices. Also, a literature review conducted by Mockshell et al. revealed that “Agricultural extension, technical assistance, and information sharing were found to be important incentives or drivers for the adoption of agroecological practices (Mockshell et al., 2023).”

6.3 Context features for agroecological transition (human and social values; culture and food traditions)

The survey results indicate limited dietary diversity and seasonal food insecurity among our sample group, which may pose challenges to the development of a sustainable food system. Most of the women surveyed reported consuming only four out of the 10 food groups daily, a practice that carries risks for malnutrition. This finding may reflect either limited knowledge of dietary diversity or restricted access to the necessary resources. In addition, a considerable proportion of women indicated experiencing occasional hunger and insufficient food at home during specific seasons. Some women of our study also highlighted that food insecurity is particularly prevalent beginning in April and continuing through July and August, a period when harvests are minimal and food preservation practices appear limited.

These findings are in line with a review of studies that suggests that the implementation of agroecological practices results in positive changes to food security and nutrition (Bezner Kerr et al., 2021; Kansanga et al., 2021). It is therefore plausible that improvements in agroecological transition could enhance dietary diversity and food security in the LBBR, although this hypothesis remains to be tested in larger-scale studies.

6.4 Enabling environment for agroecological transition (responsible governance; circular and solidarity economy)

As a result of our study, it can be said that it is necessary to empower farmers and enhance their capacity to engage in more effective governance of agroecological systems. The CREMA framework, designed to empower local decision-making, appears limited in effectiveness due to violations of regulations, including illegal farming and improper waste disposal near the lake (CREMA, n.d.). We therefore conclude that the enhancement of CREMA's implementation through the facilitation of community

education and the establishment of independent reporting mechanisms has the potential to enhance its effectiveness. Several farmers expressed a desire for greater involvement in local planning, highlighting an opportunity to enhance responsiveness and collective ownership of agroecological initiatives.

The implementation of some of the discussed measures necessitates policy discussions and the adaptation of management plans. A Rocha has highlighted that climate-adapted agriculture has been inadequately incorporated into the medium-term plans for the Bosomtwe and Bosome Freho districts (A Rocha Ghana, 2021). The CREMA management plan emphasizes the enhancement of farming methodologies; however, it is noted that climate-adapted practices are lacking, and there is promotion of waste management practices that are questionable, such as the burial of non-biodegradable materials (MAB National Committee, 2014). Targeted interventions at the Biosphere Reserve level could therefore focus on locally appropriate waste management practices and participatory training for farmers.

The food system in the region combines traditional, circular practices with increasing reliance on global markets due to cocoa cultivation. All households grow subsistence food crops manually, using family labor, with minimal input from regional or national markets. Cocoa production, however, generally creates strong financial dependence on global and national markets and most cocoa farmers rely on subsidized or free inputs from COCOBOD and MOFA, limiting opportunities for local value addition. Strengthening local input supply systems, promoting diversified crop management, and linking cocoa production to locally appropriate agroecological practices could reduce dependency and enhance resilience.

Overall, our findings suggest that locally grounded strategies, including improved governance through CREMA, participatory training, and support for diversified, climate-adapted farming, could strengthen both sustainability and farmer agency within the LBBR.

7 Recommendations

Further research should focus on governance of agroecological transition including knowledge co-production, enhancing the role of community-based structures (CREMA), also exploring how women's share in decision making can be strengthened. Research to increase overall resilience should also include agroforestry, indigenous species integration, its role in improving the landscape matrix, and development of value chains as well as circular economy and closing nutrient circles.

The implementation of locally appropriate risk management strategies, such as climate-adapted agriculture, livelihood diversification and improved access to microcredits and community-based insurances, can strengthen resilience within the agroecological system of the LBBR. This should include the diversification of crops, the introduction of drought-tolerant varieties and small-scale irrigation systems on the farm level, complemented by traditional risk management strategies such as community risk management and agricultural insurance (Tadesse et al., 2015). It is recommended to further assess the potential of agricultural insurance schemes and microcredit approaches, with

a view to enhancing the financial resilience of farmers in LBBR and promoting diversified livelihoods.

Farmer-to-farmer exchanges should be established in the pilot communities, following the guidance of Tchuwa et al., which highlights the importance of supporting lead farmers, ensuring institutional backing, and providing training materials and expense coverage (Tchuwa et al., 2015). A Rocha Ghana, with its strong experience in participatory agroecological initiatives, could effectively coordinate these exchanges (A Rocha Ghana, 2021).

Further expertise is required in key areas such as water management, soil fertility improvement, and field diversification with legumes and vegetables. Integrating these topics into farmer field schools (FFS) and demonstration plots, supported by experienced local farmers, can enhance practical learning and adoption of sustainable practices. Evidence from TAPE applications in Tanzania suggests that guided approaches combining model farms and extension support are effective in promoting gradual agroecological improvements (Mader, 2024).

Training on tree integration, including soil enrichment, microclimate regulation, pest management and diversified income opportunities, could improve both ecological and livelihood outcomes (Jose, 2009). Existing initiatives, such as climate-adapted agriculture and tree integration promoted by A Rocha Ghana, should be continued in the biosphere reserve and expanded to reach a broader group of farmers. Management plans and local strategies should be adapted to support the agroecological transition, including alternative waste management and recycling practices, in line with locally relevant and participatory approaches.

Improved training on pesticide use and application, currently provided by COCOBOD and MOFA, should emphasize minimizing chemical inputs, promoting health protection, and adopting biological control through diversification and crop rotation. Collaboration with COCOBOD to restrict the use of highly toxic chemicals, as classified by the World Health Organization, and to expand certification and training in sustainable cocoa practices is recommended (Abu et al., 2020).

The insights from our pilot study suggest several potential interventions to increase the dietary diversity: Training on post-harvest strategies, including the storage, preservation and processing of crops, may help households better utilize and store surplus harvests, potentially increasing annual agricultural production and mitigating seasonal food insecurity (Adom, 2018b).

Complementary educational initiatives, such as integrating nutrition and healthy-eating topics into school curricula and community events, as well as offering cooking classes for women and children, could further enhance dietary diversity, as demonstrated in case studies from Laos and Western Kenya (Boedecker et al., 2019; Sato et al., 2024).

Given the critical role of women in household nutrition and food system resilience, these measures should primarily target women: In other studies, their empowerment has been linked to improvements in agricultural production, food security, and nutrition outcomes as well (Bryan et al., 2024; FAO, 2023), so our findings can provide valuable direction for future research and interventions in the LBBR.

8 Conclusion

Based on the FAO classification for agroecological systems, we found that the farmers participating in our study are working non-agroecologically but generally do show good preconditions for a transition of their farms toward an agroecological system.

Evidence suggests the presence of strong local food traditions and the use of local crop varieties, alongside widespread subsistence production that contributes to household food security. The circular economy score is shaped by divergent levels of market dependence, with an overall limited local value addition: A significant proportion of farmers rely on locally sourced or exchanged inputs, indicating a certain degree of circularity and little dependency on external resources. However, cocoa farmers are highly dependent on global cocoa markets and external inputs. Platforms for knowledge sharing and participatory governance structures, such as CREMA and farmer meetings, have been established and are already fostering some empowerment and learning. The crop diversity on the farms is relatively high, and the early adoption of climate-adapted and biological practices by some farmers highlights the existing potential for further agroecological development.

Despite these strengths, the farming system faces several interrelated constraints that limit its agroecological performance and resilience: Key deficiencies include limited value addition and low income from food crops, weak producer networks, and insufficient marketing capacity, as well as a lack of supporting schemes such as access to loans, credit, and insurance. Knowledge of agroecological practices remains uneven, indicating a need for more targeted training and better use of existing knowledge-sharing platforms. Further improvements are also required in integrating livestock, trees, and nutrient recycling to strengthen synergies within farms and across the landscape.

The results of the study highlight the necessity for the implementation of strategies tailored to the local context, with the aim of enhancing financial resilience, facilitating the exchange of agroecological knowledge, and optimizing resource management. In this context, the reinforcement of community-based structures such as CREMA, the expansion of farmer-to-farmer exchange, and the improvement of technical training in agroforestry, soil fertility, water management, and post-harvest handling, alongside the promotion of microcredit schemes and community-based insurance, could significantly support a gradual, locally owned agroecological transition.

Overall, this pilot study demonstrates the potential of the FAO TAPE tool to identify entry points for agroecological transition at the local level. While the findings cannot be generalized beyond the study area, they provide valuable insights into how biosphere reserves such as Lake Bosomtwe can act as testing grounds for context-specific, participatory approaches to strengthen sustainable food systems and community resilience.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. The FAO R code is available on GitHub at the following link: https://github.com/MAUS-team/tape_calculator.

Ethics statement

The study was conducted in full accordance with ethical guidelines and FAO's data confidentiality rules for the use of the TAPE tool. TAPE interviews were initiated only after obtaining oral informed consent from all participants. A trained translator explained the confidentiality statement provided by FAO TAPE prior to the start of each interview to ensure that participants fully understood the terms of data use and protection. Participation was entirely voluntary, and participants were informed of their right to withdraw from the study at any time without consequence. Personal identifiers, including names, ages, and other sensitive information, were not recorded in published results, ensuring the anonymity and privacy of all participants.

Author contributions

CK: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. KM: Writing – review & editing. MW: Conceptualization, Supervision, Writing – review & editing. KH: Conceptualization, Methodology, Supervision, Writing – review & editing. YA: Methodology, Supervision, Writing – review & editing. TC: Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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